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Methodology for evaluating urban railway development level facing urban agglomeration

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Abstract: *As an important link within urban clusters, railway is an important guarantee for building "1-hour commuting circle" and promoting high-quality development. In order to make a scientific and accurate evaluation of it, an evaluation system of urban railway development level is constructed. The combined evaluation method of CRITIC method and cloud model, which is superior to the single evaluation method, is used to determine the index weights through the CRITIC method, and the evaluation is based on the cloud model method. Above process was applied to the case of Beijing-Tianjin-Hebei city cluster, the results show that Qinhuangdao is lagging behind in railway development, Handan and Cangzhou's railway capacities are less developed than their respective economies. For this reason, it is important to put forward corresponding suggestions for railway development according to different conditions of cities, which can stimulate the development potential of the city cluster from the shortcomings and promote overall high-quality development.*

Keywords: *urban railway; evaluation index system; CRITIC method; cloud model; Beijing-Tianjin-Hebei urban agglomeration*

1. Introduction

Urban agglomerations refer to urban groups with one or more megacities as the core and three or more large cities as the constituent units within a certain geographical range. Relying on modern transportation and comprehensive transport networks, urban agglomerations form compact spatial organization, close economic ties, and ultimately achieve a high degree of homogeneity and integration. As an important support for regional economic development, urban agglomerations can optimize the allocation of resources on a larger scale, enhance the radiation-driven role of the core cities and promote the development of each city within the urban agglomerations. As an important link within the city cluster, railway has a great influence on its development. The 14th Five-Year Plan and the outline of 2035 Visionary Goals clearly point out that the integration of transportation in urban agglomerations and urban areas should be promoted, and the construction of inter-city railways and municipal railways should be accelerated[1] . However, at present, there are large differences in the development of urban railways within some urban agglomerations, and the railway development level of some cities is relatively backward, which to a certain extent limits the healthy development of urban agglomerations as a whole. Therefore, a scientific and objective evaluation of the railway development level of cities in urban agglomerations can, on the one hand, improve the development level of "disadvantaged" cities and enable them to better integrate into the integrated development of urban agglomerations; on the other hand, it can drive the overall improvement through local improvement, stimulate the development potential of urban agglomerations by starting from the shortcomings, which is important for improving the overall economic level and promoting high-quality urban development.

In the selection of railway evaluation indexes, most of the existing researches focus on weighted average travel time and emphasize its accessibility, and few construct a comprehensive index system for evaluation. For example, Hu Rui et al. chose two indicators, weighted average travel time and daily accessibility, to analyze the link between high-speed rail and economic indicators[2] ; Guo Xinying et al. chose the weighted average travel time and accessibility coefficient based on the transport cost model to measure the accessibility of Chinese cities and its changing characteristics under high-speed rail and general railway networks[3] . Some studies have also established more comprehensive indicators, Gao Ling et al. studied the current development of Shandong Peninsula urban agglomeration transportation network by constructing an indicator system of urban transportation network construction level [4] , but the research object was the comprehensive evaluation of four modes of transportation: road, railway, water transport and air transport, and no separate analysis was made for railway; Wu Wei et al.

constructed a regional transportation development level evaluation indicator system to analyze the comprehensive transportation development level of three major urban agglomerations[5] , but the evaluation is based on the comparison between whole urban agglomerations, without detailed study of cities within the city cluster. In general, the existing literature either has a single index system or lacks special studies on railways, and is unable to make a comprehensive evaluation of the railway development level of cities, so it is necessary to build a set of scientific and comprehensive evaluation index system.

In terms of evaluation methods, entropy weight method and standard deviation method in objective assignment method determine the weights based only on the variability of data within the indicators[6] , while the CRITIC method also takes into account the correlation between indicators; traditional comprehensive evaluation methods include fuzzy comprehensive evaluation, analytic hierarchy process (AHP), etc., which have a large subjective component when making decisions, while the cloud model evaluation method presents the results in the form of three numerical characteristics (expectation, entropy and super entropy) and a cloud diagram, which is more accurate compared to the above methods. If directly calculate the weighted average value using the weights provided by the CRITIC method, the evaluation process and results lack credibility; if a single cloud model is used without considering the influence of indicator weights, it is inconsistent with reality and is unconvincing. The combined CRITIC-cloud model can evaluate the railway development level in a more scientific and accurate way.

