Gray Correlation Comprehensive Evaluation of Port Intermodal Transport Development Level Based on Expert Group Decision-Making Weight Optimization

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Abstract—This paper adopts the weight optimization method based on expert group decision-making technology to optimize the weights of the influencing factors affecting the development level of port intermodal transport, and then adopts the gray correlation comprehensive evaluation method to evaluate the development level of port intermodal transport in China from three aspects of supply capacity, service level and development environment. The results prove that the evaluation method is practical and effective, and can provide support for the evaluation of the development level of port intermodal transport in China.

1. INTRODUCTION

At present, the development of China's intermodal transport is based on the freight volume as the only indicator of the development level of different regions, which has led to the increase of freight volume in the form of subsidies and the construction of various intermodal transport parks in a rush. This development orientation has resulted in the waste of resources such as capital, land and transport capacity. However, the construction of single contract, informatization and networking, which represents the future development trend of intermodal transport, has not been paid enough attention to. There is a lack of scientific and reasonable development concepts and ideas to evaluate and guide the development of intermodal transport of each region. Therefore, it is urgent to construct the evaluation index system of intermodal transport and select the evaluation method of the development level of intermodal transport.

2. LITERATURE REVIEW

2.1 Current Status of Development Level Evaluation of Intermodal Transport

Wei Jiang et al. constructed the key influencing factors of the sustainable development of intermodal transport from macroeconomic perspective, and believed that the division of international industry, international trade and world market's newest change are the key factors affecting the development of China's intermodal transport [1]. Wang Hua pointed out that the freight capacity of ports along the Lancang River is insufficient, railway freight restricts highway freight, and the lack of supply capacity of railway transport is the main factor affecting the development of intermodal transport in Yunnan Province [2]. Ni Chaojun et al. constructed the evaluation system of regional logistics developing level, combined
with the improved Gray Correlation (GC) analysis method, divided the regional logistics developing level into three categories and searched out the core impact factors [3]. Jin Zhihong et al. established an evaluation index system for the advantages and disadvantages of intermodal transport corridor, collected and analyzed the data of intermodal transport corridor from Shandong Peninsula to Korea, and verified it with the evaluation methods adopted in the paper. Finally, according to the evaluation results, they proposed targeted policy suggestions [4].

2.2 Optimization Method of Evaluation Index Weight
There are three main methods for determining attribute weight: subjective weighing method, objective weighing method and combination weighting method. In the decision-making process of modern large-scale systems, although the subjective weighing method reflects the subjective judgment or intuition of the decision-maker, it may produce a certain degree of subjective arbitrariness in the comprehensive evaluation results or ranking [5]. Although the objective weighting method usually uses relatively perfect mathematical theories and methods, it ignores the subjective information of decision-makers, which is sometimes very important for evaluation and decision-making. Combination weighting method organically combines subjective weighting method and objective weighting method, so that the determined weighing coefficient reflects both subjective and objective information. This paper uses a combination of subjective and objective weighting method to optimize the weight of evaluation index.

2.3 Gray Correlation Method
Gray correlation analysis is to establish an appropriate mathematical model for the research system, and to grasp the main contradictions, main features and main factors affecting the system through quantitative analysis of the dynamic development process of the system [6]. Gray correlation analysis is not only one of the important parts of gray system theory, but also the cornerstone of gray system analysis, modeling, prediction and decision-making. Gray correlation analysis is to serialize and pattern the gray relation of which the operation mechanism and physical prototype are not clear or lack of physical prototype at all [7]. Then the gray correlation analysis model is established to quantify, sequence and manifest the gray relation, which can provide an important technical analysis method for the modeling of complex systems. The basic principle is to distinguish the degree of correlation among multiple factors in the system by comparing the geometric relations of statistical sequences. The closer the geometric shapes of the sequence curves are, the greater the degree of correlation between them will be. According to the order of the degree of relation, we can make a judgment on the status of each factor in the system.

