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Research on Comprehensive Development Evaluation of Logistics and Construction of Hub-and-Spoke Logistics Network in Shaanxi Province

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Abstract
As one of the important nodes along the "Belt and Road" and the New Western Land-sea Corridor, Shaanxi Province attaches great importance to further optimizing the logistics network construction of its cities. Based on the logistics-related index data of cities in Shaanxi from 2012 to 2020, this paper analyzes the spatial development level of the logistics industry in the Province with the location Gini coefficient and the location entropy coefficient and comprehensively evaluates the logistics system development level of the cities in the Province with the entropy weight-TOPSIS method, thus deciding the hub cities and spoke cities. Relying on the gravity model and the membership model, this paper also calculates the gravity and membership of the hub cities and spoke cities and constructs the "five-hub-five-spoke" logistics network with Xi'an as the first-level hub, Baoji, Yulin, Xianyang, and Weinan as the second-level hubs, and Yan'an, Tongchuan, and Shannan as spoke cites, providing corresponding suggestions for Shaanxi Province on the New Western Land-sea Corridor construction.

Keywords: *Principal component analysis; Gravity model; Logistics network; New Western Land-sea Corridor*

1. Introduction

Shaanxi Province is an important part of the construction of the "Belt and Road" and the New Western Land-sea Corridor. Located in the Midwest of China, the Province is the only road for the transportation of goods between the east and the west. Therefore, Shaanxi attaches great attention to building a logistics network with large volume, high transportation efficiency, and low costs.

2. Calculation model building

i. Location Gini coefficient model

Location Gini coefficient is an important index to measure the clustering degree of an industry in a region, and it falls between [0,1]. The larger the value is, the more concentrated the logistics industry is. According to the research results of Dai Pingsheng[1], if W_i is sorted in ascending order, the calculation formula is:

$$G_W = \sum_{i=1}^{n} w_i \frac{2i-(n+1)}{n} \qquad (1)$$

Where G_W is the Gini coefficient of the logistics industry in Shaanxi Province, n is the total number of municipal units, and the industry share W_i represents the proportion of the city i 's industry scale of transportation, warehousing, and postal services in the total industry scale of Shaanxi Province.

Learning from Luo Yinchen [2]'s practices, the Gini coefficient is divided into the following four categories:

Table 1 Gini coefficient evaluation grade

Gini coefficient value	Evaluation grade
[0, 0.4)	Highly dispersed
[0.4,0.55)	Relatively dispersed
[0.55,0.7)	Relatively concentrated
[0.7,1]	Highly concentrated

ii. Location entropy model

Location entropy can reflect the concentration degree of industry in geographical space. It is an important index to

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measure the degree of specialization of an industry in a specific area. The calculation formula is as follows:

$$LQ_{ij} = \frac{e_i / e_j}{E_i / E_j} \quad (2)$$

where e_i is the added value of the logistics industry in region i, e_j is the GDP in region j, E_i is the added value of the logistics industry in Shaanxi Province, and E_j is the GDP in Shaanxi Province. The larger the locational entropy is, the higher the concentration degree of the industry in the region is, which means more obvious specialization advantages. Generally, the location entropy is divided into four levels:

Table 2 Location entropy evaluation grade

Location entropy interval	Evaluation grade
[0,1)	Low concentration degree
[1,1.5)	Relatively high concentration degree
[1.5, 2)	High concentration degree
[2, +∞)	Extremely high concentration degree

iii. Entropy weight-TOPSIS model

The entropy weight TOPSIS method is a commonly used comprehensive evaluation method. It makes full use of the original data to calculate the weights based on the entropy weight method and accurately reflects the gaps between various evaluation schemes by calculating the ideal and negative ideal solutions [4]. The calculation procedure is as follows:

(1). Data normalization processing

Let the matrix of a certain index be A, then the index matrix can be expressed as:

$$A = \begin{Bmatrix} f_{11} & f_{12} & \cdots & f_{1m} \\ f_{21} & f_{22} & \cdots & f_{2m} \\ \vdots & \vdots & \cdots & \vdots \\ f_{n1} & f_{n2} & \cdots & f_{nm} \end{Bmatrix} \quad (3)$$

Based on the index matrix A, a normalized index matrix Z' containing elements Z'_{ij} can be obtained, and

$$Z'_{ij} = \frac{f_{ij}}{\sqrt{\sum_{i=1}^{n} f_{ij}^2}} \quad i = 1, 2 \wedge, n; j = 1, 2, \wedge, m \quad (4)$$

(2) Weighting with the entropy weight method.

