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Freight Data-Driven Research on Evaluation Indexes for Urban Agglomeration Development Degree

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Abstract: A reasonable comprehensive evaluation of the degree of urban agglomeration development is of great significance for its sustainable development. Although there are some studies on the evaluation of urban agglomeration development degree from the overall development level, only a few studies consider internal development equilibrium and internal interaction intensity. This work uses freight trip data as the main empirical data to establish three alternative evaluation indexes named the overall freight intensity, the internal freight intensity equilibrium level, and the internal freight interaction relative intensity to reflect the urban agglomeration's overall development level, internal equilibrium level, and internal interaction level, respectively. Then, this work weights the above three alternative indexes to comprehensively evaluate the comprehensive development degree of 14 Chinese urban agglomerations. Finally, this work classifies these urban agglomerations into three stages according to the comprehensive evaluation values. The research results could help us to reasonably evaluate the degree of comprehensive development of urban agglomeration.

Keywords: urban agglomeration development degree; evaluation index; overall freight intensity; internal freight intensity equilibrium level; internal freight interaction relative intensity; freight trip

1. Introduction

An urban agglomeration is a highly developed spatial form of integrated urban areas [1]. Economic globalization has made the urban agglomeration the new geographical unit for participating in global competition and the international division of labor [2], which has a major impact on the improvement of the country's international competitiveness [3]. There is a long history of research on urban agglomerations. Patrick Geddes [2] employs a comprehensive regionalization approach to explore the internal dynamics of urban areas and the urbanization process. He predicted that urban agglomerations would be the trend of urbanization development in the future. In 1945, the Japanese government proposed the concept of a "metropolitan circle", emphasizing the scope of commuting within one day and the reach range of population mobility [4]. Gottmann [5] proposed that a megalopolis is many urban areas closely linked in all aspects to form a very large whole. He further argued that the future direction of urbanization is the megalopolises gradually merging with nearby urban regions, which opened a new research field of urban geography. Hagerstrand [6] proposed the modern spatial expansion theory, which helps in understanding the spatial expansion process of urban agglomeration. McGee [7] proposed the concept of "desakota", a superurban area with characteristics of urban and rural areas in Southeast Asia and South Asia. Gottmann [8] summarized six major urban agglomerations in the world, including urban-intensive areas centered on Shanghai, which is the Yangtze River Delta (YRD) urban agglomeration in China. Hu [9] analyzed the agglomeration and dispersion phenomenon of dense urban areas in the eastern coastal regions of China. Zhou [10] referenced the European urban space system and systematically studied the Chinese metropolitan interlocking area from the aspect of socioeconomic connectivity. Wu [11] explored urban agglomeration development from the characteristic of structure and the development mechanism. Fang et al. [12] defined urban agglomerations from a more quantitative perspective. They proposed that an urban agglomeration is centered on one or more large urban areas as the foundation. All the areas in the urban agglomeration are closely interconnected via a highly developed transportation and telecommunication infrastructure, which forms regionally integrated urban areas with compact space and close economic ties. The concept of the urban agglomeration has been interpreted in different ways, such as the town cluster [13], megalopolis [5], metropolitan interlocking region [10], and global city-region [14]. Although the above researchers have their views on the term urban agglomeration, they agree on the urban agglomeration essential features in the research community. An urban agglomeration is a new regional spatial organization that has distinctly different characteristics from the individual metropolitan area in terms of form, regional distribution, and function, which plays a central role in the economic development of the country [1,2,10,15]. With the rapid development of economic globalization and integration, urban agglomerations play the role of strategic support, growth poles, and core nodes in the national productivity distribution pattern, which plays the function of agglomeration and dispersion of the flow of production factors in the country and the region [3]. It has attracted the attention of an increasing number of national governments. The United States government has given high priority to urban agglomerations [2], and the American Planning Association proposed the "America 2050" plan, hoping to break through the administrative boundaries by building a metropolitan network to share the development benefits through cooperation [16]. The Community Initiative of the European Regional Development Fund subsidizes researchers to research the "multicenter" geographical phenomenon in Europe. Japan is one of the countries with the most developed economy and the most mature metropolitan area in Asia. Since the middle of the last century, Japan has promoted "Metropolitan Region Planning", and urban areas have developed rapidly [17]. The Chinese government clearly states that to make urban agglomerations the main pattern for driving urbanization to enhance the coordinated development of various regions [18]. Overall, the urban agglomeration has developed rapidly with an emphasis on urban agglomeration development by governments. Currently, urban agglomeration has become the core area with the most dynamic and promising regions in the economic development pattern.

With the rapid development of urban agglomerations, an increasing number of urban agglomerations have appeared worldwide, especially in China. The development stages of urban agglomerations are different, and there is a large gap in the development degree among urban agglomerations. How to reasonably evaluate the comprehensive development degree of urban agglomeration is of great significance to the sustainable and coordinated development of urban agglomeration [19]. Gottmann [5] evaluated the comprehensive development degree of urban agglomeration based on the population, trade volumes, and freight volumes of the urban agglomeration. Wang et al. [20] evaluated the comprehensive development degree of urban agglomeration through social, spatial, and economic development levels. Zhang et al. [20,21] evaluated the urban agglomeration development degree from traffic and economic development levels. Xu et al. [22] evaluated the sustainable urbanization level of urban agglomeration from the comfort of life, development efficiency, environment protection, sustainable economy, sustainable society, and urban–rural integration levels. With the advent of the big data era, researchers have made great progress in data collection and mining. An increasing number of researchers are analyzing urban geography and regional economies using traffic volume data. Some researchers have extracted passenger and freight flow from roads, railways, ports, or waterways [23,24] to evaluate the comprehensive development degree of urban agglomeration. The real traffic flow volume data better reflect the comprehensive development degree of urban agglomeration. However, most of the evaluation methods only consider the total volumes of urban agglomeration but not the urban development equilibrium level within the urban agglomeration. Under the high development level of core urban areas in an urban agglomeration, the gap between the core urban area and other urban areas is growing [18], which restricts the improvement in the comprehensive development degree in the urban agglomeration to a certain extent. However, there are few studies on the internal developmental equilibrium of urban agglomerations, and most of these studies only evaluate qualitatively [25]. Lu analyzed the orientations of function and coordinated development degrees of Beijing, Tianjin, and Hebei in the Beijing-Tianjin-Hebei urban agglomeration through a simple comparison of social indicators, including GDP, infrastructure, and industrial structure [26]. Yao et al. briefly discussed the internal development equilibrium of urban agglomerations through China's population movement [18]. Moreover, there are few studies evaluating the urban agglomeration development degree from the perspective of urban spatial interaction within the urban agglomeration. As an economic union, the core development of the urban agglomeration is the connection and communication between the urban areas within the urban agglomeration, which is the interaction of urban areas within the urban agglomeration [27,28]. The economic interaction intensity between the urban areas within an urban agglomeration is extremely important for the full achievement of sustainable urban agglomeration development [29]. Increasing the interaction intensity between various urban areas within the urban agglomeration allows for more sustainable development of the urban agglomeration [30]. To measure the interaction intensity between urban areas within an urban agglomeration, the early methods used the gravity model. However, most researchers evaluate the urban interaction level by using static data such as urban distance, population, and GDP [31–34]. Moreover, the results of the gravity model often do not directly reflect the economic interaction between urban areas. In fact, freight is essentially a spatial economic interaction. The freight volume can not only reflect the urban population, the infrastructure density, and productivity but also fully reflect the economic interaction between urban areas [35,36]. Zhang et al. analyzed the economic interaction intensity between port cities around the South China Sea by using the voyage data between these cities [37]. Zhou and Yang analyzed economic interaction intensity using railway freight data from various provinces in China [38]. He and Gao analyzed the interaction intensity of the Port of Middle Yangtze through port throughput data [39]. In short, the freight data not only reflect the interaction intensity between urban areas [36–39] but also fully reflect the development level of urban areas and urban agglomerations [37,38], which is very suitable for evaluating the comprehensive development degree of urban agglomeration.

