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The Spatio-Temporal Evolution of Integrated Network of Zhongyuan Urban Agglomeration

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***Abstract*—On the basis of combing the progress of urban network research, the network contact matrix of Zhongyuan urban agglomeration is constructed from the comprehensive network evaluation index system and the improved gravity model from 2000 to 2015, the spatio-temporal evolution characteristics of integrated network are analyzed by means of social network analysis. The main conclusions are as follows: ① From 2000 to 2015, the development characteristics of radiation and agglomeration in the integrated network of Zhongyuan urban agglomeration are increasingly obvious. ② The central city of Zhengzhou has been in a growing position. The axis of network development has evolved from the cross type composed of Beijing-Guangzhou and Lianyungang-Lanzhou to the "H" type of Beijing-Guangzhou, Lianyungang-Lanzhou and Changzhi-Luoyang. ③ Network participation in 30 cities has increased in varying degrees, and the gap between the first and last city has widened. ④ Luoyang and Handan grew into regional central cities, the development of eastern and southern parts of the region is slower, and the hierarchical network system is obvious.**

Keywords—Integrated network; Spatio-temporal evolution; Zhongyuan urban agglomeration

I. INTRODUCTION

The urban network takes the city as the network node, and takes the dynamic "urban flow" as the communication mode. The ultimate aim is to realize regional resource sharing and network economy, and promote the coordinated development of the region as a whole. The GaWC network group led by Taylor has carried out a great deal of research on the network structure of the major cities in the world[1], and gradually went deep into the regional network, such as Daniels P W and so on, taking the Asia Pacific region as an example to analyze the relationship between urban transformation and industry[2]; Derudder B et al. studied the relationship changes of 132 cities around the world from 2000 to 2008, and explored their impacts on urban and regional levels[3]. Influenced by the research of GaWC, domestic scholars have also carried out a lot of research on urban network from the perspective of economic contact network[4], transportation network[5], and information network[6]. At present, the research on the network structure of Zhongyuan urban agglomeration mainly focuses on economic connection[7] and passenger flow[8]. Overall, the current urban network research has the following characteristics: First, the research area is more partial to the higher level of urbanization development, which is not thorough enough for the central and western regions represented by the Zhongyuan urban agglomeration, especially the large gaps in the development level of cities and towns, including the large area of rural areas. Second, both domestic and foreign studies tend to describe the current structural characteristics, and there are few studies based on long time sequence evolution.

Based on the above background, the paper takes the urban areas of 30 cities of Zhongyuan urban agglomeration as the object, chooses 2000, 2005, 2010, 2015 four years, uses the comprehensive evaluation index system of urban network, calculates the urban contact matrix by the improved gravity model, and uses the social network analysis method to make the system analysis of spatio-temporal evolution characteristics of integrated network of the Zhongyuan urban agglomeration, in order to enrich and develop the content of the urban network research, at the same time to provide a reference for the optimization of the spatial structure of the Zhongyuan urban agglomeration.

II. DATA AND METHODS

A. Data

According to "Zhongyuan urban agglomeration development plan", the scope includes five provinces and 30 cities. The basic geographical unit of the paper is the urban districts of 30 cities (Fig. 1). The data of population and social and economic development are mainly from the "China City Statistical Yearbook" in 2001-2016 years. Since Jiyuan has no districts, all indicators are based on city data, which is derived from the "Henan statistical yearbook" in 2001-2016 years. The

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spatial distance comes from the Intergovernmental highway mileage of Baidu maps.

