Research on the Evaluation and Promotion Path of Port-Industry-City Integration in Port Cities: A Case Study of 16 Cities in Anhui Province

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Abstract. This paper constructs an evaluation index system including 17 indicators covering three subsystems of port, industry and city, and uses the entropy weight method and coupling coordination degree model to quantitatively analyze the port-industry-city integration degree of 16 cities in Anhui Province and their surrounding cities and provinces. The results show that the overall level of port-industry-city integration in Anhui Province is relatively low, with an average synergy degree of only 0.24. Only Hefei (0.4529) and Wuhu (0.4240) have entered the low integration stage, while all other cities are in the initial embryonic stage. The integration types show differentiated characteristics: 11 cities belong to the city-driven type characterized by **advanced urban development and lagging port and industry**, and 5 cities belong to the port-driven type characterized by **advanced port development and lagging urban and industry**. Compared with advanced cities in the Yangtze River Delta and Jiangsu and Zhejiang Provinces, Anhui has obvious gaps in port function upgrading, industrial collaborative adaptation and urban service support. Meanwhile, Anhui is also faced with problems such as resource mismatch and homogeneous competition.

Keywords: port city; integrated development; coupling coordination degree

1 Introduction

The integrated development of port-industry-city has become a research hotspot. Scholars at home and abroad mainly focus on the connotation and mechanism of the integrated development of port-industry-city[1], the integrated development model, and the evaluation of the degree of integration, and have formed rich research results, but there is still room for expansion in the coverage of research objects. Foreign studies focus on the spatial evolution and industrial agglomeration effect of port cities, focusing on the analysis of the interaction and development law between ports and cities. For example, BOTTASSOA et al.[2] analyzed the impact of port activities on urban development in 13 European countries, and AkhavanM[3] analyzed the evolution patterns and common characteristics of port cities. Chinese research pays more attention to the coordinated development relationship among ports, industries and cities. The research focuses on

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the construction of evaluation index system[4] and the application of coupling coordination degree model[5], so as to carry out quantitative evaluation and analysis. For example, Wang Cheng et al.[6] and Liu Chang[7] both explored the coupling characteristics of the similarity between the shipping structure and the industrial structure of the port city, and revealed the correlation between the functional attributes of the industrial industry and the isomorphism of the shipping structure. However, the existing Chinese research has significant 'coastal bias'. Under the background of high-quality development of water transportation in the new era, the importance of port-industry-city integration development of inland river ports is prominent. Anhui Province is rich in inland river shipping resources, and has the foundation and potential to promote integration, but it faces problems such as resource mismatch and homogeneous competition. This study takes 16 port cities in Anhui Province as the object, constructs a fusion evaluation index system, uses the coupling coordination degree model to study the coordination relationship between port, industry and city, excavates the shortcomings of development, and provides reference for similar regions.

2 Evaluation Method of Port-Industry-City Integration Degree

2.1 Evaluation Index System

Following the principles of science, representativeness, availability, comprehensiveness and independence, 17 indicators are selected from the three subsystems of port, industry and city to construct the evaluation index system of port-industry-city integration, as detailed in Table 1.

Table 1. Evaluation Index System of Port-Industry-City Integration Degree

Subsystem	Indicators (units)	The nature of indicators
port subsystem	port cargo throughput (ten thousand tons), container throughput (ten thousand standard boxes), waterway freight volume (ten thousand tons), terminal length (meters), number of berths (number)	positive direction
industrial subsystem	the number of industrial enterprises above designated size (one), the main business income of industrial enterprises above designated size (100 million yuan), the added value of industrial enterprises above designated size (100 million yuan), the total profit of industrial enterprises above designated size (100 million yuan)	positive direction
urban subsystem	the added value of the secondary industry (billion yuan), the added value of the tertiary industry (billion yuan), per capita GDP (yuan), fixed asset investment (billion yuan), total retail sales of social consumer goods (billion yuan), total fiscal revenue (billion yuan), urbanization rate (%)	positive direction

2.2 Subsystem Development Level

In order to avoid the evaluation deviation of subjective factors, the entropy weighting method is used to calculate the weight of each order parameter. After the data is normalized and standardized, the entropy value and the difference coefficient are calculated in turn to obtain the weight value. The weight is positively correlated with the importance of the index.

The port, industry and city constitute a composite system, and the order parameters of each subsystem are calculated according to the positive index to calculate the contribution degree of the system order degree. The larger the value, the higher the contribution degree. The development level of the subsystem is the linear weighted integration of the order parameter contribution, and the weighting coefficient is the weight of the entropy method. The higher the value is, the better the development quality of the subsystem is.