Based on the change scope of the indexes, the information entropy tool is used to calculate the weight of each index to provide the basis for the comprehensive evaluation of multiple indexes. The Z'_{ij} calculated from Formula (4) can determine the weights of different parameters in the system. If Q_x represents the information entropy of the index, γ_{xy} represents the weight of the y^th^ order parameter of the x ^th^ subsystem, and $1 = \sum_{x=1}^{m} \gamma_{xy}$, then:

$$Q_x = -k \sum_{i=1}^{m} (Z'_{ij} \cdot \ln Z'_{ij}) \quad (5)$$

$$w_y = 1 - Q_x \quad (6)$$

$$\gamma_{xy} = \frac{w_y}{\sum_{x=1}^{n} w_y} \quad (7)$$

(3) Determination of ideal and negative ideal solutions

The normalized matrix is solved by multiplying the index weight; the maximum product of each index is selected as the ideal solution, while the minimum product is the negative ideal solution. The calculation formula is as follows:

$$Z_{ij} = Z'_{ij} \cdot \gamma_{xy} \quad (8)$$

$$Z^+ = (Z_1^+, Z_2^+, \wedge, Z_m^+) = \left\{ \max_i Z_{ij} \;/\; j = 1, 2, \wedge, m \right\} \quad (9)$$

$$Z^- = (Z_1^-, Z_2^-, \wedge, Z_m^-) = \left\{ \min_i Z_{ij} \;/\; j = 1, 2, \wedge, m \right\} \quad (10)$$

The distance D^+ between the $i(i = 1, 2, \cdots, n)$ th evaluation object and the maximum value is defined as follows:

$$D^+ = \sqrt{\sum_{j=1}^{m} (Z_j^+ - z_{ij})^2} \quad (11)$$

The distance D^- between the $i(i = 1, 2, \cdots, n)$ th evaluation object and the minimum value is defined as follows:

$$D^- = \sqrt{\sum_{j=1}^{m} (Z_j^- - z_{ij})^2} \quad (12)$$

Finally, the relative proximity C_i of each scheme is calculated:

$$C_i = \frac{D_i^-}{D_i^+ + D_i^-} \quad (13)$$

4. Logistics gravity model and its membership model

The gravity model originates from the law of universal gravitation in physics and afterward has been gradually introduced into the research of human traffic, logistics, and information flow in the field of economics. It can measure the interaction forces in terms of logistics caused by goods exchange between cities [5]. The logistics membership represents the membership degree of a city node relative to another city node, which can reflect the influence scope of the urban logistics. Drawing on the research method of Tang Jianrong et al., this paper calculates the transportation distance between any two cities through the weighted average of different transportation modes, which can express the ways of goods exchange between the two cities more objectively. The calculation formula is as follows:

The "distance" between two cities is determined as follows:

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$$d_{ij} = \sum_{k=1}^{2} \lambda_k D_{ijk} \qquad (14)$$

Where k refers to the k[th] transportation mode between the two cities, D_{ijk} refers to the distance between city i and city j when the k[th] transportation mode is selected and λ_k refers to the proportion of the k[th] transportation mode.

The weight is calculated by the proportion of the freight volume corresponding to the k[th] transportation mode in the total freight volume of Shaanxi Province.

Gravity model calculation:

$$R_{ij} = GM_i M_j / d_{ij}^2 \qquad (15)$$

Where R_{ij} refers to the logistics gravity between two cities, G is the coefficient constant of logistics gravity between two cities (in practice, the coefficient constant has no effect on the result, so its value is 1), M_i, M_j is the logistics quality between two cities (in this paper, the result of the of entropy TOPSIS calculation is used), and d_{ij} is the distance between the two cities.

Membership model calculation:

$$P_{ij} = R_{ij} / \sum_{j=1}^{n} R_{ij} \qquad (16)$$

Where P_{ij} represents the membership degree between two cities and R_{ij} represents the strength of logistics gravity, which is calculated by Formula (15).

