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Research on the Evaluation Indicator System for the Logistics Development Level of the Yangtze River Delta Urban Agglomeration

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Abstract: *Against the background that the integrated development of the Yangtze River Delta has been elevated to a national strategy, the logistics development level of cities in the Yangtze River Delta is directly related to regional industrial synergy, resource allocation efficiency, and the effectiveness of high-quality economic development. Based on the core connotation of logistics development and the needs of integrated development in the Yangtze River Delta, this study constructs an evaluation indicator system using the Analytic Hierarchy Process (AHP). The system covers five dimensions: infrastructure capacity, logistics operational efficiency, industrial synergy and supply chain resilience, green development level, and digitalization and intelligentization level. The results show that, at the stage of high-quality development, the core development dimensions of the logistics system in the Yangtze River Delta urban agglomeration have shifted toward green development, digitalization, and intelligentization. This indicates that the evaluation paradigm for regional logistics systems has moved from the traditional criteria dominated by scale expansion and circulation speed to an integrated performance-oriented system that emphasizes environmental sustainability, technological integration and innovation, and the realization of the value of data elements.*

Keywords: *Yangtze River Delta urban agglomeration; logistics development level; evaluation indicator system; Analytic Hierarchy Process*

1. Introduction

Regional logistics is a key factor in promoting high-quality and coordinated regional economic development, while the regional logistics network serves as the basic framework supporting the normal operation of the logistics system and ensuring the smooth performance of regional logistics functions [1]. Li Quanxi and other scholars first defined the connotation of regional logistics quality and summarized it in multiple dimensions, including logistics scale, economic conditions, the degree of infrastructure improvement, informatization level, and energy consumption [2]. As one of China's most economically dynamic, open, and innovative regions, the Yangtze River Delta urban agglomeration is an important growth pole and source of momentum for China's high-quality development. As an important component of regional economic development, the logistics industry directly affects regional resource allocation efficiency, industrial synergy, and the process of integrated development. With the in-depth implementation of the Outline of the Yangtze River Delta Regional Integrated Development Plan, building a modern logistics system and promoting coordinated regional logistics development have become important tasks for the integrated development of the Yangtze River Delta.

At present, cities within the Yangtze River Delta urban agglomeration differ in their economic foundations, industrial structures, and locational conditions, resulting in an uneven logistics development level. This restricts, to some extent, the optimal allocation of regional logistics resources and the full realization of coordination efficiency. Therefore, scientifically constructing an evaluation indicator system for logistics development level, accurately measuring the logistics development status of each city, and identifying regional strengths and weaknesses are of great practical significance for promoting coordinated and integrated logistics development in the Yangtze River Delta urban agglomeration and enhancing the overall regional competitiveness.

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2. Construction of the Evaluation Indicator System for Logistics Development Level

The urban logistics development level refers to the comprehensive capacity to optimize the allocation of logistics resources within a city, improve the efficiency of the logistics system, and promote the coordinated development of the urban economy, society, and environment. Urban economic development seeks to obtain greater economic, environmental, and social benefits with the least possible consumption of resources and costs, emphasizing people-oriented development, sound ecological benefits, and optimal resource allocation. Based on urban economic theory and from the perspective of symbiosis among the economy, resources, and the environment, it is possible to realize resource sharing across different logistics links, transform the negative impacts of logistics activities on urban operations into positive effects on urban development, and guide urban logistics toward efficiency, intelligence, and sustainability. According to the connotation of urban logistics development level, and taking into account the development characteristics of urban logistics in the Yangtze River Delta and existing research findings, its evaluation can be divided into five dimensions: infrastructure capacity, logistics operational efficiency, industrial synergy and supply chain resilience, green development level, and digitalization and intelligentization level. The selection of indicators considers scientific validity, representativeness, and data availability. It highlights the operational efficiency and support capacity of urban logistics while reflecting the development directions of coordination, greening, and intelligence, thereby forming the evaluation indicator system of this study.

