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Research on Coordinated Development of Traffic Accessibility and Urban Economy under the Background of High-speed Rail Network

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Abstract: In order to promote the coordinated development of traffic accessibility and urban economy under the background of high-speed rail network, the weighted average travel time, economic potential index, total economic linkages and coupling coordination degree were taken as the measurement indexes. Taking Jiangsu Province as an example, the high-speed rail traffic accessibility, the coupling coordination degree between the traffic accessibility and urban economy were quantitatively measured. The results showed that the average coordination degree between high-speed rail accessibility and urban economy in Jiangsu Province was 0.6568, which meant a medium level of coordination. However, the degrees of coupling coordination between high-speed rail traffic accessibility and urban economy of different cities in Jiangsu Province were unbalanced, different countermeasures should be adopted for cities with different coordination levels. Specifically, the coupling coordination degrees of Suzhou, Wuxi and Changzhou in southern Jiangsu were at a high level of coordination, and the economic radiation of the three central cities should be further enhanced. The coordination levels of Nanjing, Zhenjiang and Yangzhou in central Jiangsu were moderate, and the three cities' strength of economic ties with other cities should be established and enhanced; the coordination levels of Xuzhou, Suqian, Huai'an and Yancheng in northern Jiangsu were low, the coordination state of Taizhou and Nantong was mild disorder, the construction of transportation facilities of the these cities should be strengthened and the intensity of accepting the economic radiation of the core cities should be improved.

1. Introduction

With the continuous improvement of high-speed rail network, the interaction between regional transportation and urban economy is increasing gradually. As the important ways of inter-regional economic contact, high-speed railways have created differentiated economic activity space for different cities and promoted the evolution of regional economic pattern by changing the traffic

accessibility [1]. The high-speed rail traffic accessibility has an important impact on the regional economy and the high-quality development of the region. It is urgent to evaluate the coupling coordination relationship between traffic accessibility and urban economy for the coordinated development between transportation and economy, so as to take corresponding coordination countermeasures according to different coordination levels.

The concept of traffic accessibility was proposed and defined by Hansen in 1959 [2], which meant the possibility of interaction between nodes in the traffic network. With the deepening of related research, the quantitative measurement of traffic accessibility and its relationship with regional economic development have attracted more and more attention. For example, the impact of high-speed rail accessibility on local economy [3] and the promoting effect of high-speed railway on the tourism economy of cities along the railway [4] were studied. In recent years, many scholars used weighted average travel time, economic potential index, coupling coordination degree and other indicators to carry out researches. According to the geographic range, the research objects were distributed at different levels. At the national level, it was believed that the impacts of traffic accessibility on the high-quality economic development of different cities were heterogeneity [5]. At the provincial level, the coupling relationship between traffic accessibility and economy in Sichuan Province and Shandong Province were respectively analyzed [6-7]. At the regional level, the impact of intercity rail transit accessibility in the Guangdong-Hong Kong and Macao Greater Bay Area on urban economic development was studied [8]; and the coupling coordination degree between traffic accessibility and urban economy in Chengdu-Chongqing region was analyzed [9]. At the municipal level, for example, the coupling coordination degree between traffic accessibility and economy in Shenyang was calculated [10].

In summary, the above mentioned research has served as the basis and reference of this study. However, the existing studies mainly focused on the interaction between transportation and economy. Less attention was paid to consider different coordination countermeasures for cities with different coupling coordination levels. In addition, there were few reports on the relationship between the high-speed rail traffic accessibility and urban economy in Jiangsu Province. Thus, the research gap exists. The Jiangsu Province was taken as an example in this paper, the coupling and coordination relationship between traffic accessibility and urban economy under the background of high-speed railway was measured, and some suggestions were proposed to promote the coordinated development of provincial high-speed rail transportation and economy.

2. Materials and Methods

2.1. General Information

In recent years, the high-speed railway network in Jiangsu Province has developed rapidly, and the network layout was increasingly perfect. As one of the important provinces of the Yangtze River Delta, Jiangsu belonged to the first pilot provinces in China to build a strong transportation country, and its transportation infrastructures were relatively complete. In terms of high-speed rail transportation, the operational high-speed rail lines in Jiangsu province included Shanghai-Nanjing, Beijing-Shanghai, Nanjing-Hangzhou, Nanjing-Xi'an, Zhengzhou-Xuzhou, Xuzhou-Yancheng, Lianyungang-zhenjiang, Yancheng-Nantong and Lianyungang-Xuzhou. So far, a new pattern of "connecting Longhai in the north, Shanghai-Nanjing in the south, Beijing-Shanghai in the west and Jianghai in the east" has been formed.

