# An evaluation on performance of container multimodal transportation system based on AHP-Entropy method

**Master degree**

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# Abstract

In recent years, multimodal transportation has achieved rapid development with the support of the governments and stakeholders. Multimodal transportation is characterized by high transportation efficiency, low transportation cost, energy saving and environmental protection. However, the existing transportation industry development indicators are defined and counted from the perspective of a single subsystem. This contribution establishes a performance evaluation index for three container multimodal transportation subsystem from four aspects: capacity, transportation cost, service quality and sustainable development based on system engineering techniques. In order to fully reflect the differences between the decision-makers' subjective experience and preference and objective information, this contribution uses the combination of Analytic Hierarchy Process (AHP) and entropy method to determine the weight of indexes. The methodology is applied to examine performance of three container multimodal transportation subsystems in Ningbo-Shaoxing (China) multimodal transportation system. The results show that: multimodal railway is superior to highways and multimodal inland waterway. The methodology and discussion of the AHP-entropy method may be useful for similar transport systems in a make decision framework.

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# Chapter 1. Overview

## 1.1. Introduction

With the globalization of the economy, some large-scale logistics companies not only engage in close-range freight, but also carry out long-distance cargo distribution. When the goods are transported over long distances, a single mode of transport is not necessarily the best choice, as all types of vehicles have their own technological advantages and weakness. Hence, multimodal transportation defined as the shipping of goods performed by several modes of transport has become a new trend and new direction of contemporary transportation industry. EU Transport Commissioner Violeta Bulc has called for 2018 to be the "Year of Multimodality" - a year during which the Commission will raise the importance of multimodality for the EU transport system [1].

Multimodal freight transport has growth jointly with the introduction of the container in the global trade systems [2][3]. Containerization has facilitated the transportation of goods during the past few decades and currently is playing a significant role in trading all over the world due to its standardization, flexibility and low costs derived from economies of scale. Nowadays, about 90% of non-bulk cargo worldwide is transported by container [4].

## 1.2. Research objective

The multimodal container transport system is mainly composed of three subsystems: highway, railway and waterway system. Each subsystem is identical in meeting the requirements of the spatial displacement of cargo, but they adopt different technical procedures, handling equipment and organizational forms. Therefore, the technical performance (such as transportation speed, quality, reliability, cargo loss rate, etc.), the degree of adaptation to the geographical environment and economic indicators (such as energy and material consumption, investment, transportation costs, etc.) formed by each transport subsystem are not the same[5].

If you cannot measure it, you cannot manage it. Therefore, it is particularly important to assess the performance of each type of container transportation (highway, railway and inland waterway). However, a literature review indicates no conforming approval on the comparative assessing of the performance of the container transportation in the three modes of transportation. Researchers have paid much attention to some relevant topics such as freight modal choice [6][7][8], traffic network evaluation[9][10][11][12] and intermodal transportation efficiency evaluation[13][14][15]. However, performance indicators on container multimodal transports still show interesting lines of research. Effort carried out by Hanmin Z et al. providing performance indicators area an excellent basis to develop new methods and technical approaches[16].

Container multimodal transportation's strategic plan used to contains four goals: (reduce congestion, enhance the value of transportation assets, improve service quality, and meet sustainable development). Each of these objectives is addressed to enhance the performance of the transportation system. The performance assessment requires the development of appropriate performance measures. In this case, AHP (Analytic Hierarchy Process)-Entropy combined evaluation method, which takes into account the data and the subjective preferences of decision-makers to achieve unity of subjective and objective, is a good candidate to provide new tools for decision makers. AHP-Entropy makes the results more realistic and reliable has been applied in several field of research [17][18][19]. According to an extensive review, this contribution represents for the first time the application of AHP-Entropy method at container multimodal transportation system. The main steps involved with this paper were to:

$i$ ) Develop an understanding of three container transportation subsystems and their performance.

$ii$ ) Develop a performance evaluation framework for three container transportation subsystems based on reference of related research fields, characteristic of container transportation system and the four goals that guide transportation decisions.

$iii$ ) Identify data elements and data sources required to quantify the measures, and calculate weight of each indicator.

## 1.3. Thesis outline

The outline of this paper is organized as follows. After the Introduction (Section 1), Section 2 review literature of three related fields including transportation modal choice, traffic network performance evaluation and intermodal transportation efficiency evaluation. In addition, this section supports the elaboration of performance evaluation system of three container multimodal subsystem. Detailed information of weight computing methods and calculation process are given in section 3. A case study of Ningbo container multimodal system is given in section 4 Section 5 (Discussion) highlight the advantages of the method contextualizing the work in the state-of-the-art. Finally, some concluding remarks are provided in section 5.

# Chapter 2. Resaerch review

Performance evaluation refers to a process of monitoring and analysis to measure how well systems perform with regard to their intended goals and objectives [20]. Performance evaluation is not only needed to assist decision makers in setting priorities, generating financial resources, and allocating funds but also required for assessing needs and simply communicating with customers and other stakeholders. To be effective in their purpose, performance indexes need to be linked to the four objectives that guide transportation decisions[21].

There is limited research into the evaluation on performance of container multimodal transportation. However, extended literature exists into three related fields, such as transportation modal choice, traffic network performance evaluation and Intermodal transportation efficiency evaluation.

Research of freight modal choice usually takes the preference and experience of transportation stakeholders as the basis for choosing transportation mode [22-30]. Additionally, goals of evaluation on container transportation system are inherently an expression of the various stakeholders affected by the system. This includes not only the providers of transportation but also the customers and government that house the transportation infrastructure. The goals of both actors are coincident to a certain extent. Therefore, when selecting the multimodal container transportation performance evaluation index, one can refer to the index of transportation mode selection.

## 2.1. Research status of freight modal choice

Several contributions have examined various variables that affect the choice of freight modal. Early research (1959-1989) focused on transportation cost [22]. However, the modal choice context in network system should consider these factors not only in exact monetary terms or utility terms, but also in the chain of performance operation flow to serve and fulfill their purpose in process achievement [23]. Thus, researchers began to explore the factors affecting mode selection from the perspective of behavioral factors, namely preferences of transport decision makers. The Stated Preference (SP) survey and Revealed Preference (RP) survey have become the mainstream method in this type of research[30]. These recent contributions have revealed that the most repeated variables are: (1) transport speed [22][24][25][26][27][28][29], (2) transport cost [24][25][26][27][28][29], (3) punctuality [22][25][27][28], (4) reliability [22][24][26], (5) service frequency [25][27], (6) flexibility [24][26] and (7) cargo damage rate [22][27].

## 2.2. Research status of traffic network evaluation

Traffic network evaluation is the premise to give full play to the overall efficiency of the freight network. In literature, several indexes for assessing the performance of transportation network are postulated [31-35]. The five most important factors found to assess the performance of traffic network are: a) traffic network density[31][32][33][35], which is the ratio of the total mileage of the traffic network to the area, b) connectivity[31][33][34][35], which is the ratio of the number of edges to the number of nodes in a road network, c) travel time[31][33][34][35], which is the time required to travel per kilometer. d) mileage saturation rate[31][32][33], which is the ratio of the length of a road with saturation ratio equal to or greater than one to the total length of the road network, and e) cost[32][34], which is fixed assets investment in traffic network.