2.1. Infrastructure Capacity

The infrastructure capacity dimension measures the physical conditions of the logistics network, including the quantity, scale, and modernization level of ports, airports, railways, roads, and warehousing facilities. Its role is to determine the carrying capacity, service scope, and basic architecture of the entire regional logistics system. Sound infrastructure is a prerequisite for the development of multimodal transport. It directly affects the circulation efficiency of bulk cargo and foreign trade materials and provides the hardware support for regional economic scale expansion and participation in the division of labor in global supply chains. Therefore, infrastructure capacity indicators should be included in logistics evaluation, with particular attention to port cluster scale and air cargo capacity. On this basis, infrastructure capacity can be evaluated using five indicators: port cluster scale, air cargo capacity, multimodal transport nodes, road network density, and warehousing facilities. Among them, port cluster scale reflects the connection strength between the region and global supply chains as well as its foreign trade capacity, and it is a key carrier of international logistics corridors. Air cargo capacity is used to measure the rapid circulation and support level for high-value and time-sensitive goods, emergency supplies, and cross-border e-commerce commodities. The evaluation of multimodal transport nodes focuses on whether efficient connection and smooth conversion can be achieved among road, railway, waterway, and air transport. Road network density reflects the coverage and accessibility of inland transport networks within the region. Warehousing facilities provide the basic support conditions for quality stability and operational efficiency in the storage link.

2.2. Logistics Operational Efficiency

The logistics operational efficiency dimension reflects the speed, cost, and reliability of the logistics system in actual operation. Its core function is to reveal the effectiveness with which infrastructure inputs are transformed into actual logistics services [3]. Efficient operations can reduce total social logistics costs, accelerate commodity circulation and capital turnover, directly enhance the market competitiveness of enterprises within the region, and provide convenience for residents' consumption and daily life. It is therefore the most direct manifestation of the core competitiveness of the logistics system. Based on relevant literature, this study identifies five indicators for evaluating logistics operational efficiency: freight transport timeliness, share of multimodal transport, port customs clearance efficiency, vehicle empty running rate, and share of logistics costs. Freight transport timeliness directly reflects logistics speed, while the share of multimodal transport measures the degree of optimization of the transport structure. Port customs clearance efficiency is a core indicator for evaluating trade facilitation and directly affects the certainty of cross-border logistics and the international competitiveness of enterprises. The vehicle empty running rate reflects the degree of organization and informatization of the freight market as well as resource utilization efficiency. The share of logistics costs measures the support efficiency of the logistics system for the national economy.

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2.3. Industrial Synergy and Supply Chain Resilience

This dimension evaluates the depth of linkage between the logistics system and real industries within the region, especially manufacturing, as well as the system's capacity for adjustment and recovery in response to external shocks. Its significance lies in measuring the extent to which logistics is no longer an isolated link but is embedded in and serves regional industrial clusters. Strong synergy can optimize industrial inventory layout and reduce total supply chain costs, while resilience ensures the stability of industrial chains in the face of emergencies. It is therefore a key form of soft power for safeguarding regional economic security and competitiveness [4]. Based on this theoretical consideration, this study identifies three evaluation indicators for industrial synergy and supply chain resilience: industrial cluster linkage index, emergency logistics capability, and proportion of green logistics facilities. The industrial cluster linkage index evaluates how deeply logistics is embedded in regional industrial chains. Emergency logistics capability measures the ability of the logistics network to achieve rapid reconstruction, priority assurance, and resource scheduling under shocks such as natural disasters and public health emergencies. The indicator of the proportion of green logistics facilities reflects the incorporation of green elements into the construction of logistics and supply chain resilience.