2.3 System Synergy Degree Model

The concept of capacity coupling in physics and the model of capacity coupling coefficient are used to measure the degree of interaction between port, industry and city subsystems.

$$C = \left[\frac{f_1(x_1) \bullet f_2(x_2) \bullet f_3(x_3)}{\left(\frac{f_1(x_1)+f_2(x_2)+f_3(x_3)}{3} \right)^3} \right]^{1/3} = 3 \frac{\left[f_1(x_1) \bullet f_2(x_2) \bullet f_3(x_3) \right]^{1/3}}{f_1(x_1) + f_2(x_2) + f_3(x_3)} \tag{1}$$

Using the theory of synergetics, the calculation model of the synergy degree of the port-industry-city composite system is :

$$T = \sum_{i=1}^{3} \alpha_i \times f_i(x_i), \alpha_1 + \alpha_2 + \alpha_3 = 1 \tag{2}$$

$$D = (C \times T)^{\theta} \tag{3}$$

Among them, T is the comprehensive development level of the port-industry-city composite system, and α_1, α_2, α_3 are the undetermined weight, which represents the influence of the development level of the port, industry and city on the comprehensive development level of the composite system, and the weight is 1/3. D is the degree of synergy, $D \in [0,1]$,which reflects the degree of synergy of the port-industry-city composite system. The value of θ is generally 1/2.

When D tends to 1, the coordinated development efficiency of each system and element is high, and the system tends to be orderly structure. On the contrary, when D tends to 0, the correlation between systems is weak and develops disorderly.

2.4 Evaluation Standard of Port-Industry-City Integration Degree

According to the size of the synergy degree value D, the synergy degree of the port-industry-city is graded, and the corresponding integration development stage is clearly defined. The integration type is divided according to the comparative relationship between the development levels of the three subsystems. The specific evaluation criteria are shown in Table 2.

Table 2. Evaluation Standard of Port-Industry-City Integration Degree

Synergy degree value D	Degree of synergy	Integration development stage	Types of integrated development
0.9-1.0	High-quality Collaboration	High Integration Stage	(1) $\max[f_1(x_1), f_2(x_2), f_3(x_3)] = f_i(x_i)$, $\min[f_1(x_1), f_2(x_2), f_3(x_3)] = f_j(x_j)$, the subsystem S_i development is advanced and the development S_j is lagging behind. (2) $f_1(x_1) = f_2(x_2) = f_3(x_3)$, port, industry and city develop synchronously.
0.8-0.9	Good Collaboration		
0.7-0.8	Intermediate Collaboration	Development & Running-in Stage	
0.6-0.7	Primary Collaboration		
0.5-0.6	Weak Coordination	Low Integration Stage	
0.4-0.5	Verge of Imbalance		
0.3-0.4	Mild Imbalance	Initial & Embryonic Stage	
0.2-0.3	Moderate Imbalance		
0.1-0.2	Severe Imbalance		
0.0-0.1	Extreme Imbalance		

3 Comparison of Anhui Port-Industry-City Relationship Assessment

3.1 Analysis of Data Samples and Main Influencing Factors

This paper selects 16 cities in Anhui Province and 10 cities along the Yangtze River, Huaihe River and Yangtze River Delta as research samples, calculates the degree of integration of port, industry and city, analyzes the stage and type of integration development, clarifies the ranking of Anhui cities, and provides decision-making basis for the formulation of their integration development path. The entropy method is used to calculate the weight of the evaluation index system of port-industry-city in Anhui cities and surrounding cities. The results are as shown in Table 3.

Table 3. Weights of Evaluation Indexes of Port-Industry-City System in Anhui-Level Surrounding Cities

Subsystem	Indicators (units)	Weight
Port subsystem	port cargo throughput (ten thousand tons)	0.2028
	container throughput (ten thousand standard boxes)	0.3669
	waterway freight volume (ten thousand tons)	0.0866
	terminal length (meters)	0.1690
	number of berths (number)	0.1747

Industrial subsystem	the number of industrial enterprises above designated size (one)	0.2206
	the main business income of industrial enterprises above designated size (100 million yuan)	0.2597
	the added value of industrial enterprises above designated size (100 million yuan)	0.2295
	the total profit of industrial enterprises above designated size (100 million yuan)	0.2902
Urban subsystem	the added value of the secondary industry (billion yuan)	0.1733
	the added value of the tertiary industry (billion yuan)	0.2124
	per capita GDP (yuan)	0.0882
	fixed asset investment (billion yuan)	0.0804
	total retail sales of social consumer goods (billion yuan)	0.1543
	total fiscal revenue (billion yuan)	0.2434
	urbanization rate (%)	0.0480

The index weight results show the influence degree of each index on the integration of port, industry and city : the port subsystem takes container throughput, port cargo throughput and berth number as the core ; the index weight of the industrial subsystem is balanced, and the main business income of industrial enterprises has the most significant impact ; in the urban subsystem, the total fiscal revenue, the added value of the tertiary industry, the added value of the secondary industry and the total retail sales of social consumer goods have higher weights. The above core indicators can be focused to promote the integrated development of port, industry and city.