## 2.3. Research status of intermodal transport efficiency evaluation

The purpose of efficiency evaluation of intermodal transport is to evaluate the performance of intermodal transportation from the perspective of operational efficiency. In literature, seven most important factors found to assess the performance of intermodal transportation are: (1) transportation time [37][38][40][42][43]; (2) transportation cost [36][37][40][41][43]; (3) security [37][38][39][43]: which refers to cargo loss rate and personnel safety; (4) environmental factors [36][42][43]; (5) mobility[38][40][41]: which refers to average truck trip length; (6) reliability [37][38][43]; (7) information and standardization[38][42] : which refers to the standardization of electronic documents and the rate of containerization.

Table 1 gives detailed information on key indicators for evaluating performance from different perspectives.

**Table 1. Key factors of performance evaluation from difference perspective**

| Perspective | Criteria | Reference |
|---|---|---|
| Model choice | Transport speed | Jeffs and Hills (1990), Feo et al. (2011), Brooks et al. (2012), Reis (2014), Arencibia et al. (2015), Larranaga et al. (2016), Mohri et al. (2019) |
| | Transport cost | Feo et al. (2011), Brooks et al. (2012), Reis (2014), Arencibia et al. (2015), Larranaga et al. (2016), Mohri et al. (2019) |

| | | |
|---|---|---|
| | Punctuality | Jeffs and Hills (1990), Brooks et al. (2012), Arencibia et al. (2015), Larranaga et al. (2016) |
| | Reliability | Jeffs and Hills (1990), Feo et al. (2011), Reis (2014) |
| | Service frequency | Brooks et al. (2012), Arencibia et al. (2015) |
| | Flexibility | Feo et al. (2011), Reis (2014) |
| | Cargo damage rate | Jeffs and Hills (1990), Arencibia et al. (2015) |
| Traffic network | Traffic network density | Li. (1995), Zhang et al. (2005), Zhu. (2008), Liu et al. (2018) |
| | Connectivity | Li. (1995), Zhu. (2008), Nie (2010), Liu et al. (2018) |
| | Travel time | Li. (1995), Zhang et al. (2005), Zhu. (2008) |
| | Mileage saturation rate | Li. (1995), Zhang et al. (2005), Zhu. (2008) |
| | Travel cost | Zhang et al. (2005), Nie (2010) |
| | Accessibility | (2010), Liu et al. (2018) |
| | Accident rate | Li. (1995), Zhang et al. (2005) |
| Intermodal transportation | Travel speed | Hanaoka and Kunadhamraks (2009), Zhang et al. (2009), Zhang (2014), Zhu et al. (2018), Yang(2019) |
| | Travel cost | Janic (2008), Hanaoka and Kunadhamraks (2009), Zhang (2014), Wang et al. (2017), Yang（2019） |
| | Security | Hanaoka and Kunadhamraks (2009), Zhang et al. (2009), Chen (2010), Yang（2019） |
| | Environment | Janic (2008), Chen (2010), Zhu et al. (2018), Yang（2019） |
| | Mobility | Zhang et al. (2009), Zhang (2014), Wang et al. (2017) |
| | Reliability | Hanaoka and Kunadhamraks (2009), Zhang et al. (2009), Yang（2019） |
| | Information and Standardization | Hanaoka & Kunadhamraks (2009), Zhu et al.(2018) |

In summary, the three types of key include the perspective of transportation stakeholders' preference, traffic network and intermodal efficiency of operation. This provides an excellent basis for establishment of the evaluation index system in the next section. However, traffic network performance evaluation usually does not distinguish between passenger and freight. Transport decision makers usually pay more attention to transport cost instead of other factors when choosing freight mode. The analysis of efficiency evaluation of intermodal transport is to evaluate the entire intermodal system, which includes both transport corridors and nodes. Therefore, the evaluation index on multimodal transportation is not fully targeted in the currently state-of-the-art.

# Chapter 3. Research methodology

## 3.1. Establishment of evaluation indicators

According to the literature review, we found that the evaluation on container multimodal transportation system is still in an exploratory and premature stage. Based on preceding contributions and four strategic goals expected for container multimodal transportation system, this contribution develops a multi-criteria hierarchic assessment framework (see **Figure 1**).

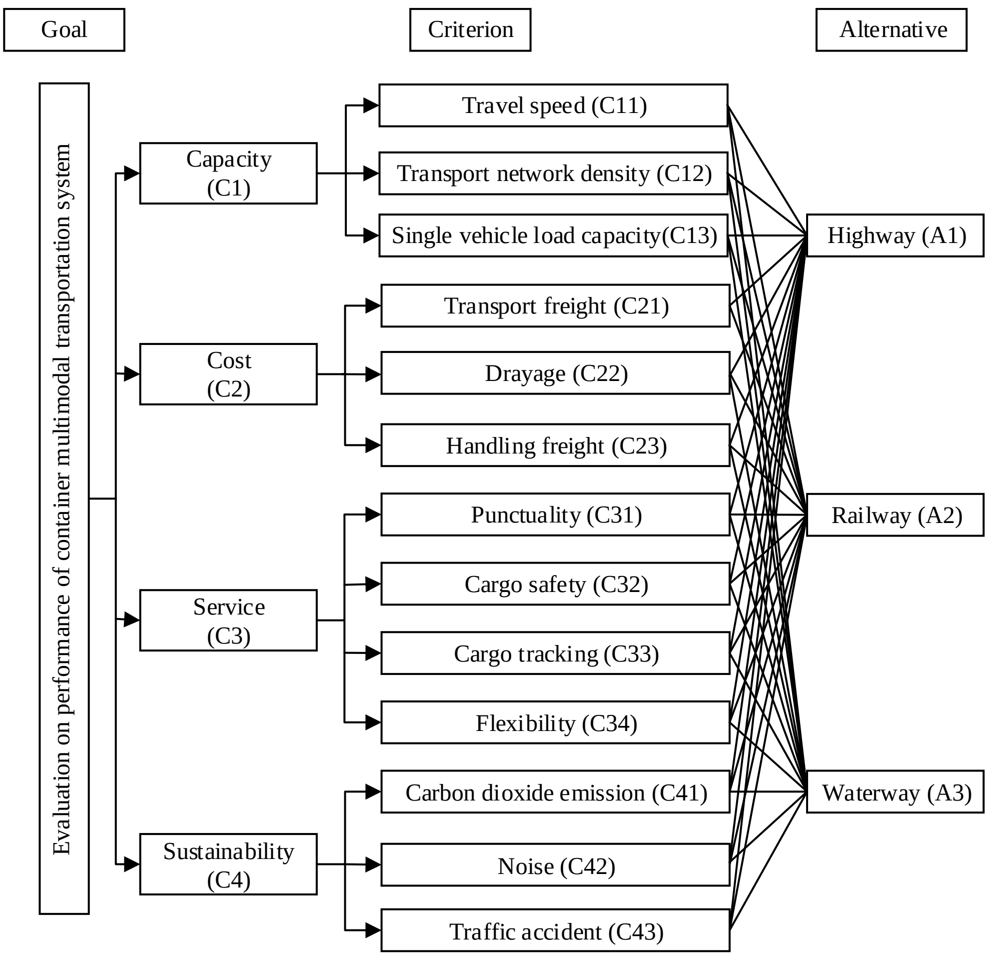


**Figure 1. The assessment framework of container multimodal transportation subsystem**

The first-level indicators postulated to evaluate the performance of container intermodal transportation system include the criteria summarized in **Figure 1** and grouped in 4 goals:

ⅰ) Capacity

One of the strategic goals of container multimodal transportation is maximize capacity and additionally reduce congestion. Transportation capacity of the three subsystems is measured from three aspects: Travel speed, transport network density and single vehicle load capacity. Travel speed refers to the average kilometers traveled per hour when transporting containers. Transport network density can reflect the regional advancement of the transportation industry. Network density is considered as the main technical indicator for evaluating the reasonable development of transportation networks according to the network planning documents. Single vehicle load capacity refers to the number of containers that can be loaded at one time for one vehicle.