It can be seen from the above literature review that although there have been many studies that have evaluated the degree of urban agglomeration development, most of them mainly consider the total volumes of urban agglomeration to establish the evaluation indexes, and only a few consider the internal development equilibrium and the internal interaction intensity, which are two important aspects of the evaluation of the degree of urban agglomeration development. The aim of this work is to use freight data that can well reflect the development level and internal interaction intensity of urban agglomerations to establish alternative evaluation indexes based on three aspects: The overall development level, the internal development equilibrium, and the internal interaction intensity. This evaluation will provide a reference for the reasonable and comprehensive evaluation of the degree of urban agglomeration development. The rest of this paper is organized as follows. Section 2 introduces the empirical research objects and freight data source. Section 3 establishes three evaluation indexes named the overall freight intensity, the internal freight intensity equilibrium level, and the internal freight interaction relative intensity and introduces the calculation method of each index. Section 4 uses the aforementioned three indexes to comprehensively evaluate the comprehensive development degree of 14 Chinese urban agglomerations. Section 5 classifies the development stages of these urban agglomerations according to the comprehensive evaluation values. The last section concludes this work and discusses some possible extensions.

2. Empirical Research Objects and Data Source

2.1. Empirical Research Objects

An urban agglomeration is an important platform for supporting national economic growth, promoting regional coordinated development, and participating in international competition and cooperation. In recent years, China's urban agglomerations have rapidly developed, and 14 urban agglomerations have submitted applications to the Chinese State Council. There are 10 urban agglomerations, including the Middle Yangtze (MY) urban agglomeration, Harbin-Changchun (HC) urban agglomeration, Chengdu-Chongqing (CC) urban agglomeration, Yangtze River Delta (YRD) urban agglomeration, Central Plains (CP) urban agglomeration, Beibu Gulf (BG) urban agglomeration, Guanzhong Plains (GP) urban agglomeration, Hothot-Baotou-Erdos-Yulin (HBEY) urban agglomeration, Lanzhou-Xining (LX) urban agglomeration, and Pearl River Delta (PRD) urban agglomeration, being approved by the Chinese State Council as national-level urban agglomerations. The other four urban agglomerations, including the Beijing-Tianjin-Hebei (BTH) urban agglomeration, Central and Southern Liaoning (CSL) urban agglomeration, Shandong Peninsula (SP) urban agglomeration, and West Side of the Straits (WSS) urban agglomeration, are being approved. Therefore, this work selects these 14 Chinese urban agglomerations as empirical research objects to establish the alternative evaluation indexes for the degree of urban agglomeration development. The distribution of the 14 Chinese urban agglomerations is shown in Figure 1.

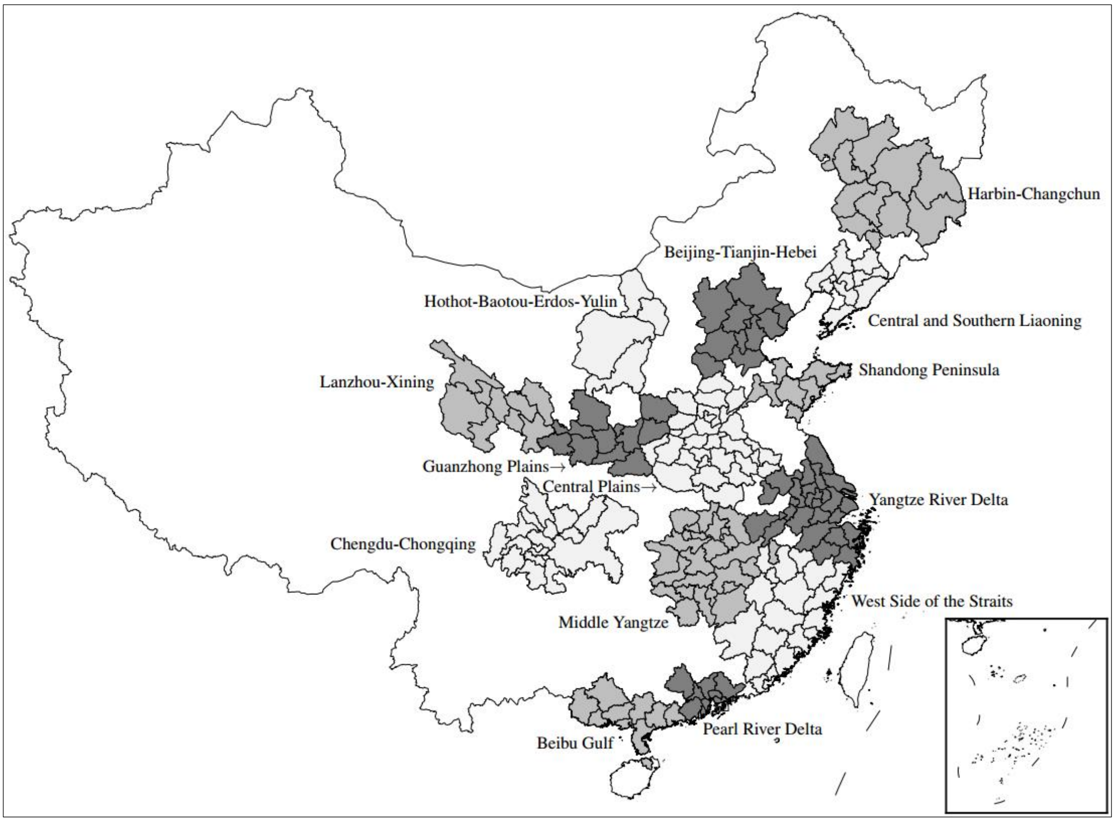

Figure 1. Distribution of 14 Chinese urban agglomerations.

