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Evaluation Study on the Level of Synergistic Development of Air Cargo in Yangtze River Delta Airport Cluster

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Abstract

The purpose of this article is to study the level of synergistic development of air cargo in the Yangtze River Delta airport cluster and to analyze the factors affecting its development. The article first reviews the rapid growth of the air cargo industry and its role in driving global trade, and then analyzes the current situation of the Yangtze River Delta airport cluster in terms of air cargo, including its uneven development and homogeneous competition. By constructing an indicator system that includes the scale of airport cargo operations, infrastructure development, cargo connectivity, and the level of urban economic development, and applying the entropy weighting method to determine the weights of the indicators, the article evaluates the level of synergistic development of the Yangtze River Delta airport cluster. The results of the study show that although the synergy of the Yangtze River Delta airport cluster has increased in 2023, its overall synergy is still in the low synergy stage. The article further explores the impact of factors such as market concentration, airport strategic positioning and route network overlap on the level of synergy development. Finally, the article puts forward suggestions to improve the level of air cargo synergy development in the Yangtze River Delta airport cluster.

Keywords: Yangtze River Delta airport cluster, air cargo, synergistic development, composite system covariance

1. INTRODUCTION

In recent years, the rapid development of the air cargo industry has had a significant impact on the freight industry. The fast and efficient nature of air transport has made it an indispensable link in globalized trade, contributing to the prosperity of cross-border trade. At the same time, air transportation also supports the development of cross-border e-commerce, improving the speed of delivery of goods and service quality.

Air transportation is particularly suitable for transporting high value-added and urgently needed goods, such as fresh food and medical products, helping to meet the market's demand for fast delivery and quality assurance. According to data from the National Civil Transport Airport Production Statistics Bulletin of past years, the cargo and mail throughput of the country's civil transport airports grew from 11,289,900 tons to 17,101,000 tons between 2010 and 2019, with the industry as a whole completing a total of 7,354,000 tons of cargo and mail transport in 2023, a year-on-year increase of 21%, respectively, recovering to 97.6% in 2019. By the end of 2022, there were 254 transportation airports in China, and with the increase in the number of airports, while enhancing China's passenger and cargo transportation capacity, there are problems such as competition among multiple airports leading to duplicated construction and waste of resources, reduced transportation efficiency, and impact on the profitability and long-term development of airports. Therefore, it is necessary to enhance the synergistic development of airport clusters to optimize the use of resources, improve overall competitiveness and promote regional economic development.

In recent years, domestic and foreign scholars' research on airport cluster synergy has shown a trend of gradual increase and depth. marcella sama et al. (2017) take Amsterdam Schiphol Airport in the Netherlands as the research object to study the synergistic development with other airports[1]. Xu Min et al. (2020) help to build the Chengdu-Chongqing world-class airport cluster by analyzing the inherent fierce competition faced by the route market of Chengdu-Chongqing Airport Cluster, the overall strength is insufficient, the degree of comprehensive transportation is not sufficiently smooth and outward, and the pro-airport industry does not give full play to the functional role of the aviation platform and other problems[2]. Yang Xinjian et al. (2020) established the cluster analysis and multidimensional scale analysis combined classification model of multi-airport system, and put forward the strategy of synergistic development of multi-airport system in order to realize the benign development among airports[3]. Lu Yangjing (2020) studied the multi-airport synergistic development model of Hainan Province and proposed a strategic guarantee for the synergistic development of multi-airports in Hainan Province[4]. Wang et al. (2021) argued that the rapid development of Guangdong relies largely on the synergistic development of the "city cluster+airport cluster" in the Greater Bay Area[5] . Zhao et al. (2022) took a multi-airport logistics system in Beijing-Tianjin-Hebei (Beijing-Tianjin-Hebei) as a basis for the synergistic development of multi-airports. (2022) constructed a system dynamics model for the Beijing-Tianjin-Hebei Multi-Airport Logistics System (MLS) as an example to find a strategy to promote the sustainable development of the MLS under the COVID-19 epidemic[6] . Fan Yuan et al. (2022) referred to domestic and international experiences to coordinate with the Beijing-Tianjin-Hebei city cluster functionally and spatially from the perspectives of regional division of labor and synergistic development, and to enhance the position and role of the Beijing-Tianjin-Hebei city cluster in the global trade and economic geography[7]. Wu et al. (2023) constructed a two-layer game-theoretic model to optimize the subsidy strategy and promote synergistic adjustments between the positioning of multiple airports and the route network[8]. Jiang Qianzhi et al. (2023) argued that the functions and positioning of airports in airport clusters should depend on the needs of their urban development, and that the staggered or differentiated development of airports in metropolitan areas should be formed under the strategies of urban functional division of labor and positioning, and optimal allocation of resources[9] .

This paper sets Yangtze River Delta (YRD) airport cluster as the research object, and analyzes the air cargo synergistic development and influencing factors of YRD airport cluster as the entry point, so as to provide theoretical support for the air cargo synergistic development measurement and development path of YRD airport cluster.

