Spatial structure of logistics network in Hubei Province based on social network analysis

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Abstract. With the increasing emphasis on the integrated development of regional logistics, research on the spatial structure of regional logistics networks has also become highly valued. Due to Hubei Province's unique location, the spatial structure of its regional logistics network discussed has strong practical significance. This paper selected data from 17 cities in Hubei Province in 2021, to construct a correlation matrix based on the improved gravity model, and social network analysis was used to analyze the spatial structure characteristics of logistics networks in Hubei Province. The results show that the direct connection between logistics network node cities in Hubei Province is relatively low, presenting a network with a simple structure and good network accessibility; Wuhan, Jingzhou, Suizhou, Xiantao, and Tianmen have strong control over logistics resources of Hubei Province, serving as intermediaries and bridges. Shiyan, Shennongjia, and Xiangyang are at the core of the logistics network spillover relationship; The spillover effect between logistics network blocks is not significant, and logistics exchanges between cities tend to establish collaboration relationships within the same block.

1 Introduction

Hubei Province is located in the central region of China, connecting with major national strategies such as the Yangtze River Economic Belt, the rise of the central region, the "Belt and Road". The construction of the logistics network in Hubei Province has a strong practical significance not only for Hubei Province but also for the whole country. In 2021, Hubei Province released the "14th Five-Year Plan" for the development of modern logistics industry in Hubei Province. The plan proposes to optimize the regional development layout of the province's logistics industry from intra provincial, inter-provincial, and international levels, and provides directions for the future development layout of logistics in Hubei Province. Analyzing the spatial structure characteristics of logistics networks in Hubei Province can help identify the problems existing in the development of regional logistics networks, promote the coordinated development of logistics between regional node cities, establish long-lasting and close logistics connections, so that the development direction and planning goals of the logistics networks in Hubei Province is consistent.

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At present, the research scope of logistics networks is also quite extensive. For example, Xiao et al. [1] studied the structure and layout of the aviation logistics network in the Beijing-Tianjin-Hebei region in order to optimize the existing route network. Luo [2] used the WIOD world input-output table to construct a global logistics service trade matrix, thereby establishing a relationship matrix, analyzed its characteristics using social network analysis, and studied the factors affecting logistics service trade using QAP regression method. However, there is more research on regional logistics networks. Some scholars believe that studying the structure of regional logistics networks can determine the current status of regional logistics integration [3]. Studying the spatiotemporal evolution and coordinated development of regional logistics networks is of great significance to the realization of regional integration [4]. Therefore, many researchers have conducted research on the logistics network structure in different regions. For example, Wang et al. [5] used 25 cities in the Yangtze River Delta as the research object, to analyze the density, centrality, cohesive subgroups, and core periphery structure of the logistics network in the Yangtze River Delta urban agglomeration by social network analysis methods. Ye and Mao [6] took Sichuan Province as an example to analyze the spatial network structure of regional logistics in Sichuan Province from 2010 to 2018 used social network analysis method, and then, QAP regression analysis method was used to determine the factors affecting the level of regional logistics specialization development. Li et al. [7] analyzed the evolution characteristics and driving mechanisms of logistics network spatial structure in the Zhengzhou Metropolitan Circle from 2008 to 2019 based on a modified gravity model and social network analysis method, with Zhengzhou and its surrounding counties (districts) as the research object. Liu et al. [8] analyzed the spatial connection characteristics and influencing factors of logistics economic networks through the research on the logistics economic spatial connection model of 21 cities in Guangdong Province.

From existing research, it can be seen that on the one hand, social network analysis is a classic method of studying the network structure. On the other hand, although there is more research on the regional logistics network structure currently, the analysis and research on that of Hubei Province is still less. Therefore, the paper will use social network analysis to analyze the logistics network structure of Hubei Province.

