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Research on the Coupling and Coordinated Development of Traffic Accessibility and Regional Economy

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Abstract

In this paper, 43 prefecture-level cities in the Bohai Rim region are taken as the research objects, and the weighted average travel time model and gravity model are revised based on the comprehensive development level of the cities. The network analysis function measures the land accessibility of cities in the Bohai Rim region. To explore the coupling and coordination effect of transportation accessibility and regional economic development, the economic gravity model is used to measure the strength of economic connections between cities in the region. The research results show that: ①The traffic accessibility has obvious characteristics of the center-periphery structure, with the core city of Beijing, Tianjin, Hebei, and Texas as the center to spread to the surrounding cities; ②The regional disparity of the total amount of economic ties shows the characteristics of taking Beijing, Tianjin and provincial capital cities as the center; ③The degree of coupling coordination between traffic accessibility and regional economy is in a preliminary coordination state as a whole, but there are still large differences between regions. Based on the above conclusions, cities in the Bohai Rim region should formulate differentiated transportation and regional economic development strategies; actively carry out inter-city transportation and economic cooperation, and achieve coordinated development of transportation and regional economy through complementary advantages of each city.

Keywords

Bohai Rim Region; Traffic Accessibility; Urban Comprehensive Development Level; Economic Connection; Coupling Coordination Degree.

1. Introduction

One of the most important indicators to judge the level of regional traffic development is traffic accessibility [1]. Accessibility refers to the convenience of getting from one area to another [2], in essence, accessibility is to study the convenience of regional economic exchanges. Academician Lu Dadao believes that improving the level of regional traffic accessibility is the premise of regional economic development [3], It can be seen that transportation is increasingly affecting economic development. Meng Yayan analyzed and expounded on the action mechanism of transportation and economy, She proposed that transportation is the basis of inter-regional economic ties, and the strength of economic ties affects the development of transportation [4]. There is a coupling effect between traffic accessibility and regional economic ties, and the spatial distribution of regional economic ties is closely related to the spatial distribution of traffic networks [5]. Taking the road network as the research object, Wu Wei and others used GIS technology to measure the regional traffic accessibility of the Yangtze River Delta [6]. Jiang Xiaowei and Cao Weidong further expanded the research object, based on the time cost and used economic gravity to analyze the transportation in Anhui Province [7]. Taking the Shandong Peninsula as the research area, Yu Jinkai improved the economic gravity formula by using multiple indicators to further study the spatial relationship between economy and

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transportation [8]. Meng Deyou analyzed the coupling and coordination of the two systems of economy and transportation, and put forward the viewpoint of coordinated development [9].

It is not difficult to find that cities with development potential and economic strength are closely related to their regional advantages, such as coastal port metropolis, provincial capital central cities, etc. However, only relying on a single city can not stimulate the development of the whole region. Over time, it will widen the gap between central cities and marginal cities. From the perspective of the whole region, it is not conducive to long-term development. Therefore, China has put forward the strategic policy of regional coordinated development. As the most economic potential urban group in the north, coordinating the coordinated development between regions is particularly important. Taking traffic accessibility as the starting point, this paper deeply studies the coupling and coordinated development of regional traffic accessibility and regional economy around the Bohai Sea.

2. Model Building

2.1. Traffic Accessibility Model Modification

2.1.1. Weighted Average Travel Time Model

The measurement of accessibility can be calculated utilizing a weighted average travel time model. The model is an improvement on the spatial interaction model, which, compared to other models, measures the share of the end city within the whole region in terms of temporal distance and uses the results as a weighting to measure the level of accessibility, the specific formula of the model is shown below:

$$A_i = \frac{\sum_{j=1}^{n}(T_{ij} * G_j)}{\sum_{j=1}^{n} G_j} \quad (1)$$

In equation (1), A_i indicates city i accessibility, which is measured in this article using weighted average travel time. T_{ij} denotes the shortest travel time between city i and city j, G_j denotes the scale of urban development or quality of development of city j, which can reflect the city's ability to attract and radiate to the surrounding area and is generally studied using the number of people living in the city and GDP for analysis. The smaller the value of A_i, the higher the accessibility level of the city i and vice versa.