In addition, Jiangsu Province was located in the Yangtze River Economic Belt, the overall economy was active, and the provincial economic comprehensive competitiveness ranked the forefront of the country. The GDP of Jiangsu Province reached to 1,1636.42 billion yuan in 2021, with an increase of 8.6% over that in 2020. However, the urban economic development in different

regions of Jiangsu Province was not balanced. The GDP and per capita GDP of cities in southern Jiangsu were the highest in recent years, followed by the cities in northern and central Jiangsu.

2.2. Methods

2.2.1. Measurement Index of Traffic Accessibility

The traffic accessibility was defined as the convenience degree of transportation from one city to another in Jiangsu province via high-speed railway in this paper. The weighted average travel time was taken as the evaluation index to measure accessibility between two cities. The calculation formula was $A_i = \sum_{j=1}^{n}(T_{ij} \times M_j) \Big/ \sum_{j=1}^{n} M_j$. A_i was the weighted average travel time of city i. The lower its value is, the higher the traffic accessibility level is, and vice versa. T_{ij} was the shortest travel time needed to reach the city j by high-speed railway; n was the total number of cities except city i in the study area; M_j was the amount of social and economic factors of the city j, $M_j = \sqrt{G_j \times P_j}$; G_j represents the gross domestic product of the city j; P_j was the population of the city j.

2.2.2. Measurement Indexes of Economic Connection Quantity

The economic potential index, economic relation force and total economic linkages were selected as indexes to reflect the ability of urban economic development. The economic potential index PA_i of the city i could be calculated according to formula $PA_i = \sum_{j=1}^{n}(M_j / T_{ij}^{\theta})$, in which the distance decay parameter θ was usually set as 1 in the evaluation of economic potential. Generally, the economic relation force R_{ij} between city i and city j could be calculated through the modified gravity model, the formula was $R_{ij} = (\sqrt{P_i \times G_i}\sqrt{P_j \times G_j}) / T_{ij}^2$. And the total economic linkages R_i of the city i j could be calculated according to formula $R_i = \sum_{j=1}^{n} R_{ij}$.

2.2.3. Evaluation Model of Coupling Coordination Degree

The coupling degree of traffic accessibility and urban economy could be calculated though formula $C_i = 2\sqrt{(A_i \times R_i)/(A_i + R_i)^2}$. A_i was the weighted average travel time of city i, which was the system value of traffic accessibility; R_i was the total economic linkages of city i, which was the system value of the city economy. However, the coupling degree could not fully reflect the coordination effect between traffic accessibility and urban economy, therefore, it was necessary to measure the coupling coordination degree. And the calculation formula was $D_i = \sqrt{C_i \times U_i}$, $U_i = \alpha A_i + \beta R_i$. D_i was the coupling coordination degree between traffic accessibility and urban economy of city i; C_i was the coupling degree of city i; U_i was the comprehensive evaluation index of the coupled coordinated development level; α and β were respectively the weight coefficient of traffic accessibility and urban economy in the coupled system. The original values of A_i and R_i need to be dimensionless when calculating the coupling degree and coupling coordination degree. The coupling coordination degree was divided into the following six levels, $D \in [0.8,1]$ indicated high level coordination, $D \in [0.6,0.8)$ indicated moderate level coordination, $D \in [0.5,0.6)$ indicated mild level coordination, $D \in [0.4,0.5)$ indicated mild level disorder, $D \in [0.2,0.4)$ indicated moderate level disorder and $D \in (0,0.2)$ indicated severe level disorder.

In the research process, the data source of T_{ij}^{H} was the official website of railway 12306.cn. If there was no direct high-speed rail between city i and city j, the statistics were based on the shortest travel time of the transfer high-speed rail, and the transfer time was calculated as 30 minutes. The data source of T_{ij}^{R} was amap.com. The data source of G_i and P_i for each city was the "2021 Statistical Yearbook of Jiangsu Province".

3. Results and Discussion

3.1. Analysis of High-Speed Railway Traffic Accessibility

Based on the statistical data, the weighted average travel times of 13 cities in Jiangsu Province under the condition of high-speed railway were calculated. And the accessibility coefficients were calculated, which referred to the ratio of an accessibility index of a city to the average value of the index of all cities in the network. As shown in Table 1, the average accessibility of high-speed railways in Jiangsu Province was 66.18 minutes. Among the 13 cities, Yangzhou had the best high-speed rail accessibility, and it's A_i of high-speed rail was 68.28 minutes. Followed by Zhenjiang, Changzhou. Taizhou had the lowest high-speed rail accessibility in the province, it's A_i was 138.17 minutes, which meant that the weighted average travel time for people in Taizhou was about twice as long as that for people in Yangzhou. According to the accessibility coefficient, the accessibility level presented regional non-equilibrium. In southern Jiangsu, 80% of the cities' traffic accessibility level was higher than the provincial average level. In central Jiangsu, the high-speed rail accessibility level was the lowest. In northern Jiangsu, 80% of the cities' traffic accessibility level were lower than the provincial average level.

