Comprehensive Evaluation of Urban Integrated Transportation Network with Multivariate Statistical Analysis: a case study of Haimen

CHANGJIANG ZHENG¹, YUHANG GU¹, JINXING SHEN¹, MUQING DU¹, GENGHUA MA² and KAI SUN¹

² College of Harbour, Coastal and Offshore Engineering, Hohai University, Nanjing 210098, China

Corresponding author: Changjiang Zheng (e-mail: zheng@hhu.edu.cn).

This work was supported in part by the funding support from the National Natural Science Foundation of China (51808187), in part by the Natural Science Foundation of Jiangsu Province (BK20170879), in part by the Fundamental Research Funds for the Central Universities (2019B13514) and in part by the Jiangsu Planned Projects for Postdoctoral Research Funds (1701086B).

ABSTRACT This paper proposed a comprehensive evaluation (CE) framework concerning multivariate statistical analysis to provide a systematic assessment and a hierarchical analysis for the urban integrated transportation network (UITN). Specifically, this research contributed the following technical approaches: Firstly, 4 criteria (scale, structure, level of service (LOS), layout) was adopted and indexes were screened from heterogeneous aspects to establish the hierarchical model using correlation coefficient method (CCM). Built upon that, fuzzy comprehensive evaluation method (FCEM) and linear dimensionless (LD) were applied to quantify and nondimensionalize the qualitative and quantitative indexes. In order to improve accuracy and guarantee rationality, this paper then integrated analytic hierarchy process (AHP) with entropy weight method (EWM) to get the index weight. At last, the combination of value analysis (VA) and grey relational analysis (GRA) was used to calculate the CE value. The experimental study shows that our introduced CE framework can offer a thorough evaluation of the UITN, the CE value of UITN in Haimen city is 0.740 and its grade level is "Medium". Pros and cons of the structural layout of each transport mode can also be judged through the hierarchical analysis of different indexes. In view of this, corresponding suggestions were given for future improved transportation planning.

INDEX TERMS AHP, CE, GRA, hierarchical analysis, multivariate statistical analysis, UITN

I. INTRODUCTION

As the significant branch of the urban transportation system, the development of UITN greatly prompts the social progress. However, with the growth of urbanization, the contradiction between the UITN planning and the increasing demand has become distinctive, negatively interfering the socioeconomic growth. Related studies suggest that in order to address the urban transport problems while coordinate the relationship between UITN construction and social progress, it is obligatory to investigate the impacts of related influence factors, with which to reasonably plan the UITN and pilot the limpid development direction [1]-[3].

In recent years, the growing diversification and complexity of transport demand urge a comprehensive and effective transportation planning [4]. As far as it is concerned, as its solid basis, a comprehensive transportation evaluation incorporating multiple layers (highway, railway, waterway, airway et al.) is essential [5]. In fact, researchers and engineers have addressed this issue both theoretically and empirically. However, in related studies, the investigation of land transport accounts for the vast majority [6]-[8] and that of the other transport modes was quite roughly mentioned and assessed.

During the planning process, the notion of UITN was raised and studied [9]. The fully development of UITN can provide powerful support for building nation's strength in transport [10] and is considered to be the pioneer of economic growth [11] since it can improve regional accessibility. In studies of assessing transportation network, accessibility was assumed as the indicator [12]-[13] and it is found that its influence degree is varied for regions of different sizes (national and continental), with which the
regional economic growth can also be predicted. However, the previous studies are mainly confined in one transport mode (especially in highway or railway network) [14]-[15]. The characteristics of different transport modes should be notified and highlighted and the spatiotemporal effects should be assessed in a more integrated network [16]. Meanwhile, with the rapid growth of social economy, residents’ travel pattern becomes more diversified, which imposes great pressure on the transportation system operation. The complex population structure and their accordingly varied travel behavior require the transformation of UITN [17]-[18]. Therefore, in order to clarify how its development can provide satisfactory transport service, it is necessary to incorporate the influence of population in the CE framework [19].

Scholars have designed the quality ranking methodology to analyze the variables and criteria adopted in transportation network evaluation [20]-[22]. In their studies, they pointed that the homogeneity and suitability of the selected variables are rather important for building the evaluation system and environmental and aesthetic impacts were presumed as the significant indexes for assessing transport projects [23]. Though the formulated plans were specifically evaluated and the results were reasonable, it is notable that the environmental and landscape factors they laid great importance on are not the only considerations. The aim of their studies is either achieving sustainability or emphasizing economic benefits [24], which is far from enough to meet the needs of the society. The transportation network system needs the CE, which should incorporate heterogeneous evaluation aspects [25]. In addition, it should also be emphasized that little attention has hitherto been paid to the operation mechanism inside the UITN and a unified and standardized measure that can quantitively and systematically assess the UITN is not built yet.

Varying from single index evaluation, CE provides a systematic and standardized method integrating qualitative and quantitative indexes for evaluating multiple units at the same time. It can comprehensively judge the overall state of the research object and its complex mechanism can be investigated by hierarchical analysis. For cities with multiple transport modes, the CE system of UITN should reflect the real situation and the coordination degree among social, transport and geographical conditions.

Scale and structure [26] are major influence factors of CE system because they are the objective reflection of the components of UITN. In addition to that, the social sentiment of the quality of transport operation can be judged from the LOS [27], so it should as well be considered. Besides, the network layout was defined as the coupling and coordination degree of capacity and demand [28], as the core of regional UITN planning, it is also an indispensable part of the CE system.

Enormous studies on the methodology of establishing the UITN evaluation framework have emerged in recent years. Data Envelopment Analysis (DEA) as an evaluation method based on convex analysis and linear programming is widely adopted in the mathematical evaluation model. Although it can calculate the output value accurately, the concept of infinitesimal that is extremely computational intensive [29]-[30] needs to be introduced in the process of programming. In contrast, FCEM is easier to implement and suitable to multi-factor and multi-level problems [31], so in this paper, FCEM and LD are adopted to quantify and nondimensionalize the qualitative and quantitative indexes respectively. AHP can integrate relevant elements to establish a hierarchical model and use less quantitative information to program the thinking process of decision-making. For its concise concept and procedures, it is usually combined with other methods to deal with evaluation problems and verified practical [32]-[34]. In this paper, AHP is integrated with EWM [35] to calculate the CE index weight, with which the accuracy can be improved. GRA can determine the development trend of the system affected by the coordinated action of multiple factors, which is also able to determine each factor’s influence degree. The spotlight of this method is that the results obtained fit that of the qualitative analysis [36]-[38]. Therefore, after obtaining the index weights, GRA and VA [39] are combined to establish the CE model.

It can be drawn that enormous researches about the transportation network evaluation focus on the unimodal (land transport), instead few can evaluate from an integrated perspective (as shown in FIGURE 1). Comprehensive and detailed evaluation should not ignore multi-layer nature of UITN and the result of evaluation is affected by the synergism of various factors.