2.1.2. Modified Indicator Selection

Accessibility reflects the ease of movement of various factors between regions and has an impact on the direction and intensity of economic linkages. With improvements in transport technology and socio-economic development, the level of accessibility to cities in the region has increased, reshaping the relative position of the nodal cities in the region. The measurement of accessibility levels cannot be limited to geographic spatial distances alone, but rather travel time distances should be used as a basis for measurement. In this paper, the accessibility model is revised in terms of both transit waiting times and comprehensive development levels to further improve the accuracy of the measurement results.

1.Transit waiting times are included in the minimum travel time.

2.Level of integrated urban development.

Most of the literature has measured the level of urban development in terms of two indicators, GDP and urban residential population, but this does not fully reflect the city's ability to radiate to the surrounding region. Therefore, this paper constructs a new indicator to measure the comprehensive development level of the city.

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2.1.3. Traffic Accessibility Model Correction

$$A_i = \frac{\sum_{j=1}^{n}(T_{ij} * M_j)}{\sum_{j=1}^{n} M_j} \tag{2}$$

Compared with equation (1), in equation (2), A_i denotes the accessibility level of city i, which is characterized by the weighted average travel time; T_{ij} denotes the shortest travel time between city i and city j, in which transit waiting time is taken into account in this paper; M_j denotes the weight of the comprehensive urban development level of the end city j, which is characterized with the help of the comprehensive urban development level in this paper.

2.2. Economic Linkage Intensity Model

In this section, the spatial distances and masses in the gravitational model are corrected. The spatial distances in the model are corrected for the shortest travel times in the weighted average travel time model and replace the quality in the model with the level of comprehensive urban development. The revised model is shown below.

$$R_{ij} = \frac{M_i M_j}{T_{ij}^2} \tag{3}$$

R_{ij} indicates the gravitational force between city i and city j. The larger the value, the stronger the economic linkage, and vice versa; the shortest travel time between city i and city j is expressed here as T_{ij}, and due to the difference in round trip time, the average round trip time T_{ij} is taken in this paper.

2.3. Coupled Coordination Model

The coupling coordination model involves 3 indicators, including the coupling degree, the coordination index and the coupling coordination degree. This article evaluates traffic and economic linkages and constructs a coupling degree model for these two systems. The specific formula is as follows.

$$C = 2 \times \left[\frac{U_1 U_2}{(U_1 + U_2)^2}\right]^{\frac{1}{2}} \tag{4}$$

C for coupling, U_1 represents the accessibility of each city, U_2 represents the total economic linkages of the cities. C closer to 1 indicates a greater interaction between the transport accessibility system and the economic linkage system, tending towards 0 indicates a smaller interaction between the two systems. To normalize the results in a positive direction, the accessibility is Max-Min normalized based on taking the inverse and the total economic links are Max-Min normalized.

Ultimately, we use this to construct a coupled coordination model for studying the interactions between systems, as shown by the following equation.

$$D = \sqrt{C \times T} \tag{5}$$

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Where $T=aU_1+bU_2$, T denotes the coordination index of traffic accessibility and economic linkages, a and b denote the weights of the two systems respectively, and both a and b take the value of 0.5 in this paper. D denotes the coupling coordination degree, the value range is [0,1], the more the value tends to 1, the higher the coupling coordination degree of the two systems. C represents the degree of coupling and reflects the interaction forces between the two systems. To better measure the degree of coupling coordination in the Bohai Rim region, the criteria for classifying the level of coupling coordination are shown in Table 1 [10].

