

The Construction, Operational Challenges, and Optimization Strategies of Smart Supply Chain Systems in the Low-Altitude Economy Scenario

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Abstract

As a key growth sector of China's strategic emerging industries, the low-altitude economy is currently in a critical stage of transitioning from commercial pilots to large-scale development. It is expected that by 2030, the global number of low altitude aircraft will reach 9.6 million. However, the lag in the construction of industrial supply chain systems has become a major bottleneck restricting the development of high-quality industries. By analyzing and reviewing existing literature from the perspective of smart supply chain, and considering the three-dimensional operational characteristics of low altitude scenarios, this document systematically examines the current status of the development of low altitude smart supply chain, identifies operational challenges and adaptive technology scenarios from a three-dimensional perspective. They provides institutional rules and industrial ecosystem construction. And they proposes corresponding optimization approaches based on the principle of problem orientation. The integration of low-altitude economy and smart supply chain has enormous development potential, but faces challenges in technology, system, and industrial transformation, requiring coordinated progress. This study provides a theoretical reference for improving industrial support infrastructure and promoting large-scale standardized development of the low-altitude economy.

Key words

Low-altitude economy; Smart supply chain; System construction; Operational difficulties; Optimization strategy.

1. Introduction

With the acceleration of urban development and the deepening of industrial digital transformation, traditional ground logistics is facing increasing limitations in terms of spatiotemporal efficiency, coverage, and emergency response. As an emerging economic form, utilizing low-altitude airspace resources, unmanned aerial vehicles, electric flying and vertical landing aircraft as the main carriers, low-altitude economy provides new solutions to overcome these spatial limitations [1]. Through a series of operations and dynamic management, the department operates in airspace ranging from 1000 to 3000 meters, demonstrating tremendous value in urban logistics, emergency rescue, and air mobility, becoming a new engine for high-quality industrial upgrading and economic development.

Smart supply chain is the main driving force for the digital transformation of logistics. Through the deep integration of artificial intelligence, the Internet of Things, and big data, smart supply chains provide intelligent decision-making through demand forecasting, inventory management, route optimization, and risk control. Generative artificial intelligence further expands the limitations of its applications, from request detection to case generation, from decision support to autonomous upgrading, creating a comprehensive capability system covering strategic, tactical, and operational levels [2]. The decision framework that combines large language models with mathematical upgrade parsers allows non-technical practitioners to complete complex case analysis through natural language interaction, reducing barriers to intelligent tools [3]. Empirical research has shown that the application of artificial intelligence in logistics can reduce costs by 15%, decrease inventory by 35%, and improve service efficiency by 65% [4].

However, there are still significant gaps. The research on low-altitude economy mainly focuses on technical aspects such as communication architecture and ISAC, without fully and systematically paying attention to the entire supply chain [1,5]. At the same time, mature smart supply chain solutions have been designed for two-dimensional ground logistics, without the need to deal with the high dynamics, strict safety constraints, and airspace control requirements of three-dimensional low altitude environments [4,6]. Based on this gap, this article analyzes and reviews the literature on building

smart supply chains, challenges, and upgrading small-scale economies.

2. Development Status of Intelligent Chain Systems; Supply Low-Altitude Economy

The low-altitude economy has entered a stage of parallel technology reintegration and expansion scenarios. At the network architecture level, low-level networks create multi technology integrations, including communication, sensing, computing, positioning, navigation, surveillance, air traffic control, and aerospace management. Generative artificial intelligence plays a core role in intelligent adaptation, uncertainty modeling, and real-time maximization. ISAC technology allows for detection and communication through shared hardware and spectrum, addressing the issues of excess equipment and insufficient spectrum, and providing a technical foundation for large-scale coordinated aircraft monitoring. It is estimated that by 2030, the global number of low altitude aircraft will reach 9.6 million, and there is an urgent need for unified network management and a coordinated timetable.

Smart supply chain technology has reached a relatively mature level on the ground. Artificial intelligence has six fundamental abilities - learning, understanding, predicting, interacting, adapting, and reasoning - applicable to 13 supply chain decision-making domains [2]. In practice, generative artificial intelligence is deployed in multinational corporations, covering customer service automation, supply negotiation, and production upgrades, with major advantages such as cost reduction, improved customer experience, and efficiency [7]. Emerging new models such as supply chain control towers and LLM decision-making frameworks have led to a shift from experience management to data management [3,6].

