Vitality Evaluation of Logistics Port Based on the Partial Order Set

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Abstract. In order to effectively evaluate the logistics vitality of twelve ports in the downstream area of the Yangtze River, a port logistics vitality evaluation index system was constructed, including four aspects: facilities, operation scale, and economic and information technology capabilities. The partial order set evaluation model was applied to evaluate the logistics port vitality downstream of the Yangtze River. The feature of this model is that it does not require precise weight values, but only needs to know the weight order of the evaluation indicators. The weight order information of the evaluation indicators was extracted by the entropy weight method, and the Hasse diagram was used to display the model effect. By comparing the advantages and disadvantages of different ports, this method can provide a scientific basis for evaluating port logistics vitality, optimizing logistics layout, and improving port economic benefits, bringing new opportunities and challenges for logistics development. The research shows that this method is feasible and effective, and the results are more accurate.

Keywords: Port logistics · Partial ordering set · Weight · Evaluation

1 Introduction

In the global supply chain and logistics system, ports play an important role in providing basic logistics services and value-added services, supporting global trade and economic development [1]. The scientific operation and precise management of logistics ports can improve port efficiency and service quality [2], promote the coordinated development of ports and related industries, and drive the overall upgrading of the logistics industry.

Scientific evaluation can provide a scientific basis for the optimization and upgrading of logistics ports, guiding ports to carry out technological innovation and management innovation, and improving the overall level of ports. For example, Wang Weixin et al. [3] constructed an index system for the logistics of Shenzhen Port and the economic development of Shenzhen and used grey correlation analysis to analyze the inherent correlation between the logistics of Shenzhen Port and the economic development of Shenzhen. Zhuang Jiaqi et al. [4] calculated the comprehensive development index of Dalian Port and the urban economy from 2010 to 2020 under the background of the "Belt and Road" initiative, analyzed the development of ports and the urban economy in the past decade,

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and analyzed the coupling coordination degree between ports and urban economy. The article [5] establishes a deep neural network prediction model for port coordinated development, uses various port logistics indicators to predict economic development trends, and realizes the nonlinear mapping relationship between port economic development level and port logistics demand side. In the context of highly digitized and globally traded logistics, data-based methods have become a necessary working method to promote intelligent and sustainable logistics development. Domestic and foreign scholars have begun to explore multi-criteria decision-making methods for analyzing and evaluating port logistics. For example, based on game models [6], evaluate the logistics transportation efficiency of port enterprises, use the AHP-EWM method [7] to calculate the location advantage of Yangtze River Economic Belt coastal ports, integrate the SBM model and hierarchical regression model, analyze the regional port logistics performance of China's "Belt and Road" initiative [8], and use a four-stage DEA model to measure the port logistics efficiency of China's coastal ports from 2014–2018 [9]. Xu et al. [10] evaluated the low-carbon emission reduction efficiency of Dalian Port using data envelopment analysis and principal component analysis. Through the research on the application of algorithms in the evaluation of logistics ports, it is found that some methods improve the calculation speed by dimensionality reduction, but this may lose some information, and the precise value of weights will also affect the judgment of results.

The partial order set evaluation method is a non-parametric evaluation method that does not require obtaining the exact weight values of each attribute. It can effectively handle uncertain information only through weight ordinal and avoid the impact of subjective bias or error brought by other evaluation methods that require specific weight values. Based on the existing research on logistics port algorithms' deficiencies and the demand for expanding fields, this study applied the partial order set evaluation method to evaluate and analyze the logistics ports downstream of the Yangtze River, demonstrated the evaluation effect through HASSE diagrams, conducted hierarchical clustering of alternative targets, and carried out a horizontal and vertical analysis of the logistics vitality of ports. This method fully considers the differences between features, improves the robustness and stability [11] of the results, makes the decision-making process more efficient and accurate, and evaluates the logistics vitality of ports more scientifically and accurately.

2 Poset Evaluation Method

The earliest partial order decision-making method was the evaluation using total order weights, which was proposed by Brüggemann et al. [12] With continuous research on the theory of partial order sets and the deepening of practice, scholars such as Yue [13] expanded the total order weights to partial order weights. Based on this, a new partial order set multi-criteria decision-making method was proposed, which fully expresses the decision-makers personal preferences and completely solves the weighting problem.

2.1 The Theoretical Basis of Posets

Definition 1 [14] Let R be a binary relation on set A if R satisfies:

(1) reflexivity: for any $x \in A$, there is xRx;
(2) anti-symmetry: for any $x, y \in A$, if xRy and only if yRx, then $x = y$;
(3) transitivity: for any $x, y, z \in A$, if xRy and yRz, then xRz.

