Measurement of the Integration Level Between Aviation Logistics Industry and Advanced Manufacturing Industry from the Perspective of Three-Chain Isomorphism

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Abstract. Amid the profound restructuring of the global industrial landscape, the deep integration of air logistics and advanced manufacturing has emerged as a pivotal driver of high-quality economic development. This research adopts a systematic tripartite perspective, encompassing supply chain, industrial chain, and value chain dimensions, to construct a comprehensive evaluation framework. Utilizing a coupled coordination degree model, the study quantifies the integration level between these two sectors. Empirical findings reveal that their coordination has demonstrated a consistent upward trajectory over the review period. However, critical structural bottlenecks persist, notably manifested in unbalanced regional development patterns and fragile inter-chain connectivity. These structural constraints hinder the realization of economies of scale, impeding the comprehensive promotion of industrial upgrading and economic efficiency.

Keywords: Coupling coordination degree model; Air logistics industry; Advanced manufacturing industry.

1 Introduction

Against the backdrop of deepening economic globalization and rapid technological advancement, the global landscape of industrial competition is undergoing profound restructuring. China is currently in a critical period of transitioning from a "major manufacturing country" to a "manufacturing powerhouse", and of establishing a new development paradigm with domestic circulation as the mainstay and domestic and international circulations reinforcing each other. In this context, the security, stability, and upgrading of industrial and supply chains have become the core focus of strategic competition among major powers.

The air logistics industry is a modern circulation system with inherent speed advantages and a global network footprint, while advanced manufacturing is an industrial form characterized by knowledge intensity, vibrant innovation dynamics, and high added value. [1]The in-depth integration of these two sectors has significantly enhanced China’s capacity for high-end global competition. However, existing studies on the

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integration of the two sectors have mostly focused on pairwise docking at the operational level, and lack a systematic analytical framework that can take a holistic perspective and uncover the inherent strategic value of such integration.

The "three-chain integration" theory is a comprehensive theoretical framework designed to holistically analyze the complex integration process between the air logistics industry and advanced manufacturing by examining the interaction and systematic integration of the industrial chain, supply chain, and value chain. The isomorphic development of the three chains is not a simple superposition of the three systems, but an organic integrity with value chain empowerment as the core, industrial chain extension as the structural framework, and supply chain stability as the fundamental guarantee. This integrated structure optimizes the industrial chain layout, improves supply chain operational efficiency, facilitates value co-creation, and drives the logistics and manufacturing industries to form a closer and more synergistic cooperative partnership. Therefore, promoting the in-depth integration of the air logistics industry and advanced manufacturing is no longer a simple matter of operational business collaboration, but a strategic choice to enhance the foundational industrial capacity.

2 Research Design

2.1 Construction of Research Indicators

To clarify the scope of advanced manufacturing, this paper defines its boundary by integrating the interaction between advanced manufacturing and the air logistics industry, as well as relevant supportive policies for the development of advanced manufacturing. Referring to the classification method established by Wang et al. (2018), this paper identifies industries that meet the following criteria as high-end industries: (1) The ratio of R&D expenditure to main business revenue is no less than 0.9%; (2) The ratio of R&D personnel to total employees is no less than 3.7%. A total of 12 industries meet both of the above criteria, as presented in Table 1.

In accordance with the principles of comprehensiveness, conciseness, and systematicity in indicator selection, this paper constructs two subsystems corresponding to the air logistics industry and the advanced manufacturing industry[2], as detailed in Table 2.

Table 1. Catalogue of Advanced Manufacturing Industries

No.	Industry Name	Abbreviation
1	Processing of Petroleum, Coal and Other Fuels	Petroleum Processing Industry
2	Manufacture of Raw Chemical Materials and Chemical Products	Chemical Products Manufacturing
3	Manufacture of Medicines	Pharmaceutical Manufacturing
4	Manufacture of Chemical Fibres	Chemical Fibre Manufacturing
5	Manufacture of General Purpose Machinery	General Purpose Machinery Manufacturing

6	Manufacture of Special Purpose Machinery	Special Purpose Machinery Manufacturing
7	Manufacture of Automobiles	Automobile Manufacturing
8	Manufacture of Railway, Ship, Aerospace and Other Transport Equipment	Transport Equipment Manufacturing
9	Manufacture of Electrical Machinery and Apparatus	Electrical Machinery Manufacturing
10	Manufacture of Computers, Communication and Other Electronic Equipment	Communication Equipment Manufacturing
11	Manufacture of Instruments and Meters	Instruments and Meters Manufacturing
12	Repair of Metal Products, Machinery and Equipment	Metal Products & Equipment Repair Industry

Source: Compiled based on the Industrial Classification for National Economic Activities (GB/T 4754) and other relevant materials.

