Improvement of Regional Spatial Interaction Based on Spatial Traffic System Accessibility: A Case Study in Shandong Province, China

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Abstract. In order to quantitatively analyze the spatial interaction among regions, a new approach on reconstruction of intercity spatial interactional model based on spatial traffic system accessibility was proposed in this paper. Multi-indicators were used to comprehensively measure urban quality instead of a single demographic or economic index. Time distance combined with traffic distance was made as the final distance instead of Euclidean distance. The coefficient of the model is modified considering the proportion of passenger quantity and freight capacity, and the shortest travel time and so on. And then an example of reconstruction of intercity gravity model in Shandong Province has been done. The results showed that Qingdao has the most comprehensive strength, while Jinan has the highest spatial interaction. Although the comprehensive development level of a city has a great influence on its radiation capacity, the accessibility of the transportation system between cities also plays a certain role. The results prove that traffic accessibility has a guide significance to the spatial interaction among regions, and the new model is fit for the actual than the older one. It is a reasonable and effective method to analysis and research the capability of spatial interaction among cities.

Keywords: Spatial interaction · Traffic system accessibility · Gravity model Shandong Province · City

1 Introduction

Cities are playing an important role in the regional and national development, as they are an agglomeration center of population, political, economic and cultural center. Since the 21st century, cities have entered a stage of rapid development in China, and the engine role they are playing has become more prominent in regional and national development. There are three expressions of urban spatial interaction, including urban attraction, urban radiation, and urban intermediation. They are important indicators used to measure the strength of urban spatial interaction. Spatial interaction refers to the mutual transmission process of population, commodity and information, technology,

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capital, labor and other factors occurring between regions [1]. And separated regions are combined into an organism with certain structure and function by spatial interaction [2]. The processing of spatial interaction is extremely complex. In the main body of the role, including cities and regions, it should also include commercial outlets, cultural facilities, green gardens and other service facilities within cities and regions; in the form of role, it is expressed as an exchange, connection and interaction, usually A kind of action is also expressed; in the geographical space, it is integrated into the division of the geographic entity's action space, which can be expressed by attracting ranges [3].

In a region, spatial flows such as people flow, logistics, information flow, technology flow, and capital flow occur frequently, in two-way or multi-directional flow. This has an important impact on the structure, function and development of regions. The spatial interaction has the characteristics of distance attenuation, and then Newton's universal gravitation formula was used to express the interaction [4]. In 1929, Reilly WJ conducted a field trip to more than 200 urban trade markets in Texas and then proposed the "retail gravity model" (also known as the "Ryley model"). In this model, the number of retail customers is proportional to the size of the urban population, and is inversely proportional to the distance of retail customers to the trade market. This model was used to divide the boundaries of retailers' control market in geospatial space [5, 6]; Next year, Converse P.D proposed the concept of breakpoint based on the Reilly model. This concept was used to determine the extent of space impact and to divide economic zones [7, 8]. In 1964, Huff D.L. proposed the Huff model based on large-scale retail stores. This model is used to measure the likelihood that a consumer is to spend in retail stores at a particular location [9]. In 1967, Wilson A.G. derived a gravity model from the theory of maximum entropy for quantitative analysis of interaction strength [10]. In 1991, Wang et al explained the spatial interaction as the macroscopic representation of population, information, capital, etc. in the two-dimensional space, and proposed the oral particle model to describe the spatial interaction [3, 11]. In the past, the distance in the model was directly expressed by the spatial Euclidean distance, not considering the importance of accessibility to population, goods, and capital flows. Due to the imbalance of social and economic development, the flow of people, goods and money between regions is more dependent on the transportation system [12]. The higher the accessibility of the transportation system is, the more convenient the connection between the two places is. The traffic system accessibility refers to the convenience of reaching a place of activity from a given location by traffic system [13]. Hansen first proposed the concept of reachability, defined it as the opportunity of interaction between nodes in the traffic network, and used gravity method to study the relationship between accessibility and land use in cities [14, 15]. The related indicators include distance, time, cost, etc. [16]. The model distance parameter is modified by the weight, time cost, and monetary cost of various modes of transportation between the two places [1, 4] to express the conventional distance in some studies [17]. However, both time distance and cost distance are difficult to accurately acquire and measure, and sometimes contradictory [18, 19]. For example, in terms of ground transportation, high-speed rail is the fastest means of transportation, but the corresponding travel cost is also very high [20]. Dong et al. [12] took this problem into consideration, and used the traffic volume and other indicators to correct the distance parameters. At the same time, the interaction coefficient was improved by using the comprehensive traffic indicators such as daily average train times and shortest travel time.