CE has been applied in various fields [40]-[42], for transportation planning, it can form a holistic evaluation of the UITN and carry out hierarchical analysis of each index. Besides, in previous studies, the fitness between the qualitative and quantitative indexes is not yet been discussed and few introduce a standardized measure for realizing CE.

Impact of different indexes on the multi-criteria evaluation

![FIGURE 1. Previous studies on transportation network evaluation](image-url)
The major contributions of this paper are summarized as follows:

1. The indexes were screened to build the evaluation index system and put forward specific methods of determining the CE index value;
2. AHP and EWM are integrated to determine the index weight, with which the accuracy is improved;
3. The combination of VA and GRA is used to establish the CE model and calculate the CE value to avoid subjectivity;
4. The case analysis proves the practicability and feasibility of the proposed model and the effectiveness of the adopted methods. Some reasonable suggestions on the improved planning of UITN in Haimen city were raised for reference.

The rest of the paper is organized as follows. Section 2 introduces the established CE index system and its components. Section 3 formulates the methodology of establishing the CE model. Section 4 presents the case analysis, which was carried out to validate our proposed evaluation framework. Finally, conclusions of this paper and some future research directions are discussed in Section 5.

II. ESTABLISHMENT OF CE INDEX SYSTEM
Based on the previous theoretical and empirical studies, it is determined to divide the preliminary CE indexes into four criteria: scale, structure, LOS and layout, which is shown in TABLE I.

The objectivity and reliability of the CE results depend on whether the selected indexes are accurate and representative. Because of the multi-layer nature of UITN, there exist various transport modes so the indexes come in great varieties. However, it can be found that some of the indexes can be deduced from the others and some of the contents of different indexes reflect overlap. Therefore, this paper adopted the Correlation Coefficient Method (CCM) to analyze and screen the indexes.

1. All the indexes have been clustered into 4 criteria, the next step is to choose one as the typical index of each transport mode in each criteria.
| Target Layer | Criteria Layer | Sub-criteria Layer | Index Layer |
|--------------|----------------|-------------------|-------------|
| Highway      | Scale          | Total mileage of highway network | Mileage of high-grade highway |
|              |                | Highway network density |            |
| Railway      |                | Total mileage of railway network | Multiple track mileage |
| Waterway     |                | Waterway network density | Mileage of high-grade waterway |
|              |                | Port scale | |
| Airway       |                | Airport level | Transport volume of airport |
|              |                | Route mileage | Number of air-routes |
| Population   |                | Total number of population | Passenger transport volume |
| Highway      | Structure      | Proportion of high-grade highway | Proportion of Expressway |
|              |                | Road grade level | Double-track mileage |
| Railway      |                | Electrification proportion | Double-track mileage |
| Waterway     |                | Proportion of high-grade waterway | Proportion of inland port berths |
|              |                | Proportion of berths of 10000 tons and above | Proportion of berths in Coastal Ports |
| Airway       |                | Proportion of high-grade Airports | |
| Population   |                | Proportion of workforce | Proportion of inhabitants |
|              |                | Proportion of floating population | Proportion of the elderly |
| Highway      | LOS            | Saturation of artery network | Pavement rate of advanced and sub-advanced pavement |
|              |                | Traffic accident rate | Road grade level |
|              |                | Asphalt pavement rate | Mileage saturation rate |
| Railway      |                | Workload of railway station | Railway line capacity |
| Waterway     |                | Port handling capacity | Waterway network congestion |
|              |                | Load uniformity of waterway network | |
| Population   |                | Congestion degree of commuting in peak hours | Commuting time |
|              |                | Commuting speed in peak hours | |
| Highway      | Layout         | Load uniformity of highway network | Highway network connectivity |
|              |                | Administrative village rate through highway | Highway network accessibility |
| Railway      |                | Railway network density | Railway station coverage |
| Waterway     |                | Graded waterway network connectivity | Grade waterway coverage |
| Airway       |                | Air service coverage | |

VOLUME XX, 2021
(1) Suppose the index set \( x = \{ \text{Scale}, \text{Structure}, \text{LOS}, \text{Layout} \} \), \( X_{y_{z_k}} \) represents the \( k_{th} \) index of the \( z_{th} \) mode in the \( y_{th} \) criteria in TABLE I. For example, when \( y = 2 \), \( z = 2 \), \( k = 2 \), \( X_{222} \) represents the index "Double-track mileage" of "Railway" mode in "Structure" criteria.

(2) Let \( X^{(y_{z_k})} = \{ x_1^{(y_{z_k})}, x_2^{(y_{z_k})}, \ldots, x_P^{(y_{z_k})} \} \) denote the sample value of the \( k_{th} \) index of the \( z_{th} \) mode in the \( y_{th} \) criteria, \( \tau \) denotes the number of samples, the correlation coefficient \( r_{ym}^{(y_{z_k})} \) can be calculated as Eq. (1).

\[
\begin{align*}
 r_{ym}^{(y_{z_k})} &= \frac{\sum_{i=1}^{\tau} (x_{yi}^{(y_{z_k})} - \bar{x}_{yi}^{(y_{z_k})})(\bar{x}_{ym}^{(y_{z_k})} - \bar{x}_{ym}^{(y_{z_k})})}{\sqrt{\sum_{i=1}^{\tau} (x_{yi}^{(y_{z_k})} - \bar{x}_{yi}^{(y_{z_k})})^2 \sum_{i=1}^{\tau} (\bar{x}_{ym}^{(y_{z_k})} - \bar{x}_{ym}^{(y_{z_k})})^2}} \\
 \end{align*}
\]

(3) Coefficient of determination \( \hat{r}_{ym}^{2} \) can be calculated as Eq. (2).

\[
\hat{r}_{ym}^{2} = \frac{\sum_{i=1}^{\tau} (x_{yi}^{(y_{z_k})} - \bar{x}_{yi}^{(y_{z_k})})^2}{\sum_{i=1}^{\tau} (\bar{x}_{yi}^{(y_{z_k})} - \bar{x}_{yi}^{(y_{z_k})})^2}
\]

(4) Choose \( \hat{r}_{ym}^{2} = \max \left\{ \hat{r}_{ym}^{2} \right\} \) as the typical index of each transport mode in each criteria.

2) Calculate the correlation coefficient between the indexes and typical indexes. In this paper, the critical value M is 0.6. If \( r_{ym}^{(y_{z_k})} \geq M \), the \( k_{th} \) index will be considered being retained; otherwise it will be deleted.

After analyzing and screening the indexes, the CE index system of UITN is shown in FIGURE 2.

Several explanations of CE indexes are as follows:

A. SCALE
1) Total mileage of highway network A1

The total mileage of the highway network can reflect the development of the highway network scale and the coordination degree between the urban economy and the overall transportation system. In this paper, the Connectivity Method (CM) and the Territory Coefficient Method (TCM) are used to calculate the total mileage of highway network, and then the average value is taken as the standard value.