Table 1. Ranking of the degree of coupling coordination

Coupling coordination D-value	Type of coupling coordination	Coupling coordination D-value	Type of coupling coordination
(0.00 to 0.10)	extreme disorder	[0.50 to 0.60)	Initial coordination
[0.10 to 0.20)	serious disorder	[0.60 to 0.70)	Mild coordination
[0.20 to 0.30)	moderate disorder	[0.70 to 0.80)	Moderate coordination
[0.30 to 0.40)	mild disorder	[0.80 to 0.90)	Highly coordinated
[0.40 to 0.50)	Impending disorder	[0.90 to 1.00)	intense coordination

3. Transport Accessibility and Regional Economic Metrics in Bohai Region

3.1. Research Regions and Data Sources

The study is on the Bohai Rim region, which includes Beijing, Tianjin, Hebei Province, Shandong Province and Liaoning Province. The data of the evaluation indicators of the comprehensive development level of cities are obtained from the *China Statistical Yearbook*, *Beijing Statistical Yearbook*, *Tianjin Statistical Yearbook*, *Shandong Statistical Yearbook* and the *Economic Yearbook of the Bohai Rim Region* in 2021.

3.2. Integrated City Level Measurement

3.2.1. Indicator System Construction

Table 2. System of indicators for evaluating the level of integrated urban development

target layer	metric layer
	Local revenue (million yuan)
	Gross regional product (million yuan)
	Gross regional product per capital (million yuan)
Level of integrated urban development	Total exports and imports of foreign economic trade (million yuan)
	Number of people registered at the end of the year (10,000)
	Number of registered unemployed persons in urban areas (10,000)
	Share of secondary sector in GDP (%)
	Share of tertiary sector in GDP (%)

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Today's cities tend to develop in a holistic and multi-faceted way. It is clear that the analysis of urban population and regional GDP by previous scholars does not provide an all-around measure of the quality of a city's development. Considering the accuracy of the data, we selected a total of eight indicators, including local fiscal revenue, gross regional product, gross regional product per capita, total import and export of foreign economy and trade, number of household registration population at the end of the year, number of urban registered unemployed persons, share of secondary industry in GDP and share of tertiary industry in GDP, as shown in Table 2.

3.2.2. Overall City Development Level Score

Based on factor analysis, rating the development level of 43 cities in the Bohai Sea Rim. In order to facilitate the subsequent calculation of accessibility and regional economy, the overall development level scores of the 43 municipalities were de-minimized and scored in the range [1, 10], with the following score conversion formula.

$$Mi = \frac{(m_i - m_{min})\,(10-1)}{m_{max} - m_{min}} \tag{6}$$

In the equation, m_i initial score, m_{max} and m_{min} are the highest and lowest scores in the original rating. The highest-ranked score is 10 and the lowest-ranked score is 1.

From Table 3 it can be analyzed that: Beijing, Tianjin and Qingdao ranked among the top three cities in the Bohai Rim region in terms of the overall score, with a high level of comprehensive urban development. Jinan, Shijiazhuang, and Shenyang, the provincial capitals, are also prominent in terms of their overall level of development. In contrast, the cities of Liaoyang, Dongying and Panjin have a lower level of development and are on the edge of the province, which is more related to their industrial structure and geographical location.

Table 3. Ratings of cities in the Bohai Sea Rim region

cities	composite score	cities	composite score
Beijing	10.00	Xingtai	2.33
Tianjin	6.79	Taian	2.33
Qingdao	5.28	Dezhou	2.32
Jinan	3.81	Weihai	2.20
Shijiazhuang	3.73	Fuxin	2.16
Shenyang	3.55	Tangshan	2.09
Baoding	3.24	Chaoyang	2.08
Linyi	3.22	Tieling	2.06
Dalian	3.11	Chengde	2.04
Weifang	2.99	Binzhou	2.03
Yantai	2.97	Anshan	1.97
Langfang	2.93	Rizhao	1.93
Jining	2.67	Zibo	1.89
Cangzhou	2.64	Zaozhuang	1.84
Zhangjiakou	2.61	Huludao	1.74

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Continued **Table 3**

Heze	2.59	Yingkou	1.60
Jinzhou	2.48	Benxi	1.32
Handan	2.48	Fushun	1.26
Dandong	2.45	Liaoyang	1.26
Liaocheng	2.45	Dongying	1.20
Hengshui	2.38	Panjin	1.00
Qinhuangdao	2.33		

3.3. Traffic Accessibility Measurement and Spatial Analysis

3.3.1. Indicator System Construction

This paper focuses on land transport in the Bohai Rim region as the main object of analysis. According to equations (1) and (2) mentioned above, using the traffic network analysis function in GIS technology, the traffic accessibility of the 43 cities in the Bohai Sea Rim region in 2020 is measured.The specific results are shown in Table 4.