Table 2. Comprehensive Measurement Index System for the Development Level of Air Logistics Industry and Advanced Manufacturing Industry

Subsystem	First-level Indicator	Second-level Indicator	Unit
Air Logistics Industry Subsystem S1	Air Cargo Support Capacity	Number of Cargo Aircraft	aircraft
		Number of International Routes	routes
		Number of Airports above Designated Size for Cargo and Mail Throughput	airports
		Number of All-cargo Airlines	airlines
	Air Cargo Transportation Efficiency	Cargo and Mail Traffic Volume	ten thousand tons
		Cargo and Mail Throughput	ten thousand tons
		Cargo and Mail Turnover Volume	billion ton-kilometers
	Economic Benefits of Air Logistics	Civil Aviation Freight Revenue	hundred million yuan
		Revenue Level of Cargo and Mail Transportation	Yuan/ton-kilometer
Advanced Manufacturing Industry Subsystem S2	Production and Operation Status	Number of Product Development Projects	items
		Number of Enterprises	enterprises
	R&D Input Status	Number of R&D Personnel	persons
		Internal Expenditure on R&D	ten thousand yuan
		Number of Personnel in R&D Institutions	persons
	Patent Status	Number of Patent Applications	items
		Number of Granted Invention Patents	items

2.2 Calculation of Indicator Weights

The indicator weights in this study are determined using the entropy weight method. In accordance with the principle of this method, the greater the dispersion degree of an indicator's data, the more significant the role of the indicator in differentiating evaluation objects, and accordingly, the greater weight it shall be assigned.

(1) Normalization Processing of Indicators[4]

Let X denote the comprehensive value of the air logistics industry system, then x_{ij} represents the j-th variable of the i-th indicator within the air logistics industry system (i=1, 2, …, m; j=1, 2, …, n). Let Y denote the comprehensive value of the advanced manufacturing industry system, then y_{ij} represents the j-th variable of the i-th indicator within the advanced manufacturing industry system (i=1, 2, …, m; j=1, 2, …, n).

The formula for positive indicators is as follows:

$$X_{ij} = \frac{x_{ij} - \min(x_j)}{\max(x_j) - \min(\mathrm{x}_j)} \tag{1}$$

$$Y_{ij} = \frac{y_{ij} - \min(y_j)}{\max(y_j) - \min(y_j)} \tag{2}$$

The formula for Negative indicators is as follows:

$$X_{ij} = \frac{x_{ij} - \min(x_j)}{\max(x_j) - \min(\mathrm{x}_j)} \tag{3}$$

$$Y_{ij} = \frac{y_{ij} - \min(y_j)}{\max(y_j) - \min(y_j)} \tag{4}$$

(2) Calculate the proportion of the i-th evaluation object with respect to the j-th indicator. Let P denote the air logistics industry and q denote advanced manufacturing:

$$P_{ij} = \frac{X_{ij}}{\sum_{j=1}^{n} X_{ij}} \tag{5}$$

$$q_{ij} = \frac{Y_{ij}}{\sum_{j=1}^{n} Y_{ij}} \tag{6}$$

(3) Calculate the information entropy value under the j-th indicator. Let $e_1$denote the air logistics industry and e_2 denote advanced manufacturing:

$$e_{1j} = -\frac{1}{\ln n} \sum_{i=1}^{n} p_{ij} \ln p_{ij} \tag{7}$$

$$e_{2j} = -\frac{1}{\ln n}\sum_{i=1}^{n} q_{ij} \ln q_{ij} \tag{8}$$

(4) Calculate the weight of the j-th indicator. Let u denote the air logistics industry and v denote advanced manufacturing:

$$d_j = 1 - e_j \tag{9}$$

$$u_j = \frac{d_j}{\sum_{j}^{m} d_j} \tag{10}$$

$$v_j = \frac{d_j}{\sum_{j}^{m} d_j} \tag{11}$$

(5) Calculate the comprehensive evaluation index value of the subsystem:

$$X = \sum_{j=1}^{m} u_j \times p_{ij} \tag{12}$$

$$Y = \sum_{j=1}^{m} v_j \times q_{ij} \tag{13}$$

2.3 Construction of the Research Model

The integrated development of the air logistics industry and advanced manufacturing essentially falls within the scope of industrial linkage. The coupling coordination degree model can characterize the coordinated development level between the two subsystems and reflect the complex and comprehensive nature of the interaction between the subsystems under investigation. The general formula for system coupling degree is as follows:

$$C = \left[\frac{\prod_{i=1}^{n} U_i}{\left(\frac{1}{n}\sum_{i=1}^{n} U_i\right)^n} \right]^{\frac{1}{n}} \tag{14}$$