For the above deficiencies, this paper firstly builds an evaluation index system of urban railway development level, then establishes a combined evaluation method based on the CRITIC method and the cloud model, and finally uses the Beijing-Tianjin-Hebei city cluster as a case study to verify the feasibility of the proposed index system and method, and explores the link between the evaluation results and the economy to identify the cities whose railway level lags behind the economy and provide them with relevant suggestions for railway development.

2. Evaluation index system construction

In this paper, six relevant indicators are selected from four aspects: construction level, transport capacity, accessibility and service level, which can objectively reflect the characteristics of the railway to build an index system of urban railway development level, as shown in Table 1. Among them, construction level and transport capacity represent the macro strength of the whole railway: construction level is the foundation of railway work organization, transport capacity reflects the operational level of the railway; Accessibility and service level emphasize the micro level of railway transport: accessibility reflects the developed level of railway passenger transport, and service level indicates the ability to undertake production tasks.

Table 1: Comprehensive evaluation index system of urban railways

Target layer	Criterion layer	Indicator layer
Level of urban railway development	Construction Level A	Railway operating mileage A_1/km
		Rail network density A_2（km/km^2)
	Transport capacity B	Rail passenger traffic B_1/ million people
		Rail freight volume B_2/ million tonnes
	Accessibility C	Weighted average travel time C_1/min
	Service Level D	Number of railway stations D_1（pcs)

The indicators are described below.

1) Railway Operating Mileage A_1: The total length of the railway main line handling passengers and freight within the jurisdiction of a city, which is an important indicator to measure the infrastructure development level of the railway transport industry.

2) Rail network density A_2: The ratio of mileage to area, which reduces the impact of cities' area differences to some extent, is calculated as

$$A_2 = \frac{A_1}{S} \tag{1}$$

where S is the area of city.

3) Rail passenger traffic B_1 and rail freight volume B_2: The number of passengers and goods carried in a given period.

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4) Weighted average travel time C_1: This paper calculates the weighted minimum travel time of other cities to reach current city, using the city's GDP as the weight, reflecting the city accessibility level from the perspective of time cost, the formula is

$$C_i = \frac{\sum_{j=1}^{n} T_{ij} \times M_j}{\sum_{j=1}^{n} M_j} \tag{2}$$

where C_i is the weighted average travel time of city i. The smaller the value, the higher the accessibility level of that city, and the larger the value, the lower the accessibility level. T_{ij} is the shortest travel time (in min) from city i to other node cities j in the region. M_j is the economic development level of city j, and we choose GDP as the indicator in this paper; n is the number of node cities in the region other than city i.

5) Number of railway stations D_1 : The number of railway stations within the city district that are capable of handling passenger and freight services, as well as technical operations such as train yielding and overtaking. As an important link between railway production and passengers or cargo owners, stations undertake a variety of functions of railway transport services.

3. Evaluation methods

3.1 Selection of evaluation methods

This paper adopts the CRITIC-cloud model combination evaluation method, which firstly determines the weights of each indicator through the CRITIC method, and then combines the cloud model method to conduct a comprehensive evaluation. CRITIC method is to comprehensively measure objective weight based on the comparison strength within indicators and the conflict between indicators. It can not only overcome the shortcomings of strong subjectivity of subjective weight method (such as analytic hierarchy process, expert scoring method, etc.), but also take into account the correlation between indicators while considering the variability of indicators, and make up for the shortcomings of some objective weighting methods (such as entropy weight method, standard deviation method). The cloud model is capable of mapping qualitative language to quantitative values, avoiding the subjectivity of evaluation, and the results are expressed through three numerical characteristics: expectation, entropy and super-entropy, which are more comprehensive and accurate than a single value.

The evaluation process based on the CRITIC-cloud model is shown in Figure 1.