Table 1: The high-speed railway traffic accessibility of Jiangsu Province

Region	Southern Jiangsu					Central Jiangsu		
City	Nanjing	Wuxi	Changzhou	Suzhou	Zhenjiang	Yangzhou	Taizhou	Nantong
Traffic accessibility(min)	98.38	93.14	76.93	112.29	70.63	68.28	138.17	131.51
Accessibility coefficient	0.96	0.91	0.75	1.10	0.69	0.67	1.35	1.29
Region	Northern Jiangsu					Average		
City	Xuzhou	Suqian	Lianyungang	Huai'an	Yancheng			
Traffic accessibility(min)	108.87	107.63	121.72	79.75	122.223	102.27		
Accessibility coefficient	1.06	1.05	1.19	0.78	1.20	1		

3.2. Analysis of Economic Linkages

The economic potential index and the total economic linkages of each city were calculated, as shown in Table 2. In terms of the total economic linkages, Suzhou, Wuxi and Changzhou were firmly ranked among the top three in Jiangsu Province under the condition of high-speed rail. Especially after the operating of high-speed railway, the sum of the three cities' total economic linkages accounted for 58.99%. It was shown that these three cities had the strong ability to influence the economies of other cities. Nanjing and Zhenjiang ranked in the top five, they also occupied the important position in economic ties with other cities. Taizhou, Nantong and other cities in northern Jiangsu had relatively small total economic linkages, indicating that these cities

were in the relatively passive position in the economic development, which was very consistent with the reality of urban economic development.

Table 2: Economic linkage indexes under the condition of high-speed railway

Region	Southern Jiangsu					Central Jiangsu	
City	Nanjing	Wuxi	Changzhou	Suzhou	Zhenjiang	Yangzhou	Taizhou
Economic potential index	331.77	572.88	707.13	400.5	767.59	486.19	245.58
Total economic linkages	23784.76	68784.52	61769.93	62349.64	35937.8	18653.35	4151.80
Region	Central Jiangsu	Northern Jiangsu					Average
City	Nantong	Xuzhou	Suqian	Lianyungang	Huai'an	Yancheng	
Economic potential index	248.95	282.53	346.86	269.28	433.94	301.61	414.99
Total economic linkages	8707.27	9636.85	8176.36	3897.72	11585.80	9557.59	25153.34

3.3. Analysis of the Coupling Coordination Degree

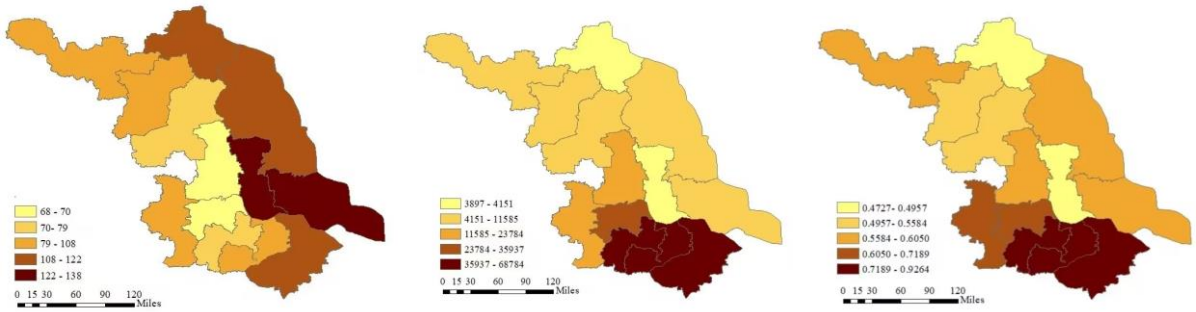
Transportation and economy were regarded as equally important in this paper, then the coupling coordination degree between land traffic accessibility and urban economy under the two kinds of land transportation conditions were calculated. As shown in Table 3, the provincial average value of coupling coordination degree under high-speed railway condition was 0.6568, which belong to the middle level coordination. Due to the differences in the number of high-speed rail routes and high-speed rail frequency in different cities, the coordination degrees of Wuxi, Changzhou, Suzhou and Zhenjiang were relatively higher than that of the other 9 cities. Under the condition of high-speed rail, the coordination degree of southern Jiangsu was mainly at a medium-high level, while the coordination degree of central Jiangsu and northern Jiangsu were mostly at a medium-low level. Taizhou and Lianyungang were affected by the geographical location and the scarcity of high-speed rail routes, and the accessibility of high-speed rail were slightly out of balance with their economy.