3. Empirical analysis

I. Spatial development level analysis of the logistics industry

(1) Location Gini coefficient analysis of Shaanxi Province

Based on the total industry volume of transportation, warehousing, and postal services in cities of Shaanxi Province from 2012 to 2020, this paper has calculated the location Gini coefficient index of Shaanxi Province as a whole, as well as that of the Guanzhong region, the northern part of Shaanxi Province, and the southern part of Shaanxi Province respectively from 2012 to 2020 with Formula (1), as shown in Table 3.

Table 3 Gini coefficients of Shaanxi Province as a whole and the regional logistics space

Year	2012	2013	2014	2015	2016	2017	2018	2019	2020
Shaanxi Province as a whole	0.479	0.479	0.516	0.596	0.586	0.589	0.584	0.599	0.611
Guanzhong region	0.481	0.467	0.514	0.586	0.572	0.572	0.559	0.568	0.573
Northern part of Shaanxi Province	0.088	0.064	0.030	0.142	0.057	0.085	0.108	0.089	0.069
Southern part of Shaanxi Province	0.231	0.239	0.241	0.248	0.231	0.228	0.227	0.227	0.217

Note: The Guanzhong region includes Xi'an, Xianyang (including Yangling District), Baoji, Weinan, and Tongchuan; the northern part of Shaanxi Province includes Yulin and Yan'an; the southern part of Shaanxi Province includes Hanzhong, Ankang, and Shangluo.

As can be seen from Table 2, the logistics industry has been becoming more and more concentrated in Shaanxi Province as a whole. From 2012 to 2014, the Gini coefficient of Shaanxi Province was between [0.4,0.55], indicating that the logistics industry in the Province was relatively dispersed during this period. From 2015 to 2020, the value was improved to [0.55-0.7], indicating that the logistics industry became relatively concentrated in the Province as a whole during this period. In 2015, the Shaanxi Provincial People's Government issued the *Medium and Long-term Plan for the Development of Logistics Industry in Shaanxi Province (2015-2020)* to accelerate the development of the modern logistics industry and actively blend into the construction of the "Belt and Road" and the New Western Land-sea Corridor. Shaanxi Province can be divided into three parts: the northern part of Shaanxi Province, Guanzhong, and the southern part of Shaanxi Province, depending on its unique geographical location. Cities in the Guanzhong region develop faster, and their Gini coefficients are highly correlated with that of Shaanxi Province; so, the region also stepped into the relative concentration stage as of 2015. By contrast, the spatial logistics industry is highly dispersed in both the northern part of Shaanxi Province and the southern part of Shaanxi Province mainly for geographical factors. Yan'an and Yulin have vast land but relatively poor industries. Although Yulin's energy industry is outstanding, its cargo collection and distribution system is relatively backward. The southern part of Shaanxi Province is mainly concentrated in the Qinling Mountains; accompanied by the relatively backward transportation is the high logistics and transportation costs.

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(2) Location entropy coefficient analysis of Shaanxi Province

Based on the total industry volume of transportation, warehousing, and postal services and the GDP index in cities of Shaanxi Province from 2012 to 2020, this paper has calculated the location entropy index of each city from 2012 to 2020 with the Formula (2).

Table 4 Location entropy index of cities in Shaanxi Province

Region	Xi'an	Xianyang	Baoji	Weinan	Tongchuan	Yulin	Yan'an	Hanzhong	Ankang	Shangluo
2012	1.518	0.779	0.820	1.018	1.280	0.375	0.270	2.039	1.480	1.332
2013	1.473	0.753	1.008	0.987	0.866	0.384	0.241	2.010	1.548	1.232
2014	1.585	0.704	0.879	0.906	0.779	0.388	0.208	1.852	1.397	1.113
2015	1.833	0.588	0.678	0.716	0.553	0.292	0.255	1.213	0.863	0.689
2016	1.752	0.713	0.670	0.786	0.638	0.342	0.203	1.227	0.865	0.770
2017	1.683	0.932	0.652	0.847	0.609	0.379	0.257	1.079	0.732	0.677
2018	1.606	1.199	0.697	0.930	0.703	0.406	0.246	1.007	0.720	0.605
2019	1.585	1.304	0.752	0.952	0.635	0.399	0.223	0.855	0.584	0.551
2020	1.541	1.411	0.765	0.848	0.613	0.360	0.192	0.761	0.497	0.524
Median	1.585	0.779	0.752	0.906	0.638	0.379	0.241	1.213	0.863	0.689
Trend	Downtrend	Uptrend	Uptrend	Uptrend	Downtrend	Uptrend	Downtrend	Downtrend	Downtrend	Downtrend