Then R is called the partial order relation on the set A. In practical applications, the partial order relation is usually represented by "$\preceq$". The evaluation object and the partial order relation form a partial order set, denoted as $(A, \preceq)$ [15]. Here, A refers to the set with a partial order relation.

If there exists a partial order relation on the evaluation set $M = (A, IC, D)$, then $\forall a_i, a_j \in A$ can be expressed as

$$a_i \leq a_j \Leftrightarrow c_j(a_i) \leq c_j(a_j) \tag{1}$$

Theorem 1 [11] Given the evaluation set $M = (A, IC, D)$ and the partial order set $(A, \preceq)$, if $a_i \geq a_j$, then $R_{ij} = 1$. Conversely, if $a_i < a_j$, then $R_{ij} = 0$. In this case, $R = (R_{ij})_{\mathrm{m} \times n}$ is called a comparison relation matrix on the partial order set $(A, \preceq)$.

When $\omega_1 \geq \omega_2 \geq \cdots \omega_n \geq 0$, Theorem 1 can be represented by the following matrix, where each row represents an alternative and each column represents an evaluation criterion or indicator.

$$X = D \cdot I = \begin{bmatrix} x_{11} & x_{11} + x_{12} & \cdots & x_{11} + x_{12} + \cdots x_{1n} \\ x_{21} & x_{21} + x_{22} & \cdots & x_{21} + x_{22} + \cdots x_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ x_{m1} & x_{m1} + x_{m2} & \cdots & x_{m1} + x_{m2} + \cdots x_{mn} \end{bmatrix} \tag{2}$$

where D is the evaluation matrix and I is the unit upper triangular matrix

$$D = \begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1n} \\ x_{21} & x_{22} & \cdots & x_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ x_{m1} & x_{m2} & \cdots & x_{mn} \end{bmatrix} \tag{3}$$

$$I = \begin{bmatrix} 1 & 1 & \cdots & 1 \\ 0 & 1 & \cdots & 1 \\ \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & \cdots & 1 \end{bmatrix} \tag{4}$$

According to the partial order relation in Theorem 1, we can make a pairwise comparison of the row vectors of the cumulative matrix and establish the following partial order relation matrix.

$$R_{ij} = \begin{cases} 1, x_i > x_j; \\ 0, x_i \leq x_j \end{cases} \tag{5}$$

Because the partial order relation matrix has the problem of information redundancy, it needs to be simplified to the HASSE matrix. The related literature [16] provides the transformation formula between the comparative relation matrix and the HASSE matrix. For any scheme $a_i \in A$, the height of the poset $(A, \preceq)$ [17] is

$$hav(a_i) = \frac{|O(a_i)|}{|O(a_i)| + |F(a_i)|} \cdot (|A - F(a_i)|) + \frac{|F(a_i)|}{|O(a_i)| + |F(a_i)|} \cdot |O(a_i)| \quad (6)$$

where the set $O(a_i) = \{y = A|a_i \succ \vee\}$ represents the number of elements in the lower set of the set A, and the set $F(a_i) = \{y = A|a_i \prec \vee\}$ represents the number of elements in the upper set of the set A.

The poset decision-making method sorts each scheme according to the size of $hav(a_i)$ the poset.

2.2 Evaluation Steps of Posets

Step 1: Normalize the original data, then number the evaluation indicators and sort them according to the weight size to obtain the adjusted evaluation matrix.

Step 2: Construct a comparison matrix based on the standardized indicator data.

Step 3: Transform the comparison matrix into the HASSE matrix according to formula (6) and draw the HASSE diagram.

Step 4: Perform linear sorting and analysis of the schemes according to formula (7).

3 Case Analysis

3.1 Construction of Index System

When constructing a port logistics vitality evaluation indicator system, it is necessary to follow principles such as scientificity, operability, and comprehensiveness. Based on the previous research and relevant criteria, this article has established a complete set of port logistics vitality evaluation indicator systems (see Table 1).

3.2 Data Sources

A sample of 12 ports downstream of the Yangtze River, including Nanjing Port, Zhenjiang Port, Suzhou Port, Nantong Port, Jiangyin Port, Yangzhou Port, Taizhou Port, Ma'anshan Port, Wuhu Port, Tongling Port, Chizhou Port, and Anqing Port, was studied. The indicator data were obtained from the "China Port Yearbook 2021", "Compilation of National Transportation Statistics", and "China Urban Statistics Yearbook".

3.3 Evaluation Process

According to the evaluation steps of port logistics vitality based on poset theory, the ordinal information of index weight is extracted by entropy weight method, and finally, the Hasse diagram of port logistics vitality is drawn (Fig. 1).