3. DATA DESCRIPTION AND PROCESSING

3.1 Raw Data and Study Area
The evaluation object of this paper is the coastal port in China. The related data of intermodal transport of coastal port X and coastal port Y are collected for empirical analysis. The data used in the present study are collected from the statistical data of port X and port Y, as well as China Ports Year Book [8]. Some of the data, such as information system construction capacity, are obtained by the author of this paper after field investigation and discussions with experts.

3.2 Data Processing
According to the three major elements (supply capacity, service level and development environment) of the high-quality development of intermodal transport, a systematic evaluation index system is established in accordance with the three major steps of primary index selection, index screening and index determination. The established index system is shown in Tab. 1.
### TABLE 1 THE ESTABLISHED INDEX SYSTEM

| First-level indicators | Second-level indicators | Third-level indicators | Fourth-level indicators |
|------------------------|-------------------------|------------------------|-------------------------|
| Development level of intermodal transport of coastal ports | Scale of intermodal transport | Ratio of intermodal transport volume to total freight volume | Market share of freight volume |
|                        |                         |                        | Average annual growth rate in the past 5 years |
|                        |                         |                        | Railway loading and unloading conditions |
| Supply capacity         | Infrastructure capacity | Ratio of loading and unloading capacity of railway lines into port to total throughput capacity | Seamless connection of port-railway |
|                        |                         |                        | Is door-to-door transportation service available |
|                        | Ability of the operator | Is there an integrated service information system for intermodal transport | |
|                        | Informatization level   | Safety accident rate of Intermodal transport | |
|                        | Safety production       | Rate of cargo damage and shortage | Utilization rate of clean energy equipment |
|                        | Energy saving and environmental protection | Loaded container rate of all trains | |
| Service level           | Operation efficiency   | Rate of direct transfer between train and ship | Rate of Changes from Bulk Cargo to Container |
|                        | Whole process service  | Realization rate of single contract | Number of dry ports |
|                        | Precise timeliness     | On-time delivery rate | |
|                        | Supporting policy system | Coordination mechanism | Policies and measures |
|                        |                         | Credit system | |
|                        | Port environment       | Average clearance time | |
|                        | Development environment | Mechanism forum discussion | |
|                        | Supporting decision-making ability | Alliance formation | |

### 4. METHODOLOGY

#### 4.1 Weight Optimization

This paper establishes a weight optimization model based on the initial weight interval of expert knowledge as the constraint condition of the weight optimization model [9]. In order to ensure the objectivity and rationality of the experts weights, according to the theory of fuzzy level division, the evaluation index weight of port intermodal transport development level is divided into 10 levels, which are represented by triangular fuzzy numbers, as shown in Tab 2.

### TABLE 2 FUZZY NUMBER REPRESENTATION OF WEIGHT INTERVAL LEVEL

| Weight interval level | Fuzzy number |
|-----------------------|--------------|
|                       | a\_k | c\_k | b\_k |
| 1                     | 0.00 | 0.05 | 0.10 |
| 2                     | 0.10 | 0.15 | 0.20 |
In order to weaken the influence of expert background information on the weighting preference, the expert reliability index is introduced to improve the credibility of the initial weight of experts [10]. In this paper, we calculate the expert reliability index based on the background information of the experts such as working years, education level and professional title, as in:

$$\omega = \sum_{i=1}^{3} \alpha_{i} q_{i}$$

Among them, $\omega$ represents the expert reliability index; $q_{i}$ represents the value of the i-th expert's background information, which can be determined according to Tab 3; $\alpha_{i}$ represents the degree of influence of different background information on the expert reliability index, where the professional title information of the expert is 0.5, the working years information of the expert is 0.4, and the educational background information of the expert is 0.1.