2.4. Green Development Level

The green development level dimension measures the performance of logistics activities in terms of energy consumption, emission control, and resource recycling. Its important role is to incorporate environmental externalities into the evaluation of the logistics system and guide the logistics development model toward coordination with the carrying capacity of the ecological environment. Promoting green logistics is not only a response to social responsibility but also a source of long-term economic benefits through energy conservation, emission reduction, and recycling. It is the core constraint and development direction for the sustainable development of the logistics system. Accordingly, this study identifies three indicators for evaluating green development level: carbon emissions per unit of freight transport, green packaging utilization rate, and new energy infrastructure. Carbon emissions per unit of freight transport is a core outcome indicator for measuring the low-carbon performance of the logistics system. The green packaging utilization rate reflects packaging pollution issues arising from consumer logistics such as express delivery and e-commerce and promotes resource recycling. The completeness of new energy infrastructure directly determines the feasibility and scope of promoting and applying clean-energy transport equipment.

2.5. Digitalization and Intelligentization Level

This dimension measures the degree of integration between the logistics system and modern information technologies, including data connectivity, automation applications, and intelligent decision-making. Its important role is to promote the transformation of the logistics system from labor- and capital-driven development to technology- and data-driven development. The intelligent development of logistics can help the logistics industry control costs [5]. Digitalization breaks information silos and realizes process visibility and coordination, while intelligentization improves operational efficiency and precision. This is the core driving force for the transformation and upgrading of the logistics industry and determines the flexibility and innovation capability of future logistics systems. Based on existing theoretical analysis, this study identifies three indicators for evaluating digitalization and intelligentization level: logistics information platform coverage, intelligent technology application, and data openness. Logistics information platform coverage reflects the degree of interconnection and interoperability of logistics data. Intelligent technology application, especially automation and unmanned technologies, can directly improve operational efficiency, accuracy, and safety. The degree of data openness determines whether high-quality logistics data can be provided.

3. AHP Analysis of the Logistics Development Level of the Yangtze River Delta Urban Agglomeration

3.1. Establishing the Analytic Hierarchy Model

Based on the logistics development characteristics of the Yangtze River Delta urban agglomeration, this study uses the Analytic Hierarchy Process to construct an evaluation indicator system for the

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logistics development level of the Yangtze River Delta urban agglomeration (see Figure 1). The evaluation indicator system for urban logistics in the Yangtze River Delta is taken as the objective layer, and the five dimensions of the indicator system are taken as the criterion layer.

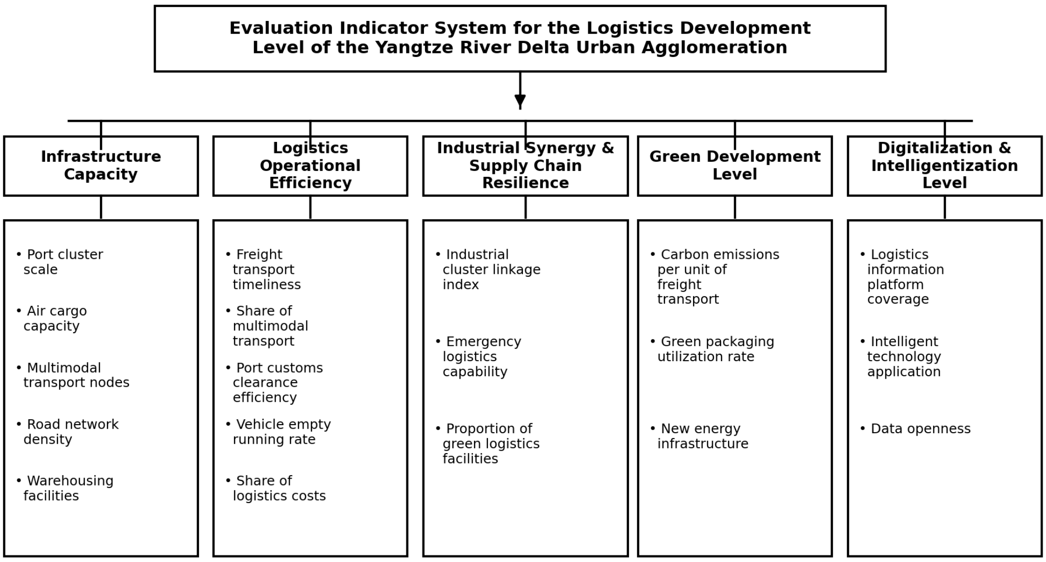

Figure 1. Evaluation indicator system for the logistics development level of the Yangtze River Delta urban agglomeration