2. STATUS QUO OF AIR CARGO DEVELOPMENT AND MEASUREMENT OF SYNERGY LEVEL IN YANGTZE RIVER DELTA AIRPORT CLUSTER

The cities covered by the "Three Provinces and One City" of the Yangtze River Delta (YRD) urban agglomeration are shown in Table 1, and the top airports in the YRD region in terms of cargo and mail throughput in 2023 are selected as the research objects, including Shanghai Pudong Airport, Hangzhou Xiaoshan Airport, Nanjing Lukou Airport, Shanghai Hongqiao Airport, Wuxi Shuofang Airport, Ningbo Lishe Airport and Hefei Xinqiao Airport. In the following, the term "Yangtze River Delta Airport Cluster" is used to refer to the collection of airports formed by these seven airports.

Table 2.1 List of Cities Covered by the Yangtze River Delta Urban Agglomeration

Province or municipality	**municipalities**
Shanghai	Shanghai
Jiangsu	Nanjing, Zhenjiang, Yangzhou, Changzhou, Suzhou, Wuxi, Nantong, Taizhou, Yancheng
Zhejiang	Hangzhou, Jiaxing, Huzhou, Shaoxing, Ningbo, Zhoushan, Jinhua, Taizhou
Anhui	Hefei, Wuhu, Chuzhou, Maanshan, Tongling, Chizhou, Anqing, Xuancheng

2.1 Status of Air Cargo Development in the Yangtze River Delta Airport Cluster

On November 5, 2018, General Secretary Xi Jinping announced at the first China International Import Expo in Shanghai that he would support the integrated development of the Yangtze River Delta region and elevate it to a national strategy.In 2019, the Outline of the Plan for the Integrated Development of the Yangtze River Delta Region issued by the Central Committee of the Communist Party of China (CPC) and the State Council pointed out the need to enhance the level of infrastructure interconnection and interoperability in the Yangtze River Delta, to collaborate on the construction of an integrated integrated and comprehensive transportation system, and to join efforts to to build a world-class airport cluster.In 2021, the Strategic Plan for the Cooperative Development of Civil Aviation in the Yangtze River Delta Region, issued by the Office of the Leading Group for Promoting the Integrated Development of the Yangtze River Delta, proposed that the system of a world-class airport cluster in the Yangtze River Delta would basically be formed by 2035, and that a high-quality system of civil aviation development with cross-border integration, clear hierarchies, and regional unity would basically be formed.The airport cluster in the Yangtze River Delta will complete a throughput of cargo and mail of 5,668,000 tons in 2023. By 2023, the YRD Airport Cluster will have a cargo and mail throughput of 5.668 million tons, which is a huge volume of air traffic and an excellent foundation for civil aviation development, making it congenitally equipped for the construction of a world-class airport cluster.

However, the Yangtze River Delta airport cluster in general shows problems such as uneven development and serious homogenized competition. Shanghai Pudong Airport basically holds the dominant power in the regional air cargo market, creating a "siphoning effect" on the air cargo business of Hangzhou, Ningbo, Nanjing and other regions, resulting in a reduction of free competition in the air cargo market, which is not conducive to the formation of a benign systemic relationship.

2.2 Construction of the measurement system for the level of coordinated development of air cargo in the Yangtze River Delta airport cluster

2.2.1 Principles for selecting indicators for measuring the level of synergistic development

The air cargo market of the Yangtze River Delta airport cluster is a holistic system, and the development of each subairport determines the overall development level of the airport cluster. According to the theory of synergetics, there exists a kind of ordinal covariates, which can characterize and determine the macro behavior of the airport subsystems in the airport cluster system that evolve in concert. These ordinal covariates play a dominant role in the development of airport subsystems towards an ordered state. Specifically, by quantitatively analyzing the ordinal covariates of each airport subsystem, it is possible to assess and quantify the degree of synergistic development of the entire airport cluster system, and thus optimize the synergistic effects of the cluster to achieve a more efficient and orderly air transport network. Therefore, the selection of sequential parametric indicators is a crucial aspect and should follow the following principles:

scientific principle

Scientificity is one of the core principles in the selection of evaluation indicators, which requires that the indicators must be based on a solid theoretical foundation and be able to clearly explain their connection with the synergistic development of the air cargo market in the Yangtze River Delta airport cluster. The selection and application of indicators should be verifiable, i.e., able to confirm their validity through experiments or data analysis. In addition, scientific indicators should also strive to be objective and reduce the interference of subjective judgment in order to reflect the state of the research object more realistically. Precision is essential in the measurement process to ensure that the error is within a manageable range, thereby enhancing the credibility of the indicators.

The principle of comprehensiveness

The principle of comprehensiveness requires that the indicators be able to cover the air cargo market of the Yangtze River Delta airport cluster from multiple perspectives, avoiding limitations due to a single viewpoint. When designing the evaluation system, it is important to ensure that all key elements or dimensions are fully considered to form a comprehensive perspective with no omissions. In addition, a balance should be maintained among the evaluation indicators to avoid overemphasizing certain indicators at the expense of others of equal importance.

the principle of comparability

The principle of comparability implies that indicators should be designed to be general enough to provide consistent measurements across time and context. Indicators with a high degree of comparability can observe the level of development of the air cargo market in each sub-airport of the YRD airport cluster. In addition, comparability requires standardization of the measurement methods of the indicators to reduce errors introduced by differences in measurement tools or procedures.

the principle of practicality

The principle of practicality requires that indicators not only be capable of being measured and applied in practice, but also fully reflect the characteristics of the subsystem. In addition, the selected indicators should be based on accessible data, so as to avoid making the evaluation impossible due to the difficulty of obtaining data, and the expression of the indicators should be concise and persuasive. At the same time, the indicators should have a certain degree of adaptability and be able to respond flexibly to changes in different environments and conditions, so that they can play their evaluative and guiding roles in diverse practical scenarios.