The basic formula of the CM can be expressed as Eq. (3), where \( A_1 \) is the total mileage of the highway network (km); \( D_N \) is the connectivity; \( S \) is the total area of the city (km\(^2\)); \( R \) is the number of connected nodes in this region; \( \xi \) is the deformation coefficient of the highway network.

The basic formula of the TCM can be expressed as Eq. (4), where \( A_2 \) is the total mileage of the highway network (km); \( K \) is the coefficient of the urban highway network; \( P \) is the total population of the city (10,000 people).

\[
\begin{align*}
A_1 &= D_N \cdot \xi \cdot \sqrt{S} \\
A_2 &= K \cdot \sqrt{P} \cdot T
\end{align*}
\]

In Eq. (5), \( A_2 \) is the scale of the railway network (km); \( T \) is the number of important towns; \( C \) is the connection coefficient.

B. STRUCTURE
1) Proportion of expressway B1

The standard value of the expressway proportion is obtained by the analogy analysis (AA).

2) Electrification proportion B4

The proportion of electrification in the railway network is directly proportional to the socioeconomic development of the city.
C. LOS

1) Saturation of artery network C1

The saturation of artery network can reflect the demand adaptability of the highway network and the degree of congestion. The evaluation standard adopted in this paper is shown in TABLE II.

| V/C       | Service level |
|-----------|---------------|
| ≤0.7      | Excellent     |
| (0.7, 0.8]| Better        |
| (0.8, 0.9]| Good          |
| (0.9, 1.0)| Poor          |
| ≥1.0      | Very bad      |

2) Waterway network congestion degree C4

The congestion degree of waterway network δ can reflect the operation condition of waterway network.

\[
\delta = \frac{M \times K}{\sum_{i=1}^{n} M_{i} \times Q_{i}}
\]

In Eq. (6), δ is the congestion degree of waterway network; \( M_{i} \) is the mileage per waterway (km); \( K_{i} \) is the planned traffic volume per waterway; \( Q_{i} \) is the capacity per waterway.

D. LAYOUT

1) Administrative village rate connected by highway D1

With implementation of rural revitalization strategy, there should be roads connecting cities and villages. Roads connecting administrative villages can drive the economic development of regions along the route and facilitate the development of urban-rural integration.

2) Railway network density D3

This paper uses the proportion of operating railway mileage per 100 m² as an indicator to evaluate the rationality of the railway network layout. In this paper, the standard value of the railway network density is determined by AA.

3) Railway station coverage rate D4

Rail travel has the advantages of punctuality, high-speed, comfort and safety, so more and more tourists prefer to travel by rail. High accessibility can bring about the boom of economy [50], thus the coverage of railway station is particularly prominent.

4) Graded waterway network connectivity D5

Graded waterway network connectivity can reflect the characteristics of the layout of the waterway network by examining the connectivity of the node ports and urban transport hubs.

5) Congestion degree of commuting in peak hours C5

Congestion degree of commuting in peak hours can reflect the urban traffic congestion situation. The evaluation standard adopted in this paper is shown in TABLE III [51]-[52].

| Situation       | Value range |
|-----------------|-------------|
| Unblocked       | ≤1.5        |
| Slow            | (1.50, 1.80) |
| Congested       | [1.80, 2.00) |
| Severely congested| ≥2.00    |

III. ESTABLISHMENT OF CE MODEL

After obtaining the screened indexes, they are nondimensionalized through dimensionless treatment, after which the evaluation value of each index is obtained. Afterwards, the integration of AHP and EWM is explored to calculate and tune the index weight. Finally, VA and GRA are combined to obtain the CE value and assess the grade level of UITN. The established CE framework is shown in FIGURE 3.

A. DIMENSIONLESS TREATMENT OF CE INDEXES

The ultimate purpose of CE is to integrate the information of multiple indexes describing the studied object to obtain a CE value and then conduct analysis to assess this object as a whole. During the process, the integration should be based on the homogeneity of each CE index. However, specific indexes of the CE index system are often non-homogeneous. On the one hand, the dimension of each index value is varied; on the other hand, because each CE index reflects different criteria of the studied object, so the representation forms of these indexes are different. In this way, these CE indexes values will be different in terms of magnitude.

The homogeneity transformation of the indexes can be solved by dimensionless treatment to convert the actual value of the index into a CE value, the integration of different CE indexes can then be proceeded. The specific methods are as follows:

1) Dimensionless treatment of qualitative indexes.

This paper uses FCEM to quantify and nondimensionalize the qualitative indexes, the results are obtained through Expert Scoring Method (ESM) and the evaluation standard is shown in TABLE IV.

| Evaluation results | Value range |
|--------------------|-------------|
| Excellent          | [0.8, 1.0]  |
| Very good          | [0.6, 0.8)  |
| Good               | [0.4, 0.6]  |
| Bad                | [0.2, 0.4)  |
| Very bad           | [0.0, 0.2]  |

2) Dimensionless treatment of quantitative indexes.

This paper uses LD to nondimensionalize the quantitative indexes. Suppose the calculated value of index \( i \) is \( p_{i} \), the upper bound and lower bound of \( p_{i} \) are \( p_{\text{max}} \) and \( p_{\text{min}} \) respectively, \( U_{d} (p_{i}) \) is the nondimensionalized standard

\[
U_{d} (p_{i}) = \frac{p_{i} - p_{\text{min}}}{p_{\text{max}} - p_{\text{min}}}
\]
function of the index value \( p_i \) of \( d_i \). The dimensionless process is formulated as Eqs. (7)-(10).

(1) Profit index (greater value is better):

\[
f_i = U_d(p_i) = \begin{cases} \frac{p_i - p_{\text{min}}}{p_{\text{max}} - p_{\text{min}}} & p_{\text{min}} < p_i < p_{\text{max}} \\ 0 & p_i \geq p_{\text{max}} \\ 1 & p_i \leq p_{\text{min}} \end{cases}
\]

(7)

(2) Cost index (smaller value is better):

\[
f_i = U_d(p_i) = \begin{cases} \frac{p_{\text{max}} - p_i}{p_{\text{max}} - p_{\text{min}}} & p_{\text{min}} < p_i < p_{\text{max}} \\ 0 & p_i \geq p_{\text{max}} \\ 1 & p_i \leq p_{\text{min}} \end{cases}
\]

(8)

(3) Interval index (the value within a fixed range is better):

\[
f_i = U_d(p_i) = \begin{cases} 1 - \max\left\{\frac{p_i - p_{\text{min}}}{p_{\text{max}} - p_{\text{min}}} \right\} & p_{\text{min}} < p_i < p_{\text{max}} \\ 0 & p_i \leq p_{\text{min}} \\ 1 & p_i \geq p_{\text{max}} \end{cases}
\]

(9)

(4) Moderate index (the value closer to the median is better):

\[
f_i = U_d(p_i) = \begin{cases} \frac{N \left( p_i - p_{\text{min}} \right)}{p_{\text{max}} - p_{\text{min}}} & p_{\text{min}} < p_i < p_{\text{max}} \\ 0 & p_i \leq p_{\text{min}} \\ 1 & p_i \geq p_{\text{max}} \end{cases}
\]

(10)

B. CALCULATION METHODS OF CE INDEX WEIGHT

Different indexes have varied impacts on the studied object and the determination of their weights reflects their priority and directly affects the CE results. Therefore, weighing treatment is required. In this paper, AHP is utilized to calculate the weights of the indexes and EWM is explored to modify the results. The specific procedures are introduced as follows:

1) Calculate the weight using AHP.

