Research on the linkage mechanism and influencing factors of Jiangsu inland shipping and regional economic system

Chen Liqin, Zhang Yongfeng

1College of Transport & Communications, Shanghai Maritime University, 201306Shanghai, China
2Shanghai International Shipping Institute, Shanghai Maritime University, 200082Shanghai, China
* Corresponding author: yfzhang@shmtu.edu.cn

Abstract. In order to cater to the new development paradigm, it is increasingly important of inland shipping system to expand domestic demand. Based on the linkage mechanism between inland shipping and regional economy, the index system of coordinated development is constructed, then the coupling coordination degree model of each index weight determined by entropy weighting method is calculated, the coupling correlation degree and coupling coordination scheduling between Jiangsu inland shipping system and regional economy system from 2009 to 2019 are enumerated, the key factors causing coupling effect in the two systems are analyzed by grey correlation analysis at the last. The result shows that the coupling between inland shipping and regional economy in Jiangsu Province has been at a high level for a long time, and the coupling coordination level has experienced a change from maladjustment to benign coupling, showing a trend of steady progress. Container throughput, cargo throughput, iron ore throughput, coal and its products throughput, GDP and per capita GDP are the key factors of the interaction between inland shipping and regional economy in Jiangsu Province. By revealing the linkage mechanism between inland shipping system and regional economic system, some suggestions to promote the coordinated development of regional systems can be put forward.

1. Introduction

As a subsystem of the logistics industry, the inland waterway system interacts and restrains each other with the regional economic system. Jiangsu Province in China is rich in resources of inland waterways, and is connected to important economic nodes, industrial and mining bases and major coastal ports along the river. The inland waterway network is an important part of the comprehensive transportation system of Jiangsu Province, which has laid a good foundation for the economic development of Jiangsu Province and the Yangtze River Delta[1]. With the acceleration of the construction of the new development paradigm, and the implementation of major national strategies such as the "One Belt and One Road", "Transportation Power", the Yangtze River Economic Belt, and the integration of the Yangtze River Delta, the mutual promotion and coordinated development of Jiangsu's inland waterway system and regional economic system is an inevitable trend for the transformation and upgrading of Jiangsu's inland waterway system.

Many scholars have analyzed the relationship between inland shipping and regional economy. Furkan et al. [2], used the MRSAM matrix model to study the analysis of the economic impact of the US MKARNS inland shipping system on the region. Raghav et al. [3] in a dynamic interdependent economic
system analyzed the impact of the interruption of the US inland waterway on the regional economic losses. Song et al. [4] and Cao et al. [5] used the method of system dynamics to establish a system dynamics model for the coordinated development of regional logistics and economy. Liu [6] and Chen [7] all used regression analysis to clarify the relevant role of river basin economy. Huang et al. [8] established autoregressive distribution lag model and VAR model, and concluded that the development of inland waterway has a one-way causal relationship with regional economic growth.

Different from the above research, this article analyzes the coupling and coordination degree of Jiangsu's inland waterway system and the regional economic system from multiple dimensions.

2. Methods description
The linkage mechanism model of inland shipping and regional economy is composed of coupling coordination model and grey correlation model. Based on the establishment of evaluation indicators for the coordination mechanism of inland shipping and regional economic linkage, the coupling coordination model mainly measures and judges the degree of interaction and mutual influence between inland shipping and regional economic systems. Then using grey correlation analyzes the key factors that affect the development of the linkage mechanism in the inland waterway and regional economic system.

3. Establishment of evaluation indicators
A comprehensive evaluation of the degree of coordinated development of a region’s economy and inland waterway linkage requires the indicator system to be divided into two categories: economic indicators and shipping indicators. This article divides economic indicators into three primary indicators: economic output, economic structure, and economic benefits. Inland shipping indicators are also divided into three primary indicators: shipping output, shipping efficiency, and shipping investment. The two indicators to reflect the specific situation divided as shown in Table 1.

