Original Research Article

Urban drone last-mile delivery model from the perspective of multimodal transportation

Yunxiang Zhong, Huilin Li
Guangdong University of Science & Technology, Dongguan, Guangdong, 523000, China

Abstract: With the rapid integration of the digital economy and the low-altitude economy, the demand for urban logistics services continues to increase. The last-mile delivery stage has become a critical bottleneck affecting logistics efficiency and cost control. Traditional ground-based delivery systems face significant challenges, including traffic congestion, rising labor costs, and growing demand for instant delivery. Drones, characterized by flexible routing, rapid response, and independence from ground traffic conditions, offer a promising solution for urban last-mile logistics. However, limitations such as restricted payload capacity, short battery endurance, and strict airspace regulation hinder the large-scale adoption of standalone drone delivery systems. From the perspective of multimodal transportation, integrating drones with ground logistics resources can form an air–ground collaborative delivery system, improving overall logistics efficiency. This paper analyzes the operational mechanism of urban drone last-mile delivery under a multimodal transportation framework. Based on multimodal transportation theory, collaborative governance theory, and supply chain management theory, the study examines the technological, network, operational, and institutional challenges faced by drone delivery systems. Furthermore, it proposes optimization strategies including technological innovation, infrastructure planning, collaborative operation mechanisms, and regulatory improvement. The study concludes that multimodal drone delivery can significantly enhance urban logistics efficiency and represents an important direction for the integration of the low-altitude economy and modern logistics.
Keywords: multimodal transportation; drone delivery; last-mile logistics; urban logistics

1. Introduction

The rapid development of e-commerce, instant retail, and community group purchasing has significantly increased the demand for efficient urban logistics services. As consumer expectations shift toward faster and more flexible delivery, logistics enterprises face increasing pressure to improve efficiency while controlling operational costs. Among all logistics stages, last-mile delivery is widely recognized as the most complex and expensive component of the supply chain.Traditional last-mile delivery systems mainly rely on ground vehicles and manual couriers. However, urban congestion, parking restrictions, and rising labor costs have significantly reduced delivery efficiency. These challenges have prompted logistics enterprises and policymakers to explore innovative delivery solutions.I Multi-modal transportation provides a potential solution to this problem. By integrating drones with other transportation modes such as electric delivery vehicles, rail transit, and automated delivery systems, an efficient air–ground collaborative logistics network can be established. Such a system can combine the speed of aerial transportation with the flexibility of ground delivery, thereby improving overall logistics efficiency. Therefore, studying urban drone last-mile delivery from a multi-modal transportation perspective is of great theoretical and practical significance.

2. Literature review and theoretical framework

Existing studies on drone logistics mainly focus on technological development, route optimization, and operational feasibility. Many researchers have emphasized the potential of drones to reduce delivery time and improve logistics efficiency, particularly in remote or hard-to-access areas. However, relatively few studies have explored drone delivery from a multi-modal transportation perspective.

Multi-modal transportation theory emphasizes the integration of multiple transportation modes to achieve efficient logistics operations. Through coordinated planning and unified management, different transportation systems can complement each other and improve overall efficiency. Collaborative governance theory provides another important perspective for analyzing drone logistics systems. Drone delivery involves multiple stakeholders, including logistics enterprises, technology providers, aviation authorities, and urban management agencies. Effective cooperation and information sharing among these stakeholders are essential for building a sustainable drone logistics ecosystem.Supply chain management theory also plays a critical role in understanding drone delivery systems. Efficient logistics operations require the coordination of logistics flows, information flows, and financial flows. Digital platforms and intelligent scheduling systems are essential tools for achieving such coordination.

Based on these theoretical perspectives, this study develops an analytical framework consisting of four key dimensions: technological support, network structure, operational coordination, and institutional environment. These four elements collectively influence the development and performance of multi-modal drone delivery systems.

3. Operational mechanism of multi-modal drone delivery

Under a multi-modal transportation framework, the urban drone delivery process can be divided into four stages: Order processing, resource scheduling, multi-modal transfer, and terminal delivery. During the order processing stage, logistics enterprises collect and classify order information through digital platforms. Orders are screened according to delivery distance, parcel weight, and time requirements to determine whether they are suitable for drone transportation.In the resource scheduling stage, intelligent logistics systems integrate real-time data such as airspace information, traffic conditions, and equipment status. Based on these data, drones and ground vehicles are dynamically allocated to achieve optimal route planning and resource utilization.The multi-modal transfer stage represents the core component of the system. Drones can transport parcels from distribution centers to intermediate transfer points, such as mobile delivery vehicles, rail transit stations, or community logistics hubs. After the aerial transportation stage, ground delivery personnel or autonomous delivery vehicles complete the final distribution.

Finally, in the terminal delivery stage, parcels are delivered to customers through flexible methods such as smart parcel lockers, community service stations, or direct home delivery. This air–ground collaborative system allows drones to focus on long-distance or time-sensitive transportation while ground vehicles handle complex urban distribution tasks.