### TABLE 3 EXPERT BACKGROUND INFORMATION LEVEL DIVISION

| Working years | Professional title       | Educational background | $q_{i}$ |
|---------------|--------------------------|------------------------|---------|
| Over 30 years | Senior engineer          | Master degree or above | 1.0     |
| 21-30 years   | Engineer                 | Bachelor degree        | 0.9     |
| 11-20 years   | Assistant engineer       | College degree         | 0.8     |
| 6-10 years    | Technical worker         | Senior high school     | 0.7     |
| 1-5 years     | Ordinary worker          | Below senior high school| 0.6    |

It is generally believed that the weight information of experts conforms to Gaussian Distribution, that is, the greater the gap between the weights level assigned by experts, the smaller the probability of membership will be. Then the probability that each index weight belongs to the i-th weight interval can be obtained, as shown in the formula. The membership function of each index weight can be obtained by weighted average of the initial weight information of the experts. Then, according to the formula, the mean and standard deviation of each index weight can be obtained, and finally the upper and lower limits of the weight change interval of each index can be obtained according to the "σ criterion", as in:

$$p_{i} = \begin{cases} 
\frac{(c_{i+k-1}-c_{i-1})}{\sum_{j=1}^{i+k-1}(c_{k}-c_{j})} \times \frac{1-\omega}{2}, & 1 \leq i \leq k-1 \\
\omega, & i = k \\
\frac{(c_{i+k-1}-c_{i+k})}{\sum_{j=k+1}^{i+k+1}(c_{k}-c_{j})} \times \frac{1-\omega}{2}, & k + 1 \leq i \leq 10
\end{cases}$$

(2)
Among them, \( p_i \) represents the probability that the weight value obtained by an expert weighting a certain index belongs to the \( i \)-th weight interval; \( \omega \) represents the expert reliability index; \( i, j \) and \( k \) represent the weight interval level; \( c_k, c_j, c_{k-i} \) and \( c_{11+k-i} \) represent the median of each weight interval.

\[
P_i = \frac{\sum_{i=1}^{n} p_i}{n} \quad (3)
\]

\[
m = E(P) = \sum_{i=1}^{10}(c_i \times p_i) \quad (4)
\]

\[
\sigma = \sqrt{D(P)} = \sqrt{\sum_{i=1}^{10}(c_i - E(P))^2 \times p_i} \quad (5)
\]

Among them, \( p_i \) represents the probability that a certain index weight belongs to the \( i \)-th weight interval; \( j \) and \( n \) represent the number of experts; \( c_i \) represents the median of the \( i \)-th weight interval; \( m \) and \( \sigma \) represent the mean and standard deviation of the probability distribution of a certain index weight; \( a \) and \( b \) represent the upper and lower limit of the change range of a certain index weight.

### 4.2 Gray Correlation Comprehensive Evaluation

With more than 20 years of deepening and development, the gray system theory has constructed a basic framework and formed an analysis system based on gray correlation analysis, a model system based on Gray Model (GM), a method system based on gray process and its generation space, and a technical system with system analysis, modeling, decision-making, control and evaluation.

#### 4.2.1 Reference sequence

Firstly, the reference sequence should be selected for gray correlation analysis. The reference sequence is the basis for standardized data processing of each system, which can be either agreed or prescribed, or a group of measured sequences. If \( X_0 \) is chosen as the reference sequence, then \( X_0, X_1, \ldots, X_{n-1}, X_n \) are taken as the comparison sequence, and \( X_i(k) \) is taken as the value of the \( i \)-th sequence at moment \( k \), \( i = 1, 2, \ldots, n; k = 1, 2, \ldots, t \). The values of the sequence at each moment form an \( n \)-dimensional vector. For example, \( X_i = (X_i(1), X_i(2), \ldots, X_i(n)) \) is the \( i \)-th sequence vector, that is, the section value of the whole array curve at time \( i \).