ⅱ) Cost

In order to enhance the value of transportation assets, this paper separately calculates the transportation costs incurred by the three transportation subsystems when transporting containers. As shown in **Figure 2**, the container multimodal transportation cost mainly includes three parts: 1. The handling freight incurred during composition and decomposition process; 2. Considering that both ends of the waterway and railway container transportation chain are transported by short-haul highway, so drayage is taken into account when calculate transportation cost of waterway and railway. 3. Transportation costs during mainline transportation;

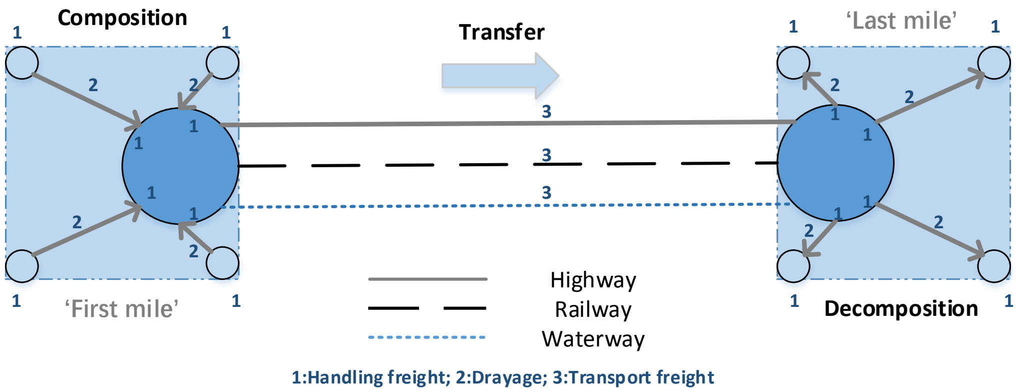


**Figure 2. Transportation cost structure**

ⅲ) Service

The advanced transportation system should be reliable, safe and convenient [31]. Therefore, this contribution mainly evaluates punctuality, which refers to the probability of freight being delivered at the destination within a given time window; Cargo Safety, which refers to damaged and lost cargo in transit; Cargo tracking, which refers to application degree of

GIS, GPS, barcode technology, radio frequency technology and other technologies; And flexibility, which refers to adaptability to the natural environment and accessibility to space activities of the three container transport subsystems.

ⅳ) Sustainability

Sustainable transportation is of great importance in today's world, due to transportation will also bring some adverse effects, such as the increase in traffic volume and traffic accidents, the large consumption of non-renewable resources in the manufacturing and operation of vehicles, and the pollutants emitted by vehicles increasing year by year, the impact of noise pollution has also increased significantly. They will seriously restrict the development of the national economy when these adverse effects have accumulated to a certain degree [44] Therefore, the social impact mainly considers the carbon dioxide emissions per million tons of kilometers and the average economic loss caused by noise and traffic accidents.

# 3.2. Weight computing

According to different sources of raw data, the methods of calculating weights can be divided into three categories: subjective weighting method, objective weighting method, and combination weighting method [45]. The subjective weighting method is a way to determine the attribute weight according to the subjective importance of decision makers (experts). In this case, raw data is obtained by experts based on subjective judgments based on experience. The original information of the objective empowerment method should be directly derived from the objective environment. The process of processing information should be to explore the interrelationships and influences of the attributes, and then determine the attributes based on the degree of connection between the attributes or the amount of information provided by each attribute weights.

The objective weighting method has advantages in determining weights based on the meaning of the attribute itself, but has poor objectivity [46]. The objective weighting method will not be affected by subjective consciousness in the calculation process, but it cannot reflect the importance that decision makers attach to different attributes. Occasionally, certain weights conflict with the real importance of the attribute. In order to take into account the preferences of decision makers on attributes and strive to reduce the subjective arbitrariness of weighting, this paper uses a subjective and objective comprehensive weighting method, which follows the formula (1).

$$W = \alpha W_{AHP} + (1-\alpha) W_{Entrophy} \tag{1}$$

Where $\alpha$ is subjective weight coefficient ($0 \leq \alpha \leq 1$); $\omega_i$ represents the comprehensive weight of the *i*-th evaluation index; $W_{\mathrm{AHP}}$ and $W_{\mathrm{Entropy}}$ represent the AHP weight and entropy weight, respectively. $\alpha = 0.60$ is used in this paper.

### 3.2.1. The subjective weighting method — AHP approach

Analytic Hierarchy Process (AHP) is a combination of qualitative and quantitative methods. It is an effective method for decision-making problems with multi-criteria and multi-attributes [47]. Decision makers should make a pairwise comparison of various indicators. The purpose is to reveal and clarify the relative importance of indicators in function of the alternatives [48]. Main steps of AHP are as follows [49]:

1. Build a hierarchy model

According to the goal that the problem needs to achieve, analyze the indicators related to the goal, and form hierarchical structure according to the affiliation between the indicators. The hierarchical structure includes three layers, namely: goal layer which refers to the goal or result of the analyzed problem; criteria layer which refers to the intermediate link required to achieve the target; alternative layer which refers to the selection measures and schemes provided to achieve the goal. The hierarchical structure of this contribution is shown in **Figure 1**.