3.2. Constructing Pairwise Comparison Matrices and Determining Indicator Weights

Using Saaty's 1–9 scale method, experts were invited to conduct pairwise comparisons of the indicators used in logistics evaluation. Based on practical considerations, the overall judgment matrix from the objective layer to the criterion layer and the judgment matrices from the criterion layer to the indicator layer were obtained. Indicator weights were then calculated based on the judgment matrices, followed by consistency tests. This section presents the judgment matrix for the overall objective and criterion layer, as well as the judgment matrix relative to infrastructure capacity, and conducts consistency tests. The remaining judgment matrices for secondary indicators, which are not listed here, all passed the consistency test.

(1) Construction of the comparison matrix from the objective layer to the criterion layer and consistency test

The expert consultation method was adopted to conduct pairwise comparisons of the first-level indicators in the criterion layer, namely infrastructure capacity, logistics operational efficiency, industrial synergy and supply chain resilience, green development level, and digitalization and intelligentization level. The judgment matrix from the objective layer to the criterion layer, namely the first-level indicator judgment matrix, is shown in Table 1. A consistency test was then conducted using the pairwise comparison matrix to determine the rationality and validity of the assigned weights. The calculation process is as follows: according to the formula, the maximum eigenvalue of the judgment matrix is obtained, then the consistency index is calculated. The consistency ratio is CR = CI/RI. When CR < 0.1, the matrix passes the consistency test.

$$\lambda max = (1/n)\Sigma[(AW)i/Wi]\ (i = 1, 2, \ldots, n);\ \ CI = (\lambda max - n)/(n - 1);\ \ CR = CI/RI$$

Table 1. Judgment matrix with respect to the overall objective criteria

	Infrastructure Capacity	**Logistics Operational Efficiency**	**Industrial Synergy and Supply Chain Resilience**	**Green Development Level**	**Digitalization and Intelligentization Level**
Infrastructure Capacity	1	1	1/3	1/2	1/4
Logistics Operational Efficiency	1	1	1/2	3	1/2
Industrial Synergy and Supply Chain Resilience	3	2	1	1	1

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	Infrastructure Capacity	Logistics Operational Efficiency	Industrial Synergy and Supply Chain Resilience	Green Development Level	Digitalization and Intelligentization Level
Green Development Level	2	1/3	1	1	1/3
Digitalization and Intelligentization Level	4	2	1	3	1

The calculation gives λmax = 5.39 and CI = 0.098. According to the RI table, the corresponding RI value is 1.11. Therefore, CR = CI/RI = 0.088 < 0.1, indicating that the matrix passes the consistency test.

(2) Construction of the comparison matrix from the criterion layer to the indicator layer and consistency test

The 19 evaluation indicators affecting the logistics development level identified above are taken as the indicator layer, and the judgment matrix from the criterion layer to the indicator layer for urban logistics evaluation, namely the secondary indicator judgment matrix, is obtained. The judgment matrix relative to infrastructure capacity is shown in Table 2. Its weights are then calculated and tested for consistency.

Table 2. Judgment matrix with respect to infrastructure capacity

	Port Cluster Scale	Air Cargo Capacity	Multimodal Transport Nodes	Road Network Density	Warehousing Facilities
Port Cluster Scale	1	1/2	1/3	1	1/4
Air Cargo Capacity	2	1	1/2	3	1/2
Multimodal Transport Nodes	3	2	1	2	1
Road Network Density	1	1/3	1/2	1	1/3
Warehousing Facilities	4	2	1	3	1

The calculation gives λmax = 5.099 and CI = 0.025. According to the RI table, the corresponding RI value is 1.11. Therefore, CR = CI/RI = 0.022 < 0.1, indicating that the matrix passes the consistency test.