Step1: Establish the judgment matrix according to the relative importance of each index in each criteria.

Suppose that element \( N_j \) in criterion layer \( N \) is the upper level of element \( G_1, G_2, G_3, \ldots, G_n \) in index layer \( G \), the judgment matrix is constructed as Eq. (11).

\[
G = \begin{pmatrix} g_{11} & g_{12} & \cdots & g_{1n} \\ g_{21} & g_{22} & \cdots & g_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ g_{n1} & g_{n2} & \cdots & g_{nn} \end{pmatrix}
\]

(11)

where \( g_{ij} \) is the relative importance of \( G_j \) relative to \( G_i \), \( g_{ij} > 0; g_{ii} = 1 \); \( g_{ji} = 1 \).

When proceeding the relative importance comparison among the indexes, this paper uses the scale of 1-9 to calibrate the relative importance of each index (as shown in TABLE V).

TABLE V

| Hierarchy of importance | Quantized value |
|------------------------|----------------|
| Equally important      | 1              |
| Index i is slightly more important than index j  | 3              |
| Index i is more important than index j           | 5              |
| Index i is quite important compared to index j   | 7              |
| Index i is extremely important compared to index j | 9            |

The relative importance between index \( i \) and \( j \) is set between any two hierarchies 2, 4, 6, 8.

Step2: Perform hierarchical single sorting and concordance test (CT).

Calculate the index weight and determine the maximum eigenvalue of the judgment matrix, then conduct the CT.

\[
CR = \frac{CI}{RI} \leq 0.1
\]

Eq. (12) indicates the formulation of concordance ratio (CR), if CR<0.1, the judgement matrix will pass the CT; otherwise the judgement matrix should be modified to reconduct CT until it is passed. The formulation of the concordance index (CI) is given in Eq. (13), where \( \nu \) denotes the order of the judge matrix. The correspondence between RI and \( \nu \) is shown in TABLE VI.

Step3: Perform hierarchical total sorting and CT.

Calculate all the index weights from the top to the bottom layer and conduct the CT for total ranking results.

2) Modify the calculated weight using EWM.

Step1: Suppose the weight obtained by AHP is \( \alpha_j = \left( \alpha_1, \alpha_2, \alpha_3, \ldots, \alpha_n \right)^T \), then transform the matrix into a standardized matrix.

\[
\tilde{G} = \left( \tilde{g}_{ij} \right)_{n \times n} = \begin{pmatrix} \frac{g_{11}}{\nu g_{11} + \nu g_{12}} & \frac{g_{12}}{\nu g_{11} + \nu g_{12}} & \cdots & \frac{g_{1n}}{\nu g_{11} + \nu g_{12}} \\ \frac{g_{21}}{\nu g_{21} + \nu g_{22}} & \frac{g_{22}}{\nu g_{21} + \nu g_{22}} & \cdots & \frac{g_{2n}}{\nu g_{21} + \nu g_{22}} \\ \vdots & \vdots & \ddots & \vdots \\ \frac{g_{n1}}{\nu g_{n1} + \nu g_{n2}} & \frac{g_{n2}}{\nu g_{n1} + \nu g_{n2}} & \cdots & \frac{g_{nn}}{\nu g_{n1} + \nu g_{n2}} \end{pmatrix}
\]

(14)

\[
S_j = -\ln n^{-1} \sum_{i=1}^{n} \frac{g_{ij}}{\nu g_{ii}} \ln g_{ij} \quad (0 \leq S_j \leq 1)
\]

(15)

\[
p_j = 1 - S_j
\]

(16)

TABLE VI

| \( \nu \) | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|----------|---|---|---|---|---|---|---|---|---|----|
| RI       | 0 | 0 | 0.58 | 0.9 | 1.12 | 1.24 | 1.32 | 1.41 | 1.45 | 1.49 |
Eqs. (15) and (16) denote the formulations of entropy of the index \( f_i (S_j) \) and the deviation degree \( (P_j) \).

Step 2: Calculate the correction coefficient \( \mu_j \)

\[
\mu_j = \frac{\sqrt{\sum p_j}}{\sqrt{n}}
\]

(17)

The correction coefficient \( \mu_j \) obtained by Eq. (17) is used to revise the index weight \( \alpha_j = \left( \alpha_{j1}, \alpha_{j2}, \alpha_{j3}, \ldots, \alpha_{jn} \right)^T \) got from AHP. In Eq. (18), \( \alpha_j^* \) is the revised weight of index \( j \).

3) Calculate the final weight of each index.

\[
w_j = \theta \cdot \alpha_j^* + (1 - \theta) \cdot \alpha_j^*
\]

(19)

Eq. (19) represents the initial weight obtained by AHP and the modified weight obtained by EWM are weighed to get the final weight of each index, where \( \theta \) is usually 0.5.

The results of the index weights are shown in TABLE VII-VIII, where \( \checkmark \) indicates CT is passed; otherwise \( \times \) is shown.

### TABLE VII

| Structure | Criteria | Layout | LOS | Weight |
|-----------|----------|--------|-----|--------|
| Scale     | 1        | 2      | 3   | 3      |
| Structure | 1/2      | 1      | 2   | 2      |
| LOS       | 1/3      | 1/2    | 1   | 1      |
| Layout    | 1/3      | 1/2    | 1   | 1      |
| \( \lambda_{max} \) | 4.0104 | CI=0.0035 | RI=0.90 | CR=0.0038 | \( \checkmark \) |

### TABLE VIII

| Structure | Scale | Structure | LOS | Layout | Weight |
|-----------|-------|-----------|-----|--------|--------|
| A1        | 1     | 2         | 2   | 2      | 0.3880 |
| A2        | 1/2   | 1         | 3   | 3      | 0.3298 |
| A3        | 1/3   | 3/4       | 1   | 1      | 0.1611 |
| A4        | 1/2   | 3/4       | 1   | 1      | 0.1411 |
| \( \lambda_{max} \) | 4.1545 | CI=0.0515 | RI=0.90 | CR=0.0572 | \( \checkmark \) |

The initial weight obtained by AHP and the modified weight obtained by EWM are weighed and calculated by Eq. (19) to obtain the final weight, the result of each index weight in each criteria is shown in FIGURE 4.