The empirical evidence from China shows a significant impact on productivity. According to the data from the provincial group, the growth rate of low-quality economic development is 1%, and the productivity of new quality logistics has significantly increased by 0.407%, maintaining stability after controlling labor and industrial structure. There are two ways for this effect: technological innovation, factor allocation, and industrial

cooperation; And indirect transmission through supply chain modernization [8]. There is regional heterogeneity: the region has a significant impact through a complete industrial chain. The western region benefits the most from weak logistics; Although the central region is limited to weak support systems, it has not shown significant impact [8].

In terms of technical implementation, the multi-drone collaborative data transmission scheme provides algorithm support for terminal delivery planning by jointly optimizing coding and deployment boxes, reducing energy consumption and providing coverage [9]. In post-disaster situations, collaborative beamforming of unmanned aerial vehicles allows for remote relay of reliable data through a series of virtual antennas, verifying the possibility of maintaining supply chain information links under extreme conditions [10]. These technological advancements have laid the foundation for building low-level smart supply chains, although large-scale demand still requires systematic coordination at different levels.

3. Operational Challenges of Low-Altitude Smart Supply Chains

Building an smart supply chain at a lower level involves three systemic challenges: inadequate technological adaptation, insufficient institutional supply, and weak industrial ecology. These three challenges constrain each other and hinder the intelligent upgrading of the entire supply chain.

3.1 Bottleneck of Scenario Adaptation at the Technical Level

Low-altitude economy includes three-dimensional operation, dynamic scheduling, and strict safety requirements. Due to physical limitations and key differences in operational logic, existing technologies primarily used for two-dimensional ground logistics in smart supply chains are difficult to directly transfer.

Firstly, the characteristics of the space do not match the ability to support communication. Unlike fixed ground route networks, low altitude space has a three-dimensional and dynamic distribution, and resource shar-

ing and open rules are inconsistent between regions, so there is no standardized spatial interface for intelligent planning. The obstruction and multiple effects of buildings have a significant impact on low altitude signals, which frequently propagate beyond the line of sight. Although ISAC can theoretically meet communication and detection needs, it is still in the pilot stage and there are obstacles to large-scale deployment, including spectrum coordination and base station modification [5]. Aerospace management knowledge is still weak, making it difficult to coordinate large-scale drone series.

Secondly, insufficient technological cooperation and data barriers hinder end-to-end intelligence. At present, low altitude intelligent technology mainly focuses on optimizing the delivery methods of destinations, including weak digitalization of front-end links such as parts supply, maintenance, and storage, and inconsistent seed standards for data and important information [6]. Due to the lack of spatial data interfaces and real-time flight inputs, mature ground architectures cannot be directly reused as supply chain control channels [6]. Insufficient data collaboration makes visual management of the entire chain difficult, and can only optimize all connections locally, rather than improving system level efficiency.

3.2 Absence of Rule System Supply at the Institutional Level

Clean delays in establishing institutions relative to technological development, and a lack of supply of standards, regulations and data consistency directly hamper the promotion of standardization and trans-regional operations.

Incomplete industry standards and regulatory systems are the main constraints. No uniform operational standard has yet been established on a national scale. The flight approval process is fastidious due to the regional differences, resulting in high cost consistency between the regions. Lack of clear provisions on security standards, service quality standards and market access qualifications makes it difficult to implement standardised replication solutions. The division of regulation results in high coordinated costs between the levels of aerospace, communications and services, further limiting the exploitation of trans-regional aircraft [1]. This institutional uncertainty discourages long-term enter-

prise investment.

Another barrier is the lack of data security and consistency. Efficient operations depend on large amounts of data on flights, logistics and user sharing, which involves a long chain of multiple entities. However, for low-level scenarios, data security regulations and confidentiality rules are not always clear, limiting information collaboration and leaving regulatory risks [1]. Such a lack of system hinders the full dissemination of the data elements, which directly affects the depth of the entire information chain.

3.3 Challenges of ecological construction at market and industry levels

A complete industrial ecosystem is needed for healthy development. At present, the limited size of the market, the unique reliability model and insufficient coordination of the industry are related, creating a structural contradiction between heavy investments and low utilization rates.

High operating costs and a unique reliability model are the most important challenges in the market. Costs of equipment procurement, maintenance, deployment of the spaces and training of the staff are still high, and the applications are focused on the delivery of the areas and are not significant enough to cover the costs. The root cause is the mismatch between supply and demand: the low-level logistics scenarios are not yet sufficiently examined and demand is focused on specific periods and regions, leaving resources idle during the idle periods; At the same time, technologies and service offerings are identical and do not meet the different needs of different industries. Large asset investments and low utilization create a negative cycle that delays cost reduction and expansion.

