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Original Paper

A Study on the Integrated Application and Development Strategies of Low-Altitude Drones in the Field of Smart Transport and Logistics

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Abstract

Against the backdrop of the implementation of low-altitude airspace reforms and the comprehensive upgrading of smart logistics systems, low-altitude UAVs, with their advantages of manoeuvrability, minimal spatial constraints and rapid response times, are gradually being integrated into multiple sectors including urban delivery, traffic inspection, emergency supply support and urban-rural logistics, becoming a key enabler in the construction of an integrated air-ground smart transport and logistics system.Based on the economic environment of the low-altitude sector, this paper systematically analyses the current status of low-altitude UAVs' practical applications in the field of smart transport and logistics. It objectively identifies the practical shortcomings in the industry's development process and, by combining policy directions with industry realities, proposes optimisation strategies that are both feasible and implementable. The aim is to provide theoretical references and practical insights for the standardised development of UAV logistics and the enhancement of quality and efficiency in the smart transport industry.

Keywords

low-altitude UAVs, smart transport, logistics and distribution, airspace management, integrated development

1. Introduction

With the comprehensive implementation of the national low-altitude economy strategy and the accelerated development of three-dimensional integrated transport infrastructure, traditional ground-based logistics models are constrained by issues such as road network congestion, geographical barriers and time constraints, making it difficult to meet the diverse and highly efficient demands of modern logistics.Smart transport logistics relies on digital and intelligent technologies to achieve resource integration and process optimisation, whilst low-altitude UAVs, as a new type of aerial transport vehicle, can effectively address the shortcomings of ground transport and bridge key gaps in urban-rural logistics, emergency transport, and urban last-mile delivery.Currently, the number of pilot cities for drone logistics in China continues to expand, and the range of practical applications is constantly growing. However, the industry as a whole remains in an exploratory phase, with numerous shortcomings still existing in areas such as regulatory frameworks, hardware infrastructure and industry standards. Therefore, clarifying the current state of integration between low-altitude drones and smart transport logistics, identifying existing issues and formulating a scientific development path holds significant practical research value.

2. Current Status of the Integration of Low-Altitude UAVs in Smart Transport and Logistics

2.1 The Routine Implementation of Urban Last-Mile Delivery: Addressing Shortcomings in Modern Logistics Services

Against the backdrop of accelerating urbanisation, urban population density continues to rise, and the demand for small-parcel, on-demand logistics in areas such as commercial districts, residential communities, medical institutions and industrial parks is increasing year on year. Traditional delivery methods, such as three-wheeled delivery tricycles and manual delivery, generally face practical challenges including restricted access, road congestion, rising labour costs and inconsistent delivery times. Leveraging their ability to operate at low altitudes, low-altitude drones are unaffected by ground traffic and pedestrian flow, enabling short-distance, point-to-point, all-weather delivery of lightweight goods, thereby effectively resolving the ‘last-mile’ logistics challenge in urban areas (Li, 2024).

At present, several leading domestic logistics and technology firms have established low-altitude delivery routes in urban areas, primarily covering the transport of small, lightweight goods such as fresh food, daily necessities, emergency medicines and medical consumables.Functions such as automated take-off and landing, autonomous route navigation, and intelligent cargo loading and unloading are being continuously optimised. These capabilities enable drones to adapt to the complex architectural environments of high-density urban areas, significantly reducing delivery times. Compared to traditional ground-based delivery, drone-based last-mile delivery effectively reduces labour requirements, alleviating labour shortages among delivery personnel. At the same time, it minimises exhaust emissions and traffic congestion caused by short-distance vehicle journeys, aligning with the development principles of green logistics and low-carbon transport. Consequently, it is gradually becoming a vital component of urban smart logistics systems.

2.2 Two-way urban-rural Logistics and Implementation in Special Scenarios: Expanding the Boundaries of Logistics Coverage

China is a vast country, with regions such as mountainous areas, hilly terrain, islands and remote villages suffering from weak transport infrastructure, low road network density and poor access conditions. Structural contradictions—such as the difficulty of logistics reaching villages and agricultural products leaving mountainous areas—have long persisted, and the imbalance in the development of urban-rural circulation systems remains prominent. Conventional logistics transport routes are costly to establish and have low delivery frequencies, making it difficult to meet the basic needs of rural residents for daily goods procurement and the external sale of agricultural and sideline products.

Low-altitude drones are characterised by strong terrain adaptability, flexible deployment and low investment costs. They can traverse natural geographical barriers such as mountains, rivers, lakes and woodlands to establish stable and efficient rural low-altitude logistics channels, thereby opening up two-way circulation links for industrial goods to reach rural areas and agricultural products to reach urban markets. In remote townships and natural village groups, drones can carry out scheduled deliveries of daily necessities, agricultural supplies and medical supplies, ensuring the stability of basic livelihood supplies at the grassroots level.At the same time, in special scenarios such as natural disasters, road collapses and extreme weather, ground transport routes are highly susceptible to disruption, hindering the transport of conventional relief supplies. Drones can rapidly reach affected areas to deliver emergency food, first-aid medicines and rescue equipment, providing vital support for emergency response and post-disaster supply guarantee, and significantly enhancing the emergency response capabilities of the transport and logistics system.