2.2. Data Source and Processing Method

This work selects road freight as the research data to establish the evaluation indexes for the degree of urban agglomeration development. Road freight transportation can better reflect the economic interaction between urban areas within an urban agglomeration because compared with other means of freight transportation, such as railways, waterways, ports, and pipelines, road freight transportation is suitable for short-distance transportation and can provide door-to-door service. In addition, road freight transportation has a large proportion of transportation volume [40]. Our road freight data are collected by China's road truck public supervision and service platform (CRTPSSP), which is the largest commercial vehicle network platform and the unique national-level supervision platform for heavy haul trucks in China. Under the joint request of the Ministry of Transport, the Ministry of Public Security, and other departments in China [41], every heavy haul truck must record their trajectories through GPS and upload to the CRTPSSP database at an average recording interval of 28 seconds. This work uses the trajectory data of approximately three million trucks recorded by CRTPSSP from 17 to 24 December 2017. This work first matches these trajectory data with the China road network. Then, it extracts the origin and the destination (OD) of each freight trip by combining the point of interest data close to the road network and gets about 1.7 million freight trips. Each freight trip can be regarded as an economic interaction between the urban areas, although it cannot distinguish whether trucks carry goods in each trip because the CRTPSSP does not record the truckload weight. Figure 2 shows the distribution of the number of freight trips between prefecture-level urban areas in China after this work process the freight truck data. In fact, the PRD urban agglomeration includes Hong Kong and Macao in China, but the PRD urban agglomeration does not include the two urban areas in our research since the CRTPSSP does not record the truck data of these two urban areas. In addition, our population and area data of the urban areas are derived from the 2017 China Statistical Yearbook.

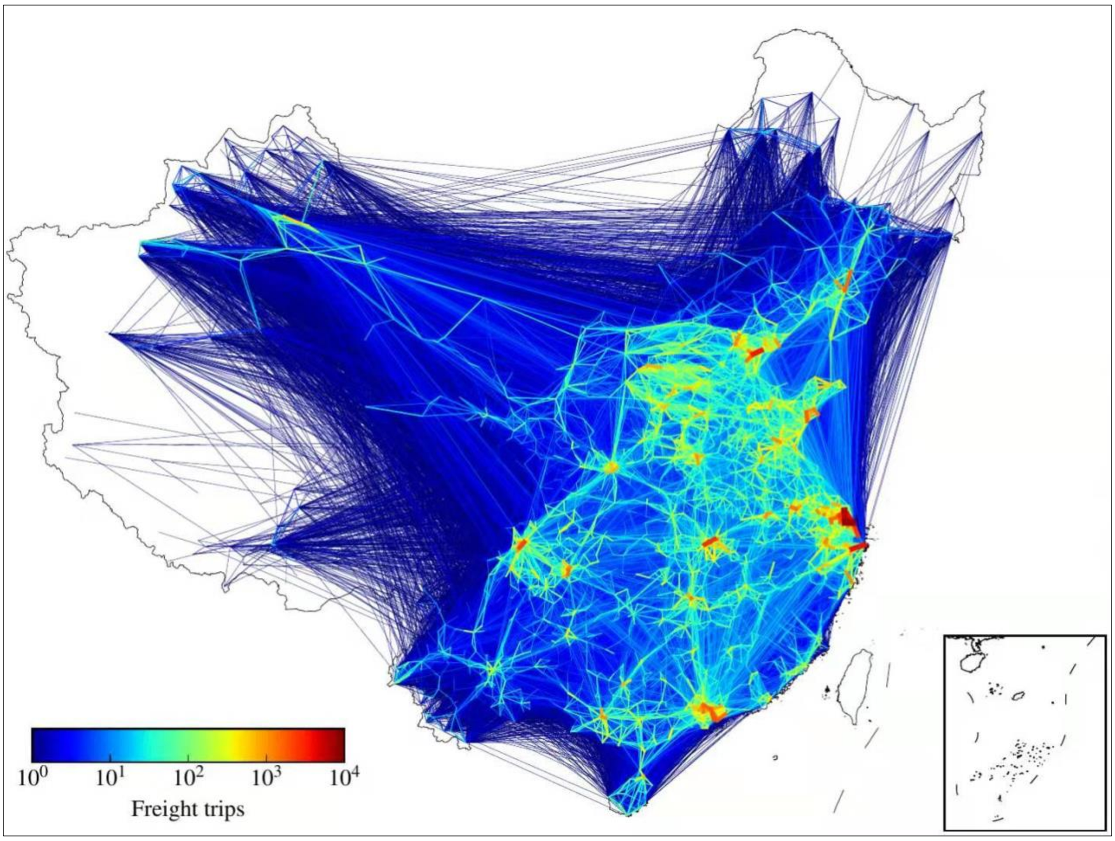

Figure 2. Distribution of freight trips between prefecture-level urban areas in China.