Table 4. Accessibility of cities in the Bohai Sea Rim region

cities	Reachability value (h)	cities	Reachability value (h)
Beijing	3.24	Tieling	5.04
Tianjin	4.06	Chaoyang	4.52
Tangshan	4.43	Huludao	3.72
Qinhuangdao	4.81	Dandong	6.34
Zhangjiakou	4.64	Ji'nan	3.06
Chengde	5.41	Qingdao,	4.16
Langfang	3.56	Zibo	3.81
Shijiazhuang	4.53	Zaozhuang	3.86
Handan	5.27	Dongying	3.94
Xingtai	4.51	Yantai	5.20
Baoding	4.28	Weifang	4.44
Cangzhou	4.15	Jining	3.72
Hengshui	3.88	Tai'an	3.08
Shenyang	4.66	Weihai	5.45
Dalian city	5.36	Rizhao	4.97
Anshan	5.13	Binzhou	3.77
Fushun	4.95	Dezhou	3.67
Benxi	4.97	Liaocheng	4.15
Jinzhou	3.84	Linyi	4.40
Yingkou	4.49	Heze	4.56
Fuxin	4.65	Liaoyang	4.97
Panjin	4.26		

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3.3.2. Spatial Analysis

To visualize the accessibility of the Bohai Sea region, ArcGIS 10.5.2 software was used to classify the traffic accessibility level of the Bohai Sea region into ten levels, based on the the Natural interruption point grading method, as shown in Figure 1.

Meanwhile, the land transport network in the Bohai Rim region is shown in Figure 2.