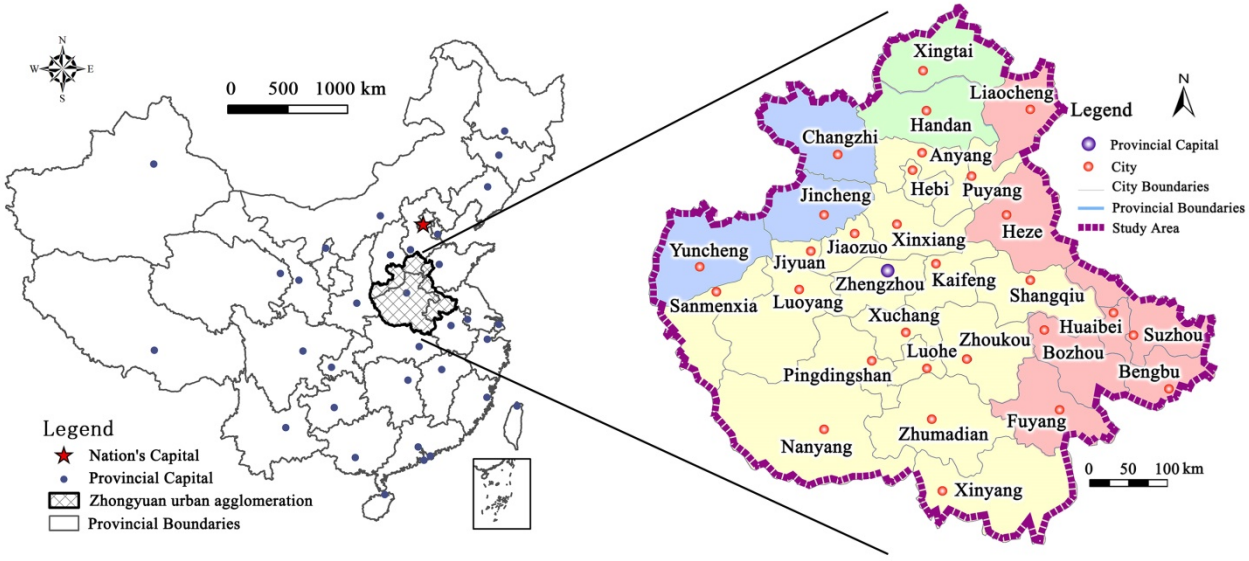

Fig. 1 Study area

B. Methods

The comprehensive urban network evaluation index system (TABLE I) is constructed from the aspects of basic scale, economic development, facilities construction, social life, ecological environment and spatial distance.

TABLE I. THE EVALUATION INDEX SYSTEM OF COMPREHENSIVE URBAN NETWORK

Objective Level	Subsystem Level	Indicator Level
Urban comprehensive strength	Basic Scale	Nonagricultural Population; Area of Built Districts;
	Economic Development	Per Capita GDP; Investment in Fixed Assets; Tertiary Industry Product; Value-Added by Industry; Amount of Foreign Capital Actually Utilized;
	Facilities Construction	Per Capita Area of Paved Roads in City; Number of Public Transportation Vehicles per 10000 Population;
	Social Life	Average Wage of Employed Staff and Workers; Students Enrollment of Regular Institutions of Higher Education Per 10000 persons; Number of Doctors per 10000 Population; Total Retail Sales of Consumer Goods;
	Ecological Environment	Per Capita Area of Green Land; Green Covered Area as % of Completed
Urban distance	Spatial Distance	Road mileage

1) Improved gravity model.

In order to reflect the directional characteristics of intercity relations, an improved gravity model is applied to measure the temporal and spatial relations of urban agglomeration. The calculation formula [9] is

$$C_{ij} = K\frac{(\sum_{h=0}^{n} W_{i-h}\times P_{i-h})\times(\sum_{f=0}^{n} W_{j-f}\times P_{j-f})}{D_{ij}} \quad (1)$$

In the formula, C_{ij} is the connection value between i and j city; K is the constant of gravity; W_{i-h} and W_{j-f} are the factor weight values that affect the strength of the cites i and j; P_{i-h} and P_{j-f} are the factor quantization values that influence the strength of i and j in cities; D_{ij} is the spatial distance of cities.

2) Social network analysis method.

a) Network Density. Network density reflects the density of the network connection as a whole. The calculation formula [10] is

$$D = \sum_{i=1}^{k}\sum_{j=1}^{k}\frac{d(n_i,n_j)}{k(k-1)} \quad (2)$$

In the formula, D is the network density, K is the number of cities, $d(n_i,n_j)$ is the relationship between cities.

b) Absolute centrality. The absolute centrality is the sum of the relationship between city A and all other cities. It is divided into outdegree and indegree. The calculation formula [10] is

$$C(n_i) = \sum_{j=1}^{n} X_{ij} \quad (3)$$

In the formula, $C(n_i)$ is outdegree or indegree, X_{ij} indicates the connection value of the cities i and j.