3. Alternative Evaluation Indexes for Urban Agglomeration Development Degree

3.1. The Overall Freight Intensity

As an economic union, the overall development level partly reflects the development degree of urban agglomerations [27]. Most researchers generally select total GDP or GDP per capita to reflect the urban agglomeration overall development level [31,32,42]. Here, this work uses the data of freight trips inside and outside (FTIO) urban agglomerations to partly reflect the urban agglomeration overall development level. A freight trip inside an urban agglomeration means that its origin and destination are both in this urban agglomeration. A freight trip outside an urban agglomeration means that only its origin or destination is in this urban agglomeration. This work analyzes the correlation between the FTIO data and GDP of the 14 urban agglomerations, as shown in Figure 3, from which we can see that the FTIO has a strong correlation with the GDP of the 14 Chinese urban agglomerations (the correlation coefficient is 0.862), indicating that choosing the FTIO data to reflect the urban agglomeration overall development level is reasonable. From Figure 3, we can also see that the FTIO of the CP urban agglomeration is much higher than the other urban agglomerations except for the YRD urban agglomeration. The main reason is that the CP urban agglomeration has the largest area and population in the 14 urban agglomerations. This work compares the areas of the 14 urban agglomerations to further illustrate this question. The results show that the area of the CP urban agglomeration ranks second among the 14 urban agglomerations, as shown in Figure 1. This leads to the CP urban agglomeration having a relatively higher amount of FTIO. However, as is known, the CP urban agglomeration is not the most developed urban agglomeration in China. This work draws the 3D bar chart of the FTIO per unit area of 14 Chinese urban agglomerations, as shown in Figure 4, the bar's volume represents the FTIO of the urban agglomeration, and the bar's height represents the FTIO per unit area of the urban agglomeration. From Figure 4, we can see that although the bar's volume of the CP urban agglomeration is the largest, the bar's height of the CP urban agglomeration is much lower than the PRD urban agglomeration and the YRD urban agglomeration. The sort on the FTIO per unit area of the PR urban agglomeration is the highest, and that of the YRD urban agglomeration is the next highest, consistent with their statuses, which is the most internationally competitive urban agglomeration in China [43]. These results show that the FTIO per unit area can be used as an evaluation index to eliminate the influence of the area on the evaluation result of the urban agglomeration overall development level and increase the degree of objectivity of the evaluation. Therefore, this work uses the FTIO per unit area as an alternate evaluation index, named the overall freight intensity, to more reasonably reflect the urban agglomeration overall development level.

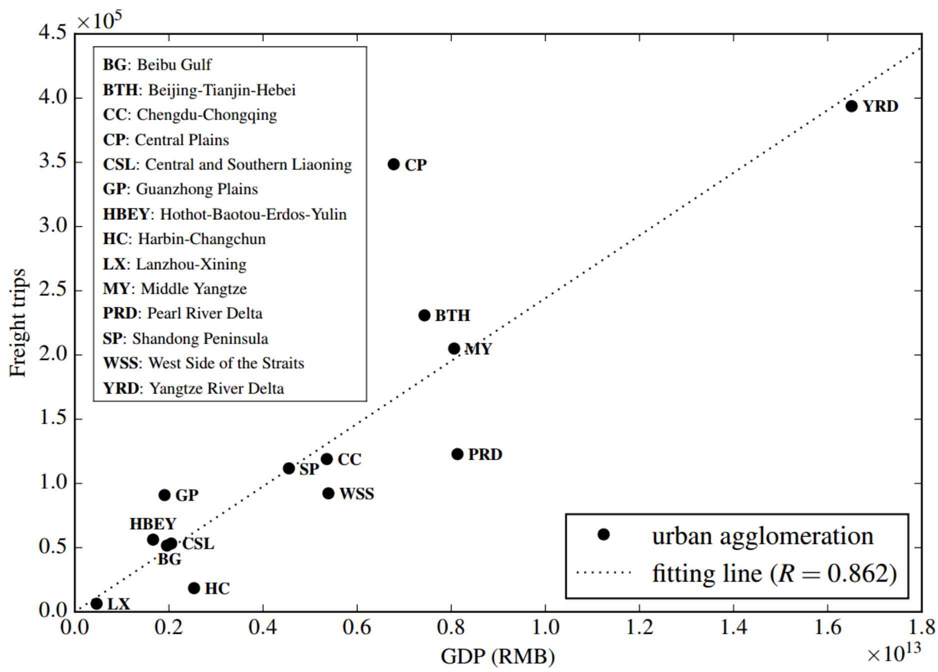

Figure 3. Correlation between the GDP and the freight trips inside and outside (FTIO) of 14 urban agglomerations.

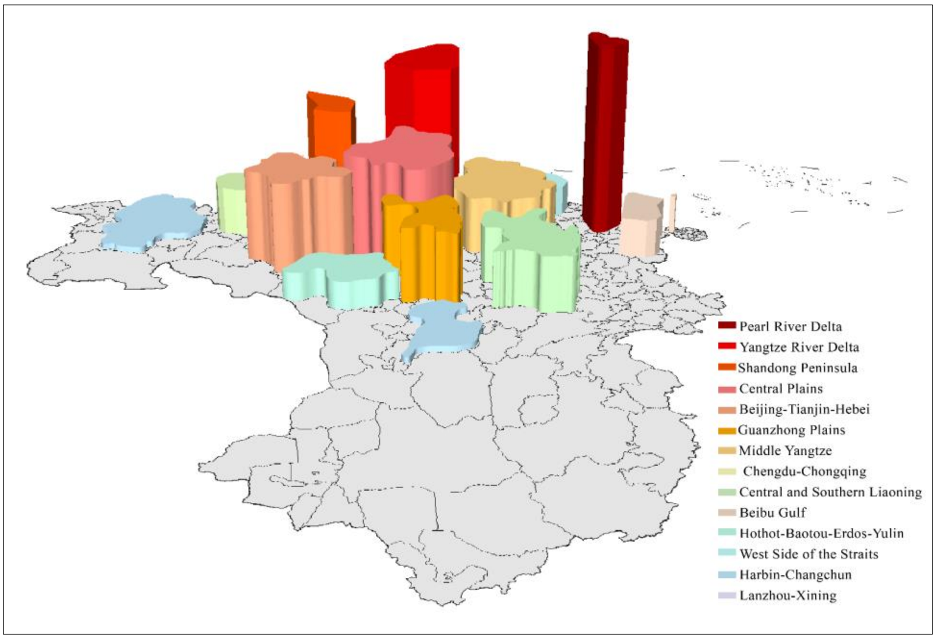

Figure 4. 3D bar chart of the FTIO per unit area of 14 Chinese urban agglomerations.