2.3 Intelligent Upgrades to Transport Operations and Maintenance: The Gradual Emergence of an Air-Ground Coordination Management Model

The development of smart transport encompasses not only improvements in freight transport efficiency but also comprehensive operational and maintenance activities such as road inspections, facility maintenance, road network monitoring and port area management. Traditional inspections of transport infrastructure largely rely on manual patrols and vehicle-based surveillance, which have limited coverage and relatively low efficiency; moreover, inspection work on high-risk sections and in remote road networks poses certain safety hazards.Equipped with high-definition cameras, infrared monitoring instruments, environmental sensors and data acquisition terminals, UAVs can conduct comprehensive, wide-ranging and high-frequency routine inspections of key areas such as motorways, national and provincial trunk roads, railway corridors, port terminals and logistics parks (Zhang & Chen, 2024).

Through real-time filming, data transmission and live monitoring, they can rapidly identify issues such as road damage, ageing infrastructure, unauthorised encroachment on roadways and non-compliant storage in port areas, thereby providing data support for transport authorities to implement precise measures and carry out timely maintenance. In trunk logistics, port shipping and intermodal transport scenarios, drones can also be used for cargo yard inspections, transport vehicle dispatch assistance and environmental monitoring around shipping routes, achieving a deep integration of aerial patrols and ground-based management.With the continuous evolution of digital technologies, data integration between low-altitude drones and smart traffic management platforms and logistics dispatch systems is becoming increasingly seamless. An integrated air-ground collaborative management model is gradually taking shape, comprehensively driving the transformation of the transport and logistics industry towards greater intelligence, precision and efficiency.

3. Current Challenges in the Integrated Application of Low-Altitude UAVs and Smart Transport and Logistics

3.1 Shortcomings in Core Technologies Limit Large-Scale Operations

At present, although domestic logistics drone manufacturing technology is becoming increasingly mature, the specialised and scalable technical framework required for smart logistics scenarios remains incomplete. Most civilian logistics drones have short flight ranges and low payload capacities; they exhibit poor flight stability in extreme weather conditions such as strong winds, rain, snow and low temperatures, and lack sufficient environmental adaptability, making it difficult to meet the demands of all-weather, large-scale logistics delivery (An & Ye, 2024).

Furthermore, in densely built-up urban environments, core technologies such as autonomous obstacle avoidance, intelligent route planning and multi-drone coordinated dispatch remain underdeveloped, posing significant flight safety risks. Insufficient data interoperability between air and ground systems means that drone operational data cannot be linked in real time with urban traffic platforms and logistics dispatch systems; the low efficiency of air-ground coordination has, to some extent, limited the widespread implementation of drone logistics.

3.2 Outdated Airspace Management Systems and Cumbersome Flight Approval Processes

Airspace resource management is a key factor influencing the development of drone logistics. The degree of refined access to low-altitude airspace in China is limited; existing airspace divisions primarily serve general aviation, with insufficient planning of dedicated low-altitude routes for logistics drones (Wang & Zhao, 2024).

Routine drone flights require joint approval from multiple departments; the approval process involves numerous steps and is time-consuming, whilst coordinating cross-regional flights is challenging, thereby increasing the time and management costs of daily operations for enterprises. Furthermore, the dynamic monitoring system for low-altitude flights is incomplete, and the coverage of digital control platforms is limited; regulatory blind spots exist in some suburban and rural areas, and unregulated, sporadic flight activities further exacerbate the pressure on safety management for low-altitude operations.

3.3 Weak Supporting Infrastructure and Insufficient Operational and Maintenance Capabilities

A comprehensive drone logistics operation system requires take-off and landing sites, charging and battery-swapping equipment, maintenance and operation service points, and communication and navigation facilities to support it. Currently, only a few pilot cities in China have completed the layout of standardised drone take-off and landing points, whilst most cities, counties and rural areas lack dedicated landing sites and energy supply facilities (Liu, 2024).

The distribution of low-altitude communication and navigation facilities is uneven, with weak signal coverage in remote areas, making it prone to issues such as flight signal interruptions and positioning errors. At the same time, the industry lacks unified standards for facility construction; various operational facilities have poor compatibility; and post-deployment operation, maintenance, and support systems are underdeveloped, making it difficult to sustain the long-term, stable, and large-scale operation of drone logistics.

3.4 Lack of Industry Standards and Immature Market-Driven Development Mechanisms

Low-altitude drone logistics is a cross-sectoral emerging industry, and unified industry regulations and institutional standards have not yet been fully established. There is a lack of uniform guidelines regarding equipment manufacturing, flight operations, service processes and safety management; equipment specifications and operational models vary significantly between different enterprises, highlighting issues of homogenised competition and disorderly development within the sector (Chen & Liu, 2024).