III. EVOLUTION CHARACTERISTICS OF INTEGRATED NETWORK

A. Global evolution characteristics

Using Arcgis10.2 to draw the integrated network space contact map of the Zhongyuan urban agglomeration (Fig. 2), to clearly reflect the evolution trend of the integrated network, the line of the connection value <2 is not shown in the diagram. Based on the connection value in 2015, we use Jenks method to

divide the contact lines from big to small into five levels: Level 1 contact (>36.888), level 2 contact (20.900~36.888), level 3 contact (12.164~20.900), level 4 contact (6.709~12.164), and level 5 contact (2.000~6.709). According to the network density and contact level, we analyze the static network hierarchy characteristics of urban agglomeration.

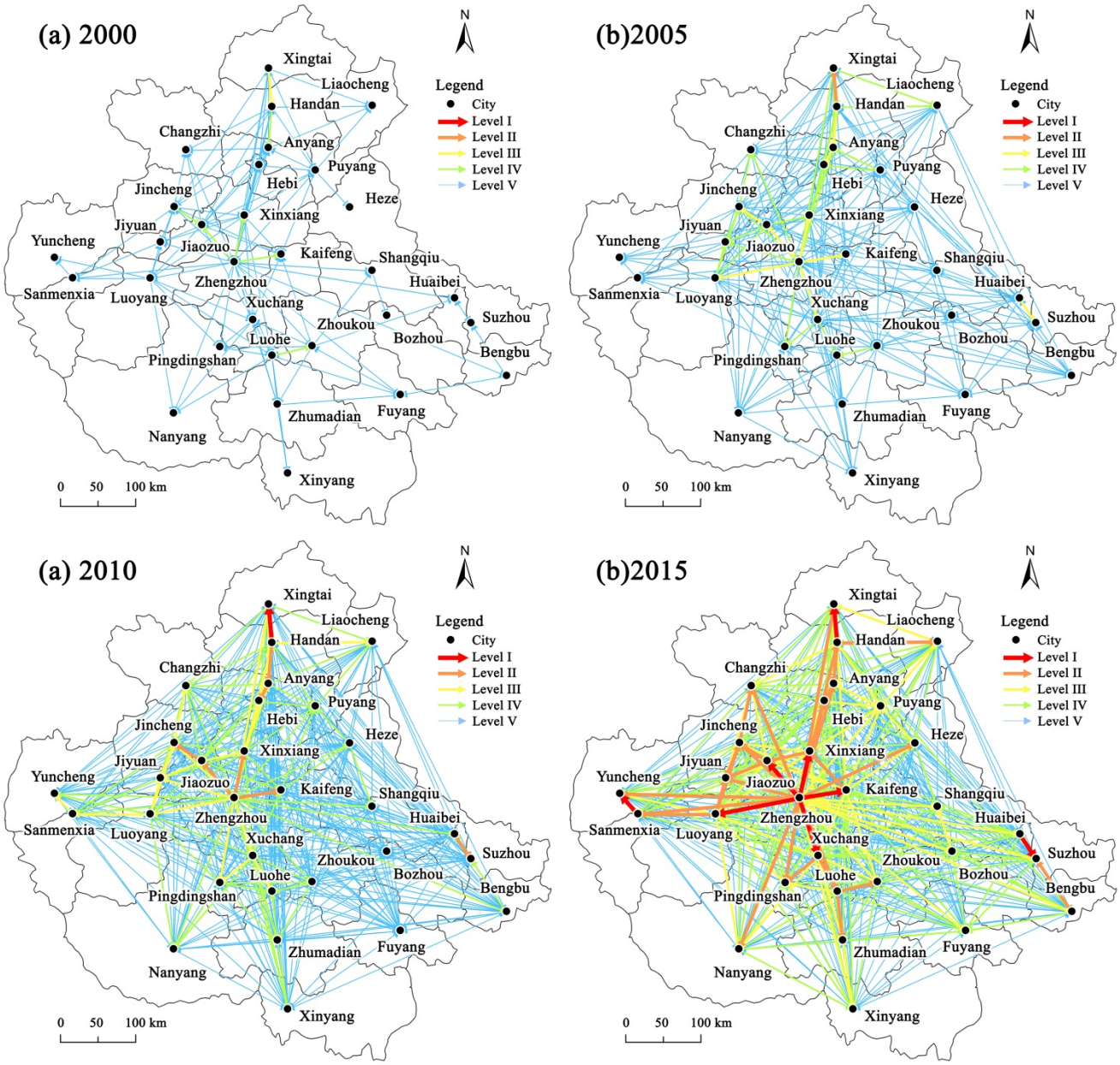

Fig. 2 The spatial relation of static networks in zhongyuan urban agglomeration from 2000 to 2015