3.2. The Internal Freight Intensity Equilibrium Level

The development history of urban agglomerations worldwide shows that the development gap between urban agglomerations has increased and there are also large gaps between urbanization levels within the urban agglomeration with the rapid development of urban agglomerations [44]. The rational development of urban agglomerations is not only the development of core cities, all the urban area has to become holistic, integrative, and participative [45]. Therefore, the internal development equilibrium level is an important index for evaluating the comprehensive development degree of urban agglomeration. The FTIO per unit area of urban agglomeration used in Section 3.1 can well reflect the overall development level of an urban agglomeration. Similarly, the FTIO per unit area of an urban area can also reflect the development level of the urban area. Therefore, this work used the equilibrium degree of the FTIO per unit area of urban areas within the urban agglomeration to reflect the equilibrium level of an urban agglomeration's internal development. At present, the popular methods for calculating equilibrium levels include the normalized entropy method, the Gini coefficient method, and the coefficient of variation (CV) method. Among them, the CV method can better characterize the degree of difference in values [46]. Hence, this work uses the CV of the FTIO per unit area of each urban area in the urban agglomeration as an alternate index, named the internal freight intensity equilibrium level, to reflect the internal development equilibrium of urban agglomeration. The specific definition of the CV is the ratio of the standard deviation to the average as follows:

$$\mathrm{CV} = \frac{\sqrt{\sum_{i=1}^{n} \frac{(x_i - \overline{x})^2}{n}}}{\overline{x}}, \tag{1}$$

where x_i is the FTIO per unit area of each urban area within the urban agglomeration, n is the number of urban areas within the urban agglomeration, and $\overline{x}$ is the average of the FTIO per unit area of all urban areas. The lower the CV, the higher the freight intensity equilibrium level of the urban agglomeration development, and vice versa. According to Equation (1), this work calculates the CV of the FTIO per unit area of each urban agglomeration, and the result is shown in Figure 5. In Figure 5, we can see that the CV of the FTIO per unit area of the SP urban agglomeration is the lowest, indicating that the internal development of the SP urban agglomeration is the most balanced. Similarly, the CV of the FTIO per unit area of the LX urban agglomeration is the largest, indicating that the LX urban agglomeration has the worst development equilibrium in the 14 urban agglomerations.

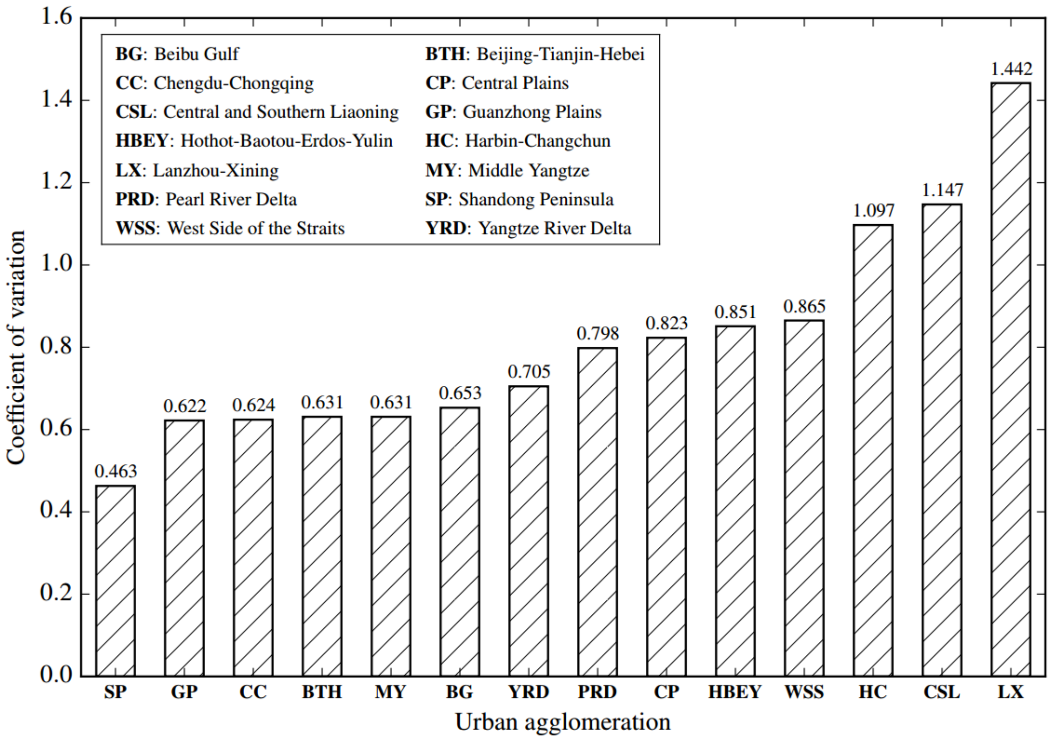

Figure 5. The coefficient of variation (CV) of the FTIO per unit area of 14 Chinese urban agglomerations

3.3. The Internal Freight Interaction Relative Intensity

An urban agglomeration is an economic union, and the relationship between its core urban areas and other urban areas in an urban agglomeration is a good interaction process of agglomeration and radiation [27]. High-intensity economic interaction between urban areas is the basic condition of urban agglomerations [28], and it is also the basic requirement for improving the comprehensive development degree of urban agglomerations [27]. Strengthening the connection and interaction between urban areas within urban agglomerations is the main development direction of urban agglomerations [26]. Therefore, quantifying the economic interaction intensity between urban areas within an urban agglomeration is an important problem. In fact, freight data can fully reflect the economic interaction intensity between urban areas [36–39]. The FTIO of the urban agglomerations used in Section 3.1 essentially reflects the total intensity of internal and external freight interaction within the urban agglomeration. Here, this work uses the ratio of the number of freight trips inside the urban agglomeration to the FTIO of the urban agglomeration as an alternate index, named the internal freight interaction relative intensity, to reflect the internal interaction level of each urban agglomeration. The calculation method of the index is as follows. First, dividing the FTIO of an urban agglomeration into inside freight trips and outside freight trips (see their definitions in Section 3.1), which quantify the internal freight interaction intensity and the external freight interaction intensity, respectively. Then, calculating the ratio of the internal freight interaction intensity to the total internal and external freight interaction intensity. The bigger the ratio of urban agglomeration is, the closer the interaction is between urban areas in the urban agglomeration and vice versa. This work calculates the ratios of the 14 urban agglomerations, and the results are shown in Figure 6. The internal freight interaction relative intensity within the YRD urban agglomeration is higher than the other 13 urban agglomerations, which indicates that the core urban areas of the YRD urban agglomeration have stronger agglomeration and radiation capability and that the regional coordinated development level is higher than the other 13 urban agglomerations. However, the internal freight interaction relative intensity of the HBEY urban agglomeration and LX urban agglomeration is very low, indicating that the internal agglomeration and radiation capacity of the urban agglomerations need to be strengthened.