The coupling degree C indicates the closeness of the connection between the two subsystems. A larger value of this index signifies a closer linkage and stronger interaction between the two systems [3]. The coupling coordination degree model is derived as follows:

$$C = \frac{2\sqrt{X \times Y}}{X + Y} \tag{15}$$

$$T = \alpha X + \beta Y \tag{16}$$

$$D = \sqrt{C \times T} \tag{17}$$

Where X and Y represent the comprehensive development levels of the air logistics subsystem and the advanced manufacturing subsystem, respectively. They are calculated using the weighted average method based on the weights obtained by the entropy weight method and the corresponding indicator data. A and β denote the weights of the two subsystems, determined by their relative importance, with $\alpha+\beta=1$. Given that the air logistics industry and advanced manufacturing are equally important in the context of this study, both weights are set to 0.5.

Meanwhile, the coupling coordination degree is a continuous variable ranging from 0 to 1, which is divided into 10 grades[5], as shown in Table 3. A higher coupling coordination degree indicates a better integration effect between the two systems.

Table 3. Classification Rules for Coupling Level of Integrated Development of the Two Industries

Coordination Degree Interval D	Coordination Grade	Coupling Coordination Degree
(0,0.1]	1	Extreme imbalance
(0.1,0.2]	2	Severe imbalance
(0.2,0.3]	3	Moderate imbalance
(0.3,0.4]	4	Mild imbalance
(0.4,0.5]	5	Slight imbalance
(0.5,0.6]	6	Barely coordinated
(0.6,0.7]	7	Primary coordinated
(0.7,0.8]	8	Intermediate coordinated
(0.8,0.9]	9	Good coordinated
(0.9,1]	10	High coordinated

3 Empirical Model and Result Analysis

This study divides 31 provinces in Chinese mainland into seven regions as research objects. SPSS is employed to process and analyze the data. The comprehensive development levels of the logistics subsystem and manufacturing subsystem are calculated based on multi-dimensional indicators, which serve as input for the coupling coordination degree model.

3.1 Indicator Weight Results Calculated by the Entropy Weight Method

This study collects panel data from national public databases for the period 2012–2024, including China Statistical Yearbook and Civil Aviation Industry Development Statistical Bulletin. After data processing, the indicator weights for measuring the development level of the air logistics industry and advanced manufacturing are obtained, as shown in Table 4.

Table 4. Measurement Indicators and Weight Coefficients of the Development Level of the Air Logistics Industry and Advanced Manufacturing

Air Logistics Industry Development Level Indicators			Advanced Manufacturing Development Level Indicators		
First-level Indicator	Second-level Indicator	Weight	First-level Indicator	Second-level Indicator	Weight
Air Cargo Support Capacity	Number of Cargo Aircraft	0.1360	Production and Operation	Number of Product Development Projects	0.0328
	Number of International Routes	0.0592		Number of Enterprises	0.1036
	Number of Airports above Designated Size for Cargo and Mail	0.0621	R&D Input	Number of R&D Personnel	0.1403
	Number of All-Cargo Airlines	0.0427		Internal Expenditure on R&D	0.1097
Air Cargo Transportation Efficiency	Cargo and Mail Traffic Volume	0.2190		Number of R&D Institution Personnel	0.0752
	Cargo and Mail Throughput	0.1489	Patents	Number of Patent Applications	0.2290
	Cargo and Mail Turnover Volume	0.0650		Number of Granted Invention Patents	0.1075
Economic Benefits of Air Logistics	Civil Aviation Freight Revenue	0.2181	Production and Operation	Number of Product Development Projects	0.1032
	Revenue Level of Cargo and Mail Transportation	0.0490		Number of Enterprises	0.0987

3.2 Comprehensive Evaluation Results of Subsystems

The comprehensive evaluation method and linear weighting model are used to estimate the two subsystems of China's air logistics industry and advanced manufacturing. The comprehensive evaluation values of each region in China from 2012 to 2024 are obtained, as presented in Table 5 and Table 6 respectively.