(3) Calculation of the weights of evaluation indicators

By solving the above judgment matrices and comparing the table data with the corresponding RI values, it can be seen that all judgment matrices pass the consistency tests and that the calculation results are acceptable. The final weights of the evaluation indicator system are therefore obtained. The weight allocation and analysis results of all factors are shown in Table 3.

Table 3. Weight allocation and analysis of secondary indicators

First-level Indicator	Weight	Second-level Indicator	Weight Relative to Objective Layer	Weight Relative to Criterion Layer	Rank
Infrastructure Capacity	0.0951	Port Cluster Scale	0.0915	0.071	11
Infrastructure Capacity	0.0951	Air Cargo Capacity	0.1931	0.0509	17
Infrastructure Capacity	0.0951	Multimodal Transport Nodes	0.288	0.1242	6
Infrastructure Capacity	0.0951	Road Network Density	0.1012	0.1052	7
Infrastructure Capacity	0.0951	Warehousing Facilities	0.3262	0.1486	5
Logistics Operational Efficiency	0.1789	Freight Transport Timeliness	0.1416	0.0708	12
Logistics Operational Efficiency	0.1789	Share of Multimodal Transport	0.1098	0.0549	16
Logistics Operational Efficiency	0.1789	Port Customs Clearance Efficiency	0.1492	0.0746	10
Logistics Operational	0.1789	Vehicle Empty Running Rate	0.3829	0.1914	3

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First-level Indicator	Weight	Second-level Indicator	Weight Relative to Objective Layer	Weight Relative to Criterion Layer	Rank
Efficiency					
Logistics Operational Efficiency	0.1789	Share of Logistics Costs	0.2165	0.1083	8
Industrial Synergy and Supply Chain Resilience	0.2583	Industrial Cluster Linkage Index	0.1222	0.0367	18
Industrial Synergy and Supply Chain Resilience	0.2583	Emergency Logistics Capability	0.648	0.1944	2
Industrial Synergy and Supply Chain Resilience	0.2583	Proportion of Green Logistics Facilities	0.2299	0.069	13
Green Development Level	0.1442	Carbon Emissions per Unit of Freight Transport	0.5374	0.1612	4
Green Development Level	0.1442	Green Packaging Utilization Rate	0.1946	0.0584	15
Green Development Level	0.1442	New Energy Infrastructure	0.268	0.0804	9
Digitalization and Intelligentization Level	0.3235	Logistics Information Platform Coverage	0.1111	0.0333	19
Digitalization and Intelligentization Level	0.3235	Intelligent Technology Application	0.2222	0.0667	14
Digitalization and Intelligentization Level	0.3235	Data Openness	0.6667	0.2	1

In the weight analysis at the objective layer, the most prominent first-level indicator is the digitalization and intelligentization level, which accounts for 32.35% of the overall influence of the indicator system. It is followed by industrial synergy and supply chain resilience, and logistics operational efficiency. This suggests that the core driving force of the logistics development level in the Yangtze River Delta urban agglomeration has shifted significantly toward new production factors represented by information technology and intelligent systems. From the overall weight distribution, the digitalization and intelligentization level and industrial synergy and supply chain resilience together constitute the key dimensions currently affecting logistics development in the Yangtze River Delta urban agglomeration. This marks a structural transformation in the evaluation orientation of the regional logistics system at the stage of high-quality development: from the previous emphasis on infrastructure scale, logistics circulation speed, and operational efficiency toward a development model led by digital technology, supported by collaborative networks, and grounded in system resilience. At the secondary indicator level, the top three indicators are data openness (20.00%), emergency logistics capability (19.44%), and vehicle empty running rate (19.14%). This indicates that the assessment of the logistics development level in the Yangtze River Delta focuses on digital coordination, resilience, and operational efficiency of the logistics system. As the indicator with the highest weight, data openness reflects the core demand for regional logistics integration and smart logistics development. A high level of data openness can promote information sharing and optimize resource allocation, thereby improving overall logistics efficiency and service quality. Overall, the evaluation of the logistics development level in the Yangtze River Delta emphasizes data-driven coordination and efficiency improvement, while also attaching great importance to the risk-resistance capacity of the system and the economic and environmental performance of actual operations.