2 Social network analysis of logistics network spatial structure

2.1 Construction of logistics networks spatial relations

The determination of correlation relationships is crucial to network analysis. According to the existing literature, the determination of spatial correlation relationships mainly adopts gravity models, Granger causality tests, etc. Among them, Granger causality tests have high requirements for the time span of time series and are extremely sensitive to the selection of lag orders. Therefore, this article will choose gravity models that have been successfully used. Each city will be attracted by logistics from other cities, and at the same time, it will also generate logistics attraction to other cities. Considering that logistics influence can be reflected by the city’s freight volume and is also related to the urban population and spatial distance, the models constructed are shown in equations (1) and (2).

$$L_{ij} = \frac{\sqrt{p_i p_j G_i G_j}}{d_{ij}^2} \tag{1}$$

$$R_{ij} = \frac{L_{ij}}{\sum_i L_{ij}} \tag{2}$$

In the formula, *i* and *j* represent different cities, and L_{ij} represents the attraction between city *i*'s and city *j*'s logistics industry, that is, the strength of the logistics industry connection; G_i and G_j respectively indicate the regional gross domestic product of city *i* and city *j*; p_i and p_j respectively indicate the permanent population of city *i* and city *j*; d_{ij} represents the distance between the two cities; R_{ij} indicates the membership degree of city *i* to city *j* in the logistics connections. Taking the average membership degree of city *i* to other cities as the threshold, if R_{ij} is higher than this threshold, it is marked with 1, indicating that there is a logistics relationship between city *i* and city *j*. Conversely, if R_{ij} is lower than this threshold, it is marked with 0, indicating that there is no logistics relationship between city *i* and city *j*.

2.2 Characteristic indicators of logistics network spatial structure

2.2.1 Overall network characteristic indicators

Network density reflects the closeness of logistics connections between cities in a network. The higher the network density, the closer the logistics spatial connections between cities. Set the number of cities in the network to N, then the maximum number of associations between cities is $N(N-1)$. If the actual number of associations in the network is L, the network density $D=L/(N(N-1))$.

The reliability and stability of the logistics network spatial structure can be reflected by correlation. If there is one or more paths connecting any two cities in the logistics network, it indicates that the network has good correlation; If multiple cities in the network need to be connected through a certain city, it indicates that the logistics network has a significant dependence on that city. Once the city is removed from the logistics network, it may cause the logistics network to collapse, indicating that the logistics network is not stable and has low correlation. The correlation of logistics networks is usually reflected by three indicators: correlation degree, grade degree, and network efficiency.

The correlation degree C can be measured using accessibility, and if the number of unreachable city pairs is V, then the correlation degree $C=1-2V/(N(N-1))$. The grade degree is the degree of pairwise asymmetric accessibility between cities in a network. The higher the grade, the stricter the spatial correlation network hierarchy, and the more concentrated the network hierarchy is from bottom to top. If K is set to the number of symmetrically reachable pairs in the network, and $maxK$ is the number of reachable pairs between cities, then the network grade degree $H=1-K/maxK$. The connection efficiency between cities in logistics networks is generally reflected by network efficiency. The lower the network efficiency, the more connections exist between cities, and the more spatial spillover channels of logistics in each city, that is, there is a phenomenon of multiple overlapping, and the spatial correlation of logistics networks is more stable. If the number of redundant connectives in the network is M, and $maxM$ is the maximum possible number of redundant connectives, then the network efficiency is $E=1-M/maxM$.

2.2.2 Network individual characteristic indicators

Centrality is an indicator in social network analysis that evaluates the stability and concentration trend of a network structure by measuring the status and role of each point in the network. The more central a city is in the logistics network, the more it can influence other cities and the more important its position is in the network. The commonly used indicators of centrality include degree centrality, betweenness centrality and closeness centrality.

Degree centrality measures and reflects the number of cities directly associated with a certain city in the logistics network. It emphasizes the individual value of a city and is divided into out-degree and in-degree. Out-degree represents the degree of the city's active spillover, while in-degree represents the degree of the city radiated by other cities. The out-degree and in-degree of city i are represented by i_{out} and i_{in}, respectively. Therefore, the degree centrality is represented by $C_{RD_i} = (i_{in} + i_{out})/(2N-2)$.

Betweenness centrality represents whether the shortest distance passes through this point, measures to what extent a city can affect other cities in the logistics network, and reflects the intermediary and moderating effect of the city on the logistics network between other cities. The higher the betweenness centrality, the more it can affect the logistics flow between other cities in the logistics network. Assuming the number of shortcuts between city j and city k is g_{jk}, where the number of shortcuts passing through city i is $g_{jk}(i)$. If the ability of city i to control the association between city j and city k is recorded as $b_{jk}(i)$, then $b_{jk}(i) = g_{jk}(i)/g_{jk}$. The absolute betweenness centrality of city i is obtained by adding up the betweenness centrality of city i relative to all other city pairs in the logistics network. After standardization, the relative betweenness centrality is obtained, as shown in equation (3).