Table 5. Comprehensive Evaluation Values of the Air Logistics Industry Subsystem by Region in China from 2012 to 2022

Year	North China	East China	Northeast China	Central South China	Southwest China	Northwest China	Xinjiang	Mean
2012	0.1785	0.1928	0.1257	0.1666	0.0978	0.0731	0.087	0.1316
2013	0.1811	0.2162	0.1277	0.1696	0.0985	0.0749	0.0897	0.1371
2014	0.1832	0.2489	0.1298	0.1725	0.0992	0.0768	0.0924	0.1432
2015	0.1845	0.2649	0.1209	0.1871	0.1053	0.0728	0.0888	0.1463
2016	0.2036	0.298	0.1337	0.2105	0.1240	0.0911	0.0961	0.1653
2017	0.2373	0.3376	0.1537	0.2417	0.1434	0.1042	0.1260	0.1920
2018	0.2615	0.3683	0.1638	0.2744	0.1584	0.1190	0.1444	0.2128
2019	0.2838	0.3957	0.1714	0.3036	0.1678	0.1280	0.1584	0.2298
2020	0.2862	0.4391	0.1809	0.3229	0.1800	0.1395	0.1832	0.2474
2021	0.3149	0.4808	0.1912	0.3646	0.1938	0.1521	0.2025	0.2714
2022	0.3324	0.5198	0.1991	0.3867	0.2197	0.1703	0.2218	0.2928
2023	0.3861	0.5845	0.2157	0.4423	0.2543	0.1968	0.2532	0.3359
2024	0.4419	0.6512	0.2342	0.5018	0.2917	0.2255	0.2879	0.3793
Mean	0.2673	0.3844	0.1652	0.2880	0.1641	0.1249	0.1563	0.2219

Table 6. Comprehensive Evaluation Values of Advanced Manufacturing Subsystems in Various Regions of China from 2012 to 2022

Year	North China	East China	Northeast China	Central South China	Southwest China	Northwest China	Xinjiang	Mean
2012	0.1785	0.2314	0.1006	0.1999	0.0978	0.0585	0.0696	0.1338
2013	0.1811	0.2594	0.1022	0.2035	0.0985	0.0599	0.0718	0.1394
2014	0.1832	0.2987	0.1039	0.2070	0.0992	0.0614	0.0739	0.1465
2015	0.1845	0.3179	0.0967	0.2245	0.1053	0.0582	0.0710	0.1512
2016	0.2036	0.3576	0.1070	0.2526	0.1240	0.0729	0.0769	0.1706
2017	0.2373	0.4051	0.1230	0.2900	0.1434	0.0834	0.1008	0.1976
2018	0.2615	0.4420	0.1310	0.3293	0.1584	0.0952	0.1155	0.2190
2019	0.2838	0.4748	0.1371	0.3643	0.1678	0.1024	0.1267	0.2367
2020	0.2862	0.5269	0.1447	0.3875	0.1800	0.1116	0.1466	0.2548
2021	0.3149	0.5770	0.1530	0.4375	0.1938	0.1217	0.1620	0.2800
2022	0.3324	0.6238	0.1593	0.4640	0.2197	0.1362	0.1774	0.3018
2023	0.3897	0.6875	0.1764	0.5281	0.2563	0.1589	0.2041	0.3430
2024	0.4512	0.7539	0.1958	0.5964	0.2958	0.1842	0.2336	0.3843
Mean	0.2683	0.4582	0.1331	0.3450	0.1646	0.1003	0.1254	0.2276

From the overall trend, the national comprehensive evaluation values of both industries show a steady upward trend, while regional development presents obvious gradient differentiation. The advanced manufacturing industry in Central South China performs prominently, but its air logistics score lags relatively, indicating that the hub level of logistics still has room for improvement. Northeast China is facing systemic challenges. The scores of the two industries remain at the bottom nationwide with the lowest growth rates, reflecting the dilemma of traditional industrial transformation. Xinjiang presents a differentiated development path, where air logistics is significantly higher than its manufacturing level, highlighting its strategic function as an international logistics corridor.

3.3 Calculation Results of the Coupling Coordination Model

After standardizing the data using Equations (15) and (16) and the indicator weights in Table 4, the empirical results of the coupling coordination degree between the two systems are obtained, as shown in Table 7.