3.2 Analysis of Development Level

As shown in Table 4, the development of ports and industries is leading in Suzhou, Wuxi and Nanjing, and Anhui is in front of Wuhu, Chizhou, Hefei and Hefei, Wuhu and Xuancheng respectively. Urban development in Suzhou, Wuhan, Nanjing ranks first, Anhui Hefei, Wuhu, Chuzhou leading. The top four of the comprehensive development of the port-industry-city complex system are Suzhou, Wuxi, Nanjing and Wuhan. Hefei, Wuhu, Ma 'anshan and Chuzhou in Anhui rank 7,10 and 11, which are at a higher level in the province.

Table 4. The Development Level and Ranking of Port-Industry-City System in Anhui and Its Surrounding Cities

Category	City	Port development level		The level of industrial development		The level of urban development		Comprehensive development level of composite system	
		Measured value	Sorting	Measured value	Sorting	Measured value	Sorting	Measured value	Sorting
Anhui province	Hefei	0.1077	10	0.1759	6	0.4556	5	0.2464	5
	Huaibei	0.0066	24	0.0264	20	0.0531	22	0.0287	25
	Bozhou	0.0283	21	0.0211	24	0.0483	25	0.0326	23
	Suzhou	0.0130	22	0.0252	21	0.0595	21	0.0325	24

	Bangbu	0.0698	13	0.0239	23	0.0731	17	0.0556	18
	Fuyang	0.0555	16	0.0439	17	0.0932	13	0.0642	14
	Huainan	0.0502	17	0.0245	22	0.0520	23	0.0423	21
	Chuzhou	0.0446	18	0.1018	10	0.1437	10	0.0967	11
	Lu 'an	0.0406	20	0.0334	18	0.0613	20	0.0451	20
	Ma 'anshan	0.0988	11	0.0560	12	0.1358	11	0.0969	10
	Wuhu	0.2270	6	0.1215	9	0.2107	6	0.1864	7
	Xuancheng	0.0666	14	0.0563	11	0.0849	16	0.0692	12
	Tongling	0.0976	12	0.0285	19	0.0645	19	0.0635	16
	Chizhou	0.1259	9	0.0172	25	0.0486	24	0.0639	15
	Anqing	0.0429	19	0.0521	14	0.0954	12	0.0635	17
	Huangshan	0.0000	26	0.0018	26	0.0435	26	0.0151	26
The surrounding cities	Pingding Mountain	0.0104	23	0.0472	15	0.0896	15	0.0491	19
	Luohe	0.0050	25	0.0532	13	0.0672	18	0.0418	22
	Zhoukou	0.0572	15	0.0458	16	0.0904	14	0.0645	13
	Wuxi	0.4828	2	0.4815	2	0.4895	4	0.4846	2
	Nanjing	0.3695	3	0.3138	3	0.6383	3	0.4405	3
	Suzhou	0.7017	1	0.9076	1	0.8275	1	0.8123	1
	Yueyang	0.1342	8	0.1945	5	0.1730	7	0.1673	9
	Huzhou	0.3568	4	0.1435	8	0.1649	8	0.2217	6
	Wuhan	0.2672	5	0.2816	4	0.7603	2	0.4364	4
	Jiujiang	0.2171	7	0.1550	7	0.1545	9	0.1756	8

3.3 Evaluation of Port-Industry-City Integration

3.3.1 Comparative Analysis of Anhui and Surrounding Cities.

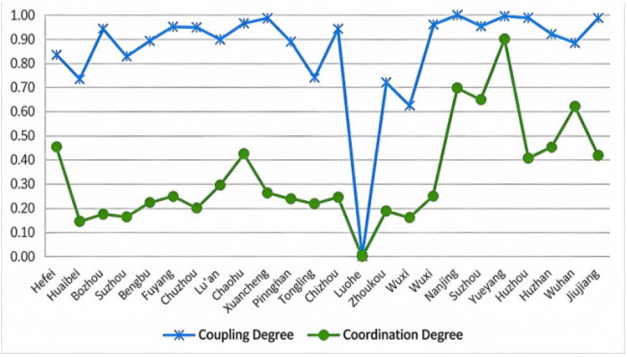

Fig. 1. Coupling Degree and Synergy Degree of Port-Industry-City Between Anhui and Its Surrounding Cities