$$C_{RB_i} = \frac{2\sum_{j=1}^{N}\sum_{k=1}^{N} b_{jk}(i)}{(N-1)(N-2)}, \quad (j \neq k \neq i, \; and\; j < k) \tag{3}$$

Closeness centrality reflects the value of a city, measured by the sum of shortcut distances between the city and other cities in the logistics network. The smaller the value, the more possible the city is in the center, the closer it is to other cities, and the less it is controlled by other cities. If the shortcut distance between city i and city j is represented by d_{ij}, then the absolute closeness centrality $C_{AP_i}^{-1} = \sum_{j=1}^{N} d_{ij}$. Normalize the absolute closeness centrality to obtain the relative closeness centrality, as shown in equation (4).

$$C_{RP_i}^{-1} = \frac{C_{AP_i}^{-1}}{N-1} \tag{4}$$

2.2.3 Block model analysis on logistics network

Block model is the main method for spatial clustering analysis in social network analysis, which can analyze the roles of each block in the network. Through the block model analysis, the internal structural status of the logistics network spatial structure in Hubei Province can be examined from a new dimension. The logistics network in Hubei Province can be divided into blocks. At the same time, cities contained in each block, the relationships and connection methods between blocks can be found. If the number of cities within each block is denoted as n_k, then the expected internal relationship ratio (EIRR) is equal to $(n_k - 1)/(N-1)$, and the actual internal relationship ratio (AIRR) is equal to the number of internal relationships divided by the total number of spillover relationships of the block. According to the actual internal relationship ratio, expected internal relationship ratio, the number of internal relationships, and the number of external relationships (reception number, spillover number), the roles of each sector in the logistics network of Hubei Province can be divided into four types: bidirectional spillover block, net benefit block, net spillover block, and broker block.

The main characteristics of the bidirectional spillover block are that its number of external spillovers is similar to its number of external acceptances, and the number of relationships between members within the block is also relatively high, with a relatively high proportion of internal relationships. The main characteristics of the net benefit block are that its number of external acceptances is higher than its number of external spillovers, and at the same time, the internal relationships account for relatively high. The net spillover block is opposite to the net benefit block, with the main characteristics that its number of external acceptances is less than its number of external spillovers, and the internal relationships account for relatively low. The main characteristics of the broker block are that its number of external spillovers and acceptances is balanced, but at the same time, the number of relationships among internal members is small, playing an intermediary and bridge role in the logistics network of Hubei Province.

3 Empirical analysis of logistics network spatial structure in Hubei Province

Hubei Province is located in central China, where various modes of transportation converge. It has a prominent position as a transportation hub, abundant natural resources, and good industrial foundation. It is also an important component of the Yangtze River Economic Belt and the Rise of Central China. At the end of 2022, Hubei Province had a total of 17 cities under its jurisdiction, including 12 prefecture-level cities, 3 county-level cities, 1 autonomous prefecture, and 1 forest area. The regional GDP is 5373.492 billion yuan and the permanent population is 58.44 million.

The paper takes the 17 cities in Hubei Province as logistics network nodes, that is Wuhan, Huangshi, Shiyan, Yichang, Xiangyang, Ezhou, Jingmen, Xiaogan, Jingzhou, Huanggang, Xianning, Suizhou, Enshi, Xiantao, Qianjiang, Tianmen and Shennongjia. Their data of 2021 are used to empirically analyze the spatial structure of logistics network in Hubei Province. The population and freight volume of each city are sourced from the Hubei Provincial Statistical Yearbook and the statistical yearbooks of each city. The distance between cities is calculated based on the shortest distance of roads searched through Baidu.

3.1 Logistics network relation intensity and correlation analysis

Using the equation (1) to calculate the logistics relation intensity between two cities in Hubei Province, as shown in Table 1. It can be seen that the logistics connection strength between Ezhou and Huanggang is the highest, and the logistics business between the two cities is closely related to. Wuhan has close logistics relations with multiple cities and plays a central node role in the spatial structure of logistics networks in Hubei Province. The logistics relations between Shennongjia and other cities are not strong, due to the long distance between Shennongjia and other cities in Hubei Province, and its relatively backward logistics infrastructure construction, resulting in limited logistics business exchanges between the city and other cities.

Table 1. Logistics relation intensity of each city.