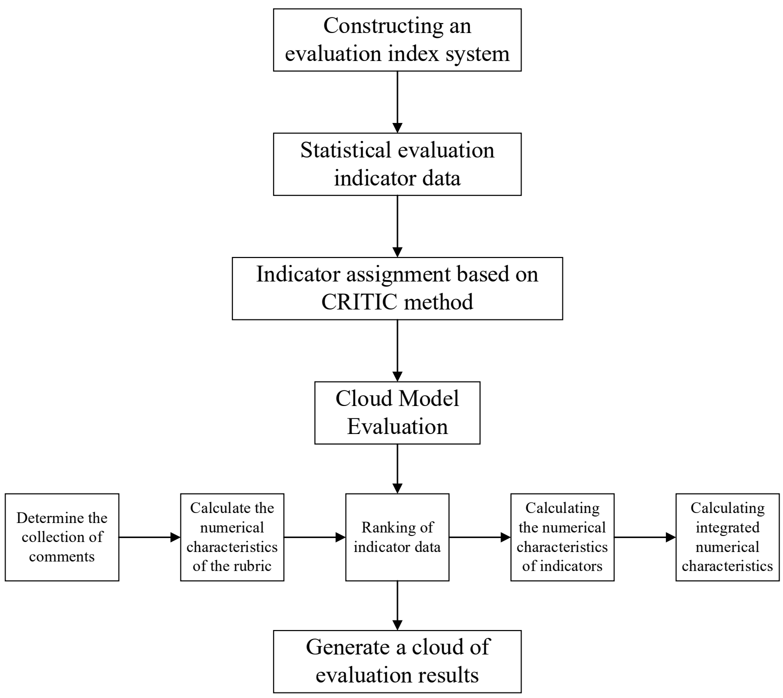

Figure 1: Evaluation process based on the CRITIC-cloud model

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3.2 Weighting of evaluation indicators based on the CRITIC method

The specific steps of the CRITIC method are as follows.

1) Obtaining data. Data from m cities on n indicators were collected according to the constructed indicator system to form the original data matrix X.

$$X = \begin{bmatrix} x_{11} & \cdots & x_{1n} \\ \vdots & \ddots & \vdots \\ x_{m1} & \cdots & x_{mn} \end{bmatrix} \tag{3}$$

where x_{ij} is the value of city i with respect to indicator j.

2) Data pre-processing. In order to eliminate the influence of dimension on evaluation results, each indicator needs to be processed forward or backward.

For positive indicators.

$$x'_{ij} = \frac{x_{ij} - \min(x_j)}{\max(x_j) - \min(x_j)} \tag{4}$$

For inverse indicators.

$$x'_{ij} = \frac{\max(x_j) - x_{ij}}{\max(x_j) - \min(x_j)} \tag{5}$$

3) Indicator contrast intensity. Calculate the standard deviation of the jth indicator according to the data in the indicator system.

$$\sigma_j = \sqrt{\frac{1}{n}\sum_{i=1}^{m}\left(x'_{ij} - \overline{x'_j}\right)^2} \tag{6}$$

where $\overline{x'_j}$ is the mean value of data for indicator j.

4) Index conflict. Expressed through correlation coefficients.

$$f_j = \sum_{i=1}^{n}\left(1 - r_{ij}\right) \tag{7}$$

where r_{ij} is the correlation coefficient between indicator i and indicator j.

5) Information quantity. Product of contrast intensity and conflict.

$$C_j = \sigma_j \times f_j \tag{8}$$

6) Calculate the weight. Weights are assigned according to information quantity carried by the indicator.

$$W_j = \frac{C_j}{\sum_{j=1}^{n} C_j} \tag{9}$$

3.3 Evaluation method based on cloud model

The specific steps of the cloud model evaluation method are as follows.

1) Determining comments set. In this paper, 85, 60, 40 and 20 quantiles are used to divide five levels of qualitative comments, graded as follows: very bad = [0, 20); poor = [20, 40); moderate = [40, 60); good = [60, 85); excellent = [85, 100]. The domain of evaluation value U = [0, 100][7].

2) Calculating the numerical characteristics of comments. Based on the bilateral constraints of

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comments $[l_{min},\ l_{max}]$ to solve the cloud numerical feature of each comment in the comment set, the formula is:

$$E_x = \frac{l_{min} + l_{max}}{2} \tag{10}$$

$$E_n = \frac{l_{max} - l_{min}}{6} \tag{11}$$

$$H_e = k \tag{12}$$

of which E_x , E_n and H_e are expectation, entropy and superentropy, respectively. E_x is the most representative numerical characteristic of the indicator, reflecting the central position of domain space. E_n indicates the degree of dispersion and fuzziness of the index. Most of the cloud droplets in the cloud model fall in the interval $[E_x - 3E_n,\ E_x + 3E_n]$. H_e is the uncertainty measure of E_n, which indirectly reflects the thickness of the cloud. k in equation (12) is related to the fuzzy degree, which is taken as 0.1 in this paper. The calculation results of the cloud numerical features of the comment set are shown in Table 2.