2. Construct a comparison matrix.

Select experts with deep theoretical foundation and broad knowledge in the related fields of container transportation, systems engineering, operations research, etc., and distribute to them a specific questionnaire (named "Expert Scoring Sheet"). Experts using a preference scale of 1 to 9 and their reciprocal (see **Table 2)** determine the relative importance between two factors in the same layer [50]. Then the pairwise comparison matrix *A* is performed as follows:

$$A = \left[ a_{ij} \right] = \begin{bmatrix} 1 & a_{12} & \cdots & a_{1n} \\ \dfrac{1}{a_{12}} & 1 & \cdots & a_{2n} \\ \vdots & \vdots & & \vdots \\ \dfrac{1}{a_{1n}} & \dfrac{1}{a_{2n}} & \cdots & 1 \end{bmatrix} \tag{2}$$

3. Determine the weight of each factor

Calculate the eigenvalues and eigenvectors of the comparison matrix by formula (3). If *A* is considered as a consistency matrix (see formula 4), the eigenvector corresponding to the largest eigenvalue ($\lambda_{max}$) associated to each indicator is the weight vector ($W_{\mathrm{AHP}}$).

$$AX = \lambda X \qquad (3)$$

4. Check the consistency of the comparison matrix.

The consistency of the comparison matrix is checked by value of the consistency ratio ($CR$).

$$CR = \frac{CI}{RI} \qquad (4)$$

$CI$ indicates the consistency index, which can be calculated by formula (5) and RI represents the random consistency index. Values of $RI$ for matrix of various sizes are given in **Table 3** [51]. In function of $n$ that is the size of the comparison matrix. If $CR$ is found to be less than 0.1, then the comparison matrix derived from expert opinion can be considered as consistent.

$$CI = \frac{\lambda_{\max} - n}{n-1} \qquad (5)$$

**Table 2. Saaty's scale definition**

| Scale | Definition |
|---|---|
| 1 | The Row index and the Column index are equally important |
| 3 | The Row index is slightly more important than the Column index |
| 5 | The Row index is obviously more important than the Column index |
| 7 | The Row index is strongly more important than the Column index |
| 9 | The Row index is absolutely more important than the Column index |
| 2, 4, 6, 8 | The scale value corresponding to the intermediate state between the above two judgments |
| Reciprocal | Comparison of Column index and Row index to obtain the judgment value |

**Table 3. The average random consistency index RI value**

| n | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| RI | 0 | 0 | 0.52 | 0.89 | 1.12 | 1.26 | 1.36 | 1.41 | 1.46 | 1.49 | 1.52 | 1.54 | 1.56 | 1.58 | 1.59 |

### 3.2.2. The objective weighting method — Entropy value method

In information theory, entropy is a measure of uncertainty. Applied to system theory, the greater the entropy value is, the greater the disorder degree of the system is. According to the characteristics of entropy, the degree of dispersion of a certain index can be judged by calculating the entropy value, and the degree of dispersion of the index represents the influence (weight) of the index in the comprehensive evaluation [52].

In this paper, the entropy weight method is adopted, which is calculated as follows:

1. Construct a comparison matrix

Determine the evaluation index and evaluation object, and construct the comparison matrix *X* of the index value corresponding to the evaluated object. Supposing there are *m* types of container transport modes and *n* pieces of indexes in the indicator system.

$$X = \begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1n} \\ x_{21} & x_{22} & \cdots & x_{2n} \\ \vdots & \vdots & & \vdots \\ x_{m1} & x_{12} & \cdots & x_{mn} \end{bmatrix}, (i = 1,...,m;\ j = 1,...,n) \tag{6}$$

Where $x_{ij}$ refers the value of the *j*-th index of the *i*-th container transport mode.

2. Indexes standardization

In order to eliminate the influence of index dimension on incommensurability, it is necessary to standardize indexes using the formula (7) [53].

$$x_{ij}' = \begin{cases} \dfrac{x_{ij} - x_j^{\min}}{x_j^{\max} - x_j^{\min}} & \text{for benefit indicators} \\ \dfrac{x_j^{\max} - x_j^{\min}}{x_{ij} - x_j^{\min}} & \text{for cost indicators} \end{cases}, (i = 1,...,m;\ j = 1,...,n) \tag{7}$$

Where $x_j^{\max}$ and $x_j^{\min}$ are the maximum and minimum values of the *j*-th index in the matrix, respectively.

3. Calculation of the index's entropy

According to the definition of entropy, entropy of the *j*-th index is determined by formula (8).

$$E_j = -\frac{\sum_{i=1}^{m} y_{ij} \ln y_{ij}}{\ln m}, (i = 1,...,m;\ j = 1,...,n) \tag{8}$$

Where $y_{ij}$ is the proportion of the index value of the *i*-th container transport mode under the *j*-th index. $y_{ij}$ is calculated by formula (9)

$$y_{ij} = \frac{x_{ij}^{'}}{\sum_{i=1}^{m} x_{ij}^{'}}, (i = 1,...,m;\ j = 1,...,n; 0 \leq y_{ij} \leq 1) \tag{9}$$

4. Calculation the index's entropy weight ($W_{Entropy}$) of the *j*-th index is determined by formula (10)

$$W_j = \frac{1 - E_j}{n - \sum_{j=1}^{n} E_j}, \sum_{j=1}^{n} W_j = 1, (j = 1,...,n) \tag{10}$$

# Chapter 4. Study case: Ningbo-Shaoxing multimodal transportation

The study case of this contribution is focused in the transportation network from Ningbo-Zhoushan Port to Shaoxing Port and Shaoxing Gaobu Railway Station in China. Ningbo-Zhoushan Port is composed of 19 port areas including Beilun, Zhenhai and Meishan. It is an important container trunk port of China [54]. Ningbo-Zhoushan Port has various transportation modes such as waterway, highway and railway. In 2019, the spatio-temporal evolution of Ningbo-Zhoushan port has experienced an impressive growth arising $2.753\times 10^7$ TEU being the 3rd largest container port in the world [55]. More than 240 international routes connect more than 600 ports in more than 100 countries and regions, making it one of the busiest ports in the world. In this sense, Ningbo Zhoushan Port-Zheganxiang Container Sea-Rail Multimodal Demonstration Project passed the inspection and was awarded the honor of "China Multimodal Demonstration Project" in December 2019. This contribution will analyze the system performance of three different alternatives: only trucks (A1), multimodal railway (A2) and multimodal inland waterway (A3).

## 4.1. Data collection

This contribution collected data on three container transportation systems by searching for relevant literature, government and enterprise statistical bulletins, industry analysis bulletins and expert investigation. Questionnaires following the AHP method have been replied by professionals of shipping industry in Ningbo city. The attribute value of evaluation indicators and data source are shown in **Table 5**. The collected data were used as inputs to estimate performance values of the corresponded alternatives.

**Table 4. Attribute values of evaluation indicators per each alternative**

| Criterion | Indicator | Highway | Railway | Waterway | Data resource |
|---|---|---|---|---|---|
| Capacity | Travel speed ($km\cdot h^{-1}$) | 60 | 50 | 12 | Reference method [56] |
| | Transport network density($m\cdot km^{-2}$) | 1185.3 | 27.3 | 95.9 | Statistics Announcement of the Ministry of Transport |
| | Single vehicle load capacity (TEU) | 2 | 56 | 28 | Collection of public statistics |

| | | | | | |
|---|---|---|---|---|---|
| Cost | Transport freight (RMB·km·TEU$^{-1}$) | 9.185 | 3.8 | 0.949 | China national development and reform commission, China railway and China national bureau of statistics Statistical bulletin |
| | Drayage (RMB·km·TEU$^{-1}$) | 0 | 10 | 10 | Reference method [57][58] |
| | Handling freight (RMB·TEU$^{-1}$) | 100 | 195 | 250 | Reference method [57][59][60] |
| Service | Punctuality | 3.6 | 4.8 | 3.75 | Expert investigation |
| | Cargo safety | 3.4 | 4.6 | 4.25 | Expert investigation |
| | Cargo tracking | 4.6 | 3.6 | 3 | Expert investigation |
| | Flexibility | 5 | 2.8 | 2.5 | Expert investigation |
| Society | Carbon dioxide emission (Tons· million tons kilometers$^{-1}$) | 190 | 160 | 14 | Collection of public statistics |
| | Noise pollution (RMB· km· million tons$^{-1}$) | 4300 | 2050 | 6000 | Reference method[44] |
| | Traffic accident (RMB· km· million tons$^{-1}$) | 1050 | 40 | 1030 | Reference method [44] |

# 4.2. Data processing and calculation

## 4.2.1. Analytic hierarchy process

1. Establish first-level indicators comparison matrix and calculate weight

According to formulas (3)~(5), the value of maximum eigenvalue $\lambda_{max}$ equal to 4.001; the consistency index of judgment matrix *CI* equal to 0; the average random consistency index *RI* equal to 0.89; the ratio of random consistency *CR* equal to 0.0003, which is less than 0.1 so that the comparison matrix meet the consistency requirements. The weight vector is shown in **Table 5**.