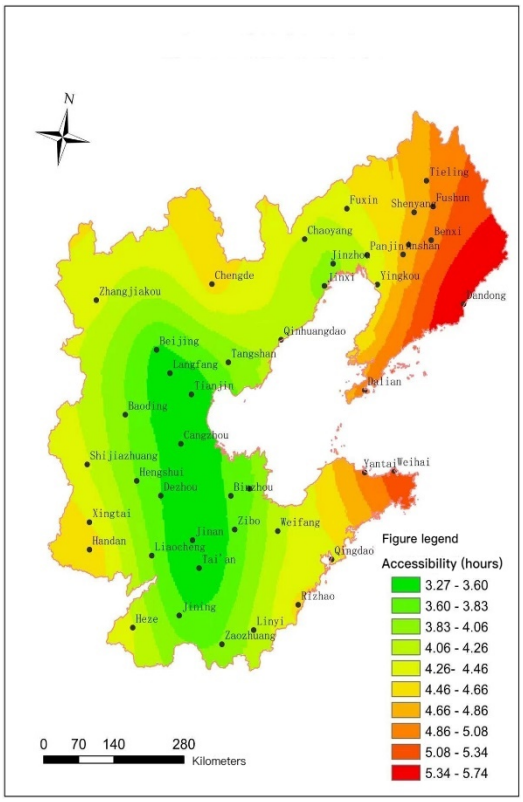

Figure 1. Accessibility to the Bohai Rim Region

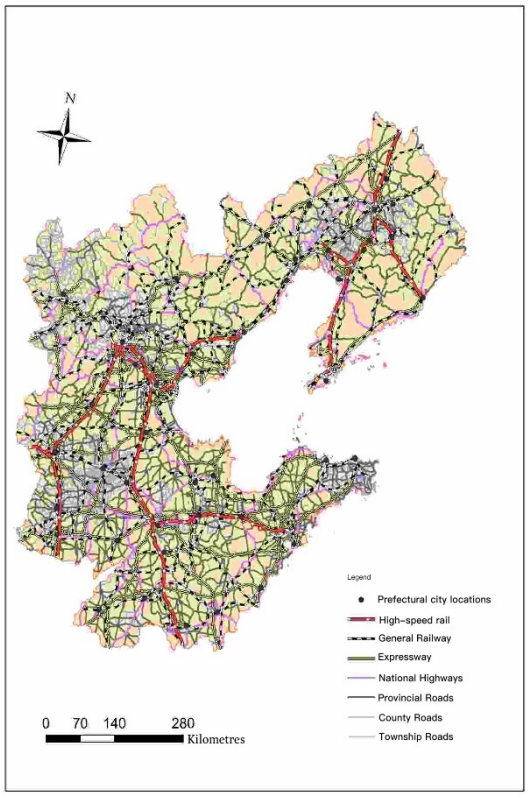

Figure 2. Land transport network in the Bohai Rim region

Analysis of urban accessibility levels in the Bohai Rim region based on the results of the calculations. The overall picture shows a center-periphery character with the geographical heart of the Bohai Rim region as the core. Beijing-Tianjin-Hebei, extending outwards and increasing gradually towards the north of the south in particular. The range of accessibility advantages is relatively consistent with the Beijing-Tianjin-Hebei core zone. Accessibility is more developed in Beijing, Tianjin, Langfang, the cities of Shijiazhuang, Baoding, Cangzhou and Hengshui in central Hebei Province and the cities of Dezhou, Jinan and Tai'an in northwestern Shandong Province, with accessibility in the center being better than in the peripheral areas.

In summary, these results show that with the improvement of the transport network, there has been a marked improvement in the overall standard of the cities. The total weighted average travel time for the 43 cities in 2020 is 189.91, a decrease of 89.42 h compared to 2010; By 2020 all cities have crossed over from being located in the 4-10h range to being within the 3-6h range, which is a good indication that accessibility levels have increased considerably. This is a good indication that the transport network has been developed even further in the course of urban development.

As shown in Figure 2, measures such as the construction of better high-speed railways and wider roads have contributed to the expansion of traffic flow; the leveling of road surfaces has been further improved and the density of the traffic network at all levels has increased, most

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notably the construction of highways, with the total mileage in 2020 increasing by a full 3.44 times compared to the total mileage in 2010. The continuous development and improvement of the road network traffic in the Bohai Rim region have enhanced the accessibility of traffic in the region.

3.4. Measurement of Total Regional Economic Linkages

The total economic linkages of cities in the Bohai Rim region were measured using equation (5) mentioned above, as shown in Table 5.

Table 5. Total inter-city economic linkages in the Bohai Rim region

cities	Total economic volume	cities	Total economic volume
Beijing	595,751,234	Fuxin	41,064,254
Tianjin	347,565,491	Linyi	37,218,641
Qingdao,	223,587,658	Dezhou	34,754,695
Jinan	178,981,451	Qinhuangdao	31,454,584
Shijiazhuang	147,574,147	Hengshui	31,057,687
Langfang	127,798,562	Liaocheng	27,974,036
Shenyang	114,954,254	Dandong	21,985,036
Baoding	83,857,451	Benxi	21,574,325
Weifang	78,599,241	Liaoyang	21,574,201
Xingtai	73,845,146	Heze	21,498,374
Tangshan	72,589,741	Dongying	21,254,131
Handan	71,748,964	Rizhao	21,064,854
Anshan	71,588,607	Tieling	19,548,362
Dalian	67,817,984	Yingkou	18,987,068
Weihai	61,482,365	Binzhou	17,037,497
Yantai	51,294,036	Tai'an	14,574,213
Zibo	51,254,261	Panjin	14,547,695
Cangzhou	51,145,258	Zaozhuang	11,254,039
Chengde	47,524,367	Huludao	8,548,695
Jining	47,159,454	Jinzhou	6,098,745
Zhangjiakou	45,754,984	Chaoyang	5,687,294
Fushun	43,947,086		

The intensity of urban economic ties in 2020 shows the following characteristics:

1.The economic linkages are mainly between the central capital cities and developed coastal cities, supplemented by peripheral cities radiating to the periphery. The analysis shows that the higher values of the total economic linkages between cities are found in the provincial capitals and the neighbouring large cities and individual developed coastal cities, while the relatively lower values are found in the peripheral cities of the provinces and the northeastern part of the Bohai Sea region.