Table 2: Numerical characteristics of evaluation levels

Grade	Cloud Models
Very bad	(10.00, 3.33, 0.10)
Poor	(30.00, 3.33, 0.10)
Moderate	(50.00, 3.33, 0.10)
Good	(72.50, 4.17, 0.10)
Excellent	(92.50, 2.50, 0.10)

3) Ranking of indicator data. This paper studies the relative level of urban railway development within urban agglomeration, and therefore divides each indicator into five classes based on the internal ranking of each indicator data within the research scope (i.e. within the urban agglomeration), as shown in Table 3.

Table 3: Criteria for grading indicators

Indicators	Very bad	Poor	Moderate	Good	Excellent
A1	≤300	(300, 600]	(600, 900]	(900, 1200]	>1200
A2	≤0.025	(0.025, 0.035]	(0.035, 0.05]	(0.05, 0.08]	>0.08
B1	≤200	(200, 600]	(600, 1000]	(1000, 1400]	>1400
B2	≤500	(500, 1000]	(1000, 1500]	(1500, 2500]	>2500
C1	>160	(140, 160]	(110, 140]	(80, 110]	≤80
D1	<10	[10, 15]	[16, 20]	[21, 30]	>30

4) Calculate the indicator number characteristics. After determining the rank corresponding to each value according to Table 3, the raw data is then transformed into numerical features in the cloud model in conjunction with Table 2.

5) Calculate the comprehensive numerical characteristics. The set of weights obtained by the CRITIC method is used as the weights of each indicator to calculate the comprehensive numerical characteristics under the condition of weighted average $(E_x,\ E_n,\ H_e)$.

$$E_x = \sum_{j=1}^{n} w_j E_{xj} \tag{13}$$

$$E_n = \sum_{j=1}^{n} w_j E_{nj} \tag{14}$$

$$H_e = \sum_{j=1}^{n} w_j H_{ej} \tag{15}$$

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where n is the number of indicators and w_j is the weight of the jth indicator, the E_{xj} , E_{nj} and H_{ej} denote the expectation, entropy and super-entropy of the jth indicator, respectively.

6) Generate the cloud map of evaluation results. The forward cloud generator method is used to generate a comprehensive evaluation cloud map from the cloud model. In order to make the error of E_x less than the specified value Δ, the number of cloud drops should be satisfied $\geq 9S^2/\Delta^2$ (S^2 is the variance).

4. Case study

4.1 Overview of the Beijing-Tianjin-Hebei City Cluster

In this paper, the Beijing-Tianjin-Hebei city cluster is chosen as a case study to verify the feasibility of the methodology. The Beijing-Tianjin-Hebei urban agglomeration is located in the north of China and is China's "Capital Economic Circle", which is also the largest economic scale and most dynamic region in northern China. The Beijing-Tianjin-Hebei city cluster defined in this paper includes the two municipalities of Beijing and Tianjin, as well as the cities of Baoding, Tangshan, Langfang, Shijiazhuang, Qinhuangdao, Zhangjiakou, Chengde, Cangzhou, Hengshui, Xingtai, Handan in Hebei Province and Anyang in Henan Province, 14 cities in total. The year of data selected in this study is 2017. The Beijing-Tianjin-Hebei city cluster is shown in Figure 2.

Figure 2: Scope map of the Beijing-Tianjin-Hebei city cluster

4.2 Evaluation process and results

Step 1: According to the CRITIC method, using the dimensionless processed data to form a data matrix, the contrast intensity, conflict and information quantity of each indicator were calculated in turn, and the weights of each indicator were obtained as shown in Table 4.

Step 2: The collected data were ranked according to Table 3, and then the numerical characteristics

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were obtained according to Table 2. Referring to Table 4, all cities calculated the weighted average of six indicators data for each, and finally obtained the comprehensive numerical characteristics of 14 cities as shown in Table 5.