Although the gravitation model is used widely now, but it is still just a basic model converted over from the Formula of universal gravitation [21]. In order to reflect influence the characteristics, rules and influential factors of urban influence, it should be amended. Based on the research results of Dong et al. [12], to better reflect urban influence of Shandong Province, we do some revision and reconstruction the quality, distance and coefficients of gravitation model and build the potential model to reflect the membership degree of the urban influence. In this paper, revision model and empirical analysis were made based on the traditional spatial interaction model according to the special traffic conditions in the study area (Shandong Province), and then the externalities of various cities in Shandong Province was calculated. In order to reflect influence the characteristics, rules and influential factors of urban influence, it should be amended. To better reflect urban influence of Shandong Province, on the base of the law of gravitation, affected by lots of comprehensive factors, we do some revision and reconstruction the quality, distance and coefficients of gravitation model and build the potential model to reflect the membership degree of the urban influence. Then we define the strength and direction of urban influence area and make analysis for spatial influence variance. In addition, the rationality and feasibility of the modified model are proved by comparing with the analysis results of the traditional spatial interaction model.

2 Reconstructing the Gravitation Model for Urban Spatial Interaction

The gravitation model is a spatial interaction model used widely, which is the mathematical equations that can be used to analyze and predict the form of spatial interaction. It has been continuously used to study urban influence.

In 1687, Newton put forward the famous gravitation model in physics. Namely, the interaction between any two objects (gravitation) in size is proportional to its mass and inversely proportional to the square of the distance.

The research status for the gravitation model and the urban region circumstance was analyzed in this paper, and the quality, distance and coefficients of gravitation model were revised and reconstructed.

$$F = \frac{K_{ij} M_i M_j}{d^2} \tag{1}$$

The city, as a principal part of the economic activity, has various influencing factors. It is apparent unconvincing to use urban GDP and the total urban populations to evaluate urban development level, especially for some of the characteristic economic cities. These measuring approaches caused limitations and deviations. Therefore, a number of cities have started to be focused on assessments of the importance of urban comprehensive quality currently. Twenty three key indicators of 17 prefecture-level cities of Shandong province were selected in this paper by using PCA algorithm to get urban quality (M).

It is more complicated to determine the coefficient of gravitation model. In general, to simplify model calculation, research scholars regard the coefficient of gravitation model as a constant that is 1. To be better improving the model performance, the urban influence coefficient was modified as follow:

$$K_{ij} = \varphi\left\{\frac{H_i}{\sum_i^j H} + \frac{C_i}{\sum_i^j C}\right\} \tag{2}$$

Where, φ is assumed urban conversion coefficient between comprehensive quality and volume of traffic, and represented in comprehensive strength and the total value of passenger and freight traffic of each city; H_{i} represents cargo of the *i*st city; C_{i} represents the passenger volume of the *i*st city.

With all the modern means of transport development, urban road network accessibility between the existing situations between the influences of urban factors. So that the railway line in Shandong Province on behalf of the city can be basically the link between the influences. The distance *d* was regard as the average Shortest time (hours) by EMU.

3 The Processing of Measuring Urban Spatial Interaction

3.1 Quality of Urban Integrated Assessment Model

In this paper, several initial indicators were selected from the Shandong Statistical Yearbook. Then Pearson correlation analysis and principal component analysis methods were used to eliminate correlations and the indicators with a commonality less than 0.9. These 23 indicators that meet the conditions are used to comprehensively measure the quality of cities in Shandong Province.