2.The intensity of economic linkages between cities shows geographical differences from north to south. High values are found in the central core urban areas, moderate values in the south and low values in the north-east. The high values are mainly found in the Bohai Sea region in

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Beijing and Langfang and Tianjin, Weihai and Yantai, Jinan and Tai'an, Xingtai and Handan, Shenyang and Fushun, while the medium and high intensity areas are also concentrated in the south in Shandong Province and in the centre and south of Hebei Province. In the north, Liaoning Province is in the low value zone. The geography of the Bohai Sea region is very diverse, especially in terms of transport accessibility and connectivity between cities. Urban development is highly related to geographical location.

3.The strength of economic ties between cities shows a certain spatial pattern. The provincial capitals, developed cities and coastal cities have relatively better transportation information and their economic linkages are stronger, while in the peripheral cities, the economic base is weaker and transportation is more inconvenient, so the linkage intensity is not high. On the whole, the strength of economic ties in the central area of the Bohai Sea region is better than that in the peripheral areas. The intensity of the links is increasing.

4. Coupling Analysis of Transport Accessibility and Regional Economy

4.1. Measurement Results

According to Equation (5) and Equation (6), the coupled coordination of transport accessibility and economic linkages in the Bohai Rim region is measured based on the land transport modes in the Bohai Rim region, as shown in Table 6.

Table 6. Degree of coordination

City	D-value	Degree of coupling coordination	City	D-value	Degree of coupling coordination
Beijing	0.97	intense coordination	Huludao	0.62	Initial coordination
Tianjin	0.86	Highly coordinated	Heze	0.62	Initial coordination
Jinan	0.82	Highly coordinated	Qinhuangdao	0.62	Initial coordination
Langfang	0.74	Moderate coordination	Zaozhuang	0.61	Initial coordination
Taian	0.73	Moderate coordination	Chaoyang	0.60	barely coordinated
Baoding	0.72	Moderate coordination	Fuxin	0.59	barely coordinated
Shijiazhuang	0.72	Moderate coordination	Handan	0.56	barely coordinated
Qingdao	0.71	Moderate coordination	Rizhao	0.54	barely coordinated
Jining	0.70	Moderate coordination	Yingkou	0.54	barely coordinated
Dezhou	0.70	Moderate coordination	Anshan	0.52	barely coordinated
Cangzhou	0.70	Moderate coordination	Dongying	0.52	barely coordinated
Hengshui	0.69	Initial coordination	Tieling	0.52	barely coordinated
Jinzhou	0.68	Initial coordination	Chengde	0.51	barely coordinated

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Weifang	0.67	Initial coordination	Yantai	0.50	barely coordinated

Continued **Table 6**

Binzhou	0.66	Initial coordination	Liaoyang	0.45	on the verge of disorder
Liaocheng	0.66	Initial coordination	Fushun	0.44	on the verge of disorder
Linyi	0.66	Initial coordination	Benxi	0.43	on the verge of disorder
Shenyang	0.65	Initial coordination	Panjin	0.40	on the verge of disorder
Zibo	0.64	Initial coordination	Weihai	0.40	mild disorder
Xingtai	0.63	Initial coordination	Dalian	0.39	mild disorder
Tangshan	0.63	Initial coordination	Dandong	0.16	serious disorder
Zhangjiakou	0.62	Initial coordination			

4.2. Results Analysis

Table 6 shows that Beijing, Tianjin and Jinan have a high degree of coupling and coordination, from both the transport and economic perspectives: these four cities have high transport accessibility, which shows that transport is playing an increasingly important role in regional development, and the level of transport development will directly affect the efficiency of regional economic development. Therefore, building a complete transport network system and improving inter-regional transport accessibility can, to a certain extent, speed up the flow of production factors between regions, reduce time costs, increase the strength of inter-regional economic ties and stimulate inter-city economic potential.