**C. CALCULATION METHODS OF CE VALUE**

In this paper, in order to eliminate the subjectivity of employing only one method, the combination of VA and GRA is utilized to obtain the CE value. The specific procedures are as follows:

1) Calculate the preliminary CE value using VA.

\[
v_i = \sum f_i z_j
\]

(20)

\[
z_j = f_j, w_i
\]

(21)

Eqs. (20) and (21) indicate the formulations of VA, where \( v \) is the preliminary CE value; \( z_j \) is the CE value of index \( j \); \( f_j \) is the evaluation value after dimensionless treatment.

2) Calculate the preliminary CE value using the GRA.

\[
r_i = E \cdot w
\]

(22)
Eq. (22) represents the basic formulation of GRA. The correlation coefficient matrix is given in Eq. (23), where \( \xi_{ij} \) is the correlation coefficient of the \( j \text{th} \) index in the \( i \text{th} \) criteria. Eq. (24) denotes the weights of \( n \) indexes, \( \sum_{i=1}^{n} w_i = 1 \).

\[
E = \begin{bmatrix} \xi_{11} & \xi_{12} & \cdots & \xi_{1n} \\ \xi_{21} & \xi_{22} & \cdots & \xi_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ \xi_{n1} & \xi_{n2} & \cdots & \xi_{nn} \end{bmatrix}
\]  

(23)

\[
W = [w_1, w_2, w_3, \ldots, w_n]
\]  

(24)

\[ w_i = \frac{1}{\sum_{j=1}^{n} w_j} \]

Step1: Determine the optimal index set.
Suppose there are \( n \) indexes, select the optimal indexes (Eq. (25)).

\[
X^* = \left[ x_{1}^*, x_{2}^*, \ldots, x_{n}^* \right]
\]  

(25)

\[
D = \begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1n} \\ x_{21} & x_{22} & \cdots & x_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ x_{n1} & x_{n2} & \cdots & x_{nn} \end{bmatrix} \quad \Rightarrow \quad C = \begin{bmatrix} c_{11} & c_{12} & c_{13} & \cdots & c_{1n} \\ c_{21} & c_{22} & c_{23} & \cdots & c_{2n} \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ c_{n1} & c_{n2} & c_{n3} & \cdots & c_{nn} \end{bmatrix}
\]  

(26)

In Eq. (26), matrix D is built according to the original data, here the dimensionless treatment is explored to standardize the indexes in matrix D to that in matrix C.

Step2: Calculate the gray correlation coefficient.
Split matrix C, suppose the reference series:

\[
C = \begin{bmatrix} c_{11} & c_{12} & c_{13} & \cdots & c_{1n} \end{bmatrix}
\]

and the comparison series:

\[
C = \begin{bmatrix} c_{i1} & c_{i2} & c_{i3} & \cdots & c_{in} \end{bmatrix}, \quad i = 1, 2, \ldots, n,
\]

then calculate the correlation coefficient \( \xi_{ik} \) (Eq. (27)).

\[
\xi_{ik} = \frac{\Delta \text{min} + \rho \cdot \Delta \text{max}}{k_{ij}^* - c_{ij}^* + \rho \cdot \Delta \text{max} - k_{ij}^* - c_{ij}^*}
\]  

(27)

where \( \rho \) is the identification coefficient, \( \rho \in [0, 1] \).

Step3: Calculate the preliminary CE value.

\[
R = \left[ r_1, r_2, r_3, \ldots, r_m \right]
\]  

(28)

In Eq. (28), according to Eqs. (22)-(24),

\[
r_i = \sum_{k=1}^{n} \xi_{ik} \cdot w_k, \quad i = 1, 2, 3, \ldots, m.
\]

3) Calculate the final CE value.

\[
\nu = \frac{\sum_{i=1}^{n} r_i}{n}
\]  

(29)

Eq. (29) denotes the formulation of getting the final CE value and the grade of the evaluated UITN can be referred in TABLE X [53].

| Grade       | CE value |
|-------------|----------|
| Unqualified | [0.0, 0.6] |
| Qualified   | [0.6, 0.7] |
| Medium      | [0.7, 0.8] |
| Good        | [0.8, 0.9] |
| Excellent   | [0.9, 1.0] |

IV. IMPLEMENTATION AND ANALYSIS

A. STUDY SITE SELECTION AND DESCRIPTION

The UITN of Haimen is selected as the study scenario to validate the proposed CE model, then corresponding discussions are given through hierarchical analysis.

Haimen city is located at the Yangtze River estuary and close to Shanghai. Benefited from its geographic location, it has rich transport compositions (involve all the 4 modes [54]), as shown in FIGURE 5.

**TABLE X**

| THE GRADE LEVEL OF THE EVALUATED UITN |
|--------------------------------------|
| Grade       | CE value |
|-------------|----------|
| Unqualified | [0.0, 0.6] |
| Qualified   | [0.6, 0.7] |
| Medium      | [0.7, 0.8] |
| Good        | [0.8, 0.9] |
| Excellent   | [0.9, 1.0] |

**FIGURE 4.** The diagram of the CE index weight.
FIGURE 5. Transport compositions of Haimen city

Highway

Railway

Waterway

Airway

FIGURE 6. The analysis of current status of UITN in Haimen.
### B. RESULTS AND DISCUSSIONS

The preliminary CE values calculated are shown in TABLE XI and the final CE value obtained is 0.740 (Eq. (29)). By referring TABLE X, the grade level of UITN in Haimen city is "Medium".

The rapid development of UITN in Haimen has strongly promoted the socioeconomic growth. However, from the perspective of CE and its obtained results, there are still deficiencies. Highway network can strive for further progress and improvement, while the development of railway, waterway and airway is still in a shallow level. The overall network connectivity reaches the average level and there is little possibility for the landing of a high-speed rail travel can provide comfortable and reliable service, more and more people tend to choose travelling by rail.

As shown in FIGURE 6 (a), the total mileage of the highway network is insufficient, which is slightly lower than the lower bound of the national level. Though the highway network connectivity reaches the average level, the proportion of expressway is rather lower (FIGURE 6 (b)). Besides, there are few high-grade highways (mainly 3rd-grade and 4th-grade highways) and the saturation of its artery network is high, which leads to the unreasonable overall layout. Considering the current situation that 1) most of the national and provincial arteries are concentrated in the main city and areas along the Yangtze River; 2) some highway channels overlap seriously; 3) insufficient highway coverage in the northern area of the city, as exhibited in FIGURE 7, it is advised that 4 national and provincial roads be routed and 4 provincial roads be newly upgraded (http://www.jshmzc.com/hmzc/zwxz/content/7bbe7b9f-0a66-45b4-8984-e7d0d9fdd13b.html).