2.2.2 Construction of the index system for measuring the level of synergistic development

By combing domestic and international literature and following the above principles, this paper selects 4 primary indicators and 13 secondary indicators to measure each subairport for research.

Table 2.2 Indicator system for measuring the level of synergistic development

Level 1 indicators	Secondary indicators	unit (of measure)	Direction of Indicators
Scale of airport cargo operations	cargo and mail throughput	tons	forward
	Cargo flight movements	lit. ten thousand flights	forward
Airport infrastructure development	Number of parking spaces	classifier for individual things or people, general, catch-all classifier	forward
	Terminal area	ten thousand square meters	forward
	Number of runways	clause (of law or treaty)	forward
	Number of parallel taxiways	clause (of law or treaty)	forward
Airport cargo connectivity	Volume of cargo flights	divide by ten thousandths of a class	forward
	Number of cargo airlines	classifier for families or businesses e.g. shops, companies	forward
	Number of cargo routes	clause (of law or treaty)	forward
	Number of cities navigated by cargo	classifier for individual things or people, general, catch-all classifier	forward
Level of urban economic development	Urban GDP	trillion dollars	forward
	Value added of tertiary industry	trillion dollars	forward
	Year-end resident population	all the people	forward

2.3 Measurement of the level of air cargo synergistic development in the Yangtze River Delta airport cluster

2.3.1 Air Cargo Synergy Modeling of Yangtze River Delta Airport Cluster

(1) Determination of weights

In the current study, the methods used by scholars to determine weights usually include subjective assignment method, objective assignment method and comprehensive assignment method. Subjective assignment methods rely on the experience and judgment of experts, such as hierarchical analysis (AHP) and Delphi method. Objective empowerment methods are based on the statistical properties of the data, such as Principal Component Analysis (PCA) and Entropy Weighting. Comprehensive assignment methods combine both subjective and objective methods to obtain a more comprehensive and accurate weight assignment. Since the subjective assignment method can lead to large differences due to the index scores given by different experts, thus affecting the assessment results, this paper chooses the entropy weight method in the objective assignment method.

Entropy weight method is an objective weight determination method based on the concept of information entropy, and its advantage is that it can automatically extract weights from the original data without relying on the subjective judgment of experts, thus reducing the interference of human factors. In addition, the entropy weight method can reflect the differences between the indicators, and for the data set with a large amount of information, it can more accurately measure the importance of each indicator, which makes the weight allocation more reasonable and scientific.

①Data Normalization

The data under each indicator were normalized to avoid the impact of the scale on data processing.

For positive indicators:

$$u_{ij} = \frac{x_{ij} - \min\{x_{1j}, x_{2j}, \ldots\ldots, x_{nj}\}}{\max\{x_{1j}, x_{2j}, \ldots\ldots, x_{nj}\} - \min\{x_{1j}, x_{2j}, \ldots\ldots, x_{nj}\}} \tag{2.1}$$

For negative indicators:

$$u_{ij} = \frac{\max\{x_{1j}, x_{2j}, \ldots\ldots, x_{nj}\} - x_{ij}}{\max\{x_{1j}, x_{2j}, \ldots\ldots, x_{nj}\} - \min\{x_{1j}, x_{2j}, \ldots\ldots, x_{nj}\}} \tag{2.2}$$

Where u_{ij} denotes the normalized data (i=1,2,......,n), (j=1,2,......,m) for the j item under the i scheme.

② Calculate the weight of the indicator

$$P_{ij} = u_{ij} / \sum_{i=1}^{n} u_{ij} \tag{2.3}$$

In the formula P_{ij} denotes the indicator weight of program i under indicator j (i=1,2,...... ,n), (j=1,2,...... ,n).

③Calculate information entropy

$$e_j = -k \sum_{i=1}^{n} P_{ij} \ln(P_{ij}) \tag{2.4}$$

where $k = \frac{1}{\ln(n)}$, which satisfies $e_j > 0$, where Eq. e_j denotes the entropy value of the jth indicator (j=1,2,...... ,m).

④ Calculate the information entropy redundancy

$$g_j = 1 - e_j \tag{2.5}$$

In the formula g_j denotes the information entropy redundancy of the jth indicator (j=1,2,...... ,m).

⑤ Calculation of indicator weights

$$W_j = g_j / \sum_{j=1}^{m} g_j \tag{2.6}$$

In the formula W_j denotes the weight of the jth indicator (j=1,2,...... ,m).

(2) Subsystem orderliness model

$$S_i = \sum_{j=1}^{n} W_j u_{ij} \tag{2.7}$$

where S_i is the subsystem ordering degree, and W_j is the weight of each indicator, and u_{ij} is the dimensionless data of each indicator.

Composite System Synergy Model

$$C_i = \gamma \cdot \sqrt[n]{\left|\prod_{i=1}^{k} [S_i(k) - S_i(k-1)]\right|} \tag{2.8}$$

where i ≥ 2. C_i denotes the degree of synergy of the composite system, which varies from -1 to 1.

$$\gamma = \begin{cases} 1, & \prod_{i=1}^{k} [S_i(k) - S_i(k-1)] > 0 \\ -1, & \prod_{i=1}^{k} [S_i(k) - S_i(k-1)] \leq 0 \end{cases} \tag{2.9}$$

The degree of synergy of the composite system indicates the degree of synergy between the subsystems within the composite system. γ It is used to judge the direction of synergistic development among the subsystems, in which $S_i(k) - S_i(k-1)$ denotes the current ordering degree of the ith subsystem minus the previous ordering degree, is used to judge the direction of change of the ordering degree of the ith subsystem, and if it is a positive number, it means that the ordering degree increases, and if it is a negative number, it means that the ordering degree decreases. $\prod_{i=1}^{k} [S_i(k) - S_i(k-1)]$ is used to judge whether the change trend of the subsystems is the same.