Lij	Wuhan	Huangshi	Shiyan	Yichang	Xiangyang	Ezhou	Jingmen	Xiaogan	Jingzhou	Huanggang	Xianning	Suizhou	Enshi	Xiantao	Qianjiang	Tianmen	Shennongjia
Wuhan	-	1544.36	48.02	264.75	392.08	856.43	240.40	4133.66	647.82	6192.63	1511.74	421.09	45.92	377.32	156.38	290.07	2.06
Huangshi	-	-	5.29	26.38	37.29	756.14	19.45	97.80	53.76	2778.78	219.43	29.12	5.39	17.82	10.39	16.02	0.23
Shiyan	-	-	-	27.19	137.35	2.02	16.20	9.92	24.99	14.03	5.08	15.74	5.19	2.12	2.57	3.36	1.21
Yichang	-	-	-	-	196.70	10.15	299.46	51.77	822.64	68.44	35.71	44.60	78.83	22.32	36.95	31.84	2.64
Xiangyang	-	-	-	-	-	14.71	321.14	92.65	295.99	102.26	35.96	221.89	25.43	19.78	27.76	36.92	5.01
Ezhou	-	-	-	-	-	-	7.83	45.31	21.09	9588.96	70.34	12.21	2.01	7.59	4.19	6.89	0.09
Jingmen	-	-	-	-	-	-	-	55.89	623.48	53.44	23.80	53.64	16.88	18.47	40.62	46.98	0.95
Xiaogan	-	-	-	-	-	-	-	-	110.84	312.10	108.11	143.72	8.06	54.50	28.49	75.92	0.42
Jingzhou	-	-	-	-	-	-	-	-	-	145.25	82.01	70.85	45.42	83.29	241.97	119.15	1.85
Huanggang	-	-	-	-	-	-	-	-	-	-	389.38	85.59	13.66	49.70	28.04	46.00	0.61
Xianning	-	-	-	-	-	-	-	-	-	-	-	28.23	6.42	43.96	18.72	25.76	0.25
Suizhou	-	-	-	-	-	-	-	-	-	-	-	-	6.91	14.89	14.70	28.89	0.62
Enshi	-	-	-	-	-	-	-	-	-	-	-	-	-	2.88	3.63	3.74	0.46
Xiantao	-	-	-	-	-	-	-	-	-	-	-	-	-	-	44.60	68.55	0.12
Qianjiang	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	89.03	0.15
Tianmen	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.18
Shennongjia	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Using the equation (2) to calculate the logistics relation membership degree of each city in Hubei Province, as shown in Table 2. The larger the membership degree, the higher the dependence of logistics between the two cities. The probability of Wuhan belonging to Huanggang is 0.31, and the probability of Huanggang belonging to Wuhan is 0.36. The two cities have an equal degree of interdependence and are at a relatively low level, similar to Wuhan and Ezhou. The probability of Wuhan belonging to Xiaogan is 0.78, and the probability of Xiaogan belonging to Wuhan is 0.24, indicating an unequal dependency between the two cities in the logistics relation. Wuhan's radiation and influence on Xiaogan are stronger than those on Wuhan. This kind of asymmetrical dependence in logistics relation is also reflected between Wuhan and most other cities, Huanggang and Ezhou, Huanggang and Huangshi, Xiangyang and Shiyan, etc., indicating that there is an asymmetrical dependence in logistic relation between cities in Hubei Province's logistics network.

Table 2. Membership degree of logistics relation.