As illustrated in **Fig.** 1, in terms of coupling degree, the three subsystems of port-industry-city in Wuxi, Suzhou, Yueyang, Jiujiang, as well as Xuancheng and Lu'an in

Anhui Province show a relatively high coupling degree, indicating consistent development pace.In terms of synergy degree, Suzhou ranks first in integration level, which is in the high integration stage; Wuhan, Nanjing and other cities are at the forefront, in the development & running-in stage; Hefei and Wuhu in Anhui Province take the leading positions in the province (ranking 5th and 7th respectively), and are in the low integration stage.

3.3.2 Comparative Analysis of Anhui Cities.

As shown in **Fig.** 2, according to the coupling degree, the three port-industry-city subsystems in Xuancheng, Lu'an, Wuhu, Fuyang, Huainan and other cities of Anhui Province show a steady growth trend.In terms of synergy degree, Hefei and Wuhu take the lead in the province in terms of integration level, with their synergy degree far higher than the provincial average of 0.24, making them benchmarks for integrated development in Anhui Province.

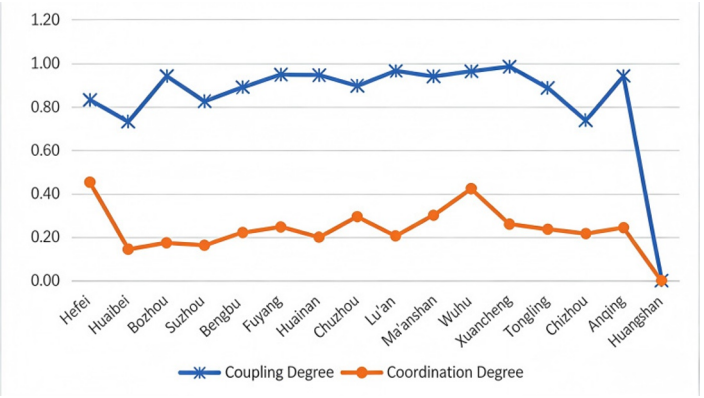

Fig. 2. Coupling Degree and Coordination Degree of Port-Industry-City in Anhui

As shown in Table 5, from the perspective of the evaluation standard for port-industry-city integration, among cities in Anhui Province, 11 cities including Hefei and Huaibei belong to the city-driven type, where urban development is ahead of port and industry development;5 cities such as Chuzhou and Ma'anshan belong to the port-driven type, where port development is ahead of urban and industrial development.

In terms of development stage, only Hefei and Wuhu have entered the low integration stage, while most cities in the province are still in the initial & embryonic stage, indicating that their integration level needs to be improved urgently.

Table 5. Evaluation Table of Port-Industry-City Integration Degree in Anhui

City	Synergy degree	Development level index	Integration development stage	Degree of integration	Integration development stage
Hefei	0.4529	f3>f2>f1	The development of the city is advanced, and the development of the port is lagging behind.	Verge of Imbalance	Low Integration Stage

Huaibei	0.1450	f3>f2>f1	The development of the city is advanced, and the development of the port is lagging behind.	Severe Imbalance	Initial Embryonic Stage
Bozhou	0.1751	f3>f1>f2	The development of the city is advanced, and the industrial development is lagging behind.	Severe Imbalance	Initial Embryonic Stage
Suzhou	0.1640	f3>f2>f1	The development of the city is advanced, and the development of the port is lagging behind.	Severe Imbalance	Initial Embryonic Stage
Bangbu	0.2226	f3>f1>f2	The development of the city is advanced, and the industrial development is lagging behind.	Moderate Imbalance	Initial Embryonic Stage
Fuyang	0.2470	f3>f1>f2	The development of the city is advanced, and the development of the port is lagging behind.	Moderate Imbalance	Initial Embryonic Stage
Huainan	0.2001	f3>f1>f2	The development of the city is advanced, and the industrial development is lagging behind.	Moderate Imbalance	Initial Embryonic Stage
Chuzhou	0.2945	f1>f3>f2	Port development is ahead, industrial development lags behind.	Moderate Imbalance	Initial Embryonic Stage
Lu'an	0.2089	f3>f1>f2	The development of the city is advanced, and the industrial development is lagging behind.	Moderate Imbalance	Initial Embryonic Stage
Ma 'anshan	0.3015	f1>f2>f3	The port development is advanced, and the urban development is lagging behind.	Mild Imbalance	Initial Embryonic Stage
Wuhu	0.4240	f1>f3>f2	Port development is ahead, industrial development lags behind.	Verge of Imbalance	Low Integration Stage
Xuancheng	0.2613	f3>f1>f2	Urban development is advanced, and the development of malicious industry is lagging behind.	Moderate Imbalance	Initial Embryonic Stage
Tongling	0.2375	f1>f3>f2	Port development is ahead, industrial development lags behind.	Moderate Imbalance	Initial Embryonic Stage
Chizhou	0.2174	f1>f3>f2	Port development is ahead, industrial development lags behind.	Moderate Imbalance	Initial Embryonic Stage
Anqing	0.2445	f3>f2>f1	The development of the city is advanced, and the development of the port is lagging behind.	Moderate Imbalance	Initial Embryonic Stage
Huangshan	0.0000	f3>f2>f1	The development of the city is advanced, and the development of the port is lagging behind.	/	/