Drawing on the research of Huang Jie[12] and other scholars, this paper categorizes the air cargo synergy level of the Yangtze River Delta airport cluster into four levels, as shown in the following table.

Table 2.3 Criteria for classifying synergies

C-value	**[-1,0]**	**(0,0.3]**	**(0.3,0.7]**	**(0.7,1]**
hierarchy	uncoordinated	low level of coordination	General synergy	high degree of coordination

2.3.2 Determination of the weights of the indicators

The data are mainly from the official websites of airports, the official website of the Civil Aviation

Administration of China (CAAC), the China Urban Statistical Yearbook, the official websites of local statistical bureaus and the OAG database. Due to the impact of the global epidemic in 2020, the air cargo industry was severely impacted, which had a certain impact on the accuracy of the evaluation results. Therefore, in order to ensure the objective accuracy of the evaluation, this paper selects the five-year data from 2019-2023 to measure the level of synergistic development of the air cargo market in the Yangtze River Delta airport cluster.

Table 2.4 Indicator weights for measuring the level of synergistic development

Level 1 indicators	**weights**	**Secondary indicators**	**weights**
Scale of airport operations	17.41%	cargo and mail throughput	12.95%
		Flight movements	4.46%
Airport infrastructure development	42.82%	Number of parking spaces	7.13%
		Area of cargo terminal building	17.37%
		Number of runways	9.16%
		Number of parallel taxiways	9.16%
Airport connectivity	17.98%	Volume of cargo flights	4.52%
		Number of cargo airlines	3.35%
		Number of cargo routes	5.09%
		Number of cities navigated by cargo	5.02%
Level of urban economic development	21.79%	Urban GDP	5.90%
		Value added of tertiary industry	7.74%
		Year-end resident population	8.15%

2.3.3 Calculation of Orderliness of Air Cargo Subsystems of Airports in the Yangtze River Delta Airport Cluster

According to Equation (2.7), the orderliness of air cargo subsystems of airports in the Yangtze River Delta airport cluster in 2019-2023 is derived, and the results are shown in Table 2.5 and Figure 2-1.

Table 2.5 Orderliness of Air Cargo Subsystems by Airports in the Yangtze River Delta Airport Cluster, 2019-2023

vintages	Shanghai Pudong Airport	Hangzhou Xiaoshan Airport	Shanghai Hongqiao Airport (SHA)	Nanjing Lukou Airport	Wuxi Shuofang Airport	Ningbo Lishe Airport	Hefei Xinqiao Airport
2019	0.8809	0.2996	0.4041	0.2299	0.0168	0.0598	0.0478
2020	0.8573	0.2831	0.3990	0.2346	0.0262	0.0701	0.0456
2021	0.8483	0.2777	0.4109	0.2152	0.0304	0.0631	0.0420
2022	0.7986	0.2740	0.3858	0.2136	0.0189	0.0534	0.0345
2023	0.8903	0.3045	0.4330	0.2271	0.0340	0.0776	0.0588

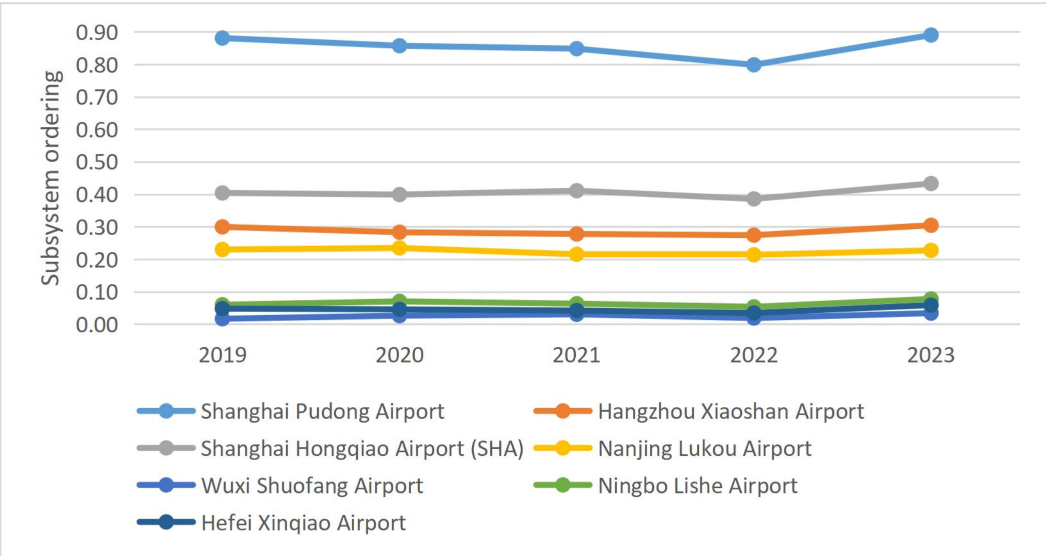

Figure 2-1 Trend of Air Cargo Subsystem Orderliness Changes by Airports in the Yangtze River Delta Airport Cluster, 2019-2023

2.3.4 Calculation of the level of air cargo synergistic development of the Yangtze River Delta airport cluster

The air cargo subsystem ordering degree of each airport in the Yangtze River Delta airport cluster in Table 2.5 is brought into Equation (2.8) and Equation (2.9) to obtain the results of the calculation of the composite system synergy degree and synergistic development level of air cargo of the Yangtze River Delta airport cluster in the period of 2019-2023, and the results are shown in Table 2.6 and Figure 2-2.