Pij	Wuhan	Huangshi	Shiyan	Yichang	Xiangyang	Ezhou	Jingmen	Xiaogan	Jingzhou	Huanggang	Xianning	Suizhou	Enshi	Xiantao	Qianjiang	Tianmen	Shennongjia
Wuhan	-	0.27	0.15	0.13	0.20	0.08	0.13	0.78	0.19	0.31	0.58	0.35	0.17	0.46	0.21	0.33	0.12
Huangshi	0.09	-	0.02	0.01	0.02	0.07	0.01	0.02	0.02	0.14	0.08	0.02	0.02	0.02	0.01	0.02	0.01
Shiyan	0.00	0.00	-	0.01	0.07	0.00	0.01	0.00	0.01	0.00	0.00	0.01	0.02	0.00	0.00	0.00	0.07
Yichang	0.02	0.00	0.08	-	0.10	0.00	0.16	0.01	0.24	0.00	0.01	0.04	0.29	0.03	0.05	0.04	0.16
Xiangyang	0.02	0.01	0.43	0.10	-	0.00	0.17	0.02	0.09	0.01	0.01	0.19	0.09	0.02	0.04	0.04	0.30
Ezhou	0.05	0.13	0.01	0.01	0.01	-	0.00	0.01	0.01	0.48	0.03	0.01	0.01	0.01	0.01	0.01	0.01
Jingmen	0.01	0.00	0.05	0.15	0.16	0.00	-	0.01	0.18	0.00	0.01	0.04	0.06	0.02	0.05	0.05	0.06
Xiaogan	0.24	0.02	0.03	0.03	0.05	0.00	0.03	-	0.03	0.02	0.04	0.12	0.03	0.07	0.04	0.09	0.03
Jingzhou	0.04	0.01	0.08	0.41	0.15	0.00	0.34	0.02	-	0.01	0.03	0.06	0.17	0.10	0.32	0.13	0.11
Huanggang	0.36	0.49	0.04	0.03	0.05	0.84	0.03	0.06	0.04	-	0.15	0.07	0.05	0.06	0.04	0.05	0.04
Xianning	0.09	0.04	0.02	0.02	0.02	0.01	0.01	0.02	0.02	0.02	-	0.02	0.02	0.05	0.03	0.03	0.01
Suizhou	0.02	0.01	0.05	0.02	0.11	0.00	0.03	0.03	0.02	0.00	0.01	-	0.03	0.02	0.02	0.03	0.04
Enshi	0.00	0.00	0.02	0.04	0.01	0.00	0.01	0.00	0.01	0.00	0.00	0.01	-	0.00	0.00	0.00	0.03
Xiantao	0.02	0.00	0.01	0.01	0.01	0.00	0.01	0.01	0.02	0.00	0.02	0.01	0.01	-	0.06	0.08	0.01
Qianjiang	0.01	0.00	0.01	0.02	0.01	0.00	0.02	0.01	0.07	0.00	0.01	0.01	0.01	0.05	-	0.10	0.01
Tianmen	0.02	0.00	0.01	0.02	0.02	0.00	0.03	0.01	0.04	0.00	0.01	0.02	0.01	0.08	0.12	-	0.01
Shennongjia	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-

After binarization processing is carried out according to the membership degree of each city in Hubei Province, the relationship matrix is established. The relationship matrix is imported into UCINET 6.0, and the Netdraw drawing tool is used to generate the structural topology of Hubei Province logistics network in 2021, as shown in Figure 1. From the topology diagram, it can be seen that the spatial correlation of the logistics network in Hubei Province presents a network structure. Although it can be seen that cities such as Wuhan, Yichang, Xiangyang, Jingmen, and Jingzhou are in a core position in the network, their core position is not very significant. It shows that the "one main and two auxiliaries" strategy of Hubei Province (where the "one main and two auxiliaries" strategy refers to the development framework established by Hubei Province in 2003 with Wuhan as the center, and Xiangyang and Yichang as the sub-centers), has promoted the logistics development of Wuhan, Xiangyang and Yichang, but the promotion effect is limited. The logistics development of these cities has not driven the construction of the entire logistics network in Hubei Province, with a relatively simple network structure.

3.2 Overall structure characteristics Analysis

According to the calculation, the density of the logistics network in Hubei Province in 2021 is 0.2794, with 76 actual connections in the network. As the maximum density of logistics network is 1, it can be judged that the logistics network density in Hubei Province is low, indicating that the logistics relations between node cities are not close enough, and most cities have not yet formed direct logistics relationships. However, the correlation degree of Hubei's logistics network in 2021 is 1, indicating good accessibility between cities in the logistics network, and there are no isolated city nodes in the network. The grade degree of the logistics network in Hubei Province is 0, indicating that the grade between each node city in the logistics network is not obvious, that is, the central node city in the logistics network in Hubei Province is not prominent. Meanwhile, the network efficiency is 0.7333, which further indicates that the logistics network in Hubei Province has high resilience, is not easily be destroyed, and has high stability.