4. Challenges in implementing multi-modal drone delivery

Despite its potential advantages, the implementation of multi-modal drone delivery faces several challenges. First, technological limitations remain significant. Most logistics drones currently have a flight endurance of approximately 30 minutes and a payload capacity of less than five kilograms. These limitations restrict their ability to handle long-distance or large-volume deliveries. Second, infrastructure and network planning remain inadequate. The construction of drone take-off and landing sites, logistics hubs, and transfer facilities often lacks unified standards. In some cities, insufficient infrastructure limits operational efficiency, while in others, redundant construction leads to wasted resources. Third, operational costs remain relatively high. The procurement of drone equipment, infrastructure construction, and flight route approvals require significant financial investment. For many small and medium-sized logistics enterprises, these costs represent a major barrier to adoption. Finally, regulatory and institutional barriers also hinder the development of drone logistics. Airspace management policies are still evolving, and the approval procedures for drone flights can be complex and time-consuming. In addition, issues related to safety, privacy protection, and liability determination remain unclear in many regions.

5. Optimization strategies

To promote the development of multi-modal drone delivery systems, several optimization strategies should be implemented. First, technological innovation should be strengthened. Research on advanced battery technology, lightweight materials, and hydrogen-powered drones can improve flight endurance and payload capacity. At the same time, intelligent navigation and obstacle avoidance technologies should be further developed. Second, infrastructure planning should be optimized. Cities should establish standardized networks of drone take-off and landing facilities based on urban spatial structure and logistics demand. A three-level logistics network consisting of regional distribution centers, transfer hubs, and community delivery stations can improve overall efficiency. Third, collaborative operational mechanisms should be established. Governments, logistics enterprises, and technology providers should strengthen cooperation and build information-sharing platforms to improve coordination among different stakeholders. Finally, regulatory systems should be improved. Governments should accelerate low-altitude airspace reform, simplify approval procedures for drone flights, and establish dedicated airspace corridors for logistics drones. Clear legal frameworks should also be developed to address safety management and liability issues.

6. Conclusion

The integration of drones into urban logistics systems represents an important innovation in modern transportation. From a multi-modal transportation perspective, combining aerial and ground transportation resources can significantly improve last-mile delivery efficiency and reduce logistics costs. However, the large-scale application of drone delivery still faces challenges related to technology, infrastructure, operational coordination, and regulatory frameworks. Addressing these challenges requires coordinated efforts from governments, logistics enterprises, and technology providers. In the future, further research should focus on quantitative analysis of drone logistics systems, including cost–benefit evaluation and route optimization models. In addition, different cities may require differentiated development strategies based on their population density, infrastructure conditions, and logistics demand.

With continuous technological advancement and policy support, multimodal drone delivery has the potential to become an important component of urban logistics systems, contributing to the development of efficient, intelligent, and sustainable urban transportation networks.

Fundings

The research is supported by: "An Empirical Study on the Impact of ESG Information Disclosure by GEM Listed. Companies on Audit Reports" (Project No.: GKY-2025BSQDW-34)".

About the author

Yunxiang Zhong (2006.07-), female, native of Xingning, Guangdong, Han nationality, bachelor's degree, no professional title, research direction: Low-altitude economy.

References

[1] Alverhed, E., Hellgren, S., Isaksson, H., Olsson, L., Palmqvist, H., & Flodén, J. (2024). Autonomous last-mile delivery robots: A literature review. European Transport Research Review, 16(4).

[2] Garg, V. (2023). Drones in last-mile delivery: A systematic review on efficiency, accessibility, and sustainability. Transportation Research Part D: Transport and Environment, 123, 103831.

[3] Pratelli, A., Brocchini, L., & Petri, M. (2024). Optimising drone-assisted logistics for urban last-mile delivery: Applications, methodologies and emerging trends. Journal of Urban Development and Management, 3(3), 188–197.

[4] Patro, R. K., Chandra, S., & Patro, J. P. (2024). Drone integration in last-mile delivery operations. International Journal of Supply Chain and Logistics, 8(1), 45–60.

[5] Agatz, N., Bouman, P., & Schmidt, M. (2018). Optimization approaches for the traveling salesman problem with drone. Transportation Science, 52(4), 965–981.

[6] Murray, C. C., & Chu, A. G. (2015). The flying sidekick traveling salesman problem: Optimization of drone-assisted parcel delivery. Transportation Research Part C, 54, 86–109.

[7] Dorling, K., Heinrichs, J., Messier, G. G., & Magierowski, S. (2017). Vehicle routing problems for drone delivery. IEEE Transactions on Systems, Man, and Cybernetics, 47(1), 70–85.

[8] Lim, S., Jin, X., Srai, J. S., & Mandal, S. (2018). The impact of drones in last mile logistics. International Journal of Physical Distribution & Logistics Management, 48(9), 901–921.

[9] Qin, C., Narayanan, A., & Pournaras, E. (2025). Coordinated multi-drone last-mile delivery: Learning strategies for energy-aware and timely operations. arXiv preprint.

[10] Imran, N. M., Mishra, S., & Won, M. (2021). Towards fully autonomous drone-based last-mile delivery. arXiv preprint.