Responsibilities regarding flight safety, compensation for cargo damage, and airspace usage regulations remain ambiguously defined, leading to insufficient consumer confidence. Coupled with the high costs associated with drone procurement, operation and maintenance, and airspace coordination, profitability is difficult to achieve through logistics delivery alone. Consequently, most enterprises rely on policy support to sustain operations, and a sustainable commercial development model has yet to be established.

4. Optimisation Strategies for the Integrated Development of Low-Altitude UAVs and Smart Transport Logistics

4.1 Tackling Core Key Technologies to Enhance Scenario Adaptability

Leveraging a collaborative innovation model involving industry, academia and research, focus on tackling key technical challenges in areas such as flight endurance, payload capacity, anti-interference capabilities and intelligent flight control for logistics drones. Upgrade propulsion systems and airframe designs, develop specialised logistics drones suitable for multiple scenarios, and enhance flight performance in adverse weather conditions.Refine multi-sensor fusion obstacle avoidance technology and establish a dynamic intelligent route planning system to enhance flight safety in complex urban environments. Establish an integrated air-ground data sharing platform to break down data silos between transport, logistics and airspace sectors, achieving integrated coordination of order dispatching, flight control and cargo transfer, thereby comprehensively enhancing the level of intelligent operations.

4.2 Optimise airspace Management Systems and Establish Streamlined Approval Mechanisms

Building upon national low-altitude airspace reform policies, we will open up low-altitude resources in a tiered and categorised manner. In line with logistics transport requirements, we will plan dedicated low-altitude logistics flight routes at the city, county and rural levels.Integrate the management functions of civil aviation, transport, public security and air traffic control departments to establish an integrated online flight declaration platform, thereby simplifying the approval process for routine logistics drone flights and reducing approval times. Utilise technologies such as big data, BeiDou positioning and geofencing to establish a comprehensive low-altitude surveillance system, enabling real-time monitoring of flight paths and automatic risk alerts, and creating a standardised, orderly and safe low-altitude operating environment.

4.3 Coordinate the Overall Layout of Facilities and Improve the Comprehensive Support System

Incorporate supporting infrastructure for drones into specialised urban transport and logistics planning. Following a “hub + node + terminal” model, rationally deploy standardised take-off and landing platforms, smart charging and battery-swapping stations, and operations and maintenance service points within logistics parks, commercial districts and township service points. Address communication and navigation shortcomings in rural and remote areas, strengthen full-coverage low-altitude airspace signals, and ensure stable drone flight.Establish a mechanism for the joint construction and sharing of facilities, standardise construction criteria, and promote the seamless integration of UAV facilities with existing courier outlets and transport hubs to reduce construction costs for enterprises.

4.4 Improve Industry Standards and Regulations, and Foster Sustainable Operational Models

Industry regulators should expedite the introduction of operational management regulations for drone logistics, unifying technical standards for equipment, flight operation protocols, safety production requirements and service evaluation systems, whilst clarifying corporate accountability and mechanisms for holding parties responsible for flight safety. Refine the management of qualifications for drone logistics personnel, and strengthen safety training and day-to-day supervision. Guide enterprises to expand into diverse service scenarios, broadening profit channels by integrating specialised services such as pharmaceutical delivery, fresh produce cold chain logistics, transport inspections and emergency support. By leveraging large-scale operations to reduce per-trip transport costs, enterprises can gradually move away from reliance on policy support and establish a sustainable, market-driven development model.

5. Conclusion

The deep integration of low-altitude drones with smart transport and logistics represents the inevitable direction for the transformation and upgrading of modern logistics and the practical development of the low-altitude economy.At present, the application scenarios for drone logistics in China continue to expand and technical practices are maturing, playing a vital supporting role in multiple fields such as urban last-mile delivery, two-way circulation between urban and rural areas, intelligent transport operations and maintenance, and emergency supply support. The widespread adoption of low-altitude logistics models has not only alleviated pressure on ground transport operations and addressed shortcomings in logistics services in remote areas, but has also comprehensively enhanced the intelligence and precision of transport infrastructure management, injecting new momentum into the development of a smart transport and logistics system.

However, the industry still faces practical challenges such as gaps in core technologies, lagging airspace management, inadequate infrastructure and a lack of industry standards, which constrain the large-scale and routine development of low-altitude UAV logistics.Moving forward, the industry must prioritise technological innovation, leverage airspace reform, build upon infrastructure development, and rely on regulatory frameworks to ensure multi-stakeholder collaboration and the continuous resolution of development bottlenecks. Through comprehensive optimisation and upgrading, we can promote the standardised and high-quality integration of low-altitude drones, accelerate the construction of a three-dimensional smart transport and logistics system that integrates air and ground operations, and support the long-term, stable development of the transport and logistics sector.

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