The height values of each port are calculated according to Eq. (6), and the results are shown in Table 2.

Table 1. Index system of port logistics vitality

First-order index	Secondary index
Port logistics facility capacity	Berth length C11 (m)
	Warehouse area C12 (10,000 square meters)
	The number of berths of 10,000 tons for production C13 (a)
	Water area C14 (Ten thousand square meters)
Port logistics operation scale capacity	Cargo throughput C21 (megaton)
	Container throughput C22 (Wan TUE)
	Design year pass capability C23 (Tons of)
	Foreign trade throughputC24 (Ten thousand tons)
Port logistics economic capacity	Investment in port and shipping constructionC31 (Hundred million yuan)
	Port traffic capacity C32 (points)
	Per capita GDP of port cities C33 (100 million yuan)
Digital capability of Port	Logistics information automation level C41 (points)
	Logistics technology innovation ability C42 (points)
	Management service level C43 (points)

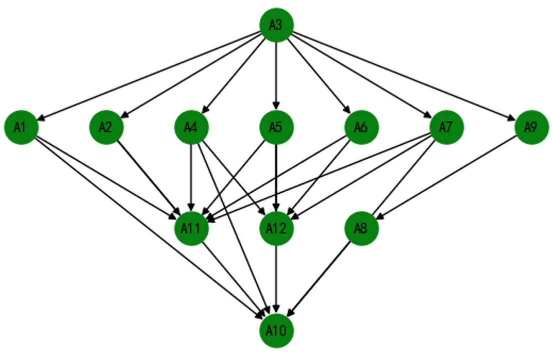

Fig. 1. Hasse diagram of port logistics vitality

3.4 Analysis of Evaluation Results

The Hasse diagram shown in Fig. 1 provides clear hierarchical clustering information for the logistics ports, dividing the 12 ports into four levels. Specifically, the first level consists of A3, the second level includes A1, A2, A4, A5, A6, A7, and A9, the third level is made up of A11, A12, and A8, and the fourth level is represented by A10. It is worth noting that partial order set theory has the characteristic that the

Table 2. Height Calculation Results

port	Next set	Previous Video	Height value
Nanjing Port	3	2	7.20
Zhenjiang Port	3	2	7.20
Suzhou Port	12	1	11.08
Nantong Port	4	2	8.00
Jiangyin Port	4	2	8.00
Yangzhou Port	3	2	7.20
Taizhou Port	4	2	8.00
Ma'anshan Port	2	3	4.80
Wuhu Port	3	2	7.20
Tongling Port	1	9	1.20
Chizhou Port	1	8	1.33
Anqing Port	1	6	1.71

upper subset cases are better than the lower subset cases. Therefore, it is clear from the Hasse diagram that as the level increases, the logistics vitality of the port also increases, and vice versa. Their partial order comparison relationship can be expressed as: $\{A3\} \succ \{A1, A2, A4, A5, A6, A7, A9\} \succ \{A8, A11, A12\} \succ \{A10\}$.

According to the height value results calculated from Table 2, we have sorted the 12 logistics ports by their vitality. Suzhou Port ranked the highest, while Tongling Port's logistics vitality was relatively low compared to other ports. This ranking result provides important reference significance for the analysis of future logistics port competitiveness. Furthermore, Suzhou Port's high ranking can be attributed to its outstanding performance in many indicators. For example, in terms of port cargo throughput, container throughput, and logistics information automation level, Suzhou Port is in a leading position. This indicates that Suzhou Port has a higher overall development level and market competitiveness. Conversely, Tongling Port's low ranking is mainly due to its relative lack of logistic operational scale and logistic informationization capabilities. This prompts us to strengthen the management and construction of Tongling Port in the future to improve its logistics vitality and market competitiveness.

4 Conclusion

This study constructs a logistics port vitality evaluation model based on partial order set theory and presents the ranking of each logistics port intuitively through actual data from 12 ports. This method does not require specific weight values but only requires an understanding of the size order of the weights, making logistics port vitality evaluation and ranking more intuitive. This weight order-based evaluation method is more flexible, and the weight order can be easily obtained in practical applications, avoiding problems caused by the lack of specific weight values that prevent evaluation and ranking, which reduces the application's difficulty. Furthermore, this method has good robustness without requiring specific parameter settings, and it can still obtain optimal evaluation results, avoiding the problem of inconsistent evaluation results due to different parameter settings. This model belongs to non-parametric decision methods, providing a new perspective for analyzing and evaluating the level of port vitality. However, further improvement is needed in terms of indicator selection. In the future, this model can be further improved and expanded based on actual conditions to better serve port construction and economic development.

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