#### 4.2.2 Correlation coefficient

The correlation degree, in essence, is the degree of difference in geometric shapes between curves. Therefore, the difference between the curves can be used as a measure of the degree of correlation. Correlation analysis uses the difference between the curves of the sequences as a measurement of the correlation. For a reference sequence \( X_0 \), there are several comparison sequences \( X_1, X_2, \ldots, X_{n-1}, X_n \). The correlation coefficient \( \xi_i(k) \) of the comparison sequence and the reference sequence at each moment (i.e. each point in the curve) can be calculated, as in:

\[
\xi_i(k) = \frac{\min_{k} |X_0(k)-X_i(k)| + \max_{k} |X_0(k)-X_i(k)|}{|X_0(k)-X_i(k)| + \max_{k} |X_0(k)-X_i(k)|} \quad (6)
\]

In the above formula, \( \xi_i(k) \) is called the correlation coefficient of \( X_i \) to \( X_0 \) at moment \( k \), that is, the relative difference between the comparison curve \( X_i \) and the reference curve \( X_0 \) at the \( k \)-th moment. The resolution coefficient \( \xi \), which we will discuss in the following part, is generally chosen between 0 and 1, usually 0.5.

\( |X_0(k) - X_i(k)| \) is the absolute difference between each point on the curve of comparison sequence \( X_i \) and each point on the curve of reference sequence \( X_0 \), which is denoted as \( \Delta X_{i-0}(k) \).

\[
\Delta X_{i-0}(k) = |X_0(k) - X_i(k)| \quad (7)
\]

\( \min_{i} = \min_{k} |X_0(k) - X_i(k)| \) is a two-layer formula taking the minimum value of absolute difference to calculate. The first layer is to take the minimum of the absolute difference between each
point on the curve of comparison sequence \( X_i \) and each point on the curve of reference sequence \( X_0 \), and then the minimum value is selected from these minimum values. It is abbreviated as \( \Delta \text{min} \).

\[
\Delta \text{min} = \min \min_{i,k} |X_0(k) - X_i(k)| \quad (8)
\]

\( \Delta \text{max} = \max \max_{i,k} |X_0(k) - X_i(k)| \) is a two-layer formula taking the maximum value of absolute difference to calculate. The first layer is to take the maximum of the absolute difference between each point on the curve of comparison sequence \( X_i \) and each point on the curve of reference sequence \( X_0 \), and then the maximum value is selected from these maximum values. It is abbreviated as \( \Delta \text{max} \).

\[
\Delta \text{max} = \max \max_{i,k} |X_0(k) - X_i(k)| \quad (9)
\]

The correlation coefficient \( \xi_{i}(k) \) can also be simplified as the following formula:

\[
\xi_{i}(k) = \frac{\min_{i} + \max_{i}}{\min_{i} + \max_{i} + \max_{i}} \quad (10)
\]

4.2.3 Correlation degree: Since the correlation coefficient contains values of \( n \) moments, there are too many values, the information is too scattered, and it is not easy to compare. Therefore, it is necessary to centralize the correlation coefficient of each moment into one value, which is generally obtained by calculating the average value. This value is the correlation degree we need. The general formula is as in:

\[
R(i) = \frac{1}{n} \sum_{k=1}^{n} \xi_{i}(k) \quad (11)
\]

By taking the correlation coefficients obtained by each sequence data at each moment term by term, a correlation coefficient matrix can be obtained, as in:

\[
\xi(ik) = \begin{pmatrix}
\xi_{11} & \xi_{12} & \xi_{13} & \cdots & \cdots & \cdots & \xi_{1t} \\
\xi_{21} & \xi_{22} & \xi_{23} & \cdots & \cdots & \cdots & \xi_{2t} \\
\xi_{31} & \xi_{32} & \xi_{33} & \cdots & \cdots & \cdots & \xi_{3t} \\
\vdots & \vdots & \vdots & \ddots & \ddots & \ddots & \vdots \\
\xi_{n1} & \xi_{n2} & \xi_{n3} & \cdots & \cdots & \cdots & \xi_{nt}
\end{pmatrix} \quad (12)
\]

In this formula, \( i, k, n \) and \( t \) have the same meaning as above.