Table 1 the Evaluation Index System of Coordinated Development between Inland Shipping and Regional Economy.

| primary indicator               | secondary indicator                                      |
|--------------------------------|---------------------------------------------------------|
| inland shipping system          |                                          |
| shipping output                 | Cargo throughput totaled \(X_1\) (kt)                   |
|                                | Coal and product throughput \(X_2\) (kt)                |
|                                | Iron ore throughput \(X_3\) (kt)                       |
|                                | Container throughput \(X_4\) (kt)                      |
|                                | Mineral building material throughput \(X_5\) (kt)      |
| shipping efficiency            | Cargo turnover \(X_6\) (bn km)                        |
|                                | The average transport distance \(X_7\) (km)           |
|                                | Inland shipping capacity \(X_8\) (kt)                 |
| shipping investment            | Fixed asset investment in water transportation \(X_9\) (b CNY) |
| regional economy system        |                                          |
| economic output                | Regional GDP \(Y_1\) (b CNY)                         |
|                                | Value added of transportation, warehousing and         |
|                                | postal industry \(Y_2\) (b CNY)                      |
|                                | GDP per capita \(Y_3\) (b CNY)                       |
|                                | Value added rate of the secondary industry \(Y_4\) (%) |
|                                | Value added rate of the tertiary industry \(Y_5\) (%) |
| economic structure             | The proportion of secondary industry in GDP \(Y_6\) (%) |
The proportion of tertiary industry in GDP \( Y_7 \) (%)

Labor productivity growth rate \( Y_s \) (%)

Above-scale industrial added value rate \( Y_s \) (%)

Through using the range standardization method to process the data, the entropy weighting method is used to calculate the weight of each indicator.

4. Construction of model

4.1. Establish a coupling coordination model

Coupling refers to the interaction and mutual influence between two or more systems. The degree of coupling correlation between the inland waterway system and the regional economic system measures the strength of the interdependence, coordination and interaction about them. The coupling degree formula is expressed as follows:

\[
C = \left[ \frac{u_1 + u_2}{2} \right]^k
\]

Where \( C \) represents the degree of coupling, and \( C \in [0,1] \), which represents the degree to which the inland shipping and regional economic subsystems influence each other through their respective coupling factors. \( u_1 \), \( u_2 \) respectively represents the comprehensive contribution value between the inland shipping system and the regional economic system; \( k \) is the adjustment coefficient and because of the two systems of inland shipping and regional economy, the value of \( k \) is 2.

Discuss the coupling degree \( C \) between partitions as follows. The specific criteria are shown in Table 2.

Table 2  Coupling Stage and Criterion.

| \( C \)   | Coupling Stage          |
|---------|-------------------------|
| (0,0.3] | low-level coupling      |
| (0.3,0.5] | antagonistic phase      |
| [0.5,0.8] | be well coupled         |
| [0.8,1]  | high level of coupling  |

\( D \) is the degree of coupling coordination, which is a factor used to measure the degree of coordination between systems or elements. Intermediate variables \( T \) need to be used when calculating the degree of coordination.

\[
D = \sqrt{T \times C}
\]

Where \( T = au_1 + bu_2 , \quad a + b = 1 \), and \( T \in [0,1] \), and according to the importance of the two systems, select values for \( a \) and \( b \). It is assumed that the two are equally important, taking \( a+b=1 \), and \( D \in [0,1] \). The judgment of coupling coordination level is shown in Table 3.
Table 3  Coupling Coordination Grade and Criterion.

| D       | Coupling Coordination Grade | D       | Coupling Coordination Grade |
|---------|-----------------------------|---------|-----------------------------|
| (0.0,1] | extreme imbalance           | (0.5,0.6] | barely coordination        |
| (0.1,0.2] | severe imbalance           | (0.6,0.7] | primary coordination       |
| (0.2,0.3] | moderate disorder         | (0.7,0.8] | intermediate coordination   |
| (0.3,0.4] | mild disorder             | (0.8,0.9] | well coordination          |
| (0.4,0.5] | on the verge of            | (0.9,1]  | quality coordination       |