Based on the analysis of both first-level and secondary indicators, digitalization and intelligentization level is the most critical core dimension affecting the logistics development level of the Yangtze River Delta urban agglomeration. This shows that intelligent capacity driven by data and technology has become the primary strategic support for the transformation and upgrading of the regional logistics system.

4. Conclusions and Recommendations

4.1. Conclusions

Based on the logic of constructing an indicator system, this study examines the current logistics development status of the Yangtze River Delta urban agglomeration and identifies five relevant

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dimensions and 19 specific indicators that can reflect its current logistics development. It establishes a logistics evaluation indicator system by comprehensively applying literature research and expert interviews. The Analytic Hierarchy Process is then used to calculate the comprehensive weights of the indicator system, and the judgment matrices pass the consistency tests. Among the indicators, digitalization and intelligentization, industrial synergy and supply chain resilience, and logistics operational efficiency have relatively high weights and exert the greatest influence. The indicator system constructed in this paper can comprehensively reflect the multidimensional characteristics of logistics development in the Yangtze River Delta urban agglomeration. Subsequent empirical research can collect relevant data based on this framework for comprehensive measurement, identify weaknesses in regional coordinated development, and provide a scientific basis and decision-making reference for formulating differentiated regional logistics coordination policies, optimizing resource allocation, and enhancing the overall supply chain competitiveness of the Yangtze River Delta.

4.2. Recommendations

The indicator weight analysis shows that data openness, emergency logistics capability, and vehicle empty running rate rank among the top three indicators. This further confirms that the core focus of current logistics development lies in digital coordination, system resilience, and operational efficiency. Therefore, in promoting the modernization of the logistics system in the Yangtze River Delta urban agglomeration, priority should be given to data openness and sharing as well as the integration of intelligent technologies as the core pathways, so as to promote the interconnection of logistics information and the reconstruction of logistics processes within the region. At the same time, systematic construction of emergency logistics systems and supply chain resilience must be highly emphasized. Through the improvement of contingency plans, resource scheduling networks, and multimodal transport systems, the region's stable operation and rapid recovery capacity in complex environments can be enhanced. In addition, transport organization and resource allocation efficiency should be continuously optimized, with special attention paid to controlling operating cost indicators such as vehicle empty running rate, so as to achieve simultaneous improvement in economic and environmental benefits. It is worth noting that although green development level and infrastructure capacity rank relatively low in the indicator system, their importance should not be overlooked. In the future coordinated development of logistics in the Yangtze River Delta, under the drive of smart platforms and digital technologies, green concepts should be deeply integrated with infrastructure modernization. Energy consumption can be reduced through intelligent scheduling, and facility utilization efficiency can be improved through data sharing, thereby forming a sustainable development loop of "technology-driven emission reduction, intelligent facility upgrading, and green system operation." This is not only a key path for shifting from scale expansion to quality and efficiency improvement, but also an important guarantee for realizing low-carbon and intensive logistics development in the Yangtze River Delta. In subsequent policymaking and practical implementation, digital monitoring systems should be used to dynamically evaluate green development performance and infrastructure efficiency, identify weak links, guide resources toward green technologies and new infrastructure, and gradually build a modern logistics ecosystem that is technologically advanced, environmentally friendly, and operationally efficient.

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