Lack of cooperation in the industrial chain is a structural constraint. The low-altitude smart supply chain covers aircraft manufacturing, communication technologies, logistics and regulation, involving many entities from all over the sky. Lack of effective coordination mechanisms and insufficient integration of resources resulted in upgrading difficulties at system level. Manufacturers focus on the content, communications companies focus on the networks, operators focus on the terminals and integration difficulties result in inconsistent standards. The Industrial Cluster effect is not yet

visible, the joint ventures are geographically dispersed and the links between chains are inefficient [8].

4. Optimization Paths for Low-Altitude Smart Supply Chain Systems

4.1 Technology Adaptation Optimization: Building an Integrated Air-Ground Support System

At the technical level, emphasis should be placed on the low visibility requirements to promote the integrated upgrading of communication networks and full chain cooperation.

First, smart support for communication networks and airspace management should be strengthened. Large-scale implementation of ISAC technologies should be accelerated and a three-dimensional change in the formation of ground base station processes should be encouraged to improve the quality of low signal coverage and resilience capability [5]. Network performance analysis methods (e.g. random geometry) are used to scientifically plan the density and height parameters of the original station to balance communication coverage probabilities and radar detection coverage probabilities [5]. Intelligent airspace management systems should be built using dynamic allocation algorithms and conflict prediction models to support the coordinated operation of heterogeneous aircraft [1]. Generative artificial intelligence could play a role in intelligent adaptation and simulation uncertainty in this process, improving the efficiency of dynamic airspace resource planning [1].

Second, the barriers on the entire data chain should be broken to promote intelligent end-to-end collaboration. Integrated low supply chain data standards and interface specifications should be developed to promote data interconnection between aircraft manufacturing, storage, delivery and maintenance links. Based on the mature architecture of a smart supply chain control tower, and coupled with low visibility characteristics, an integrated air-to-ground supply chain vision and decision-making platform should be built to optimize real-time sensing and collaboration on the status of the entire supply chain [6]. An LLM-focused intelligent

decision framework should be introduced that reduces technical barriers for supply chain practitioners by using complex optimization models, supports scenario analysis and pattern verification through natural language interactions, and improves decision efficiency at tactical and operational levels[3].

4.2 Institutional Supply Improvement: Establishing Unified Standards and Co- ordinated Regulation

At the institutional level, standard development and regulatory innovation should be accelerated, and a complete system covering industry access, operational norms, and data security should be implemented.

One of them is to improve industry standards and regulatory systems. A unified low-end logistics business code should be developed nationwide, clarifying safety standards, service quality standards, and market access standards, in order to reduce the compliance operating costs of cross regional enterprises. People should simplify and standardize the flight permit procedures, coordinate and unify the applicable rules for inter regional aviation flight permit applications, and gradually achieve autonomous and dynamic management of airspace resources. A unified regulatory mechanism should be implemented among various departments, and information sharing and policy coordination between space management, communication supervision, and logistics departments should be strengthened to address coordination issues arising from violations. On the premise of ensuring safety, sufficient resources should be provided for large-scale smart supply chain operations, and the open scope of low space should be appropriately expanded.

Secondly, data security and consistency mechanisms should be improved. For low altitude situations, data security rules and privacy protection rules should be established to clarify the norms for the collection, storage, sharing, and use of flight data, logistics data, and user information, and to clarify the responsibilities of each entity in terms of data security. A carefully designed data management system should be implemented to implement different protection measures for data sensitivity at different levels, promote command propagation of data elements, while ensuring security and

confidentiality. The research and implementation of data security technology should be promoted, including the introduction of confidential computing and collaborative learning techniques in certain data in the supply chain, in order to make available but invisible data possible and balance the relationship between data usage and security protection.

4.3 Industrial Ecological Construction: Cultivating Coordinated Industrial De- velopment

At the industrial level, the implementation plan should be expanded and the coordination of the industrial chain should be strengthened to resolve the contradiction between heavy activities and low utilization rates.

Firstly, a variety of scanners should be implemented to promote large-scale development. On the basis of merging terminal delivery scenarios, the expansion should be extended to various scenarios, including emergency logistics, medical material transportation, inspection and maintenance, and rural delivery, to increase market demand and improve the utilization of space equipment and resources. The eastern region can leverage mature industrial chains and technological foundations to focus on low-end urban logistics and high-quality manufacturing supply chains; The western region can leverage its lower economic advantages instead of relying on ground logistics, emphasizing material distribution and emergency support in remote areas; The central region should accelerate the establishment of a support system and gradually unleash the unique impact of low-altitude economy. Screen expansion can alleviate a significant amount of activity costs, creating a positive cycle of scale and profitability effects.