4.2. Grey relational analysis

The degree of coupling coordination only analyzes the degree of coupling between the two systems as a whole. In order to reveal the interaction between the indicators of the two systems, gray correlation analysis is introduced. The gray correlation degree is used to analyze the key factors of the interaction between the two subsystems, so as to further reveal the coupling between the inland waterway shipping system and the regional economic system mechanism.

Determine the correlation coefficient \( \xi(j) \) between the two indicators.

\[
\xi(j) = \min_{i} \min_{j} \left| \frac{Z_x^i - Z_y^j}{\rho \max_{i} \max_{j} |Z_x^i - Z_y^j|} \right| + \rho \max_{i} \max_{j} |Z_x^i - Z_y^j| 
\]

(3)

Among them, \( \xi(j) \) represents the correlation coefficient between the two indicators at time \( j \), \( i=1,2,\ldots,m \), \( j=1,2,\ldots,n \), \( Z_x^i \) and \( Z_y^j \) respectively represent the standardized values of the indicators of the inland waterway system and the regional economic system, \( \rho \) is the resolution coefficient, usually \( \rho = 0.5 \).

Average the correlation coefficient \( \xi(j) \) to get the correlation matrix \( \gamma \).

\[
\gamma_{ij} = \frac{1}{k} \sum_{i=1}^{k} \xi(j), k = 1, 2, \ldots, n
\]

(4)

Where \( k \) represents the number of samples.

Finally, calculate the average correlation degree of each indicator on the basis of the correlation degree matrix \( \gamma \).

\[
\gamma_{i} = \frac{1}{n} \sum_{j=1}^{n} \gamma_{ij} \quad (i = 1, 2, \ldots, m; j = 1, 2, \ldots, n)
\]

\[
\gamma_{j} = \frac{1}{m} \sum_{i=1}^{m} \gamma_{ij} \quad (i = 1, 2, \ldots, m; j = 1, 2, \ldots, n)
\]

(5)

As a result, a gray correlation matrix between the inland waterway system and the regional economic system is established. By comparing the size of \( \gamma_{ij} \), it is possible to analyze which indicators in the regional economic system are more closely related to the inland waterway system.

\[
\gamma = \begin{bmatrix}
\gamma_{11} & \gamma_{12} & \cdots & \gamma_{1n} \\
\gamma_{21} & \gamma_{22} & \cdots & \gamma_{2n} \\
\vdots & \vdots & \ddots & \vdots \\
\gamma_{m1} & \gamma_{m2} & \cdots & \gamma_{mn}
\end{bmatrix}
\]

(6)

5. Empirical analysis

This paper uses time series data as a sample, and selects relevant data on inland shipping and regional economic development in Jiangsu Province from 2009 to 2019 to empirically study the coupling and
coordination relationship between inland shipping and regional economy. The data comes from the Jiangsu Statistical Yearbook, Statistical Bulletin of National Economic and Social Development of Jiangsu Province and China Shipping Database.

5.1. Determine the weight of the evaluation index
Establish an evaluation index system for the coordinated development of inland shipping and regional economic coupling, and select the original data related to inland shipping and regional economic development in Jiangsu Province from 2009 to 2019 for modeling calculations.

5.2. Establish a coupling coordination model
Calculate the comprehensive contribution value $u_1$ of the inland water navigation subsystem to the total system each year, and the comprehensive contribution value $u_2$ of the regional economic subsystem to the total system. From this, calculate the coupling degree $C$ and the coupling coordination degree $D$ of the two subsystems to divide the coupling phase and the coupling level. The calculation results are shown in Table 4.