4.2.4 Resolution coefficient: \( \zeta \) is called the resolution coefficient, and the smaller the value of \( \zeta \), the greater the resolution. The value of \( \zeta \) is distributed in the interval \((0, \infty)\), but the general value interval is \((0, 1]\), more generally \( \zeta = 0.5 \). In the gray correlation analysis method proposed by Professor Deng Julong, the value of gray correlation coefficient is between 0 and 1, and different gray correlation coefficient distributions. However, the selection of the resolution coefficient does not affect the ranking of the gray correlation degree and only changes the relative value.

5. RESULTS AND DISSERTATION

In this section, fuzzy decision-making method is adopted to process the initial weights of experts, and the weight change interval is calculated as the constraint condition of the weight optimization model, and then the Lagrange Multiplier Method is used to solve the optimization model of traffic safety state evaluation index weight to obtain the optimal weight. Then we calculate the gray correlation degree of each evaluation index based on the data of the two ports.
### Table 4 The Index Weight and Gray Correlation Degree of Second-Level Indicators

| First-level indicators                                      | Second-level indicators | Weights of second-level indicators / Gray correlation degree |
|-------------------------------------------------------------|-------------------------|---------------------------------------------------------------|
| Development level of intermodal transport of coastal ports  | Supply capacity         | 0.33/0.769                                                    |
|                                                             | Service level           | 0.48/0.826                                                    |
|                                                             | Development environment  | 0.19/0.716                                                    |

### Table 5 The Index Weight and Gray Correlation Degree of Third-Level Indicators

| Third-level indicators                                      | Weights of third-level indicators / Gray correlation degree |
|-------------------------------------------------------------|---------------------------------------------------------------|
| Scale of intermodal transport                               | 0.079/0.729                                                    |
| Infrastructure capacity                                     | 0.069/0.631                                                    |
| Ability of the operator                                     | 0.092/0.697                                                    |
| Informatization level                                       | 0.089/0.583                                                    |
| Safety production                                           | 0.130/0.646                                                    |
| Energy saving and environmental protection                   | 0.125/0.561                                                    |
| Operation efficiency                                        | 0.101/0.632                                                    |
| Whole process service                                       | 0.053/0.572                                                    |
| Precise timeliness                                          | 0.072/0.615                                                    |
| Supporting policy system                                    | 0.063/0.594                                                    |
| Port environment                                            | 0.103/0.684                                                    |
| Scientific decision-making ability                          | 0.025/0.493                                                    |