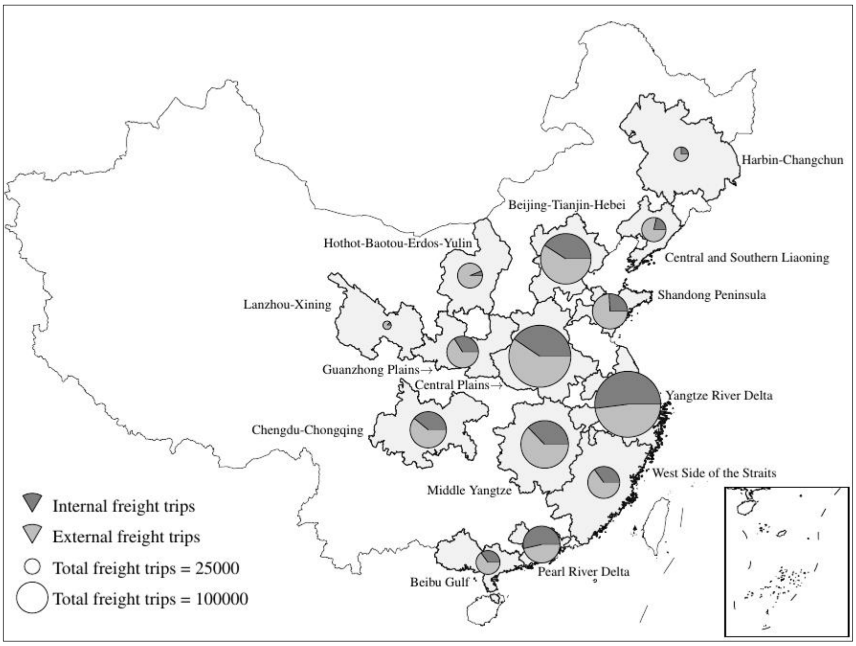

Figure 6. The FTIO and the ratio of internal and external freight trips within the 14 Chinese urban agglomerations.

4. Comprehensive Evaluation

In this section, this work uses the abovementioned three alternative indexes from different perspectives to comprehensively evaluate the comprehensive development degree of 14 Chinese urban agglomerations. How to determine the weight of each index is the key to comprehensive evaluation [47]. To date, the methods for calculating weights are mainly divided into two types: Subjective weighting methods, such as the Delphi method [33] and analytic hierarchy process [48], and objective weighting methods, including principal component analysis [49], the entropy method [50], and the criteria importance through intercriteria correlation (CRITIC) method [51]. The subjective weighting method is determined by experts based on their own experience and subjectively attaching importance to each index, but it is a lack of objectivity [52]. Therefore, this work uses the objective weighting method to determine the weight of the indexes. The objective weighting method is derived from the attribute data and is not related to the specific meaning of the attribute. The weight of each index is determined by the association degree of each index or the amount of information provided by each index. Such a method is highly objective and has a strong mathematical theoretical basis, so it is widely used [53]. Here, this work chooses the CRITIC method to weight the three evaluation indexes, which can consider both the contrast intensity of the alternative performance in every single criterion, and the conflict of the evaluation criteria with each other [51]. The calculation process of the CRITIC method is as follows. First, using the maximum difference normalization method to standardize the three evaluation indexes. The internal freight intensity equilibrium level is a negative index, and the other two indexes are positive. For the negative index, its standardized value is

$$x_i^* = \frac{x_{max} - x_i}{x_{max} - x_{min}} (i = 1, 2, \ldots, n), \quad (2)$$

where n is the number of urban agglomerations, x_i is the index value of urban agglomeration i, x_{max} is the maximum value of the index, and x_{min} is the minimum value of the index. For the positive index, its standardized value is

$$x_i^* = \frac{x_i - x_{min}}{x_{max} - x_{min}}(i = 1, 2, \ldots, n) \tag{3}$$

The three evaluation indexes before and after standardization are shown in Table 1. Then, calculating the amount of information C_j contained in the evaluation index j as

$$C_j = \sum_{i=1}^{m} \left(1 - r_{ij}\right), (i, j = 1, 2, \ldots, m), \tag{4}$$

where m is the number of indexes, and r_{ij} is the correlation coefficient between indexes i and j. Finally, calculating the weight W_j of index j as

$$W_j = \frac{C_j}{\sum_{j=1}^{m} C_j}, (j = 1, 2, \ldots, m) \tag{5}$$

Table 1. The evaluation values and the rank of the comprehensive development degree of 14 urban agglomerations.

Name	Overall Freight Intensity		Internal Freight Intensity Equilibrium Level		Internal Freight Interaction Relative Intensity		Evaluation Value	Rank	Stage
	Value	SV	Value	SV	Value	SV			
PRD	21930.000	1.000	0.798	0.658	0.535	1.000	0.867	1	I
YRD	18599.622	0.844	0.705	0.753	0.520	0.969	0.846	2	
SP	15303.562	0.689	0.463	1.000	0.259	0.419	0.728	3	II
BTH	10456.024	0.461	0.631	0.829	0.409	0.734	0.687	4	
CP	12142.927	0.540	0.823	0.632	0.405	0.727	0.633	5	
CC	6430.270	0.272	0.624	0.836	0.391	0.697	0.620	6	
GP	8488.702	0.368	0.622	0.837	0.338	0.585	0.617	7	
MY	6466.309	0.273	0.631	0.828	0.373	0.658	0.606	8	
BG	4423.671	0.177	0.653	0.806	0.349	0.609	0.553	9	
WSS	3417.667	0.130	0.865	0.589	0.349	0.608	0.454	10	
CSL	5479.300	0.227	1.147	0.301	0.216	0.328	0.287	11	III
HBEY	3213.600	0.121	0.851	0.603	0.060	0	0.272	12	
HC	697.689	0.002	1.097	0.353	0.250	0.399	0.259	13	
LX	648.718	0	1.442	0	0.126	0.138	0.042	14	

SV = standard value.

Using the CRITIC method, we obtain the weights of the overall freight intensity, the internal freight intensity equilibrium level and the internal freight interaction relative intensity as 0.307, 0.389, and 0.304, respectively, and further obtain the equation for calculating the comprehensive development degree of urban agglomerations as follows:

$$F = 0.307X_1 + 0.389X_2 + 0.304X_3, \tag{6}$$

where F is the evaluated value of the comprehensive development degree of urban agglomeration, X_1, X_2, and X_3 are the standardized numbers of the overall freight intensity, internal freight intensity equilibrium level and internal freight interaction relative intensity, respectively. From Equation (6), we can see that the weights of the three evaluation indexes are all between 0.3 and 0.4, indicating that each index is of nearly equal importance to the others. This is because each of the evaluation indexes contains a large amount of information, and the correlations between the indexes are low. This also reflects that the three evaluation indexes, i.e., the overall freight intensity, internal freight intensity equilibrium level, and internal freight interaction relative intensity, are very reasonable.

This work substitutes the index data of each urban agglomeration into Equation (6) and obtain the evaluation results of the comprehensive development degree of 14 urban agglomerations, as shown in Table 1.