**Table 5. First-level indicators comparison matrix**

| | Capacity | Cost | Service | Sustainability | Weight |
|---|---|---|---|---|---|
| Capacity | 1 | 0.762 | 0.923 | 1.393 | 0.243 |
| Cost | 1.312 | 1 | 1.211 | 1.828 | 0.319 |
| Service | 1.083 | 0.826 | 1 | 1.509 | 0.263 |
| Society | 0.718 | 0.547 | 0.662 | 1 | 0.175 |

2. Establish second-level indicators comparison matrix and calculate weight

(1)According to formulas (3)~(5), the value of maximum eigenvalue $\lambda_{max}$ equal to 3.000; the consistency index of judgment matrix *CI* equal to 0; the average random consistency index *RI* equal to 0.59; the ratio of random consistency *CR* equal to 0, which is less than 0.1 so that the comparison matrix meet the consistency requirements. The weight vector is shown in **Table 6**.

**Table 6. Second-level indicators of transport capacity comparison matrix**

| | Transport speed | Transport network density | Single vehicle load capacity | Weight |
|---|---|---|---|---|
| Transport speed | 1 | 1.232 | 1.222 | 0.380 |
| Transport network density | 0.812 | 1 | 0.992 | 0.309 |
| Single vehicle load capacity | 0.818 | 1.008 | 1 | 0.311 |

(2)According to formulas (3)~(5), the value of maximum eigenvalue $\lambda_{max}$ equal to 3.000; the consistency index of judgment matrix *CI* equal to 0; the average random consistency index *RI* equal to 0.59; the ratio of random consistency *CR* equal to 0, which is less than 0.1 so that the comparison matrix meet the consistency requirements. The weight vector is shown in **Table 7**.

**Table 7. Second-level indicators of transportation costs comparison matrix**

| | Transport freight | Drayage | Handling freight | Weight |
|---|---|---|---|---|
| Transport freight | 1 | 2.362 | 2.402 | 0.544 |
| Drayage | 0.423 | 1 | 1.017 | 0.230 |

| | | | | |
|---|---|---|---|---|
| Handling freight | 0.416 | 0.983 | 1 | 0.226 |

(3)According to formulas (3)~(5), the value of maximum eigenvalue $\lambda_{max}$ equal to 4.001; the consistency index of judgment matrix *CI* equal to 0; the average random consistency index *RI* equal to 0.89; the ratio of random consistency *CR* equal to 0.0003, which is less than 0.1 so that the comparison matrix meet the consistency requirements. The weight vector is shown in **Table 8**.

**Table 8. Second-level indicators of service level comparison matrix**

| | Punctuality | Cargo safety | Cargo tracking | Flexibility | Weight |
|---|---|---|---|---|---|
| Punctuality | 1 | 3.371 | 2.954 | 1.311 | 0.319 |
| Cargo safety | 0.297 | 1 | 0.876 | 0.389 | 0.418 |
| Cargo tracking | 0.339 | 1.141 | 1 | 0.444 | 0.125 |
| Flexibility | 0.763 | 2.571 | 2.253 | 1 | 0.141 |

(4)According to formulas (3)~(5), the value of maximum eigenvalue $\lambda_{max}$ equal to 3.000; the consistency index of judgment matrix *CI* equal to 0; the average random consistency index *RI* equal to 0.59; the ratio of random consistency *CR* equal to 0, which is less than 0.1 so that the comparison matrix meet the consistency requirements. The weight vector is shown in **Table 9**.

**Table 9. Second-level indicators of social impact comparison matrix**

| | $CO_2$ emission | Noise | Traffic accident | Weight |
|---|---|---|---|---|
| $CO_2$ emission | 1 | 1.990 | 0.932 | 0.388 |
| Noise | 0.503 | 1 | 0.469 | 0.195 |
| Traffic accident | 1.072 | 2.134 | 1 | 0.416 |

Through calculation, the result of subjective weight of each evaluation index is shown in **Table 10**.

## 4.2.2. Entropy value method

1. Indexes standardization

The data in **Table 4** is normalized by formula (7) to obtain the matrix X'.

$$X' = \begin{bmatrix} 1.000 & 1.000 & 0.000 & 0.000 & 1.000 & 1.000 & 0.054 & 0.000 & 1.000 & 1.000 & 0.000 & 0.430 & 0.000 \\ 0.792 & 0.000 & 1.000 & 0.654 & 0.000 & 0.290 & 1.000 & 1.000 & 0.000 & 0.091 & 0.171 & 1.000 & 1.000 \\ 0.000 & 0.059 & 0.482 & 1.000 & 0.000 & 0.000 & 0.000 & 0.555 & 0.050 & 0.000 & 1.000 & 0.000 & 0.020 \end{bmatrix} \quad (11)$$

3. Calculation of the index's entropy

The entropy value of each index calculated by formulas (8) and (9) is:

$$E = [0.625 \quad 0.196 \quad 0.574 \quad 0.611 \quad 0.000 \quad 0.529 \quad 0.185 \quad 0.593 \quad 0.175 \quad 0.261 \quad 0.378 \quad 0.557 \quad 0.087] \quad (12)$$

4. Calculation the entropy weight

The objective weight of each index calculated by formula (10) is:

$$W_{Entropy} = [0.046 \quad 0.098 \quad 0.052 \quad 0.047 \quad 0.122 \quad 0.057 \quad 0.099 \quad 0.049 \quad 0.100 \quad 0.090 \quad 0.076 \quad 0.054 \quad 0.111] \quad (13)$$

### 4.2.3. Comprehensive Empowerment

The comprehensive weight of each index calculated by formula (1) is:

$$W = [0.075 \quad 0.089 \quad 0.070 \quad 0.122 \quad 0.091 \quad 0.067 \quad 0.089 \quad 0.085 \quad 0.058 \quad 0.057 \quad 0.070 \quad 0.041 \quad 0.087] \quad (14)$$

The final results are reflected in **Table 10** in detail including the relevance rank of each indicator. This rank show how the most important indicators are Transport Freight and Drayage (Cost criteria) and Cargo Safety (Service criteria).