3.3.3 Comparative Analysis of Anhui and Surrounding Provinces.

This study takes seven provinces as research samples: Anhui, Jiangxi, Henan, Hubei, Hunan, Jiangsu, and Zhejiang. There are differences in index weights between the provincial level and the city level.

Anhui, Zhejiang, Jiangsu, Hubei, and Hunan have relatively high coupling degrees, with consistent development paces among subsystems; Henan has a low coupling degree and unbalanced development.

As shown in Table 6, in terms of synergy degree: Jiangsu (0.9193) is in the High Integration Stage; Zhejiang (0.7322) is in the Development & Running-in Stage; Hubei (0.3962) and Anhui (0.3882) are in the Initial Embryonic Stage with Mild Imbalance; Hunan, Jiangxi, and Henan have synergy degrees lower than 0.3, characterized by Moderate Imbalance.

Anhui ranks 4th among the seven provinces in synergy degree, with a huge gap compared with Jiangsu and Zhejiang. The insufficient industrial support for port development and weak urban carrying capacity have become the core shortcomings.

Table 6. Evaluation Table of Port-Industry-City Integration Degree in Surrounding Provinces

Provinces	Synergy degree	Development level index	Integration development stage	Degree of integration	Integration development stage
Anhui	0.3882	f1>f3>f2	Mild Imbalance	The port development is advanced and the industrial development is lagging behind.	Initial Embryonic Stage
Jiangxi	0.2555	f3>f2>f1	Moderate Imbalance	Urban development is ahead, port development lags behind.	
Henan	0.2384	f3>f2>f1	Moderate Imbalance	Urban development is ahead, port development lags behind.	
Hubei	0.3962	f3>f1>f2	Mild Imbalance	The development of the city is advanced and the industrial development is lagging behind.	
Hunan	0.2768	f3>f2>f1	Moderate Imbalance	Urban development is ahead, port development lags behind.	
Zhejiang	0.7322	f2>f1>f3	Intermediate Coordination	Industrial development is ahead, urban development lags behind.	Development & Running-in Stage
Jiangsu	0.9193	f2>f3>f1	High-quality Coordination	Industrial development is ahead, port development lags behind.	High Integration Stage

4 Conclusion

This paper constructs an evaluation index system and uses the entropy weight method and coupling coordination degree model to quantitatively analyze the port-industry-city integration degree of Anhui Province and its surrounding cities and provinces. The main conclusions are as follows: Firstly, the overall port-industry-city integration in Anhui Province is at the initial stage with obvious regional differences. The average synergy degree of the province is only 0.24. Only Hefei and Wuhu have entered the low integration stage, while all other cities remain in the initial embryonic stage, with Huangshan having a particularly weak foundation. Secondly, the types of integrated development are polarized. Eleven city-driven cities suffer from weak port functions, and five port-driven cities are faced with low industrial levels and inadequate urban supporting facilities, resulting in the underdeveloped radiation and driving role of ports. Thirdly, there is a significant gap compared with advanced cities in the Yangtze River Delta and surrounding provinces, with prominent core shortcomings. Problems such as resource mismatch and homogeneous competition also exist within the province, restricting integrated development.

To promote the integrated development of port-industry-city in Anhui Province, it is necessary to base on the characteristics of inland river ports and formulate differentiated

strategies for the two types of cities. By strengthening port function upgrading, promoting industrial synergy and adaptation, and improving urban service and support capacity, the benign interaction and in-depth integration of ports, industries and cities can be achieved.

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