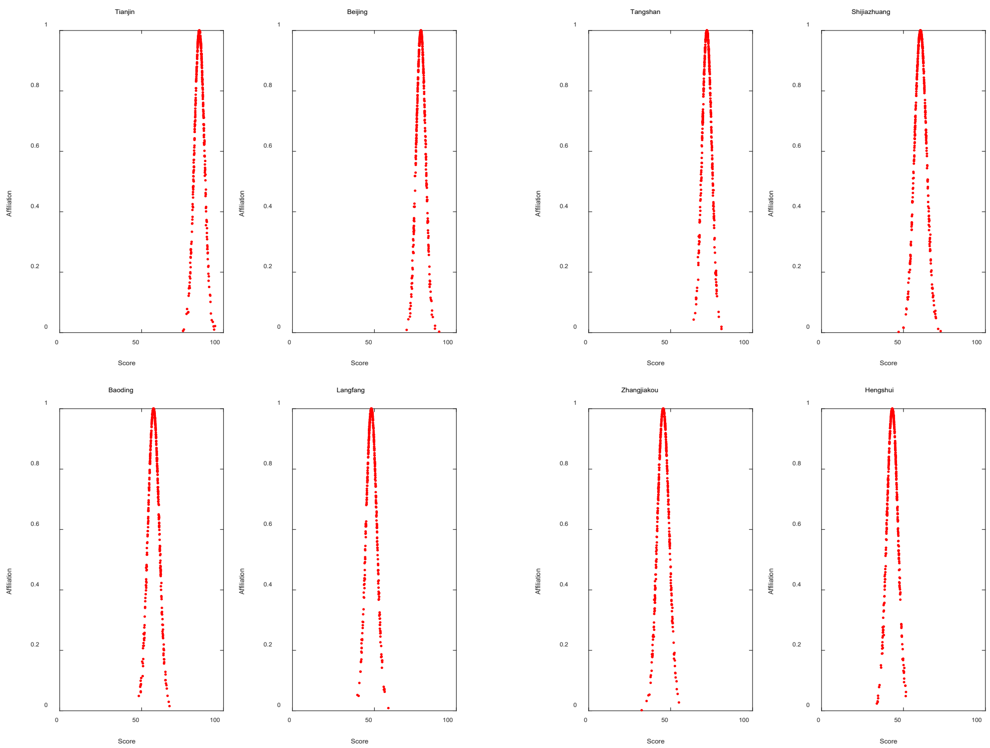
Table 4: Beijing-Tianjin-Hebei Railway Evaluation Indicator Weights

Criterion layer	Weights	Indicator layer	Weights
A	0.347	A_1	0.181
		A_2	0.166
B	0.306	B_1	0.132
		B_2	0.174
C	0.184	C_1	0.184
D	0.164	D_1	0.164

Table 5: Evaluation results of urban rail level

Ranking	City	Digital features	Grade
1	Tianjin	(85.21, 3.11, 0.10)	Excellent
2	Beijing	(78.31, 2.92, 0.10)	Good
3	Tangshan	(72.14, 3.04, 0.10)	Good
4	Shijiazhuang	(60.39, 3.72, 0.10)	Good
5	Baoding	(57.25, 3.46, 0.10)	Moderate
6	Langfang	(48.12, 3.33, 0.10)	Moderate
7	Zhangjiakou	(45.47, 3.63, 0.10)	Moderate
8	Hengshui	(43.18, 3.47, 0.10)	Moderate
9	Chengde	(41.77, 3.18, 0.10)	Moderate
10	Cangzhou	(40.48, 3.61, 0.10)	Moderate
11	Handan	(40.03, 3.48, 0.10)	Moderate
12	Anyang	(36.06, 3.48, 0.10)	Poor
13	Qinhuangdao	(34.92, 3.44, 0.10)	Poor
14	Xingtai	(33.07, 3.33, 0.10)	Poor

Step 3: Generate cloud droplets based on numerical features through the forward cloud generator method. In this paper, the number of cloud drops was set at 400, and the cloud map of 14 cities' evaluation results was obtained as Figure 2.