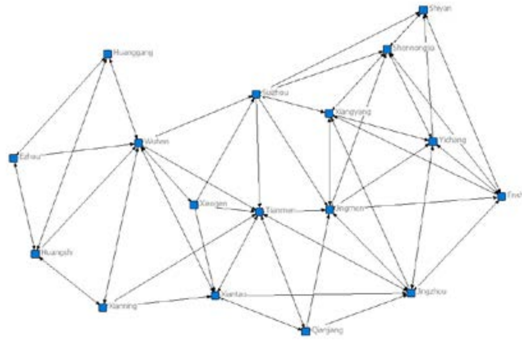

Fig. 1. Spatial correlation structure of logistics network in Hubei Province.

3.3 Logistics network centrality analysis

3.3.1 Degree centrality

It can be seen from Table 3 that the average out-degree and in-degree of 17 cities are both 4.471. Wuhan, Yichang, Jingzhou, and Enshi have higher out-degrees, indicating that these cities have a greater degree of logistics spillovers to other cities. Secondly, In-degrees of Shiyan, Xiangyang, Jingmen, Tianmen, and Shennongjia are all greater than their out-degrees, indicating that the logistics influence of these cities on other cities is less than that of other cities. Furthermore, it can be seen that there is not much difference in out-degree of each city in Hubei Province, indicating that the logistics influence of each city on other cities is equivalent. The average degree centrality of logistics in 17 cities is 27.94, while the centrality of 9 cities, including Wuhan, Yichang, Xiangyang, Jingmen, Jingzhou, Enshi, Xiantao, Tianmen, and Shennongjia, is higher than the average. It is indicated that these cities have more direct relationships with other cities in the logistics network, and most of them located in the central region of Hubei Province. Huanggang, Xianning, Ezhou, and Xiaogan rank in the bottom 4 in terms of degree centrality, indicating that the logistics of these cities are weakly related to other regions.

Table 3. Centrality of Logistics Network in Hubei Province.

City	Degree centrality				Betweenness centrality		Closeness centrality			
	Out-degree	In-degree	Centrality (%)	Rank	Centrality (%)	Rank	inCloseness (%)	Rank	outCloseness (%)	Rank
Wuhan	6	6	37.5	1	41.379	1	38.095	12	57.143	1
Huangshi	4	3	21.88	12	1.042	14	23.881	16	42.105	7
Shiyan	3	5	25	10	0.567	15	47.059	7	27.586	17
Yichang	6	5	34.38	5	3.062	12	44.444	10	34.783	12
Xiangyang	5	7	37.5	2	6.656	8	55.172	3	33.333	15
Ezhou	3	2	15.63	16	0	16	23.529	17	41.026	8
Jingmen	5	7	37.5	3	6.037	9	57.143	2	34.043	14
Xiaogan	4	1	15.63	17	0	17	28.07	15	50	2
Jingzhou	6	6	37.5	4	23.195	3	55.172	4	41.026	9
Huanggang	3	3	18.75	14	8.125	7	29.091	13	41.026	10
Xianning	4	2	18.75	15	3.958	11	28.571	14	48.485	4
Suizhou	5	3	25	11	15.435	5	51.613	5	40	11
Enshi	6	5	34.38	6	5.943	10	44.444	11	34.783	13
Xiantao	4	5	28.13	9	28.9	2	45.714	8	50	3
Qianjiang	4	3	21.88	13	8.171	6	45.714	9	43.243	5
Tianmen	4	7	34.38	7	22.805	4	59.259	1	43.243	6
Shennongjia	4	6	31.25	8	1.392	13	51.613	6	28.07	16
Mean Value	4.471	4.471	27.94		10.392		42.858		40.582	

3.3.2 Betweenness centrality

The average betweenness centrality of the logistics network in 17 cities is 10.392, and there is a significant imbalance in the betweenness centrality of logistics networks among cities in Hubei Province. The betweenness centrality of Wuhan, Jingzhou, Suizhou, Xiantao, and Tianmen is higher than the mean, which indicates that these cities have strong control when they are related to other cities in the logistics network of Hubei Province. As the capital of Hubei Province, Wuhan has strong advantages in acquiring and attracting logistics resources and information, and also has strong control over logistics network resources and information. The remaining cities are basically distributed in the middle part of Hubei Province. Their geographical location is conducive to obtaining logistics information and resources. At the same time, they also play the role of intermediary and bridge in the logistics network, connecting the eastern and western regions' logistics of Hubei Province. The bottom two cities are Ezhou and Xiaogan, with betweenness centrality of 0. The reason is that these two cities are adjacent to Wuhan and deeply controlled and influenced by Wuhan in the logistics network, making these two cities unable to control and influence other cities in the logistics network.