**Table 10. Combination weight calculation result**

| Criterion | Indicator | $W_{AHP}$ | $W_{Entropy}$ | $W$ | Rank |
|---|---|---|---|---|---|
| Capacity | Travel speed(C11) | 0.093 | 0.046 | 0.068 | 9 |
| C1 | Transport network density(C12) | 0.075 | 0.098 | 0.090 | 5 |
| 0.234 | Single vehicle load capacity(C13) | 0.076 | 0.052 | 0.072 | 7 |
| Cost | Transport freight(C21) | 0.173 | 0.047 | 0.103 | 1 |
| C2 | Drayage(C22) | 0.073 | 0.122 | 0.100 | 3 |
| 0.280 | Handling freight(C23) | 0.072 | 0.057 | 0.064 | 11 |
| Service | Punctuality (C31) | 0.084 | 0.099 | 0.071 | 8 |
| C3 | Cargo safety (C32) | 0.110 | 0.049 | 0.101 | 2 |
| 0.289 | Cargo tracking (C33) | 0.033 | 0.100 | 0.067 | 10 |

| | | | | | |
|---|---|---|---|---|---|
| | Flexibility (C34) | 0.037 | 0.090 | 0.059 | 12 |
| Society | Carbon dioxide(C41) | 0.068 | 0.076 | 0.073 | 6 |
| C4 | Noise (C42) | 0.034 | 0.054 | 0.042 | 13 |
| 0.198 | Traffic accident(C43) | 0.073 | 0.111 | 0.091 | 4 |

# 4.3. Results and analysis

## 4.3.1. Container multimodal transportation performance grade

Through the sequential procedures of the AHP-Entropy in section 4.2.1 and 4.2.2, the weight value corresponding to each index is obtained shown in **Table 11**. After dimensionless processing of each attribute value in **Table 4**, it is multiplied by the corresponding weight value, and then added to obtain the performance score of each subsystem.

As the results in the case of Ningbo-Shaoxing, the score of multimodal railway (A2 0.53) was higher than those of the others (A1 0.47 and A3 0.28 for truck single mode and multimodal inland waterway, respectively). The results reveal that the transportation performance of multimodal railway is preferred. The main reason for such a pattern is because multimodal railways have large transport volumes, which are easy to form economies of scale. Besides, the service qualities (punctuality, security) of multimodal railways are also more attractive. Most importantly, multimodal railway also presents high performance in sustainability.

## 4.3.2. Sensitivity analysis

According to the weighting results in **Table 11**, among the 13 indicators, the five indicators of transport freight (C21), cargo safety (C32), drayage (C22), traffic accident (C43) and transport network density (C12) have a strong influence on the performance evaluation of the container multimodal transportation system. Therefore, the sensitivity analysis of these five indicators is performed by conducting a total of 20 experiments. Through sensitivity analysis, it is possible to know the robustness and feasibility of results obtained, so as to guide users to make decisions at a higher level [61].

These experiments were conducted to investigate the influence of indicators weights on the ranking order of alternatives. The summary of these experiments is shown in **Table 11**. From this table, it can be realized that the weights of the five important indicators were changed (-20%, -10%, +10%, +20%). **Figure 3** shows the influence on ranking of alternatives when changing the weights of indicators. From **Table 11** and **Figure 3**, it can be noticed that all of 20 experiments, the alternative 'A2' attained the highest score. Hence, it can be concluded that this research provides a precise and robust ranking of considered alternatives and also gives an evidence for insensitivity of rank for alternative 'multimodal railway (A2)' with indicators weights. For example, with the increase in the weight of travel freight, scores of railway transportation and waterway transportation are gradually higher. On the contrary, scores of highway are gradually lower. This is because railway and waterway transportation are easy to form economies of scale due to their large volume of transportation, thereby reducing transportation costs [62][63]. This is in line with the characteristics of multimodal transport [64].

**Table 11. Experiments for sensitivity analysis**

| Number of experiment | Definition | Score of each alternative | | | Ranking order |
|---|---|---|---|---|---|
| | | Highway(A1) | Railway(A2) | Waterway(A3) | |
| Expt.0 | No change | 0.4699 | 0.5346 | 0.2772 | A2＞A1＞A3 |
| Expt.1 | $W_{C21}$-20% | 0.4802 | 0.5314 | 0.2604 | A2＞A1＞A3 |
| Expt.2 | $W_{C21}$-10% | 0.4748 | 0.5327 | 0.2687 | |
| Expt.3 | $W_{C21}$+10% | 0.4640 | 0.5355 | 0.2853 | |
| Expt.4 | $W_{C21}$+20% | 0.4586 | 0.5369 | 0.2936 | |
| Expt.5 | $W_{C32}$-20% | 0.4805 | 0.5092 | 0.2481 | A2＞A1＞A3 |
| Expt.6 | $W_{C32}$-10% | 0.4752 | 0.5219 | 0.2627 | |
| Expt.7 | $W_{C32}$+10% | 0.4646 | 0.5474 | 0.2918 | |
| Expt.8 | $W_{C32}$+20% | 0.4593 | 0.5601 | 0.3064 | |
| Expt.9 | $W_{C22}$-20% | 0.4581 | 0.5465 | 0.2834 | A2＞A1＞A3 |
| Expt.10 | $W_{C22}$-10% | 0.4640 | 0.5406 | 0.2803 | |
| Expt.11 | $W_{C22}$+10% | 0.4758 | 0.5287 | 0.2742 | |
| Expt.12 | $W_{C22}$+20% | 0.4817 | 0.5227 | 0.2711 | |
| Expt.13 | $W_{C43}$20% | 0.4793 | 0.5253 | 0.2824 | A2＞A1＞A3 |
| Expt.14 | $W_{C43}$-10% | 0.4746 | 0.5300 | 0.2798 | |
| Expt.15 | $W_{C43}$+10% | 0.4652 | 0.5393 | 0.2747 | |
| Expt.16 | $W_{C43}$+20% | 0.4605 | 0.5439 | 0.2721 | |
| Expt.17 | $W_{C12}$-20% | 0.4594 | 0.5452 | 0.2816 | A2＞A1＞A3 |
| Expt.18 | $W_{C12}$-10% | 0.4647 | 0.5399 | 0.2794 | |

| | | | | |
|---|---|---|---|---|
| Expt.19 | $W_{C12}$+10% | 0.4751 | 0.5293 | 0.2751 |
| Expt.20 | $W_{C12}$+20% | 0.4804 | 0.5241 | 0.2729 |