(1) Select Initial Variables According to the Research Topic (n = 17, p = 23).

$$X = \begin{vmatrix} X_{11} & X_{12} & \cdots X_{1p} \\ X_{21} & X_{22} & \cdots X_{2p} \\ \cdots & \cdots & \cdots \\ X_{n1} & X_{n2} & \cdots X_{np} \end{vmatrix} \tag{3}$$

(2) Normalize the raw data with Z-score method formula, on the one hand is to eliminate the effect on the analysis results that the different indicators have different dimension, and on the other hand is to eliminate the impact that different indicators have different magnitudes with the analysis results;

$$Z_{ij} = \frac{X_{ij} - \bar{X}}{S_j^2} \tag{4}$$

Where, $\overline{X} = \frac{\sum_{i=1}^{n} X_{ij}}{n}$ is the mean For the J*th* variable, $S_j^2 = \frac{1}{n}\sum_{i=1}^{n}(X_{ij} - \overline{X_j})^2$ is the sample variance for the J*th* variable. The results standardized (omitted).

(3) Solve the correlation coefficient matrix. According to the relationship established by analyzing the original variable characteristics, the formula below:

$$R = (r_{ij})_{p*p} \tag{5}$$

Which $r_{ij} = \frac{1}{n}\sum_{i=1}^{n} Z_{ki}Z_{kj}$, Where i = 1, 2, 3…; j = 1, 2, 3, …

(4) Calculate eigenvectors and eigenvalues for the correlation coefficient matrix. The principal component matrix can explain the meaning of each composite factor (principal component). The first principal component mainly reflects urban economic development level; the second component mainly reflects the social development level of each city; the third component mainly reflects the urban natural resource status; the fourth component reflects the urban location conditions. For the verification, the above-mentioned four principal component factors were extracted. From the obtained results, the contribution rate of the factors (principal component) has exceeded 85%, so the above four principal components are sufficiently representative (Table 1).

Table 1. Eigenvalue, principal component and the cumulative rate of the principal component

		Initial eigenvalues		Extraction sums of squared loadings		
Component	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1.000	13.084	56.887	56.887	13.084	56.887	56.887
2.000	4.655	20.240	77.127	4.655	20.240	77.126
3.000	2.325	10.108	87.235	2.325	10.108	87.234
4.000	1.213	5.272	92.507	1.213	5.272	92.506
5.000	0.561	2.437	94.944			
6.000	0.371	1.614	96.558			
7.000	0.235	1.023	97.581			
8.000	0.184	0.800	98.381			
9.000	0.112	0.488	98.869			
10.000	0.091	0.396	99.265			
11.000	0.071	0.308	99.573			
12.000	0.050	0.217	99.790			
13.000	0.023	0.099	99.889			
14.000	0.019	0.081	99.970			
15.000	0.052	0.023	99.993			
16.000	0.015	0.064	100.000			
17.000	0.044	0.019	100.000			
18.000	0.037	0.016	100.000			
19.000	0.023	0.010	100.000			
20.000	0.055	0.024	100.000			
21.000	0.040	0.018	100.000			
22.000	−0.025	−0.011	100.000			
23.000	−0.038	−0.017	100.000			

(5) Carry out the linear combination to gain the comprehensive evaluation indicators function, with the variance of each principal component contribution rate as a weight, calculate the integrated scores for each principal component, and test the reliability of the scores.

(6) Array the scores according to the value and the load factor matrix tested in the sixth step. Then take a comprehensive evaluation for the 23 economic indicators for these cities (Table 2).