3.3.3 Closeness centrality

According to closeness centrality, it is divided into in-closeness and out-closeness, which respectively represent the centrality of each city in the benefit and spillover relationship in the logistics network. The average in-closeness centrality of 17 cities is 42.858, while cities such as Huangshi, Ezhou, Xiaogan, and Xianning have an in-closeness centrality below the average, indicating that these cities occupy a core position in the benefit relationship of logistics network and receive spillover effects generated by other cities in the network. The average out-closeness centrality of 17 cities is 40.582, while out-closeness centrality of Shiyan, Shennongjia, and Xiangyang ranks lower than other cities, indicating that these cities are at the core position in the spillover relationship of logistics network. These cities are important node cities in the logistics development planning of northwestern Hubei Province. With the normalization of logistics infrastructure construction and operation management, they have significant spillover effects on other cities in the logistics network.

Table 4. Spillover effects of logistics network blocks in Hubei Province.

Block	Internal relations	External relations		Number of cities within the block	EIRR (%)	AIRR (%)	Type
		reception	spillover				
I	14	2	6	5	25.00	70.00	Bidirectional spillover block
II	8	8	8	4	18.75	50.00	Bidirectional spillover block
III	22	9	7	6	31.25	75.86	Net benefit block
IV	2	11	9	2	6.25	18.18	Broker block

3.4 Block model analysis

Using the CONCOR algorithm, with the maximum segmentation depth of 2 and the concentration standard of 0.2, 17 cities were divided into 4 blocks, as shown in Table 4. The members of Block I include five cities, namely Wuhan, Huangshi, Xianning, Ezhou, and Huanggang. The members of Block II have four cities, namely Qianjiang, Xiaogan, Tianmen, and Xiantao. Block III has six cities, namely Xiangyang, Shennongjia, Shiyan, Enshi, Yichang, and Suizhou. Block IV has two cities, namely Jingmen and Jingzhou. There are a total of 76 correlation relationships among 17 cities, with 46 relationships within four logistics network blocks and 30 relationships between four blocks. The spillover effect between each block in the logistics network is not significant, and logistics businesses of each city tends to establish network collaboration relationships within the same block. Based on the benchmark judgment of block's characteristics, it shows that Plate I and Plate II are "bidirectional spillover block", Plate III is "net benefit block", and Plate IV is "broker block".

Table 5. Density Matrix and Image Matrix of Logistics Network Blocks in Hubei Province.

Block	Density matrix				Image matrix			
	I	II	III	IV	I	II	III	IV
I	0.7	0.25	0.033	0	1	0	0	0
II	0.1	0.667	0.042	0.625	0	1	0	1
III	0	0.042	0.733	0.5	0	0	1	1
IV	0	0.25	0.583	1	0	0	1	1

By calculating the network density of blocks, the correlation between blocks can be understood. The overall network density of logistics network spatial correlation in Hubei Province in 2021 is 0.2794. If the network density value of block is greater than the overall network density value, the value is assigned as 1. Otherwise, it is assigned as 0. The image matrix can be obtained, as shown in Table 5. In combination with Figure 2, it can be seen that there are correlations within each block in Hubei Province, but the spillover effects of the logistics network between each block are very small.