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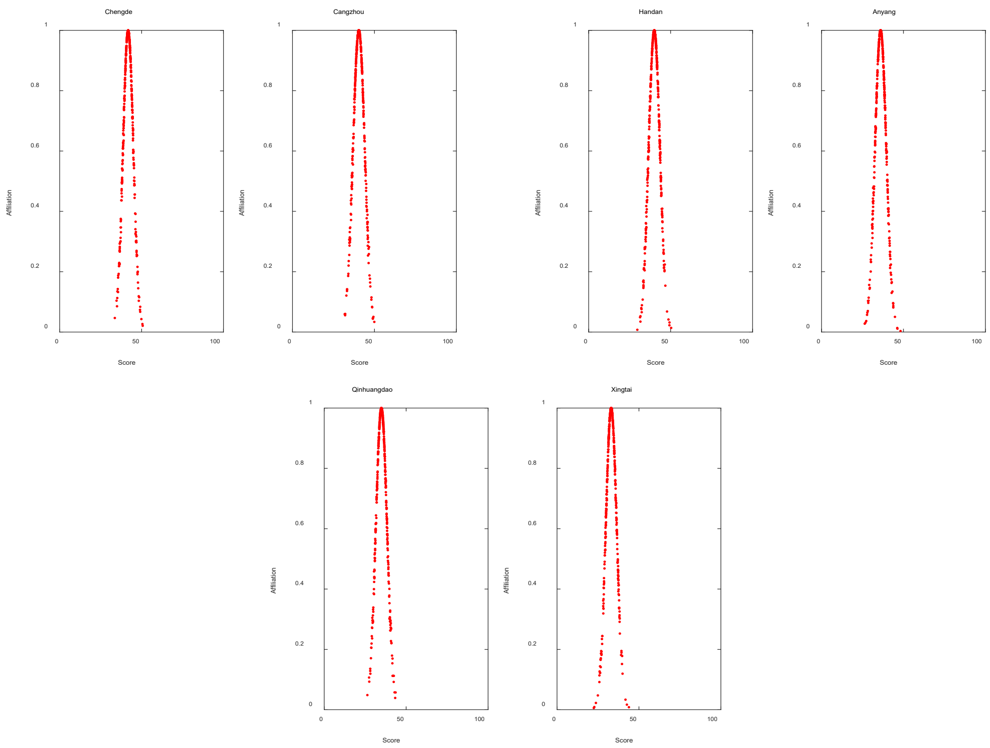

Figure 3: Cloud chart of evaluation results by city

In order to compare the relationship between a city's railway development level and its economic size more visually, this paper presents an economic-railway relationship diagram based on the internal ranking within city groups, as shown in Figure 3.

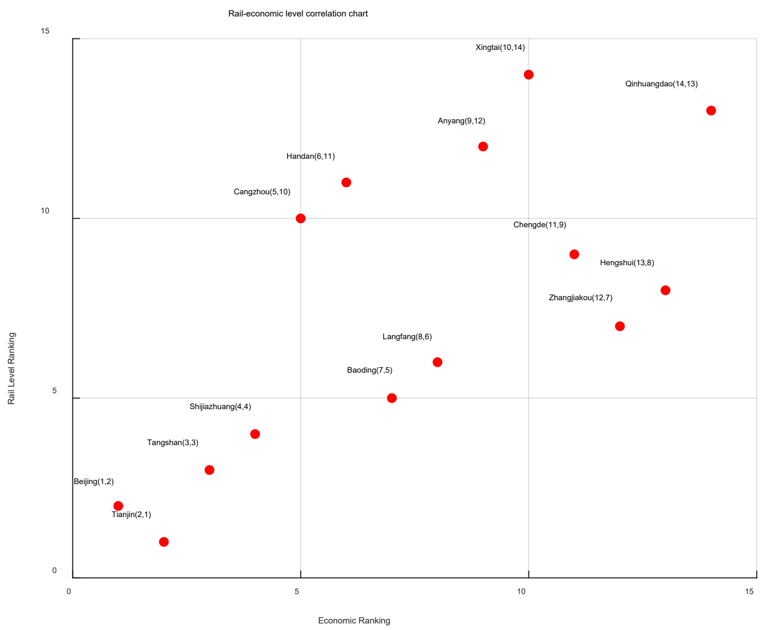

Figure 4: Economy-Rail Ranking Relationship

4.3 Result analysis and development proposals

This study compares and analyses the evaluation results from two perspectives: the level of inter-city railway development and the city's own railway-economic development relationship.