(1) The development level of integrated network is gradually improving, and the interaction development between radiation and agglomeration is obvious. The network connection lines of urban agglomeration increased from 116 in 2000 to 650 in 2015, and the network density increased from 0.133 in 2000 to 0.747 in 2015. In 2000, the urban agglomeration had three ~ five level contact lines. At this time, the integrated network was in the primary stage and the network connection was looser, and the main performance was the radiation from Zhengzhou to outward, the space was stronger in the north than in the south. In 2005, the urban agglomeration had two ~ five level contact lines. By this time, the integrated network connection was still weak. While the radiation effect of Zhengzhou increased, the connection between the adjacent cities was also increasing, and the space showed that the north was stronger than the south, the west was stronger than the east. In 2010, five levels of contact lines all appeared, the integrated network was in a rapid growth stage, and the urban connection tended to be close. With Zhengzhou as the center, the central cities cluster of 7 cities appeared, including Kaifeng, Xinxiang, Jiaozuo, Jiyuan, Luoyang, Pingdingshan and Xuchang. In 2015, the integrated network was further developed; the high level contact lines increased obviously and extended along the Beijing-Guangzhou and the

Lianyungang-Lanzhou lines, the interaction between cities was frequent. The radiation range of 8 cities in Zhengzhou, Kaifeng, Luoyang, Xinxiang, Xuchang, Jiaozuo, Handan and Jincheng had covered the whole area.

(2) The status of Zhengzhou as central city is continuously enhanced, and the "H" type network structure with the core backbone of Beijing-Guangzhou, Lianyungang-Lanzhou and Changzhi - Luoyang is forming. Relying on the location advantage of the center zone and the political advantage of the provincial capital city, Zhengzhou has a stable central position in the integrated network. The radiation intensity of the urban agglomeration appears to be a trend of decreasing outer circle with Zhengzhou as the center. From the spatial pattern and temporal sequence to observe the three development axis, the earliest formation of the Beijing-Guangzhou axis is also the strongest. The regional development axis of Beijing-Guangzhou, Lianyungang-Lanzhou cross is unchanged, and the Changzhi - Luoyang axis is still developing.

B. Cities evolution characteristics

According to the indegree and outdegree of the cities (TABLE II), the evolution characteristics of the integrated network nodes are analyzed.

TABLE II. THE ABSOLUTE DEGREE OF STATIC NETWORKS IN ZHONGYUAN URBAN AGGLOMERATION FROM 2000-2015

Cities	2000		2005		2010		2015	
	OutDegree	*InDegree*	*OutDegree*	*InDegree*	*OutDegree*	*InDegree*	*OutDegree*	*InDegree*
Zhengzhou	85.626	6.402	207.950	22.248	343.922	65.909	823.865	164.026
Kaifeng	22.108	22.184	23.241	46.584	106.998	88.400	341.958	153.219
Luoyang	20.929	17.031	105.650	24.193	181.075	60.768	357.594	139.905
Pingdingshan	0	16.707	14.036	42.142	110.583	82.863	119.478	177.032
Anyang	14.042	32.442	31.110	69.876	98.986	120.501	151.018	197.109
Hebi	2.189	25.361	14.876	76.311	51.541	142.749	117.447	223.230
Xinxiang	35.371	16.122	82.518	44.911	169.368	90.440	290.090	172.541
Jiaozuo	32.249	23.649	95.386	45.840	186.670	85.544	241.966	177.076
Puyang	15.733	14.571	40.010	45.248	54.792	108.643	86.139	193.030
Xuchang	13.810	20.279	104.425	27.819	198.964	61.955	299.061	142.901
Luohe	30.698	12.392	16.352	40.201	33.110	112.951	162.462	156.477
Sanmenxiang	5.937	13.614	6.700	29.965	38.622	103.665	120.092	160.123
Nanyang	0	9.683	10.709	29.995	16.675	91.654	108.224	132.961
Shangqiu	2.076	4.141	4.845	22.706	19.264	83.708	34.215	178.529
Xinyang	0	5.995	0	20.816	9.614	93.193	29.832	171.383
Zhoukou	16.846	11.904	29.965	33.894	72.277	85.143	119.623	161.769
Zhumadian	5.779	15.198	6.135	31.265	49.397	95.208	69.250	180.683
Jiyuan	4.345	24.801	23.383	66.052	69.058	123.993	99.350	228.209
Xingtai	31.501	9.297	52.876	46.421	141.622	106.431	122.444	185.275
Handan	35.356	21.706	98.673	35.417	246.383	80.952	300.934	134.072
Liaocheng	0	11.985	26.230	34.843	36.879	92.492	138.626	120.585
Heze	0	2.744	24.310	40.145	69.674	82.373	107.066	156.694
Huaibei	6.003	7.931	25.392	34.886	84.109	69.254	158.507	133.327
Bozhou	0	2.076	0	17.124	2.021	63.927	40.563	174.917
Suzhou	0	9.406	6.039	32.974	13.900	88.066	46.248	206.177
Bengbu	10.180	2.383	17.603	29.846	74.081	50.768	163.158	110.482
Fuyang	2.362	10.023	4.311	21.567	10.977	85.225	33.171	169.129
Changzhi	0	14.424	16.271	51.923	79.533	93.758	127.327	165.824
Jincheng	34.843	15.331	55.061	55.864	128.090	98.012	200.093	177.288
Yuncheng	0	8.200	0	20.981	5.939	95.580	36.953	202.783