As can be seen from the table, the development level of the logistics industry in all regions fluctuated significantly from 2012 to 2020. Except for Xianyang, Baoji, Weinan, and Yulin, the location entropy of other cities, all showed a downtrend. Amongst others, Xi'an always maintained a locational entropy of above 1, indicating that the logistics industry in this region has a significant concentration effect. However, the region's entropy kept declining as of 2015 for two reasons. The first reason, also the major reason, was that the establishment of the Xixian New District was formally approved by the China State Council, which put most areas of Xianyang under the administration of Xi'an. The second reason is that the gradual dispersion of Xi'an's logistics industry towards the surrounding counties reduced the concentration effect. The location entropy of Xianyang increased year by year from 2015 and became greater than 1 in 2018, indicating that the logistics industry in this region has become more concentrated. Baoji and Weinan's logistics industry showed an upward trend, and their location entropy coefficients were close to 1, which also indicates that the logistics industry in this region is producing an agglomeration effect. Though adjacent to the provincial capital Xi'an, Tongchuan's agglomeration effect regarding the logistics industry is declining. As Tongchuan has a small geographical area and population and is greatly influenced by the provincial capital city, it is very difficult for the logistics industry to produce an obvious agglomeration effect in this region. The location entropy coefficient of the three cities in the southern part of Shaanxi province showed a significant decline from 2012 to 2020, which also means from agglomeration to dispersion. The location entropy coefficient of the two cities in the northern part of Shaanxi Province increased but was still at a low level; therefore, the region had never formed an agglomeration effect, and its spatial distribution of logistics industry is scattered and formed no industrial advantages.

II. Comprehensive evaluation of logistics system

This paper has collected the 2019 statistical yearbooks and statistical bulletins of 10 municipal units in Shaanxi Province and selected several indexes, including relevant economic development indexes, basic indexes of logistics development, logistics supply-demand level index, and informatization level index. Based on Formula (3) and Formula (4), this paper has normalized the original data and then, based on the normalized data, calculated the weights with Formulas (5)-(7). SPSSAU software has been used to do the calculations, as shown in Table 5.

Table 5 Indexes and weights for comprehensive evaluation of logistics system

First-level dimension	Second-level index	Weight
Economic development level	Gross regional product	0.0588
	Per capita gross regional product	0.0143
	Gross industrial output value above designated size	0.0337
	Fiscal revenue	0.0922
Logistics development basics	Freight volume	0.0425
	Rotation volume of freight transport	0.0575
	Length of highways in operation	0.0125
	Passenger volume	0.043
	Turnover of	0.0352

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	passenger traffic	
Logistics supply-demand level	Year-end permanent population	0.0351
	Number of logistics enterprises	0.1157
	Number of e-commerce enterprises	0.1948
Informatization level	Business value of post and telecommunications services	0.1545
	Internet users	0.0566
	Number of mobile phone users	0.0535

The weights are multiplied by the normalized data to select the maximum value as the ideal solution (Formula 9) and the minimum value as the negative ideal solution (Formula 10). Then, the distance between the i^{th} evaluation object and the maximum and minimum values is calculated by using Formulas (11) and (12). Finally, the comprehensive evaluation index of the logistics system of each city is calculated by substituting the above calculation results into Formula (13) and then ranked, as shown in Table 6:

Table 6 Comprehensive evaluation values of logistics systems in cities of Shaanxi Province

City	D^+	D^-	C_i
Xi’an	0.0214	0.2784	0.9286
Xianyang	0.2487	0.0452	0.1538
Baoji	0.2554	0.0385	0.1310
Weinan	0.2501	0.0474	0.1593
Tongchuan	0.2824	0.0070	0.0242
Yan’an	0.2587	0.0381	0.1284
Yulin	0.2435	0.0899	0.2697
Hanzhong	0.2635	0.0250	0.0865
Ankang	0.2677	0.0200	0.0695
Shangluo	0.2762	0.0111	0.0385

According to the table above, the comprehensive logistics evaluation ranking of the 10 cities in Shaanxi Province is as follows: Xi’an, Yulin, Weinan, Xianyang, Baoji, Yan’an, Hanzhong, Ankang, Shangluo, and Tongchuan.