### Table 6 The Index Weight and Gray Correlation Degree of Fourth-Level Indicators

| Fourth-level indicators | Change interval of weights of fourth-level indicators | Optimized weights /Gray correlation degree | Port X | Port Y |
|-------------------------|-------------------------------------------------------|-------------------------------------------|--------|--------|
| Ratio of intermodal transport volume to total freight volume | [0.037,0.048] | 0.041/0.563 | 80 | 20 |
| Market share of freight volume                               | [0.015,0.032] | 0.021/0.469 | 60 | 20 |
| Average annual growth rate in the past 5 years                | [0.016,0.034] | 0.017/0.398 | 80 | 40 |
| Railway loading and unloading conditions                      | [0.021,0.045] | 0.029/0.453 | 100 | 100 |
| Seamless connection of port-railway                           | [0.009,0.025] | 0.020/0.429 | 100 | 100 |
| Ratio of loading and unloading capacity of railway lines into port to total throughput capacity | [0.011,0.024] | 0.020/0.391 | 80 | 80 |
| Is door-to-door transportation service available               | [0.067,0.113] | 0.092/0.467 | 50 | 50 |
| Is there an integrated service information system for intermodal transport | [0.076,0.098] | 0.089/0.504 | 80 | 60 |
| Safety accident rate of Intermodal transport                  | [0.081,0.102] | 0.086/0.442 | 0 | 100 |
| Rate of cargo damage and shortage                             | [0.039,0.051] | 0.044/0.416 | 100 | 60 |
| Utilization rate of clean energy equipment                     | [0.075,0.097] | 0.086/0.372 | 80 | 80 |
| Loaded container rate of all trains                            | [0.024,0.051] | 0.039/0.406 | 100 | 60 |
| Rate of direct transfer between train and ship                | [0.027,0.064] | 0.049/0.423 | 100 | 0 |
| Rate of changes from bulk cargo to container                  | [0.040,0.059] | 0.051/0.415 | 40 | 80 |
| Realization rate of single contract                           | [0.019,0.042] | 0.027/0.364 | 0 | 0 |
| Number of dry ports                                           | [0.014,0.031] | 0.025/0.438 | 100 | 60 |
| On-time delivery rate                                         | [0.051,0.083] | 0.072/0.367 | 80 | 100 |
| Coordination mechanism                                        | [0.021,0.032] | 0.026/0.497 | 90 | 90 |
| Policies and measures                                        | [0.012,0.027] | 0.017/0.503 | 100 | 100 |
| Credit system                                                | [0.013,0.039] | 0.019/0.469 | 0 | 0 |
| Average clearance time                                        | [0.854,0.124] | 0.103/0.531 | 100 | 80 |
| Mechanism forum discussion                                    | [0.007,0.016] | 0.010/0.367 | 100 | 0 |
| Alliance formation                                           | [0.005,0.013] | 0.008/0.372 | 0 | 100 |
| Is there a medium and long-term development planning          | [0.005,0.010] | 0.007/0.409 | 100 | 100 |
It can be seen from Tab 6 that among the four levels of indicators that affect the development level of port intermodal transport, the indicator with the largest gray correlation degree is the ratio of intermodal transport volume to total freight volume, with a gray correlation degree of 0.563 and a weight of 0.041. The indicator with the largest weight is the informatization level, with a weight of 0.089 and a relatively large gray correlation degree of 0.504. It shows that the ratio of intermodal transport volume to total freight volume and the development level of port intermodal transport informatization can better reflect the development level of port intermodal transport compared with other indicators. This is because when the intermodal transport volume accounts for a large proportion, it indicates that this port focuses on developing intermodal transport, and its level may be ahead of other ports. Under normal circumstances, the port will first build infrastructure, and when its informatization construction reaches a certain level, it indicates that it has entered a higher stage of development. Among the three levels of indicators affecting the development level of port intermodal transport, the indicator with the largest gray correlation degree is the scale of intermodal transport, with a gray correlation degree of 0.729 and a weight of 0.079; the indicator with the largest weight is safety production, with a weight of 0.130 and a gray correlation degree of 0.646. It shows that the scale of port intermodal transport is an important indicator of the development level of port intermodal transport.

According to the final calculation results in Tab 6, the comprehensive score of port X is 70.7, and that of port Y is 65.4. According to field research, the development level of intermodal transport of Port X is indeed higher than that of Port Y, but the development level of intermodal transport of both ports is not high, which is in line with the actual situation. The above results prove that the weight optimization model and gray correlation evaluation method established in this paper are effective and have certain practical application value.

6. CONCLUSION
This paper firstly uses the weight optimization method based on expert group decision-making technology to optimize the index weights that affect the development level of port intermodal transport, and solves the problem of too subjective weighting. Secondly, taking the actual data of port X and port Y as examples, this paper uses gray correlation comprehensive evaluation method to evaluate the development level of intermodal transport of the two ports, and the evaluation results are in line with the actual situation. It shows that the method studied in this paper can evaluate the development level of port intermodal transport in China and has a certain universal significance.

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