4.3.1 Comparison of railway development level between cities

As can be seen in Figure 3, Beijing and Tianjin are at the top of the ranking in terms of railway level and economic scale because Beijing, as the capital of the country, is the core city of the Beijing-Tianjin-Hebei city cluster and has a huge economic scale; it has Beijing-Shanghai, Beijing-Kowloon, Beijing-Harbin, Beijing-Guangzhou and other railway trunk lines, so the railway development level of Beijing is high. As a municipality directly under the central government, Tianjin has a higher level of development than any other prefecture-level city, with a higher GDP index; a number of major lines such as the Beijing-Shenzhen Line and the Beijing-Shanghai Railway also pass through Tianjin. The city that lags behind in both rankings is Qinhuangdao, mainly because it is on the periphery of the entire urban agglomeration's spatial location. In terms of both economy and transportation, it has less communication with other cities, and railway development are constrained by the city's inadequate transport infrastructure.

4.3.2 Comparison of cities' own rail-economic development levels

Combined with Figure 4 it is easy to see that railway development in Cangzhou and Handan lags behind the economic scale. Handan is located at the southern edge of the city cluster, and has less interaction with the central circle. Compared to other cities, Handan has a large mountainous area. As a transition zone between the Taihang Mountains and the North China Plain, the traffic carrying rate is limited. Cangzhou City has a shift in development focus due to the presence of a large coal port, where the advantages of shipping outweigh rail transport. In addition, the inadequate yard facilities at Cangzhou station and the low level of passenger transport development with the provincial capital Shijiazhuang as well as Beijing and Tianjin are deficiencies of Cangzhou Railway itself[8] .

4.3.3 Suggestions for development strategies

For cities that are lagging behind in rail development, this paper gives the following development suggestions.

1) For cities located in remote areas, the railway network and infrastructure should be strengthened to improve the railway connections between marginal cities and central area. For example, Qinhuangdao has a "very bad" rail mileage rating and Handan has a "very bad" rail network density rating, so the construction of a modern railway network should be accelerated to compensate in time for the limited railway development caused by the lack of capacity; The railway stations in Qinhuangdao and Cangzhou are rated as "very bad", so it is important to pay attention to the construction of infrastructure such as depots in the station system, increase investment and financial expenditure on railway transport.

2) In cases where the development of railways is limited by natural factors, full use should be made of good natural and cultural resources, relying on the railway trunk lines to promote tourism features and historical culture. For example, Handan can rely on its long historical and cultural heritage to attract passenger traffic through a range of means such as tourism publicity, so as to achieve an increase in passenger volume and thus develop railway. Qinhuangdao can rely on its coastal advantage to bring about demand for rail transport through tourism, driving the construction of intercity railways between Qinhuangdao and other cities[9] .

3) If the development of railways is limited by other modes of transport taking over the market share, multimodal transport can be adopted to transform the competitive relationship into a cooperative one. For example, Cangzhou has a "very bad" rail freight volume rating, but due to its seaport advantage, shipping is relatively developed, and the railway can achieve its own freight volume growth by means of sea-rail intermodal transport, thus gaining the opportunity for further development.

5. Conclusion

As an important link within urban agglomerations, a scientific and accurate evaluation of railways is helpful to build the "1-hour commuting circle" and inject new vitality into the healthy development of urban agglomerations. This paper firstly constructs an evaluation system for the development level of urban railways from four aspects: construction level, transport capacity, accessibility and service level; then designs a combined evaluation method of CRITIC method and cloud model, determines the evaluation index weights through CRITIC method, establishes an evaluation model of urban railways based on cloud model theory, and makes a comprehensive evaluation of urban railways development level; finally, takes the Beijing-Tianjin-Hebei city cluster as a case study to evaluate the railway development level of internal cities and analyse the relationship between railway development level and

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economy. The results show that the economic-rail ranking of Qinhuangdao city is (14, 13), both lagging behind; Cangzhou city and Handan city are (5, 10) and (6, 11) respectively, whose railway development lags behind the economic level. For this reason the paper proposes corresponding development strategies considering the different situations of each city.

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