#### 2) Railway

The railway scale of Haimen City is so small. It possesses only one Ningqi Railway and its length is just 38km, no wonder it provides poor railway LOS for its low railway line capacity (FIGURE 6 (c)). The layout is also not perfect, the function of the railway station should be strengthened as well. At present, for the high-speed rail travel can provide comfortable and reliable service, more and more people tend to choose travelling by rail.

| Criteria | Index | Evaluation value | Dimensionless value | Index weight | Integrated weight | CE value (VA) | Δ | Σ | Δk | CE value |
|----------|-------|------------------|---------------------|--------------|-------------------|---------------|----|----|----|----------|
| Scale    | A1    | 2562.8km         | 0.645               | 0.460        | 0.115             | 0.074         | 0.355| 0.355| 0.355| 0.068    |
|          | A2    | 38km             | 0.667               | 0.294        | 0.073             | 0.049         | 0.333| 0.333| 0.333| 0.045    |
|          | A3    | 0.9              | 1.000               | 0.123        | 0.031             | 0.031         | 0.000| 0.000| 0.000| 0.031    |
|          | A4    | 0.7              | 0.800               | 0.123        | 0.031             | 0.025         | 0.200| 0.200| 0.200| 0.023    |
| Structure| B1    | 1.58%            | 0.351               | 0.120        | 0.030             | 0.011         | 0.649| 0.649| 0.649| 0.010    |
|          | B2    | 19.50%           | 0.975               | 0.131        | 0.033             | 0.032         | 0.025| 0.025| 0.025| 0.028    |
|          | B3    | 100%             | 1.000               | 0.123        | 0.031             | 0.031         | 0.000| 0.000| 0.000| 0.031    |
|          | B4    | 100%             | 1.000               | 0.058        | 0.014             | 0.014         | 0.000| 0.000| 0.000| 0.014    |
|          | B5    | 9.07%            | 0.363               | 0.054        | 0.014             | 0.005         | 0.637| 0.637| 0.637| 0.005    |
|          | B6    | 60.70%           | 0.767               | 0.279        | 0.070             | 0.054         | 0.233| 0.233| 0.233| 0.051    |
|          | B7    | 63.15%           | 0.734               | 0.234        | 0.059             | 0.043         | 0.266| 0.266| 0.266| 0.040    |
| LOS      | C1    | 0.74             | 0.600               | 0.108        | 0.027             | 0.016         | 0.400| 0.400| 0.400| 0.015    |
|          | C2    | 97.80%           | 1.000               | 0.219        | 0.055             | 0.055         | 0.000| 0.000| 0.000| 0.055    |
|          | C3    | 14               | 0.583               | 0.219        | 0.055             | 0.032         | 0.417| 0.417| 0.417| 0.030    |
|          | C4    | 0.764            | 0.860               | 0.061        | 0.015             | 0.013         | 0.140| 0.140| 0.140| 0.012    |
|          | C5    | 1.334            | 0.666               | 0.394        | 0.098             | 0.066         | 0.334| 0.334| 0.334| 0.062    |
| Layout   | D1    | 100%             | 1.000               | 0.358        | 0.089             | 0.089         | 0.000| 0.000| 0.000| 0.089    |
|          | D2    | 2.62             | 0.760               | 0.337        | 0.084             | 0.064         | 0.240| 0.240| 0.240| 0.060    |
|          | D3    | 3.31 km/100 km2  | 0.735               | 0.113        | 0.028             | 0.021         | 0.265| 0.265| 0.265| 0.019    |
|          | D4    | 65%              | 0.722               | 0.141        | 0.035             | 0.025         | 0.278| 0.278| 0.278| 0.023    |
|          | D5    | 1.56             | 0.867               | 0.031        | 0.008             | 0.007         | 0.133| 0.133| 0.133| 0.006    |
|          | D6    | 75%              | 0.882               | 0.020        | 0.005             | 0.004         | 0.118| 0.118| 0.118| 0.003    |
|∑         |       |                  |                     | 4            | 1                  | 0.760        |      |      |      | 0.720    |
However, Haimen Station of Ningqi Railway is of low service level and its functions are imperfect, so its layout needs to be further optimized to improve its transport efficiency. As shown in FIGURE 8, it is suggested that a high-speed railway be newly built and Haimen North Railway Station be newly set (https://www.yangtse.com/content/1236900.html) to realize high-speed railway travel and improve the railway network density and railway station coverage, which further optimize the transport structural layout and improve LOS.

3) Waterway

Although the scale of the port reaches the national average level, the cognition of port is vague and its functions are not fully exploited. The proportion of high-grade waterway is quite low (FIGURE 6 (e), FIGURE 9) so its interflow with high-grade ports is rather limited. The waterway network congestion degree goes beyond the upper bound of the standard value (FIGURE 6 (f)), thus low LOS and poor transport efficiency are provided and the advantages of waterway transport can't be given into full play, which strongly restrict its development. In view of this, it is suggested to build a high-quality inland waterway network with the artery of Yangtze River as the core and the 3rd-grade waterways as the framework (as shown in FIGURE 10). The purpose is to connect the sea port and Haimen port with the 3rd-grade waterway channels to strengthen the River-Ocean combined transport (http://jtysj.nantong.gov.cn/ntjy/upload/27d6130b-22f5-4337-b2ce-23ee9d52b523.pdf).

4) Airway

Haimen residents mainly used Nantong Xingdong International Airport for travelling while its airway development is lagged behind. As shown in FIGURE 6 (g), the airport has few airlines and flights and small air service coverage. To meet the rapid growth of Haimen economy, in the long run, it is suggested to learn from the construction experience, scale and positioning of Chengdu Tianfu Airport and build a 4F airport in Haimen. Haimen Airport Economic Zone should be recognized as the Regional Aviation Hub and Advanced Aviation Industrial Agglomeration Zone, which takes airway transportation, air logistics and international business as the main development industries (https://www.ettoday.net/news/20190215/1378443.htm).
V. CONCLUSIONS AND DIRECTIONS FOR FUTURE WORKS

This paper proposed a CE framework to comprehensively evaluate UITN with multivariate statistical analysis. Due to the diversity of the evaluation indexes, 4 criteria was adopted and indexes were screened through CCM. In the next, FCEM and LD were used to quantify and nondimensionalize the qualitative and quantitative indexes. Then the weights of the selected CE indexes are calculated through the integration of AHP and EWM. After obtaining the weights, the CE value was given by the combination of VA and GRA. At last, the case of UITN in Haimen was chosen to apply our established CE model, the results were analyzed and suggestions for the improved UITN planning were raised for reference.