Table 2.6 Composite System Synergy and Level of Synergistic Development of Air Cargo in the Yangtze River Delta Airport Cluster, 2020-2023

vintages	Synergy of air cargo composite system in Yangtze River Delta airport cluster	Level of synergistic development
2020	0.0079	low level of coordination
2021	-0.0074	uncoordinated
2022	-0.0093	uncoordinated
2023	0.0286	low level of coordination

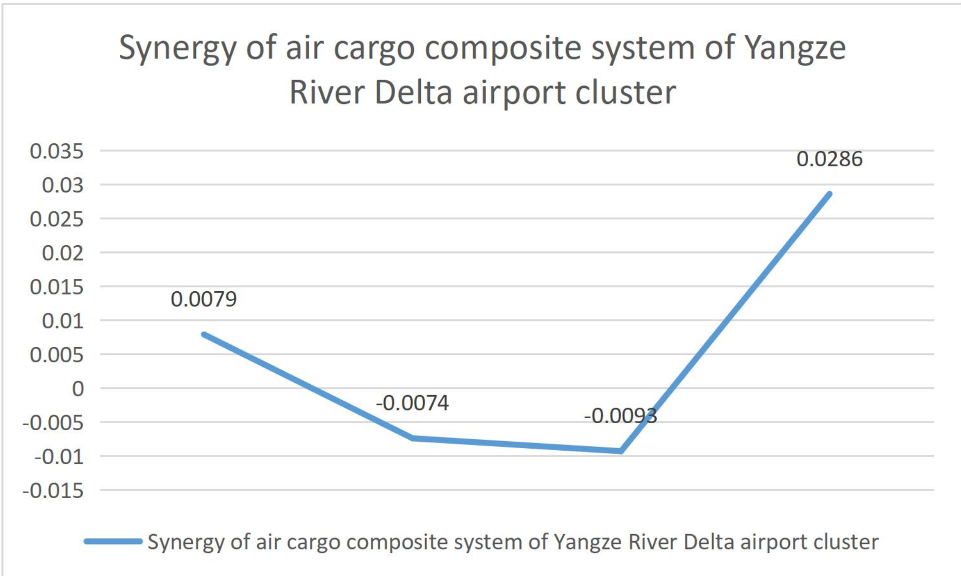

Figure 2-2 Trend of Air Cargo Complex System Synergy of Yangtze River Delta Airport Cluster, 2020-2023

2.4 Analysis of the level of air cargo synergistic development of the Yangtze River Delta airport cluster

As shown in Figure 2-2, the synergy of the air cargo composite system of the Yangtze River Delta airport cluster between 2020 and 2022 decreases year by year, from 0.0079 in 2020 to -0.0093 in 2022, indicating that the synergistic development of the air cargo composite system of the Yangtze River Delta airport cluster during the three years has not achieved good results. The main reason lies in the impact of the global epidemic, the air cargo industry has been seriously impacted, the demand for civil aviation cargo decreased, and the number of cargo routes and flights also decreased, resulting in the decline of the synergy of the air cargo composite system of the Yangtze River Delta airport cluster during the three years; during the period of 2022-2023, the synergy of the air cargo composite system of the Yangtze River Delta airport cluster had a significant rebound, from -0.0093 in 2022 The main reason is that after the epidemic, the civil aviation cargo industry recovered, and the cargo and mail throughput and airline flights of the airports in the YRD airport cluster gradually recovered to the pre-epidemic level. Meanwhile, according to the previous analysis of the orderliness of air cargo subsystems of airports in the Yangtze River Delta airports group, it can be seen that the airports have continuously opened new international cargo routes in recent years, such as Hangzhou opened full freight charter flights covering Europe and Asia, such as Liege and Spain, Wuxi opened a full freight route of Wuxi-Incheon, and Hefei added new freight routes to Dallas and New York. In addition, airports have strengthened the infrastructure of air cargo and continuously optimized the protection system of the entire cargo service chain.

According to Table 2.3 on the composite system synergy development level of air cargo in the Yangtze River Delta airport cluster, it can be seen that the degree of air cargo synergy in the Yangtze River Delta airport cluster belongs to the primary level, which is still in the exploratory stage, and there is still a big gap from the development level of high synergy. According to the principle of the composite system synergy model, the more significant the growth of the airport subsystem in terms of orderliness, the more significant its contribution to the enhancement of the synergy effect of the whole airport cluster composite system, and vice versa. As can be seen from Figure 2-1, from an overall perspective, the increase in the degree of orderliness of each airport air cargo subsystem is insignificant, which seriously hinders the development of air cargo synergy in the Yangtze River Delta airport cluster. However, from the post epidemic period, most airports, led by Shanghai Pudong Airport and Shanghai Hongqiao Airport, are experiencing rapid growth in air cargo subsystem orderliness, which also leads to a significant increase in the synergy of air cargo synergy of the Yangtze River Delta airport cluster in 2022-2023. Looking forward, with the rapid development of airports in the field of cargo transportation, the air cargo market synergy of the Yangtze River Delta airport cluster is expected to realize a significant increase.