Secondly, people need to strengthen the coordination of the industrial chain and cultivate industrial groups. Cross departmental industrial coordination mechanisms should be implemented to achieve resource integration and standard coordination between aircraft manufacturing, communication technology, logistics manufacturing, regulatory services, and other entities, thereby creating relevant industrial synergies between upstream and downstream. Based on the existing industrial foundation, it is necessary to cultivate regional industrial groups with low-income economies and utilize

the advantages of geographical proximity to improve support efficiency and innovation vitality. Major enterprises should be encouraged to proactively establish industrial ecosystems, integrate technological resources, data, and scenarios, create open and shared low-end smart supply chain platforms, and reduce restrictions on the participation of small and medium-sized enterprises.

5. Conclusion

This article reviews literature on low-cost economies and smart supply chains, analyzes operational challenges at the technological, institutional and industrial levels and recommends best practices to achieve them. Research shows that the low-cost economy and the integration of a smart supply chain have great potential. A low economy can improve logistics productivity directly through innovation, factor allocation and collaboration, and have an indirect impact through supply chain modernization. However, the current construction faces various challenges, including insufficient technological adaptation, insufficient institutional supply and a weak industrial ecology, which limits large-scale development.

These conclusions are of practical importance: building a low-level smart supply chain cannot rely on the impetus of a unique technology, but requires coordinated progress between technology, institutions and industry. Integrated standards and industrial ecosystem culture must be promoted together to promote efficiency, safety and sustainability. Future research can conduct empirical research to assess the economic benefits in different scenarios and explore specific applications that generate artificial intelligence in low-end supply chains.

References

- [1] Wang, Y., et al. (2025). *Toward realization of low-altitude economy networks: Core architecture, integrated technologies, and future directions*. IEEE Transactions on Cognitive Communications and Networking, 11(5), 2788-2820. <https://doi.org/10.1109/TCCN.2025.3601015>.
- [2] Jackson, I., Ivanov, D., Dolgui, A., & Namdar, J. (2024). Generative artificial intelligence in supply chain and operations management: A capability-based framework for analysis and implementation. *International Journal of Production Research*, 62(17), 6120-6145. doi: 10.1080/00207543.2024.2309309.
- [3] Sukharamwala, U. C., & Won, D. (2026). LLM4SCM: A framework for intelligent supply chain decisions. *International Journal of Production Research*. doi: 10.1080/00207543.2026.2682360.
- [4] Chen, W., et al. (2024). Artificial intelligence in logistics optimization with sustainable criteria: A review. *Sustainability*, 16(21), 9145. <https://doi.org/10.3390/su16219145>.
- [5] Jiang, Y., et al. (2025). *Integrated sensing and communication for low altitude economy: Opportunities and challenges*. IEEE Communications Magazine, 72-78. <https://doi.org/10.1109/MCOM.001.2400685>.
- [6] Chien, C.-H., Chen, P.-Y., Trappey, A. J. C., & Trappey, C. V. (2022). Intelligent supply chain management modules enabling advanced manufacturing for the electric-mechanical equipment industry. *Complexity*, 2022, 8221706. <https://doi.org/10.1155/2022/8221706>.
- [7] Wamba, S. F., et al. (2024). ChatGPT and generative artificial intelligence: An exploratory study of key benefits and challenges in operations and supply chain management. *International Journal of Production Research*, 62(16), 5676-5696. doi:10.1080/00207543.2023.2294116.
- [8] Wang, Y. (2026). Internal logic and empirical investigation on the impact of low-altitude economy on new quality productive forces in logistics industry. *Journal of Commercial Economics*, (11), 84-87. https://kns.cnki.net/kcms2/article/abstract?v=GB7hzhCfPWiXHKLmk_sDQM8f4ANzRWXWiB8FF6Z07UmEFECei4nlHhQngWhHs0wEveALt4enEIS2UJ_sHKsWLy5R-uoJAX87PWM7HHnTBVDqrXglWu6cG0hyLu0w24GKWyEqINShJA0pf4AtXA Hn2INo-c6PqWP&uniplatform=NZKPT.
- [9] Wei, Q., Li, R., Bai, W., & Han, Z. (2025). *Multi-UAV-enabled energy-efficient data delivery for low-altitude economy: Joint coded caching, user grouping, and UAV deployment*. IEEE Internet of Things Journal, 12(14), 27519-27532. <https://doi.org/10.1109/JIOT.2025.3562872>.
- [10] Zheng, X., et al. (2025). UAV swarm-enabled collaborative post-disaster communications in low altitude economy via a two-stage optimization approach. *IEEE Transactions on Mobile Computing*, 24(11), 11833-11851. doi:10.1109/TMC.2025.3583510.