Found: (1) The degree of network participation in each city has gradually increased, and the polarization gap has gradually expanded. In the past 2000-2015 years, the degree of indegree and outdegree in each city increased significantly. In 2000, there were 9 cities with an indegree / outdegree of 0, and no such cities after 2010. Meanwhile, the outdegree increased from 85.626 in 2000 to 790.694 in 2015, and the indegree increased from 30.366 in 2000 to 117.727 in 2015. The number of cities with more outdegree than indegree increased from 11 fluctuations in 2000 to 12 in 2015, among which Zhengzhou, Luoyang, Xinxiang, Handan and Jiaozuo were always extraversion cities.

(2)The regional central cities in Luoyang and Handan are gradually formed, and hierarchical network system appears. The status of Zhengzhou's extraversion center is stable.

Luoyang and Handan have been rising continuously in the past 15 years, forming the regional radiation center. Kaifeng increased its position rapidly after 2005, and jumped to second place in the region in 2015. However, the status of Zhoukou and Puyang declined significantly. The cities of Shangqiu, Nanyang, Zhumadian, Xinyang, Zhoukou, Bozhou, Fuyang, southern and eastern cities of Zhongyuan urban agglomeration lack strong driving force and extraversion cities, and the speed of development is slightly lagging behind.

IV. Conclusion and Discussion

A. Conclusion

The paper analyzes the spatio-temporal evolution characteristics of integrated network of Zhongyan urban agglomeration from two aspects of the whole and the nodes in 2000-2015 years. The main conclusions are as follows:(1) The development level of the integrated network of Zhongyuan urban agglomeration is gradually increasing, and the interactive development trend of radiation and agglomeration is obvious.(2) The status of Zhengzhou as network center is stable, the development axis of urban agglomeration from two lines composed of Beijing-Guangzhou and Lianyungang-Lanzhou evolution to three lines composed of Beijing-Guangzhou, Lianyungang-Lanzhou and Changzhi-Luoyang, among which the Beijing-Guangzhou axis is the highest level. And Zhengzhou, Kaifeng, Xinxiang, Jiaozuo, Jiyuan, Luoyang, Pingdingshan, Xuchang show the advantages of urban cluster.(3) The network participation of 30 cities have different degrees of promotion, and the polarization gap between the first and last cities is widening.(4) Luoyang and Handan have become regional central cities, while the cities in the Eastern and southern of the urban agglomeration, Nanyang, Zhumadian, Xinyang, Zhoukou, Bozhou and Fuyang lack of strong driving force cities, the speed of development is slightly lagging. The hierarchical network system of Zhongyuan urban agglomeration has been obvious.

B. Discussion

Urban network is a complex giant system. This paper only analyzes the evolution of integrated urban network with the help of macro statistical data. It will be the next research direction to combine the dynamic flow data such as Internet data, information flow data, capital flow data and statistical data to make a comprehensive comparison of urban network.

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