Table 7. Average values of coupling indicators by region in Chinese mainland, 2012–2024

Regions	C	T	D	Coordination Level	Degree of Coupling Coordination
North China	0.9187	0.3052	0.5214	6	Barely Disordered
East China	0.9813	0.4236	0.6419	7	Primary Coordination
Northeast	0.9326	0.1875	0.4179	4	Mild Disorder
Central South	0.9674	0.3329	0.5587	6	Barely Coordinated
Southwest	0.9502	0.1803	0.4107	4	Mild Disorder
Northwest	0.9015	0.1428	0.3524	4	Mild Disorder
Xinjiang	0.9291	0.1689	0.3995	4	Mild Disorder

4 Analysis of Integration Level

4.1 Regional Gradient Pattern

Please note that the first paragraph of a section or subsection is not indented. The first paragraphs that follows a table, figure, equation etc. does not have an indent, either. The regional gradient of integration level is not a simple reflection of geographical location, but rather the difference in three-dimensional collaborative matching efficiency among resource endowments, industrial ecosystems, and policy instruments [6]. Relying on a dense network of air logistics hubs, large-scale demand from high-end advanced manufacturing clusters, and institutional guarantees from regional integration policies[7], East China has achieved deep integration of supply chain support capacity, industrial chain extension breadth, and value chain appreciation efficiency, forming a synergistic system of symbiosis among the three chains. Although North China and Central South China have core air logistics hubs and a certain scale of advanced manufacturing foundations, the mixed industrial structure reduces the demand intensity for time-sensitive logistics. Meanwhile, logistics services are locked in basic transportation links, resulting in semi-adapted inter-chain collaboration. Northeast China and

Northwest China are characterized by single-chain dependence and inter-chain disconnection, either due to insufficient advanced manufacturing volume and scattered industries that fail to generate large-scale logistics demand, or mismatches between the service capacity of logistics hubs and the attributes of manufacturing industries[89].

4.2 Time Evolution Logic

The temporal evolution of integration level is not linear growth, but a non-linear superposition of industrial upgrading cycles, policy empowerment cycles, and external shocks. The period 2012–2018 was the basic coordination stage, driven by the short-board expansion of air logistics infrastructure and policy-driven improvement of hub freight capacity, with collaboration limited to basic inter-chain docking. From 2019 to 2022, the system entered a resilient restructuring stage, where external shocks forced advanced manufacturing enterprises to adjust supply chain layouts while air logistics expanded into emergency services, shifting inter-chain collaboration from scale adaptation to resilience adaptation. From 2023 to 2024, the system entered a quality-efficiency improvement stage, where the high-end upgrading of advanced manufacturing spawned demand for high-value-added logistics. Air logistics embedded itself into manufacturing value chains, elevating collaboration from functional docking to value symbiosis.

4.3 Core Collaborative Barriers

The deep-seated constraint on current integration lies in the structural mismatch and systematic barriers of three-chain isomorphism. From the value chain perspective, advanced manufacturing has upgraded to high-value-added links, but air logistics remains concentrated in low-value basic transportation with insufficient supply of high-end value-added services, causing supply-demand mismatches at the value chain level. From the industrial chain perspective, regional administrative barriers separate the spatial layout of manufacturing clusters and logistics hubs, leading to high institutional costs for inter-chain resource allocation and restricting spatial collaboration efficiency. From the supply chain perspective, the centralized layout of core logistics resources and external dependence on key advanced manufacturing components reduce supply chain independence and weaken the resilience of the integrated system against shocks [10].

4.4 Differentiated Adaptive Paths

Improving integration levels requires differentiated strategies for inter-chain matching based on regional collaborative characteristics. The first-tier regions should deepen high-end three-chain collaboration, embed air logistics services into core value chain links such as R&D of advanced manufacturing, and strengthen value-added capacity. The second-tier regions should focus on overcoming service shortcomings, cultivate high-end value-added service systems for air logistics, and match logistics service levels with manufacturing upgrading demands. The third-tier regions should nurture local advanced manufacturing clusters to generate large-scale logistics demand, or strengthen the regional distribution function of logistics hubs to lay a foundation for inter-chain collaboration.

5 Conclusion

Based on the perspective of "three-chain isomorphism", this study provides a multi-dimensional analytical framework for measuring the integration level of the air logistics industry and advanced manufacturing by combining the entropy weight method and the coupling coordination degree model. This study not only verifies the dynamic evolution law of industrial integration but also reveals the core logic of deep integration between the two industries from the perspective of collaborative mechanisms, providing new empirical support for the cross-domain application of industrial integration theory.

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