3. ANALYSIS OF THE CAUSES OF THE LOW LEVEL OF SYNERGISTIC DEVELOPMENT OF THE YANGTZE RIVER DELTA AIRPORT CLUSTER

3.1 Air Cargo Market Concentration Analysis

In this section, we choose to use Herfindahl-Hirschman Index (HHI) to measure the air cargo market concentration of the Yangtze River Delta airport cluster, and the formula is as follows:

$$\mathrm{HHI} = \sum_{i=1}^{N} (X_i/X)^2 = \sum_{i=1}^{N} S_i^2 \tag{3.1}$$

Table 3-1 Air Cargo Market Concentration in the Yangtze River Delta Airport Cluster

airport	Pudong/ Shanghai	Xiaoshan/ Hangzhou	Hongqiao/ Shanghai	LuKou/ Nanjing	ShuoFang/ Wuxi	LiShe/ Ningbo	Xinqiao/ Hefei	add up the total
cargo and mail throughput (tons)	344.01	80.97	36.32	38.35	12.56	14.28	11.46	537.95
Freight market share	63.95%	15.05%	6.75%	7.13%	2.33%	2.65%	2.13%	100.0%

The HHI value of the air cargo market in the Yangtze River Delta (YRD) airports cluster is 0.443. According to the market structure classification based on the HHI value, the air cargo market in the YRD airports cluster belongs to the high oligopoly type I, with the Shanghai Pudong Airport accounting for the majority of the air cargo volume in the cluster. According to the market structure-market behavior-market performance analysis framework (SCP framework), the airport cargo business is a natural monopoly with public welfare attributes, and its performance includes not only tangible airport cargo revenue, but also intangible products, i.e., providing better transportation services for cargo owners. Therefore, the high degree of monopolization of the air cargo market in the YRD airports group is not conducive to the synergistic development of the air cargo market in the YRD airports group, as it poses a continuous challenge to the operation of Shanghai Pudong Airport and interferes with the operation of other airports.

3.2 Strategic positioning analysis of airports

In order to determine whether the strategic positioning of each airport in the Yangtze River Delta airport cluster matches its actual positioning in the context of coordinated development, drawing on the relevant research of Zhang Maosheng[13] , this section selects eight indicators, namely, cargo and mail throughput, flight movements, the number of cities with cargo throughput, the number of freight operating companies, the number of parking slots, the city's GDP, the value added of the tertiary industry, and the year-end resident population, and adopts the ward system clustering (sum of squares method) to cluster the aviation market of the Yangtze River Delta airport cluster, and the specific steps are as follows:

Assuming that there are a total of n study subjects in the Yangtze River Delta airport cluster (n=7 airports), which are now categorized into m classes, denoted as G1 , G2 ,.... .Gm ; ni denotes the sample size of class Gi , .$\overline{X}^{(j)}$ denotes the center of gravity of class Gi , Gi denotes the ith sample in the class group (i=1,2,.... .n), then the sum of squared deviations of the samples in class Gi is:

$$W_t = \sum_{i=1}^{n_j} (X_{(i)}^{(j)} - \overline{X}^{(j)})' (X_{(i)}^{(j)} - \overline{X}^{(j)}) \tag{3.2}$$

where W_t is the sum of squared deviations for the class group Gi . Now according to Ward's method of merging, the study subjects are merged into k classes and their total sum of squared deviations is:

$$W = \sum_{t=1}^{k} W_t = \sum_{t=1}^{k} \sum_{t=1}^{n_t} (X_{(i)}^{(t)} - \overline{X}^{(t)})' (X_{(i)}^{(t)} - \overline{X}^{(t)}) \tag{3.3}$$

The calculation is performed using the above equation to obtain the minimum value of W, when k is the optimal number of clusters.

In clustering and merging of research objects, the basic method is as follows: firstly, the research objects are divided into i classes, whose total sum of squared deviations W is 0. On this basis, the sum of squared deviations of two different clusters are calculated separately, and the two clusters which have the smallest increase in W are chosen to be grouped together, and so on, until the research objects are merged into one class.

Suppose there are two new classes Gq consisting of two two-class totals g and h , with interclass squared distance:

$$D_{gh}^2 = W_q - (W_g + W_h) \tag{3.4}$$

D_{gh}^2 denotes the squared distance between classes Gg and Gh , where Gq = {Gg , Gh }, and Wq , Wg , Wh are the sums of squares of the samples disjointed in the classes Gq , Gg , and Gh , respectively, by using the definition of Wi :

$$W_i = \sum_{i=1}^{n_j} (X_{(i)}^{(j)} - \overline{X}^{(j)})' (X_{(i)}^{(j)} - \overline{X}^{(j)}) =$$

$$\sum_{i=1}^{n_g} (X_{(i)}^{(g)} - \overline{X}^{(j)})' (X_{(i)}^{(g)} - \overline{X}^{(j)}) + \tag{3.5}$$

$$\sum_{i=1}^{n_h} (X_{(j)}^{(h)} - \overline{X}^{(j)})' (X_{(j)}^{(h)} - \overline{X}^{(j)})$$

where$\overline{X}^{(j)} = \frac{1}{n_i}(n_g\overline{X}^{(g)} + n_h\overline{X}^{(h)})$, is obtained by collation:

$$d_{gh}^2 = \frac{n_g n_h}{n_j}(\overline{X}^{(g)} - \overline{X}^{(h)})' (\overline{X}^{(g)} - \overline{X}^{(h)}) \tag{3.6}$$