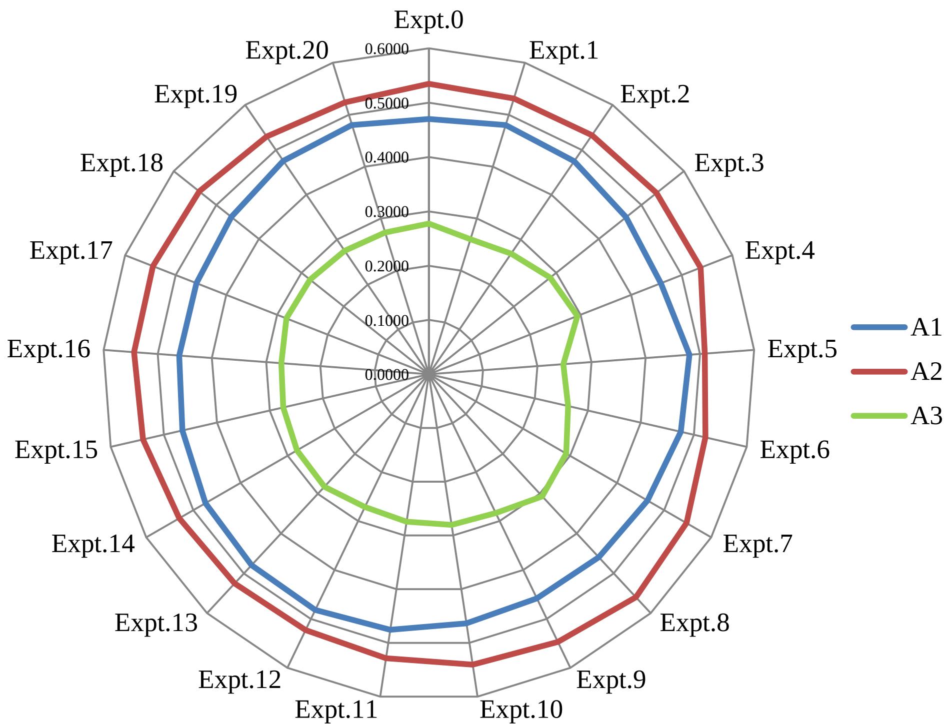


**Figure 3. Result of sensitivity analysis (The experiment description is shown in Table 11)**

# Chapter 5. Discussion

This contribution combines the characteristics of container transportation and the four strategic goals of the container transportation system (reduce congestion, enhance the value of transportation assets, improve service quality, and meet sustainable development) to establish performance evaluation index system applied at three container multimodal transportation subsystems (highway, railway, inland waterway). Existing contributions are often only suitable for one or two transportation subsystems [11][12][13]. This contribution uses 3 subsystems and the weighted assessment of functional attributes, which included the capacity-oriented (travel speed, transport network density and single vehicle load capacity); the cost-oriented (transport freight, handling freight and drayage); the service-oriented (punctuality, cargo safety, cargo tracking and flexibility) and the sustainability oriented indicators (carbon dioxide, noise and traffic accident). The quantification allows determining the importance of a number of performance indicators. However, existing contributions tend to overlook the depth impact of sustainable development on the container transportation system [14][24][29], which has been considered in our methodology.

Evaluation index methods can scientifically and consistently evaluate the development level of container transportation in different regions and different modes of transportation. In this sense, the evaluation results of this contribution show divergences with other literature [14]. For instance, Kunadhamraks P and Hanaoka S conclude that trailer unique mode is better than that of multimodal railways and intermodal waterways when they evaluate the logistics performance of intermodal transportation in Thailand. There are two reasons identified for these differences: *i)* Kunadhamraks P and Hanaoka S pays more attention to transportation costs and service quality in comparison to our analysis which emphasizes the importance of sustainable development, and *ii)* the entropy method determine the objective weight based on the actual data of each transportation mode, so weights include the transportation development status of Ningbo-Shaoxing system. This comparison reflects that divergences with other contributions may be associated not only to the application example itself but also inherently to the method applied.

This contribution uses the AHP-Entropy combination weighting method to calculate the weight of each indicator. This method is rarely used in the research of transportation performance evaluation [20][21]. However, it turns out that this method not only avoids the subjective weighting method being too artificial, but also overcomes the disadvantage that the objective weighting is too dependent on the sample. In this contribution, the subjective weight coefficient α equal to 0.6, the main reason is that the weight distribution obtained by the subjective weighting method is more in line with the actual situation. This is mainly reflected in the three most important indicators calculated by the AHP method (travel speed, transport freight and cargo safety) and entropy method (drayage, cargo tracking and traffic accidents). In comparison, shippers or forwarders tend to pay more attention to the first three indicators (travel speed, transport freight and cargo safety). The use of combined weighting is to minimize the loss of information and make the weighting result as close as possible to the optimal result.

Advanced computational models oriented to mode choice in intermodal freight has provided robust and tools for transportation industry. For instance, agent-based model or mixed logit models are postulated proving its suitability in mode choice under different restrictions [26][27]. AHP differs from other complex methods for its simplicity and traceability, which may be an advantage oriented to the comprehensiveness from make decisions agents perspective. Also, this method seems suitable to be applied to other transportation fields in similar manner that done by Macharis C, Meers D and Lier T V [65]. In this sense, the methodology base on AHP-entropy may be useful to support make decision process that results from the movement of people and freight.

The AHP-entropy method as an evaluation of the performance of container multimodal is subject to limitations that deserve further research. The primary limitation is that our analysis does not include indicators that emphasize the connection and coordination between the three subsystems. This point may be improved considering Logistics system collaborative analysis that presumably may correct these limitations [66]. In addition, transportation performance scores under different alternatives can be used as input to obtain the optimization combine model in scenarios analysis with various constraints.

# Chapter 6. Conclusion

The transportation industry used to be one of the pillars of the national economies structure. Container multimodal transportation has the advantages of high efficiency, convenience, safety and reliability, and economic intensiveness, which is a development trend in the logistics research and applications. Based on comprehensive analysis of the factors affecting the performance of container multimodal transportation system, this contribution postulates the performance evaluation index system from the four aspects of capacity, cost, service, sustainability and calculates the weight of each index. These aspects correspond to the four strategic goals of the container transportation system. This contribution shows the application of AHP-Entropy method for the first time at container multimodal transportation performance evaluation. As a practical example, the method applies to the Ningbo-Shaoxing container multimodal system. The superiority of multimodal railway is revealed. This method has implied advantages (e.g. simplicity, comprehensiveness and combined subjective/objective weight method) in comparison to others of the proposed methods used in assessing the performance of three container multimodal transportation subsystems, which greatly promotes the scientific development of the container transportation industry.

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# Annex A1. Expert soce table

## A1.1. Problem Description

The thesis takes “evaluating the performance of three container transport subsystems (road, railway, inland waterway)” as research goal, and uses AHP to weight multiple evaluation indicators. The criteria framework is shown in **Figure 1**.