The advancements and innovations are as follows:

1) Our CE model can provide a systematic view of UITN, the CE value can be referred to assess the studied object's general development trend and comprehensive level, based on which the improved decisions can be made.

2) The integration of AHP and EWM can improve the accuracy of the index weight and the subjectivity of employing one approach is avoided through averaging the value of VA and GRA.

3) The established CE framework exhibits adequate practicability and feasibility, it provides a theoretical foundation for partial-global planning and structural layout optimization of UITN.

There are several promising future research directions stemmed from this study. During the process of dimensionless treatment of qualitative indexes, ESM is applied and kind of subjective, so it is the same with the process of determining the weight by applying AHP (ESM). Methods shunning subjectivity in the analysis are few and therefore worth studying. Besides, with the rapid development of the transportation system, pipeline transport has gradually come into practice and is also a significant component of the UITN, the index selection of pipeline transport and its evaluation criteria is also an interesting direction for digging into. Such extensions will make our study more scientific and functional and be addressed in our future works.

REFERENCES
[1] Hatzopoulos, M., and E. J. Miller. "Institutional integration for sustainable transportation policy in Canada." Transport Policy 15.3 (2008):149-162.
[2] Nagurney, A. . "Sustainable Transportation Networks." Books (2015).
[3] Yao, S., and L. Lan. "Research on Regional Transportation Network Development Strategies Based on Regional Synergy: A Case Study of Guangdong-Hong Kong-Macao Greater Bay Area." International Conference on Smart Vehicular Technology, Transportation, Communication and Applications (2018).
[4] Xiong, Qiao, Ji Hu, and Jiating Kuai. "Comprehensive Transportation Corridor Layout of Urban Agglomeration Based on Improved Ant Colony Algorithm." ICTE 2019. Reston, VA: American Society of Civil Engineers, 2020. 77-85.
[5] Rahimi-Golkhadan, Armin, and Michael J. Garvin. "A Socio-Economic Comparison of Urban Areas with Different Transportation System Diversity." Construction Research Congress 2020: Infrastructure Systems and Sustainability. Reston, VA: American Society of Civil Engineers, 2020.
[6] Zeng, Jin, and Fangrong Qi. A Comprehensive Evaluation Model and Empirical Research on Railway Freight Rates under a Competitive Environment. No. TRBA-21-02158. 2021.
[7] Li, Wei, et al. "Quantitative Modeling and Comprehensive Evaluation of Urban Rail Transit Network Dynamic Accessibility." 2018 3rd IEEE International Conference on Intelligent Transportation Engineering (ICITE). IEEE, 2018.
[8] Yin, Huahuan, et al. "Evaluation Model of Urban-Rural Transportation Integration Development Level." IOP Conference Series: Materials Science and Engineering. Vol. 688. No. 2. IOP Publishing, 2019.
[9] Adamski, Andrzej. "Integrated transportation systems." Modeling and Management in Transportation. EURO WG on Transportation 1 (1999): 21-34.
[10] El-Adawy, Islam H., Ibrahim S. Abotaleb, and Eric Vechan. "Social network analysis approach for improved transportation planning." Journal of Infrastructure Systems 23.2 (2017): 05016004.
[11] Li, Bin, et al. "Estimation of regional economic development indicator from transportation network analytics." Scientific reports 10.1 (2020): 1-15.
[12] Fayyaz, S. Kiavash, Xiaoyue Cathy Liu, and Richard J. Porter. "Dynamic transit accessibility and transit gap causality analysis." Journal of Transport Geography 59 (2017): 27-39.
[13] Bikdeli, Sona, Sirous Shafaqi, and Fatemeh Vosouqi. "Accessibility modeling for land use, population and public transportation in Mashhad, NE Iran." Spatial Information Research 25.3 (2017): 481-489.
[14] Kelle, Peter, et al. "Evaluation of operational and environmental sustainability tradeoffs in multimodal freight transportation planning." International Journal of Production Economics 209 (2019): 411-420.
[15] Shao, Zeng-Zhen, et al. "Evaluation of large-scale transnational high-speed railway construction priority in the belt and road region." Transportation Research Part E: Logistics and Transportation Review 117 (2018): 40-57.
[16] Yatskiv, Irina, and Evelina Budilovich. "A comprehensive analysis of the planned multimodal public transportation HUB." Transportation research procedia 24 (2017): 50-57.
[17] Dong, Lei, et al. "Population-Weighted Efficiency in Transportation Networks." Scientific Reports, vol. 6, no. 1, 2016, pp. 26377–26377.
[18] Zhao, F. X. , H. Y. Shang : "Role of transportation network on population distribution evolution." Physica A: Statistical Mechanics and its Applications 577.45(2021):126076.
[19] Li, R. , et al. "Simple spatial scaling rules behind complex cities." Nature Communications 8.1(2017).
[20] Salehi, Alireza, Farhad Hosseinizadeh Lotfi, and Mohsen Rostamy Malkhalifeh. "Evaluation and ranking of rail freight and passenger transportation in same Asian countries with new method in Data Envelopment Analysis." JOURNAL OF MATHEMATICAL EXTENSION 15 (2019).
[21] Nassereddine, M., and H. Eskandari. "An integrated MCDM approach to evaluate public transportation systems in Tehran." Transportation Research Part A: Policy and Practice 106 (2017): 427-439.
[22] Seker, Sukran, and Nezir Aydin. "Sustainable public transportation...
system evaluation: A novel two-stage hybrid method based on IVIF-AHP and CODAS." International Journal of Fuzzy Systems 22.1 (2020): 257-272.

[23] Pathak, Devendra Kumar, Lakshman S. Thakur, and Shams Rahman. "Performance evaluation framework for sustainable freight transportation systems." International Journal of Production Research 57.19 (2019): 6202-6222.

[24] Branco, José Eduardo Holler, et al. "Evaluation of the economic and environmental impacts from the addition of new railways to the brazilian's transportation network: An application of a network equilibrium model." Transport Policy (2020).

[25] Krapp, Agustina, Jesus M. Barajas, and Audrey Wennink. "Equity-oriented Criteria for Project Prioritization in Regional Transportation Planning." Transportation Research Record (2021): 03611981211001072.

[26] Qiang, Yuezhao, et al. "Energy-efficiency models of sustainable urban transportation structure optimization." IEEE Access 6 (2018): 18192-18199.

[27] Rahimi, Mohammad, Armand Baboli, and Yacine Rekik. "Multi-objective inventory routing problem: A stochastic model to consider profit, service level and green criteria." Transportation Research Part E: Logistics and Transportation Review 101 (2017): 59-83.

[28] Zhu, Xiaojing, et al. "Optimizations of network layout and transport service frequencies in view of interests of transit line operators and utilizers." Archives of Transport 50 (2019).

[29] Mahmoudi, Reza, et al. "The origins, development and future directions of data envelopment analysis approach in transportation systems." Socio-Economic Planning Sciences 69 (2020): 100672.