Table 2. Urban comprehensive quality in Shandong

Ranking	City	Quality value	Ranking	City	Quality value	Ranking	City	Quality value
1	Qingdao	100	7	Jining	29.57	13	Liaocheng	14.56
2	Jinan	70.47	8	Weihai	20.32	14	Binzhou	12.76
3	Yantai	52.62	9	Tai'an	19.17	15	Zaozhuang	11.07
4	Weifang	44.88	10	Heze	16.58	16	Rizhao	8.86
5	Linyi	34.78	11	Dongying	15.92	17	Laiwu	0.85
6	Zibo	30.98	12	Dezhou	15.5			

3.2 Correction of the Coefficient for Urban Influence

The route and navigation data in Shandong Province are difficult to obtain. Therefore, according to the regional accessibility characteristics, the transportation system composed of train and automobile in the reconstruction of spatial interaction model were mainly considered in this paper. The urban road and traffic data [22] in 2015 for 17 cities in Shandong was collected. According to the formula (2), the coefficient K_{ij} was calculated. Moreover, the final coefficients were calculated by the coefficients K_{ij} multiplied with 100. The coefficient of gravitation model was as follows (Table 3):

Table 3. The coefficient of gravitation model

City	Coefficient	City	Coefficient
Jinan	3.869	Heze	0.324
Qingdao	2.378	Weihai	0.233
Zibo	1.108	Dezhou	0.230
Yantai	0.860	Tai'an	0.172
Jining	0.837	Liaocheng	0.131
Linyi	0.794	Laiwu	0.039
Weifang	0.724	Dongying	0.022
Rizhao	0.697	Binzhou	0.010
Zaozhuang	0.569		

Table 4. The economic distance among cities in Shandong province

Cities	Qingdao	Jinan	Yantai	Zibo	Weifang	Weihai	Dongying	Linyi	Jining	Tai'an	Zaozhuang	Binzhou	Dezhou	Liaocheng	Rizhao	Heze	Laiwu
Qingdao	0	2.44	4.12	1.68	1.08	5.87	4.91	4.19	7.39	3.3	4.8	5.2	3.48	8.47	7.6	9.18	5.11
Jinan		0	6.39	0.66	1.25	8.26	3.3	4.08	2.7	0.7	2.18	12	1.05	2.06	5.73	4.25	3.85
Yantai			0	5.15	4.74	5	9.3	6.57	9.6	8.6	10.7	5.5	9.25	9.78	14.3	13.2	9.44
Zibo				0	0.57	7.07	2.43	6.7	3.95	1.5	3.03	1.5	1.81	3.71	8.37	5.87	4.03
Weifang					0	6.19	3.5	7.9	5.2	2.2	3.72	10.7	2.4	5.02	9.63	7.1	4.08
Weihai						0	9.23	7.87	11.1	9.4	10.8	6	10.6	11	13.8	12.9	11.3
Dongying							0	7.64	3.94	4.5	6.87	1	5.38	5.62	9.33	7.4	5.89
Linyi								0	3.17	3.4	3.65	4.3	6.25	7.27	1.61	4.71	4.53
Jining									0	1.8	5.51	4.75	4.92	3.47	4.68	1.57	5.7
Tai'an										0	1.47	4.5	1.61	4.88	11.9	3.4	1.38
Zaozhuang											0	4.5	2.88	6.28	5.18	3.86	2.83
Binzhou												0	2	4.5	4.5	10	4
Dezhou													0	3.18	7.63	4.41	2.75
Liaocheng														0	7.84	1.69	7.3
Rizhao															0	6.38	6.07
Heze																0	4.42
Laiwu																	0

3.3 Measuring the Impact of the Economic Distance Among Cities

The traditional concept of distance has being a serious challenge. In a region with convenient transportation, the time, transportation costs and currency costs were used to measure economic distance among cities gradually. In Shandong province, the urban railway lines is the main transport way, and most cities have the railway lines and national highway. First, the OD cost matrix analysis tool in ArcGIS10.2 software is used to calculate the traffic distance between two cities. The average shortest time (hours) by EMU from the one to another is showed below (Table 4).