That is, the distance between the totals g and h is:

$$d_{gh}^2 = \sum_{j=1}^{m} \left|X_{g_j} - X_{h_j}\right|^2 \quad (g, h = 1,2, \ldots n) \tag{3.7}$$

Its interclass distance can be expressed as:

$$D_{gh}^2 = \frac{n_g n_h}{n_j} d_{gh}^2 \tag{3.8}$$

The relevant data of the Yangtze River Delta airport cluster in 2023 were selected from the statistical yearbook of each region, OAG database, national airport production statistics bulletin and the official website of each airport. The clustering analysis of the Yangtze River Delta airport cluster was carried out using spss software, and the results are shown in Figure 3-2.

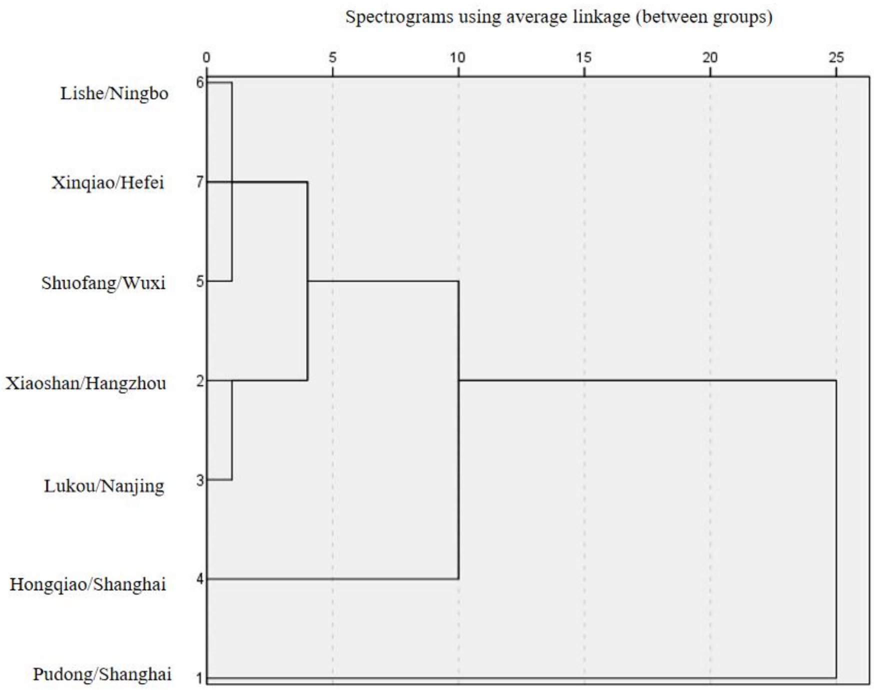

Figure 3-2 Spectral map of clustering results of Yangtze River Delta airport clusters

In the Outline of the Plan for the Integrated Development of the Yangtze River Delta Region, the Yangtze River Delta airport cluster is categorized into four categories: international hub airports, domestic hub airports, regional hub airports and important passenger and cargo airports. Therefore, the clustering spectrum map in this section is used as a basis to categorize the seven airports in the Yangtze River Delta airport cluster into four levels, as shown in Table 3.2.

Table 3.2 Hierarchical Clustering Table for Yangtze River Delta Airport Cluster

arrangement of ideas	**Airport clustering**
Level 1	Shanghai Pudong Airport
Level 2	Hangzhou Xiaoshan Airport, Nanjing Lukou Airport
Level 3	Shanghai Hongqiao Airport
Level 4	Wuxi Shuofang Airport, Ningbo Lishe Airport, Hefei Xinqiao Airport

From Table 3.2, the first level includes Shanghai Pudong Airport, which is an international hub airport; the second level includes Hangzhou Xiaoshan Airport and Nanjing Lukou Airport, which are domestic hub airports; the third level includes Shanghai Hongqiao Airport, which is a regional hub airport; and the fourth level includes Wuxi Shuofang Airport, Ningbo Lishe Airport and Hefei Xinqiao Airport, which are important airports for passenger and cargo transportation. However, Table 3.3 shows that all seven airports are strategically positioned as hub airports, which implies that airports will continue to increase their routes when airspace resources are limited, resulting in a complex airspace structure for the YRD airport cluster. The number of airports in the YRD region accounts for 7.3% of the country's total, and the density of airports is more than three times the national average, much higher than that of

Beijing-Tianjin-Hebei (0.42 airports per 10,000 square kilometers) and the Pearl River Delta (0.50 airports per 10,000 square kilometers), and the airspace resources of the YRD region have not been effectively coordinated, which will result in the contradiction between the demand for air transportation and the airspace resources becoming more and more prominent, so the strategic position of the seven airports in the YRD is also a key factor. Therefore, based on this background, the strategic position of the seven airports will also become an obstacle to the synergistic development of air cargo in the Yangtze River Delta airport cluster. Meanwhile, Hangzhou Xiaoshan Airport, Nanjing Lukou Airport, Shanghai Hongqiao Airport and Hefei Xinqiao Airport are strategically positioned as international/domestic hub airports, and there is a high duplication rate of domestic destinations for freight transportation among the four airports, which will lead to unhealthy competition among the airports, resulting in a waste of airspace resources and is not conducive to the synergistic development of the airports.