Table 3: Coupling coordination degrees between traffic accessibility and economy

Region	Southern Jiangsu					Central Jiangsu	
City	Nanjing	Wuxi	Changzhou	Suzhou	Zhenjiang	Yangzhou	Taizhou
Coordination degree	0.7044	0.9061	0.8409	0.9264	0.7189	0.6050	0.4957
Coordination Level	Middle	High	High	High	Middle	Middle	Mild disorder
Rank	5	2	3	1	4	6	12
Region	Central Jiangsu	Northern Jiangsu					Average
City	Nantong	Xuzhou	Suqian	Lianyungang	Huai'an	Yancheng	
Coordination degree	0.5892	0.5764	0.5516	0.4727	0.5584	0.5921	0.6568
Coordination Level	Low	Low	Low	Mild disorder	Low	Low	Middle
Rank	8	9	11	13	10	7	—

3.4. Further Discussion Based on the Heat-Maps

According to the data in Table1-3, ArcGIS10.8 was used to draw the Heat-Maps of the high-speed rail accessibility, the total amount of economic linkages and the coupling coordination degrees of 13cities in Jiangsu Province. As shown in Figure 1(a), the high-speed rail accessibility of western cities in Jiangsu was higher than that of eastern cities. As shown in Figure 1(b), after the operating of high-speed rail, the total amount of economic linkages of Suzhou-Wuxi-Changzhou were the highest, followed by Nanjing and Yangzhou, and the total amount of economic linkages of Taizhou, Nantong and Lianyungang were the lowest. As shown in Figure 1(c), the coupling coordination degree was higher in the southern Jiangsu than that in other regions of Jiangsu. The coordination degrees in southern Jiangsu were mainly of medium and high levels, the coordination degrees in central Jiangsu except Taizhou were mostly of medium levels, while the coordination degrees in northern Jiangsu were generally low levels.



(a) high-speed rail accessibility (b) total economic linkages (c) coupling coordination degree

Figure 1: Heat-Maps of the major measurement indexes

4. Conclusions and Suggestions

Under the background of high-speed rail network, the coordinated development of traffic and urban economy was an important problem affecting and restricting the high quality development of Jiangsu Province. The coupling coordination relationship between high-speed rail traffic accessibility and urban economy was taken as the research object in this paper. And the coupling coordination degrees between the high-speed railway traffic accessibility and urban economy of 13 cities in Jiangsu Province were measured. The conclusions were as follows:

(1) The high-speed rail traffic accessibility of Jiangsu Province was unbalanced. The high-speed rail accessibility in southern cities was better than that in northern cities.

(2) Under the background of high-speed rail network, the total economic linkages of Suzhou, Wuxi and Changzhou ranked the top in the province, followed by Nanjing and Zhenjiang, and Lianyungang was the lowest.

(3) The average coupling coordination level between high-speed rail accessibility and urban economy in Jiangsu Province was moderate. The coordination degrees of cities in southern Jiangsu belonged to the high level, coordination degrees of cities in the central Jiangsu belonged to the middle level, and coordination degrees of cities in the northern Jiangsu belonged to the low level.

The above conclusions provided some enlightenment for the relevant departments of transportation and economy. In order to promote the coordinated development between provincial transportation and urban economy, different countermeasures should be adopted for cities with different coordination levels. The suggestions were as follows:

(1) For cities with a high level of coupling coordination between traffic accessibility and urban economy, such as Suzhou, Wuxi and Changzhou in southern Jiangsu. It was suggested to focus on

further enhancing the economic radiation of their central cities. So as to give play to their core functions in the province, promote the orderly flow efficiency of all kinds of resources, and improve the level and quality of population employment.

(2) For cities with a middle level of coupling coordination between traffic accessibility and urban economy, such as Nanjing, Zhenjiang, Yangzhou and other cities in central Jiangsu. It was suggested to further actively establish and strengthen economic linkages with other cities. So as to give full play to their leading role in the development of provincial economy, and promote the coordinated development of provincial transportation and economy by virtue of their advantaged geographical location.

(3) For cities with a low level of coupling coordination between traffic accessibility and urban economy, such as Xuzhou, Suqian, Lianyungang, Huai'an, Yancheng in northern Jiangsu, and Taizhou and Nantong in central Jiangsu. It was suggested to focus on strengthening the construction of transportation facilities and actively establish economic linkages with other cities. So as to improve the strength of accepting the economic radiation of core cities and vigorously promote economic development.

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