Xi’an is the only city at the first level. It tops Shaanxi Province in terms of both the spatial development level of the logistics industry and the comprehensive development level of the logistics system and goes far ahead of other cities. It has built two international logistics hub ports (Xi'an Land Port and Xi'an AirPort), five regional hub logistics parks (Lintong, Jinghe New City, Fengdong New City, Huyi Qindu, and Changan Yinzhen), and 11 logistics centers (Xinfeng, Yanliang, Gaoling, Economic Development Zone, Qinhan, Sanqiao, Zhouzhi, High-tech Zone, Aerospace City, Baqiao, and Lantian). It has integrated the best resources in the Province to vigorously develop multimodal transport and speed up the construction of logistics channels, which marks that Xi’an has become an important logistics hub in the great Guanzhong region and even the great Northwest of China.

The second level includes four cities: Yulin, Weinan, Xianyang, and Baoji. Yulin is rich in coal resources. As an important energy and chemical logistics hub base in China, it has already built a nationwide coal logistics service network, which plays a very supportive role in promoting the development of Yulin’s logistics industry. As the second most populous city in Shaanxi Province, secondary to Xi’an only, Weinan has a huge logistics service market and also unique industries. It has formed a logistics enterprise cluster integrating a variety of ownership, a variety of service models, and a variety of levels. Located in the heart of the Guanzhong Region, Xianyang is a newly-emerging industrial city closest to Xi’an, the provincial capital of Shaanxi Province. It owns the largest fruit production and processing base and animal products production and processing base in Shaanxi and the advantageous resource Xi'an Xianyang International Airport, which makes the city an important link between the East and the West of China. Baoji is the geometric center and transportation hub city of the adjacent areas of Shaanxi, Gansu, Ningxia, and Sichuan. With an intricate road traffic network, it serves as the bridgehead for goods to go west.

The third level includes five cities: Yan’an, Hanzhong, Ankang, Shangluo, and Tongchuan. Compared with first-level and second-level cities, these cities have a lower level of economic development and relatively poor logistics infrastructure. Taking the location Gini coefficient, the location entropy coefficient, and the comprehensive evaluation indexes of the logistics system into account, this paper selects the third-level cities as spoke cities, Xi’an as the first-level hub city, and Yulin, Weinan, Xianyang, and Baoji as second-level hub cities.

III. Logistics gravity and membership analysis

According to the statistical yearbook of Shaanxi Province in 2020, the total freight volume of the Province reached 1,547.58 million tons, but 99% was contributed by railway transport and road transport, which indicates that the freight transport modes between cities in Shaanxi Province are dominated by road transport and railway transport. Therefore, this paper has selected the highway mileage and railway mileage between cities and calculated the weighted "distance" with the Formula (14), as shown in Table 7.

Table 7 Weighted "distance" between cities in Shaanxi Province

Region	Xi’an	Xianyang	Baoji	Weinan	Tongchuan	Yulin	Yan’an	Hanzhong	Ankang	Shangluo
Xi’an	-	27.0	171.9	67.3	99.8	591.4	319.9	263.0	219.0	138.5

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Xianyang	27.0	-	151.0	87.2	120.9	592.3	338.1	272.2	245.4	168.8
Baoji	171.9	151.0	-	237.1	259.8	731.2	477.0	205.0	388.8	315.8
Weinan	67.3	87.2	237.1	-	140.0	585.6	357.2	327.9	277.7	158.7
Tongchuan	99.8	120.9	259.8	140.0	-	497.7	249.5	340.9	303.3	211.3
Yulin	591.4	592.3	731.2	585.6	497.7	-	267.6	866.4	816.3	688.0
Yan'an	319.9	338.1	477.0	357.2	249.5	267.6	-	581.1	544.3	452.2
Hanzhong	263.0	272.2	205.0	327.9	340.9	866.4	581.1	-	223.0	389.2
Ankang	219.0	245.4	388.8	277.7	303.3	816.3	544.3	223.0	-	272.0
Shangluo	138.5	168.8	315.8	158.7	211.3	688.0	452.2	389.2	272.0	-

The logistics evaluation value calculated in Table 6 is then taken as the logistics "quality" and substituted into the Formula (15) to calculate the logistics gravity between cities in Shaanxi Province. To facilitate the calculation of the result data, the logistics "quality" value is enlarged by 10 times, while the weighted "distance" value is reduced by times. The calculation results are shown in Table 8.