5. Classification of the Urban Agglomeration Development Stage

In Table 1, we can see the development degree evaluation values and the rank of 14 Chinese urban agglomerations. However, only ranking the urban agglomeration evaluation values does not give us a clear understanding of the development stage of each urban agglomeration. Here, this work uses the unweighted pair group method with the centroid averaging (UPGMC) method, a widely used hierarchical clustering method [54], to classify the urban agglomerations according to the evaluation values. First, this work sets the 14 urban agglomerations as the initial 14 clusters, and the centroid of each cluster is its evaluation value. Then, this work calculates the distance (i.e., the absolute value of the difference) of the centroid between each of the two clusters, and the nearest neighboring clusters combine to a new cluster. The new cluster's centroid is the average of the centroids of its all initial component clusters. For example, first calculating the centroid distance between every two clusters for the initial 14 clusters and picking a pair with the minimum distance. The results show that the centroids of cluster CC and cluster GP are the nearest, and so they can be combined into a new cluster named CC-GP. The centroid of cluster CC-GP is the average of the centroids of cluster CC and cluster GP. Now there are 13 clusters, including cluster CC-GP and the 12 other initial clusters, where the nearest two clusters are cluster MY and cluster CC-GP. Therefore, the two clusters are combined to form a new cluster named cluster MY-CC-GP whose centroid is the average of the centroids of cluster MY, cluster CC, and cluster GP. Similarly, this process iterates until a single cluster is obtained, as shown in Figure 7. However, the single cluster includes all urban agglomerations, which does not make sense in the urban agglomeration development stage division. Hence, this work defines a rule that the number of urban agglomerations included in all clusters is at least two. According to this rule, we finally obtain three clusters, i.e., three development stages, see Table 1. Stage I includes the PRD and YRD urban agglomerations, and their average evaluation values are 0.857. Stage II includes SP, BTH, CP, CC, GP, MY, BG, and WSS urban agglomerations, and their average evaluation values are 0.612. Stage III includes CSL, HBEY, HC, and LX urban agglomerations, and their average evaluation values are 0.215.

Figure 8 shows the spatial distribution of the development stages of 14 Chinese urban agglomerations. From Figure 8, we can see that from the eastern and southern regions to the western and northern regions, the development levels of 14 urban agglomerations gradually decrease. This is partly due to the differences in historical culture, geographical conditions, policy environment, and natural resources between the eastern, central, and western regions of China, resulting in a disequilibrium pattern in the development of these regions [55]. However, different urban agglomerations at the same development stage have some similar characteristics, see Table 1. These results help to better analyze the potential development problems of urban agglomerations at each stage from various perspectives.

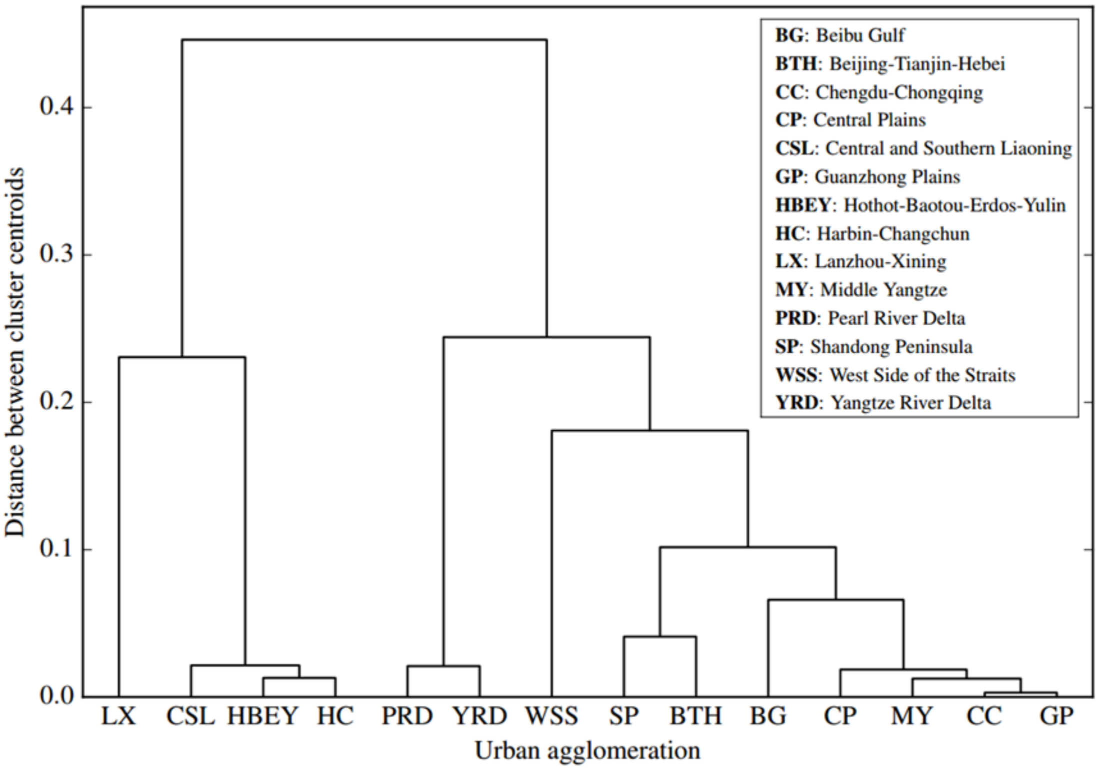

Figure 7. The hierarchical clustering dendrogram of the 14 Chinese urban agglomerations.