It can be seen from Table 4, that the degree of coupling between Jiangsu’s inland navigation and regional economy has gone through two different stages. From 2009 to 2010, the coupling between Jiangsu’s inland navigation system and the regional economic system was at a low level of coupling. After 2010, the two The degree of coupling between $C \in (0.7,0.96)$, tends to a higher level of coupling, indicating that the Jiangsu inland waterway system and the regional economic system have a strong correlation and leading role, and maintain a strong mutual influence relationship.

In-depth analysis of the evolution logic of the coupling degree and coordination degree between Jiangsu’s inland waterway and the regional economic system from Fig 1. In the context of time, taking 2010, 2012, and 2017 as the nodes, the comprehensive contribution value and coupling coordination degree of inland waterway shipping and regional economy fluctuate greatly. In 2010, the economic development of the Yangtze River Delta region showed a trend of high growth and steady development; in the same period, Shanghai International Shipping Center construction has driven the ports in the Yangtze River Delta into a period of rapid development. The development of inland waterway has been upgraded simultaneously, and the degree of coupling and coordination between the two systems has shown an upward trend. In 2011, the Jiangsu Provincial Government issued the Provincial Government’s Implementation Opinions on Accelerating the Development of Water Transport in Inland Rivers such as the Yangtze River, proposing to speed up the development of water transport. In 2012, the economy of Jiangsu Province also grew steadily during the transformation and upgrading, so the coupling between the two reached its peak. In 2017, Jiangsu Province actively promoted the deepening of supply-side structural reforms, and the economic development was stable and progressing; the introduction of the Jiangsu Province Trunk Channel Network Plan and the Jiangsu Province Inland Port Layout Plan accelerated the transformation and upgrading of inland waterway shipping, so the degree of coupling between the two and the degree of coordination rose slightly.

Figure 1 Integrated contribution value and coupling coordination between inland shipping and regional economy in Jiangsu from 2009 to 2019
5.3. Grey relational analysis

Table 5 shows the gray correlation matrix of inland shipping and regional economy in Jiangsu Province. The average correlation between the indicators of the inland waterway system and the regional economic system reached 0.726, indicating that the inland waterway system as a whole has a strong coupling effect on the regional economic system. Among them, the average correlation degree of container throughput, cargo throughput, iron ore throughput and coal and its product throughput to the regional economic system indicators exceeds 0.75, and the volume of cargo turnover has the weakest impact on the regional economy, but the correlation degree still reaches 0.66. In the regional economic system, the average correlation of each indicator to the inland waterway system exceeds 0.64, indicating that regional economic development also has a strong coupling effect on the inland waterway system. Among them, the regional

Table 4 The coupling degrees of inland shipping system and regional economic system in Jiangsu from 2009 to 2019.

| Year | U1   | U2   | C    | Coupling Stage       | D    | Coupling Coordination Grade |
|------|------|------|------|----------------------|------|-----------------------------|
| 2009 | 0.046| 0.434| 0.119| low-level coupling   | 0.169| severe imbalance             |
| 2010 | 0.087| 0.741| 0.143| low-level coupling   | 0.243| moderate disorder            |
| 2011 | 0.227| 0.574| 0.661| be well coupled      | 0.515| barely coordination          |
| 2012 | 0.323| 0.427| 0.962| high level of coupling| 0.601| primary coordination        |
| 2013 | 0.539| 0.370| 0.932| high level of coupling| 0.651| primary coordination        |
| 2014 | 0.647| 0.382| 0.872| high level of coupling| 0.670| primary coordination        |
| 2015 | 0.734| 0.319| 0.713| be well coupled      | 0.613| primary coordination        |
| 2016 | 0.715| 0.309| 0.710| be well coupled      | 0.603| primary coordination        |
| 2017 | 0.680| 0.424| 0.896| high level of coupling| 0.703| intermediate coordination   |
| 2018 | 0.620| 0.339| 0.835| high level of coupling| 0.633| primary coordination        |
| 2019 | 0.779| 0.335| 0.707| be well coupled      | 0.627| primary coordination        |