4 Results and Analysis

According to the quality, distance and coefficient from the model of urban spatial interaction, gravitation model was constructed and the visualization results are shown as follows. Jinan, Qingdao, Zibo, Weifang have a greater potential, which form a city chain along Jiaoji railway. Jinan and Qingdao have the strongest spatial interaction, while Jinan has the highest comprehensive radiation level. Spatial radiation intensity in Laiwu and Binzhou are relative minimal. Jinan, as the political, cultural and technology education center of Shandong Province, is also a communications hub and the economic center of Midwest of Shandong Province. This city lies at the junction of the Jinghu, Jingfu, Jiqing, Jitai and Jiliao railways (Fig. 1).

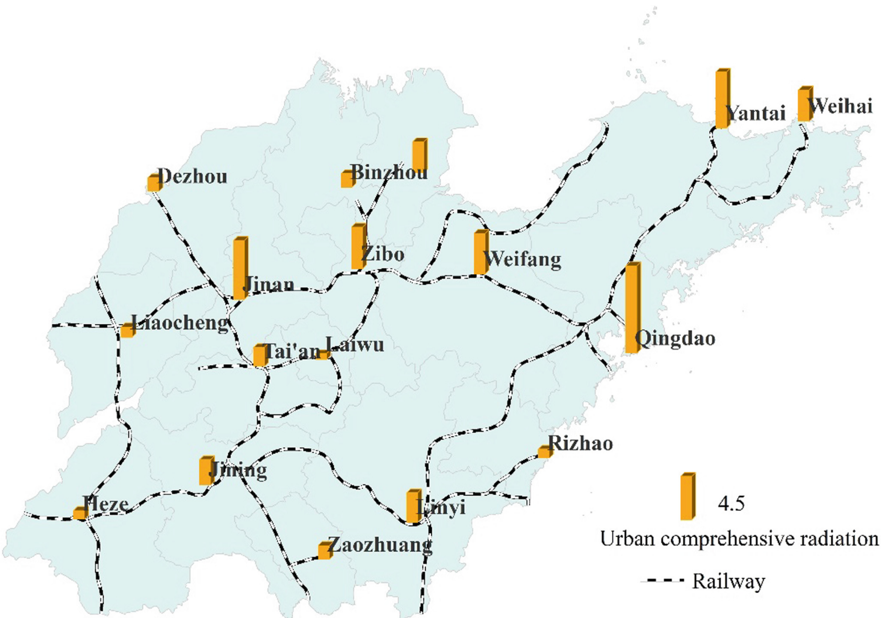

Fig. 1. The degree of the urban spatial interaction in potention model for 17 cities in Shandong province

Therefore, Jinan has a relative disperse influence among all the cities, but has the higher radiation on the cities along the Jiaoji railway. Qingdao is an international port and tourist city. As the development of modern manufacturing and modern services, Qingdao has a certain scientific research strength, so the spatial influence of Qingdao on other cities is also relative large. In Shandong province, four vertical and four horizontal trunk railways will be focused on and the railway will cover most cities, important ports and major industrial and mining enterprises. In addition, more facility construction in passenger and cargo hub of Jinan and Qingdao will be increased, and Qingdao, Rizhao and Yantai railway will be connected into three ports for accelerating the seamless transfer of passenger and cargo (Fig. 2).