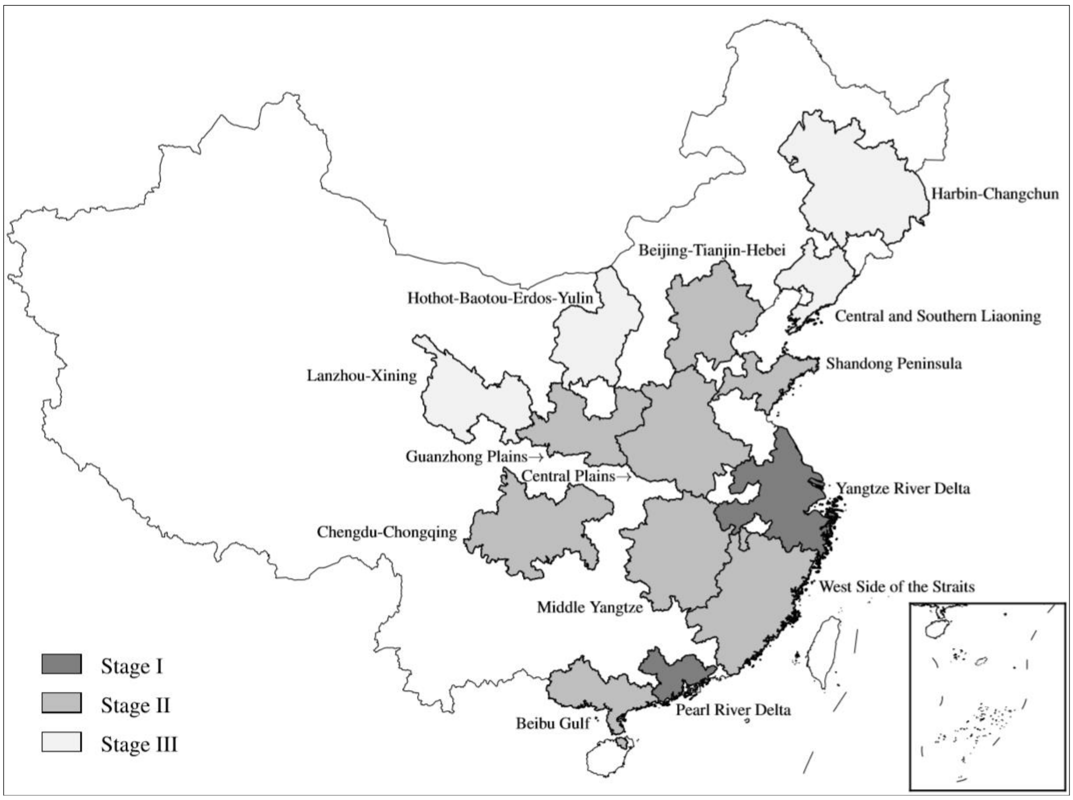

Figure 8. Spatial distribution of development stages of 14 Chinese urban agglomerations

6. Conclusion and Discussions

Reasonable evaluation of the comprehensive development degree of urban agglomeration is of great significance for promoting its coordinated and sustainable development. The degree of urban agglomeration development depends not only on the rapid development of the core urban area in this urban agglomeration but also on the degree to which the core urban area leads all other urban areas in this urban agglomeration to commonly and harmoniously develop. This work first extracted the road freight trip data from the truck trajectories recorded by China's road truck public supervision and service platform. Then, based on the freight trip data, this work used 14 Chinese urban agglomerations as empirical research objects to establish three alternative evaluation indexes named the overall freight intensity, the internal freight intensity equilibrium level, and the internal freight interaction relative intensity to reflect the urban agglomerations' overall development level, internal equilibrium level, and internal interaction level, respectively. Further, this work introduced the calculation methods of the above three evaluation indexes and calculate these indexes for 14 Chinese urban agglomerations. Furthermore, this work used the CRITIC method to weight each index and calculated the comprehensive development degree evaluation values for each urban agglomeration. Finally, this work used the UPGMC method to classify the 14 urban agglomerations into three development stages.

There are three main contributions of this work. First, the evaluation indexes established in this work comprehensively consider the overall development level, the internal equilibrium level and the internal interaction level of urban agglomerations. However, most previous studies only considered one or two of these three evaluation directions. Second, this work uses freight data that can well reflect the economic interaction between urban areas to evaluate the internal interaction intensity of urban agglomerations, which is more reasonable than using the gravity model to calculate the interaction between urban areas. Third, using the three evaluation indexes proposed in this work to comprehensively evaluate the degree of comprehensive development and classify the development stages of 14 Chinese urban agglomerations is helpful for gaining a deeper understanding of urban agglomeration development problems from various perspectives.

Furthermore, this work can proffer advice for the future development of the 14 Chinese urban agglomerations according to problems reflected by these three evaluation indexes. From Table 1, we can see for the urban agglomerations at stage I, i.e., the PRD and YRD urban agglomerations, their overall freight intensity, and the internal freight interaction relative intensity are both at the highest level, but their internal freight intensity equilibrium is only at a medium level. In the future, these two urban agglomerations should focus on enhancing regional coordinated development to decrease the gap of the internal urban area development degrees. For the urban agglomerations at stage II, the evaluation values of the overall freight intensity, internal freight intensity equilibrium level, and internal freight interaction relative intensity of urban agglomerations show irregularities. For example, the internal freight intensity equilibrium level of the SP urban agglomeration is the highest among the 14 urban agglomerations, indicating that the urban development of the urban agglomerations is the most balanced. However, the internal freight interaction relative intensity of the SP urban agglomeration is low, indicating that the internal interaction intensity is much lower than the external interaction intensity in this urban agglomeration. In the future, the SP urban agglomeration should improve the overall development level and focus on strengthening the urban interaction intensity while maintaining the internal development equilibrium to improve its comprehensive development degree. Another example is the BTH urban agglomeration, in which internal freight intensity equilibrium and the internal freight interaction relative intensity are both at the upper level, but its overall freight intensity level needs to improve. The BTH urban agglomeration should drive the development of other urban areas through the two core urban areas (i.e., Beijing and Tianjin) in the future, which can promote the coordinated and balanced development of the BTH urban agglomeration. For the urban agglomerations at stage III, most of their evaluation index values are at a low level. For example, although the internal freight intensity equilibrium of the HBEY urban agglomeration is at a medium level, its overall freight intensity level is at a low level, and its internal freight interaction relative intensity is much lower than the other 13 urban agglomerations. The HBEY urban agglomeration should improve its comprehensive development degree from the previous three aspects, especially focusing on strengthening the economic interaction of its urban areas. Another example is the LX urban agglomeration in which three evaluation values are all extremely low. Therefore, the LX urban agglomeration should endeavor to promote its development degree from three aspects, including the overall development level, the internal development equilibrium, and the internal interaction intensity. Of course, this work only proposes some advice for several typical Chinese urban agglomerations. Different urban agglomerations need to generate specific development strategies by combining with their specific conditions and ultimately achieve a coordinated and sustainable development state.

There is still room for further improvement in the data and the comprehensive development degree evaluation method. The freight trip data used in this paper have been able to properly reflect the overall development level, internal development equilibrium, and internal interaction relative intensity of urban agglomeration. If we have more detailed socioeconomic data and multimodal passenger and freight transportation data, we can more comprehensively evaluate the degree of urban agglomeration development. In terms of the evaluation method, this work chooses an objective method named the CRITIC method to weight the indexes. From this, this work can further combine the subjective method with the knowledge and experience of experts in different fields, such as economics, geography, and urban planning, making the urban agglomeration comprehensive development degree evaluation more scientific and reasonable.

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