Table 5 The grey relevancy matrix between inland shipping and regional economy in Jiangsu from 2009 to 2019.

| Indicator | Y1   | Y2   | Y3   | Y4   | Y5   | Y6   | Y7   | Y8   | Y9   | Average |
|-----------|------|------|------|------|------|------|------|------|------|---------|
| Shipping output | X1 | 0.820 | 0.748 | 0.822 | 0.691 | 0.745 | 0.753 | 0.861 | 0.704 | 0.649 | 0.755 |
|           | X2 | 0.834 | 0.752 | 0.837 | 0.686 | 0.737 | 0.746 | 0.836 | 0.693 | 0.644 | 0.752 |
|           | X3 | 0.884 | 0.756 | 0.888 | 0.672 | 0.719 | 0.723 | 0.803 | 0.706 | 0.632 | 0.754 |
|           | X4 | 0.811 | 0.783 | 0.813 | 0.715 | 0.752 | 0.765 | 0.828 | 0.693 | 0.670 | 0.759 |
|           | X5 | 0.795 | 0.685 | 0.794 | 0.692 | 0.750 | 0.762 | 0.770 | 0.691 | 0.650 | 0.732 |
| Shipping efficiency | X6 | 0.807 | 0.690 | 0.795 | 0.591 | 0.623 | 0.610 | 0.650 | 0.623 | 0.561 | 0.661 |
|           | X7 | 0.804 | 0.721 | 0.800 | 0.669 | 0.708 | 0.720 | 0.817 | 0.716 | 0.630 | 0.732 |
GDP and the per capita GDP have the highest average correlation to the inland waterway system, both reaching 0.78, indicating that these two factors are the key factors affecting the development of inland waterway navigation in Jiangsu Province. From the comparison of the correlation between the two indicators, the correlation between iron ore throughput and per capita GDP is the highest, reaching 0.888, which has a strong coupling effect; the volume of cargo turnover in inland shipping and the scale of the regional economy. The correlation between the above industrial value-added rates is the lowest, only 0.561, but still achieves a medium coupling effect.

6. Conclusion
This paper constructs an index system reflecting the linkage mechanism between inland waterway shipping and regional economy, uses coupling coordination degree model to empirically analyze the coupling and coordination effects between the two systems, and reveals the key factors of the interaction by gray correlation, and finally came to the conclusion that the research showed as following.

a) The coupling correlation between Jiangsu's inland waterway system and the regional economic system is generally on the rise, at a relatively high level of coupling; the level of coupling coordination has experienced an improvement from imbalance to benign coordination, and the degree of coupling coordination has gradually stabilized.

b) The average correlation degree of container throughput, cargo throughput, iron ore throughput, and coal and its product throughput in the inland waterway system to the regional economic system indicators exceeds 0.75, which are the key factors to regional economic development, having a strong coupling effect.

c) The regional GDP and per capita GDP in the regional economic system have the highest average correlation to the inland waterway system, which is a key factor affecting the development of inland waterway navigation in Jiangsu Province.

The following suggestions are put forward for the joint development of Jiangsu's inland waterway and regional economy.

a) The development of inland waterway shipping is ushering in a period of strategic opportunities. Under the new development paradigm, attention should be paid to the linkage development between the two, and the transformation and upgrading of the inland shipping system should be promoted to promote economic development.

b) According to the functional positioning of different inland river ports, inland water ports Infrastructure construction should implement personalized and differentiated customization around the transportation needs of regional leading industries to ensure that warehousing, distribution, loading and unloading, and waterways can meet the needs of regional industrial development, and realize the systemic linkage development of inland shipping and regional economy.

c) The inland waterway system will also develop simultaneously with the growth of regional GDP. The development of the inland waterway economic belt can maximize the linkage effect of the two systems.

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