[30] Park, Yong Shin, et al. "Environmental efficiency assessment of US transport sector: A slack-based data envelopment analysis approach." Transportation Research Part D: Transport and Environment 61 (2018): 152-164.

[31] Cui, Jixian, et al. "Emergency monitoring layout method for sudden air pollution accidents based on a dispersion model, fuzzy evaluation, and post-optimality analysis." Atmospheric Environment 222 (2020): 117124.

[32] Seker, Sukran, and Nezir Aydin. "Sustainable public transportation system evaluation: A novel two-stage hybrid method based on IVIF-AHP and CODAS." International Journal of Fuzzy Systems 22.1 (2020): 257-272.

[33] Ma, Fang, et al. "Evaluation of urban green transportation planning based on central point triangle whiten weight function and entropy-AHP." Transportation Research Procedia 25 (2017): 3634-3644.

[34] Blagojević, Aleksandar, et al. "The application of the fuzzy AHP and DEA for measuring the efficiency of freight transport railway undertakings." Operational Research in Engineering Sciences: Theory and Applications 3.2 (2020): 1-23.

[35] Huang, Wencheng, et al. "Using entropy-TOPSIS method to evaluate urban rail transit system operation performance: The China case." Transportation Research Part A: Policy and Practice 111 (2018): 292-303.

[36] Yuan, Changwei, Dayong Wu, and Hongchao Liu. "Using grey relational analysis to evaluate energy consumption, CO2 emissions and growth patterns in China's provincial transportation sectors." International Journal of environmental research and public health 14.12 (2017): 1536.

[37] Canbulut, Gülçin, Erkan Köse, and Oğuzhan Ahmet Arik. "Public transportation vehicle selection by the grey relational analysis method." Public Transport (2021): 1-18.

[38] Hu, Miaohang, and Neila Bhouri. "Evaluation of Resilience Indicators for Public Transportation Networks by the Grey Relational Analysis." 2020 IEEE 23rd International Conference on Intelligent Transportation Systems (ITSC). IEEE, 2020.

[39] Usenko, L. N., et al. "Formation of an integrated accounting and analytical management system for value analysis purposes." (2018).

[40] Sun, Yougang, et al. "An Intelligent Coupling 3-Grade Fuzzy Comprehensive Evaluation Approach With AHP for Selection of Levitation Controller of Maglev Trains." IEEE Access 8 (2020): 99509-99518.

[41] Chen, Mingxing, Dadao Lu, and Liangsong Zha. "The comprehensive evaluation of China’s urbanization and effects on resources and environment." Journal of Geographical Sciences 20.1 (2010): 17-30.

[42] Chen, Jeng-Fung, Ho-Nien Hsieh, and Quang Hung Do. "Evaluating teaching performance based on fuzzy AHP and comprehensive evaluation approach." Applied Soft Computing 28 (2015): 100-108.

[43] Rm, A , et al. "Determining the relative importance of sustainability evaluation criteria of urban transportation network." Sustainable Cities and Society 47.

[44] Seker, S. , and N. Aydin. "Sustainable Public Transportation System Evaluation: A Novel Two-Stage Hybrid Method Based on IVIF-AHP and CODAS." International Journal of Fuzzy Systems 22.1(2020):257-272.

[45] Vu, A ., A. Ji, and A. Lb , "A Case Study of the Evaluation of the Quality of Connections on the Railway Transport Network in the South Bohemian Region." Transportation Research Procedia 53(2021):66-71.

[46] Wei, et al. "Risk Evaluation of Railway Coal Transportation Network Based on Multi Level Grey Evaluation Model." IJOP Conference Series: Earth and Environmental Science 108.4(2018):42108-42108.

[47] Nassereddine, M. , and H. Eskandari . "An integrated MCDM approach to evaluate public transportation systems in Tehran." Transportation Research Part A Policy and Practice 106.dec.(2017):427-439.

[48] Watanabe, T. , M. Shibata , and T. Suzuki . "Evaluation of Inter-Regional Transportation Network Considering Multi-Mode Route Alternatives." Asian Transport Studies 4(2016):210-227.

[49] Yang, Yuwei , J. Chen , and Z. Du . "Analysis of the Passenger Flow Transfer Capacity of a Bus-Subway Transfer Hub in an Urban Multi-Mode Transportation Network." Sustainability 12(2020).

[50] Saif, Muhammad Atiullah, Mohammad Maghrour Zefreh, and Adam Torok. "Public transport accessibility: a literature review." Periodica Polytechnica Transportation Engineering 47.1 (2019): 36-43.

[51] Colak, Serdar, et al. "Understanding Congested Travel in Urban Areas." Nature Communications, vol. 7, no. 1, 2016, pp. 10793–10793.

[52] Kong, Xiangjie, et al. "Urban Traffic Congestion Estimation and Prediction Based on Floating Car Trajectory Data." Future Generation Computer Systems, vol. 61, 2016, pp. 97–107.

[53] Záková, Jacek. "Design and evaluation of transportation systems." Scientific And Technical Conference Transport Systems Theory And Practice. Springer, Cham, 2017.

[54] Branch, Melville C. Comprehensive city planning: Introduction & explanation. Routledge, 2018.
Changjiang Zheng received the Ph.D. degree in transportation planning and management from Southeast University in 2006. Now he is a professor and doctoral supervisor of the college of civil and transportation engineering, Hohai University. His current research interests include different aspects of transportation planning and management.

Genghua Ma received the bachelor’s degree from Hohai University in 2006. Now she is an experimentalist of the college of harbour, coastal and offshore engineering, Hohai University. Her current research interests include the harbour waterway design and traffic planning.

Yuhang Gu received the bachelor’s degree from Guilin University of Electronic Technology. He is currently pursuing the master's degree in the college of civil and transportation engineering, Hohai University, China. His research interests include the path optimization under connected environment and multimodal transport.

Jinxing Shen received the M.S. degree from Hohai University in 2009 and the Ph.D. degree in transportation planning and management from Southeast University in 2015. Now he is an associate professor and master supervisor of the college of civil and transportation engineering, Hohai University. His research interests are mainly in the optimization of the multimodal public transportation system.

Muqing Du received the Ph.D. degree in transportation planning and management from Southeast University in 2014. Now he is an associate professor and master supervisor of the college of civil and transportation engineering, Hohai University. His current research interests include the optimization model and algorithm of traffic network.

Kai Sun received the bachelor’s degree from Guilin University of Electronic Technology. He is currently pursuing the master's degree in the college of civil and transportation engineering, Hohai University, China. His research interests include the sustainable transport.

Genghua Ma received the bachelor’s degree from Hohai University in 2006. Now she is an experimentalist of the college of harbour, coastal and offshore engineering, Hohai University. Her current research interests include the harbour waterway design and traffic planning.