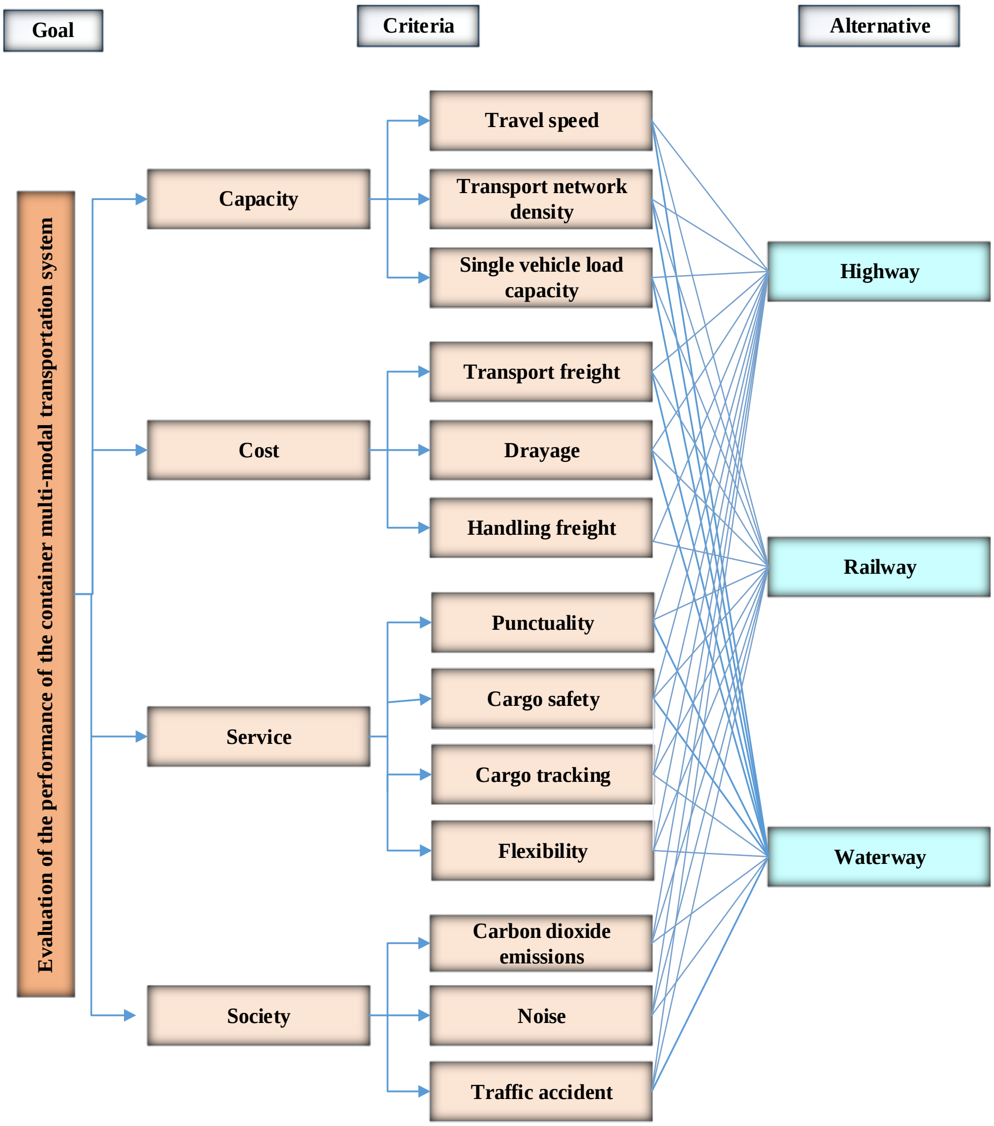


**Figure 1 Multi criteria assessment framework**

## A1.2. Scoring instructions

The expert scoring table is divided into two parts, namely expert scoring table 1 and expert scoring table 2.

The purpose of scoring table 1 is to judge the relative importance of indicators to the performance of container multimodal transportation. The multi criteria assessment contains a total of thirteen indicators. Their detailed description is shown in **Table 1**. The indicator's relative importance measurement grades are divided into nine scales, which are shown in **Table 2**. Experts need to compare the importance of one indicator relative to other indicators based on their experience, and then score them.

Scoring table 2 requires experts to evaluate the service levels of the three subsystems based on experience. The evaluation grades are excellent, great, good, fair and poor.

**Table 1 Explanation of Performance Evaluation indicator System**

| Criterion | Indicator | Description |
|---|---|---|
| **Capacity** | Transport speed | average kilometers traveled per hour |
| | Transport network density | Mileage of a certain transportation mode per 100 square kilometers |
| | Single vehicle load capacity | Number of containers that can be loaded at one time for one vehicle |
| **Cost** | Transport freight | Price per kilometer for transporting a TEU |
| | Drayage | Freight caused by drayage at the two ends of the transportation chain |
| | Handling freight | Charges for loading and unloading goods |
| **Service** | Punctuality | The probability of freight being delivered at the destination within a given time window |
| | Cargo Safety | Damaged and lost cargo in transit |
| | Cargo tracking | Application degree of GIS, GPS, barcode technology, radio frequency technology and other technologies |
| | Flexibility | Adaptability to the natural environment and accessibility to space activities |
| **Society** | Carbon dioxide emissions | Carbon dioxide emissions per million tons of kilometers |
| | Noise | Average economic loss caused by noise pollution caused by transportation per million tons of kilometers |
| | Traffic accident | Average economic loss caused by traffic accidents per million tons of kilometers |

**Table 2 Scale definition**

| Scale | Definition |
|---|---|
| **1** | The Row index and the Column index are equally important |
| **3** | The Row index is slightly more important than the Column index |
| **5** | The Row index is obviously more important than the Column index |
| **7** | The Row index is strongly more important than the Column index |
| **9** | The Row index is absolutely more important than the Column index |
| **2, 4, 6, 8** | The scale value corresponding to the intermediate state between the above two judgments |
| **Reciprocal** | Comparison of Column index and Row index to obtain the judgment value |

## A1.3. Contents of the scoring table

Please fall in the Expert score sheet 1 according to the nine scales shown in Table 2.

**Expert score sheet 1**

**Score First-level indicators**

| | Capacity | Cost | Service | Society |
|---|---|---|---|---|
| Capacity | 1 | | | |
| Cost | Not filled | 1 | | |
| Service | Not filled | Not filled | 1 | |
| Society | Not filled | Not filled | Not filled | 1 |

**Scoring second-level indicators of transport capacity**

| | Transport speed | Transport network density | Single vehicle load capacity |
|---|---|---|---|
| Transport speed | 1 | | |
| Transport network density | Not filled | 1 | |
| Single vehicle load capacity | Not filled | Not filled | 1 |

**Scoring second-level indicators of transportation costs**

| | Transport freight | Drayage | Handling freight |
|---|---|---|---|
| Transport freight | 1 | | |
| Drayage | Not filled | 1 | |
| Handling freight | Not filled | Not filled | 1 |

**Scoring second-level indicators of service level**

| | Punctuality | Cargo safety | Cargo tracking | Flexibility |
|---|---|---|---|---|
| Punctuality | 1 | | | |
| Cargo safety | Not filled | 1 | | |
| Cargo tracking | Not filled | Not filled | 1 | |
| Flexibility | Not filled | Not filled | Not filled | 1 |

**Scoring second-level indicators of social impact**

| | $CO_2$ emission | Noise | Traffic accident |
|---|---|---|---|
| $CO_2$ emission | 1 | | |
| Noise | Not filled | 1 | |
| Traffic accident | Not filled | Not filled | 1 |

Please refer to the evaluation level given in Table 3 to rate the following qualitative indicators.

**Table 3 Evaluation grades**

| Evaluation grades | Excellent | Great | Good | Fair | Poor |
|---|---|---|---|---|---|
| Score | 5 | 4 | 3 | 2 | 1 |

**Expert score sheet 2**

| | Highway | Railway | Inland waterway |
|---|---|---|---|
| Punctuality | | | |
| Cargo safety | | | |
| Cargo tracking | | | |
| Flexibility | | | |