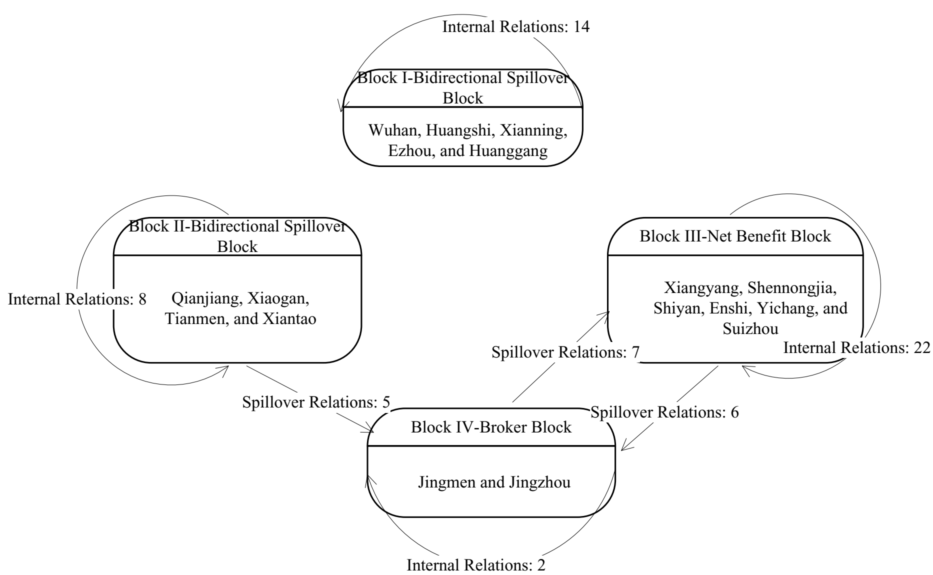

Fig. 2. Correlation between logistics network blocks in Hubei Province.

There is a logistics network collaboration relationship within Block III, while also receiving spillovers from Block IV. It indicates that the process of building the Southwest Ecological Economic Circle and the Northwest High-end Manufacturing Economic Belt in Hubei Province has brought about the demand for information flow and logistics, requiring various materials to be imported from other cities. While receiving the spillover, Block III' logistics also spills over into Block IV, indicating that the logistics development of western Hubei Province will also benefit other cities. There is no direct spillover effect between block II and block III, but block II spills over through Plate IV to Plate III. This once again shows that block IV is located in the central part of Hubei Province and plays an indispensable role as a bridge in the logistics network. Block I has no relationship with other blocks, only internal correlation. Cities in block I and block II are located in the same Wuhan Metropolitan Circle, but the urban economic development within the circle is unbalanced. Block I has realized internal cooperation in logistics networks, resulting in no correlation with the logistics among other blocks and no spillover effect of this block on other sectors.

4 Conclusion

Based on the data of prefecture-level cities and county-level cities under the provincial government in Hubei Province in 2021, a modified gravity model was constructed to determine the spatial correlation of the logistics network in Hubei Province. On this basis, social network analysis methods were used to empirically study the structural characteristics of the logistics network in Hubei Province, and the main research conclusions are drawn as follows.

Firstly, the logistics network in Hubei Province has fewer direct relations and presents a network structure, with overall good accessibility and no isolated cities in the network. There is an obvious asymmetry relationship in the degree of logistics dependence between cities. The network has a certain level attribute, but the network structure is simple and the level is not prominent. Cities with high levels of economic development are in a dominant position in the network structure, but their dominant position is not obvious.

Secondly, cities such as Wuhan, Yichang, Xiangyang, Jingmen, and Jingzhou have higher degree centrality and more direct relationships with other cities. Huanggang, Xianning, Ezhou, and Xiaogan have lower degree centrality and fewer direct relationships with other cities. Wuhan, Jingzhou, Suizhou, Xiantao, and Tianmen have relatively high betweenness centrality, and strong control over logistics resources in the network, playing a role as intermediaries and bridges. Ezhou and Xiaogan are deeply controlled and influenced by Wuhan, losing control over logistics resources, resulting in a betweenness centrality of 0. The in-closeness centrality of cities such as Huangshi, Ezhou, Xiaogan, and Xianning is lower than the average, which mainly receives spillover effects from other cities in the logistics network. Shiyan, Shennongjia, and Xiangyang ranked lower in terms of the out-closeness centrality, indicating that these cities are in the core position in the spillover relationship of the logistics network.

Thirdly, the logistics network in Hubei Province is divided into four blocks. Block I consisting of Wuhan, Huangshi, Xianning, Ezhou, and Huanggang, and block II, consisting of Qianjiang, Xiaogan, Tianmen, and Xiantao, are the “bidirectional spillover blocks”. Block III, consisting of Xiangyang, Shennongjia, Shiyan, Enshi, Yichang, and Suizhou, is the “net benefit block”. Block IV, consisting of Jingmen and Jingzhou, is the “broker section”. The spillover effect between different blocks is not significant, and logistics businesses of each city tend to establish network collaboration relationships within the same block.

The calculation results analyzed the spatial structure characteristics of the logistics network in Hubei Province in 2021. Due to the difficulty and incompleteness of data collection, the development law of the logistics network spatial structure characteristics in Hubei Province was not analyzed. In future research, appropriate data will continue to be explored and selected to summarize and analyze the development law of the logistics network spatial structure characteristics in Hubei Province.

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