Table 8 Logistics gravity between cities in Shaanxi Province

Region	Xi'an	Xianyang	Baoji	Weinan	Tongchuan	Yulin	Yan'an	Hanzhong	Ankang	Shangluo
Xi'an	-	196.30	4.12	32.62	2.26	0.72	1.17	1.16	1.35	1.86
Xianyang	196.30	-	0.88	3.22	0.26	0.12	0.17	0.18	0.18	0.21
Baoji	4.12	0.88	-	0.37	0.05	0.07	0.07	0.27	0.06	0.05
Weinan	32.62	3.22	0.37	-	0.20	0.13	0.16	0.13	0.14	0.24
Tongchuan	2.26	0.26	0.05	0.20	-	0.03	0.05	0.02	0.02	0.02
Yulin	0.72	0.12	0.07	0.13	0.03	-	0.48	0.03	0.03	0.02
Yan'an	1.17	0.17	0.07	0.16	0.05	0.48	-	0.03	0.03	0.02
Hanzhong	1.16	0.18	0.27	0.13	0.02	0.03	0.24	-	0.12	0.02
Ankang	1.35	0.18	0.06	0.14	0.02	0.03	0.03	0.12	-	0.04
Shangluo	1.86	0.21	0.05	0.24	0.02	0.02	0.02	0.02	0.04	-

As can be seen from Table 8, Xi'an holds an incomparable leadership position in terms of logistics gravity in Shaanxi Province. It has the largest two logistics gravity values with Xianyang and Weinan. Among them, the gravity between Xi'an and Xianyang reaches 196.30, with the distance between the two cities being the closest, only 27 km. The logistics gravity values between Xi'an and Baoji and between Xi'an and Tongchuan are in the third and fourth places, while that between Xi'an and Yulin, which is far away, is the smallest. For cities in the northern part of Shaanxi Province, as they are far away apart, the logistics gravity between them is relatively weak. For example, the logistics gravity between Yulin and Yan'an is only 0.48, which is far less than that between Xi'an and Xianyang and even smaller than that between Xi'an and Yan'an (1.17). However, as Yan'an is far distant from Xi'an, Yan'an is finally included in the common radiation range of Xi'an and Yulin. The logistics gravity value among the three cities of the Southern Part of Shaanxi Province is also weak, with that between Hanzhong and Ankang being the largest, 0.12, and that between Hanzhong and Shangluo being 0.02 only.

The logistics gravity value from Table 8 is then substituted into the Formula (16) to calculate the logistics membership value between cities, as shown in Table 9.

Table 9 Logistics membership between hub cities and spoke cities in Shaanxi Province

Region	Xi'an	Yulin	Xianyang	Weinan	Baoji
Yan'an	0.5533	0.2297	0.0821	0.0761	0.0351
Hanzhong	0.6377	0.0171	0.0987	0.0704	0.1482
Ankang	0.6993	0.0146	0.0922	0.0746	0.0313
Shangluo	0.7482	0.0088	0.0834	0.0978	0.0203
Tongchuan	0.8191	0.0251	0.0925	0.0714	0.0171

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Generally, researchers classify a spoke city into the radiation range of the corresponding city which has the largest logistics membership against the spoke city. However, as Xi'an has an extremely high primacy ratio in Shaanxi Province, the development of other cities is relatively limited. Additionally, as a result of the unique geographical factors of Shaanxi Province, only the city clusters in the Guanzhong region are closely connected, and neither the southern part of Shaanxi Province, which is influenced by the Qinling Mountains nor the northern part of Shaanxi Province, which is restricted by the Loess Plateau, has sound transportation infrastructure construction. Therefore, this paper takes Xi'an as the first-level hub to radiate the Guanzhong city group, the southern part of Shaanxi Province, and the northern part of Shaanxi Province. The major sub-radiation regions of Xianyang, Baoji, Weinan, and Yulin are Tongchuan, Hanzhong, Shangluo, and Yan'an.

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