Based on the differences in the rank order of the number of economic linkages and transport accessibility, the coupling coordination is further classified into 3 types: lagging transport development, synchronous transport and economic development, and lagging economic development. Under the condition of highway traffic, the ranking of Binzhou, Dezhou and Zaozhuang is significantly higher than their ranking of traffic accessibility, indicating that the regional economic development is constrained by the traffic conditions and belongs to the type of lagging traffic development. The transport accessibility ranking of Chengde, Jinzhou and Xuzhou is significantly higher than their economic linkages, indicating that the transport advantage is not a significant contributor to economic development and is of the lagging economic development type. The other cities are closer in ranking in terms of economic linkages and transport accessibility, and belong to the type of synchronization between economic and transport development. The opening and operation of high-speed railways has improved the constraints of traffic conditions on the economic development of Qingdao and Jinan and Dalian, and the gap between the ranking of traffic accessibility and economic linkages is narrowing, with Jinan, Qingdao and Dalian changing from lagging traffic development to synchronizing traffic and economic development. Dandong, Heze, Tieling and Yingkou are of the lagging economic development type.

This shows that when the demand for inter-regional economic links is lower than the level of accessibility, this results in a certain degree of waste of transport resources in the region and

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does not give full play to the role of transport in driving economic development. It can be seen that the demand for regional economic links and transport accessibility are mutually constrained and influenced by each other, and only when the two are mutually promoted can the coordinated development of the regional economy be promoted.

5. Conclusion and Recommendations

5.1. Conclusion

1.Spatial Analysis of Transport Accessibility in the Bohai Sea Rim Region.

The accessibility of the Bohai Sea region is characterized by a clear centrer-periphery structure, with higher accessibility levels concentrated in Jinan, Lucian and the Beijing-Tianjin-Hebei metropolitan area, while accessibility levels gradually decrease towards the periphery, especially in the Weihai region of Shandong Province and the Dandong region of Liaoning Province, which are peripheral areas with low accessibility by road.

2. Analysis of regional economic linkages around the Bohai Sea.

The total economic linkages of the Bohai Sea region are divided into three main gradients. The first gradient is the ultra-high value zone, mainly cities such as Beijing, Tianjin, Langfang, Jinan, Qingdao, Shenyang and Shijiazhuang, which have a large number of super cities, are clearly central in the region and have a wide radiation range. The second gradient is the medium and high value zone, mainly in the south of Hebei Province and Shandong Province. Although there are no mega-cities in this region, the time and distance costs between cities are low and inter-city links are strong, driving economic development. The third gradient is the low value area, which mainly includes the Bohai Sea region of Liaoning Province (excluding Shenyang and Dalian), which is at the edge of the region, with low land accessibility and low economic linkages with the region. The influence of land accessibility on the city's economy is well illustrated, as is the fact that areas with better economic development will in turn promote transport development.

3. Analysis of the degree of coordination between transport accessibility and regional economic coupling.

The coupling and coordination between transport accessibility and regional economy in the Bohai Sea region are in an uneven state of development, with Beijing, Tianjin, Hebei and western Lucian cities such as Jinan having a relatively good coupling and coordination, showing a decreasing feature from the center to the periphery. The northeastern region of Liaoning and the eastern region of Shandong, which are located at the edge of the region, have a disproportionate degree of coupling and coordination. As a whole, the level of economic development in most regions is higher than the level of transport accessibility, indicating that the construction of transport infrastructure lags behind the development of the economy and restricts economic development.

5.2. Recommendations

1. Strengthen the construction of transportation networks in the Bohai Rim and optimize the structure of transportation networks.

2. Further enhance the radiation capacity of central cities and drive the economic development of neighboring cities.

3. Formulating differentiated transport policies to drive the development of peripheral cities.

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