Table 3.3 Information on the Strategic Positioning of Airports in the Yangtze River Delta Airport Cluster

Airport name	**strategic positioning**	**guidance document**
Shanghai Pudong Airport	international airport hub	Outline of the Plan for the Integrated Development of the Yangtze River Delta Region
Hangzhou Xiaoshan Airport	International/domestic hub airports	Outline of the Plan for the Integrated Development of the Yangtze River Delta Region
Nanjing Lukou Airport	International/domestic hub airports	Outline of the Plan for the Integrated Development of the Yangtze River Delta Region
Shanghai Hongqiao Airport	International/domestic hub airports	Outline of the Plan for the Integrated Development of the Yangtze River Delta Region
Wuxi Shuofang Airport	Regional hub airports	Outline of the Plan for the Integrated Development of the Yangtze River Delta Region
Ningbo Lishe Airport	Regional hub airports	Outline of the Plan for the Integrated Development of the Yangtze River Delta Region
Hefei Xinqiao Airport	International/domestic hub airports	Outline of the Plan for the Integrated Development of the Yangtze River Delta Region

3.3 Analysis of overlapping freight route networks

Route network is the core component of air transportation system, and its planning and design have a crucial impact on the development of the whole air transportation industry. A scientific and reasonable route network planning can not only promote the growth of air transport business and improve transport efficiency, but also effectively optimize resource allocation and reduce operating costs, thus enhancing the comprehensive competitiveness of the whole civil aviation transport system. Referring to the relevant study by Leung's Da[12] , the following is an analysis of the overlap of cargo routes in the Yangtze River Delta airport cluster, using the number of passages to domestic/international cities from the seven airports in 2023 as the basis for classification, and stipulating that routes with more than six passages (including six) are high-frequency routes, routes with three to five passages are middle-frequency routes, and routes with fewer than two passages (including two) are low-frequency routes. The statistical results of domestic and international cargo routes are shown in Table 3.4 and Table 3.5.

The domestic and international cargo HFTPs of the Yangtze River Delta airport cluster account for an absolute proportion of the HFTPs, and there is a very high duplication rate among the HFTPs. The overall duplication rate of the domestic cargo HFTPs exceeds 95%, of which the domestic cargo HFTPs of Wuxi Shuofang and Shanghai Hongqiao airports are covered by 100%. The overall repetition rate of international cargo HF destinations is around 85%, of which the international cargo HF destinations of Wuxi Shuofang Airport and Ningbo Lishe Airport are covered by 100%. Such a distribution of cargo destinations on the one hand shows that the air cargo of the Yangtze River Delta airports group has good regional connectivity, but on the other hand, it also implies that there is competition in the air cargo market of the Yangtze River Delta airports group, and there may even be excessive competition due to the fact that certain air routes or the market is already saturated, which has seriously caused a waste of resources on air routes.

Table 3.4 Classification and Distribution of Domestic Cargo Access Points in the YRD Airport Cluster

Classification of waypoints	**Waypoint Properties**	**Number of waypoints**	**Distribution of waypoints**
High Frequency Access Points (HFAPs)	More than 6 flights within the airport complex (including 6 times)	160	Mainly domestic first and second tier cities, including municipalities, provincial capitals, provincial economic cities and popular tourist cities
IF navigational point	3-5 flights within the airport complex	5	Mainly in third and fourth tier cities in China
low-frequency access point	Less than 2 flights within the airport complex (including 2 times)	10	Predominantly in fourth- and fifth-tier cities in China

Table 3. 5 Classification and Distribution of International Cargo Access Points in the Yangtze River Delta Airport Cluster

Classification of waypoints	**Waypoint Properties**	**Number of waypoints**	**Distribution of waypoints**
High Frequency Access Points (HFAPs)	More than 6 flights within the airport complex (including 6 times)	103	Focus on popular tourist and economic cities in Hong Kong, Macao, Taiwan, Japan, Korea, Southeast Asia and other regions and countries
IF navigational point	3-5 flights within the airport complex	10	The most popular tourist cities in Asia, as well as the political and economic centers and popular tourist cities in some European countries.
low-frequency access point	Less than 2 flights within the airport complex (including 2 times)	7	Focusing on political and economic cities and popular tourist cities around the world

4. CONCLUSION

The level of air cargo synergy in the Yangtze River Delta airport cluster is still in its infancy, and despite improvements in 2023, it still faces many challenges. Shanghai Pudong Airport dominates the regional air cargo market, leading to greater competitive pressure on other airports. The similar strategic positioning and lack of differentiation among airports exacerbates duplication and waste of resources. In addition, the high overlap of cargo route networks has led to waste of resources and increased competition. In order to enhance the level of synergistic development of the Yangtze River Delta airport cluster, it is necessary to optimize the strategic positioning of the airports, reduce route overlap, improve the efficiency of resource utilization, and promote cooperation and coordination among airports through policy guidance and market mechanisms. In the future, with the further development of airports in the field of cargo transportation, the air cargo market synergy of the Yangtze River Delta airport cluster is expected to realize a significant increase.

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