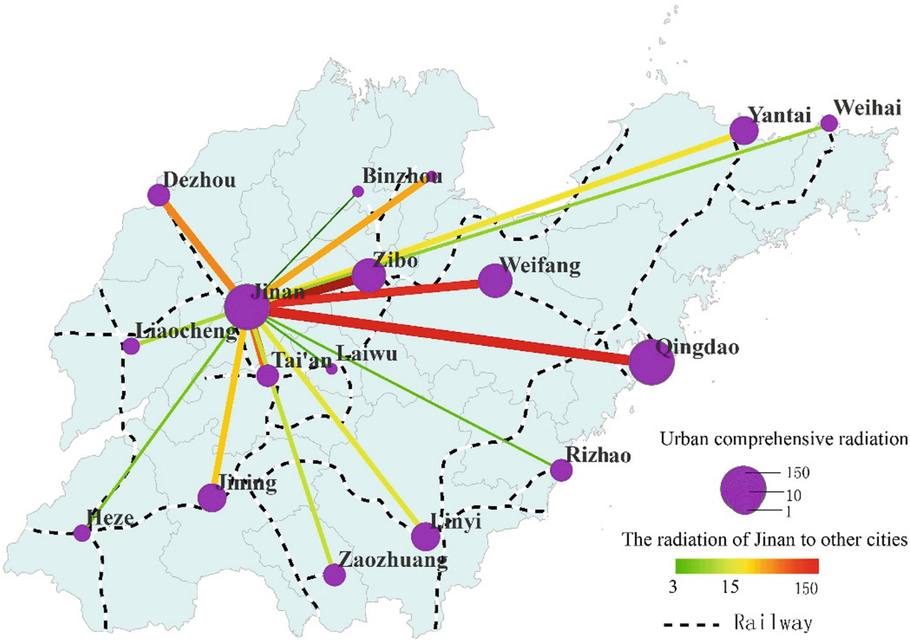

Fig. 2. The spatial interaction strength of Jinan to the other cities

5 Discussion and Conclusions

The distance parameter was modified and a new economic gravitation model was then reestablished with GIS technology. Seventeen municipalities in Shandong province were selected in this paper, and then the strength and direction of urban spatial influence and comparing the differences characteristics between them were measured. We can conclude that Qingdao has the most comprehensive strength, while Jinan has the highest spatial influence. And the factors which affect the strength and direction of cities were analyzed. The spatial orientation of the economic development for cities were made clear, and the links and cooperation in economic between cities coordinated and the channel of economic will be built. Besides for offering decision-making references for integration of urban space and spatial diffusion of outside space, the reference value for the development of urban regional integration and the plan to build urban spatial construction will be also provided. They are mainly characterized by the following:

Based on the gravity law, the various indicators were integrated and the model was reconstructed. The PCA algorithm was used to evaluate the urban comprehensive quality. This made up for the shortcomings of the previous model and the deviation caused by the single indicator measurement.

Urban influence and overall urban strength are closely related to the transportation system accessibility. The cities around Jiaozhou Railway and Intercity Railway have a strong spatial interaction. However, some important factors affecting the connection between cities are difficult to quantify, such as urban historical background, political factors, and urban structural characteristics. The scale of spatial interactions in each city varies widely. As a socio-economic entity, a city is different from a simple physical entity. The influence between cities varies with the size of the city and the strength of the city.

The spatial distance between cities is not the determining factor of the size of inter-city influence. Through this study above, Qingdao is closer to Weihai than Yantai. However, compared with the later, the degree of spatial interaction of Weihai is greater than the former. And we can see that the inter-city strength are affected by many factors, such as traffic conditions, resources, environment, population exchanges and others.

Transportation is the supporting system of regional economic linkages. The spatial interaction between cities satisfies the distance attenuation. The improvement of road network will increase the influence of the city on the strength and scope, and thus can determine the interaction of urban space in depth and width. The intensity of spatial interactions between cities increases with time and distance.

In this paper, the distance and space interaction coefficients are modified, and the urban spatial interaction model of Shandong Province is reconstructed, and the comprehensive radiation amount of 17 cities in Shandong Province is calculated. It can be seen from the results that the comprehensive radiation ranking of each city is not completely consistent with the urban quality ranking. That is to say, although the comprehensive development level of a city has a great influence on its radiation capacity, the accessibility of the transportation system between cities also plays a certain role. It can be seen from the study that urban influence is static, but it is different essentially. So we handle urban influences calculated as time series data, and we will evaluate scientifically the strength of urban influence in the later research. In the model reconstruction process, it is a thorny problem to amend the parameters. As for how to make the modified parameters better, more rational and more scientific in modeling reconstruction will be made in a further study.

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