The Structure Evolution of China's Urban Networks from the Perspective of Flows

–Take 2007-2014 as an Example

Youyang You

International Business School

Yunnan University of Finance and Economics

Kunming, China

85621767@qq.com

Abstract—**China's massive high-speed rail construction in a short time has exerted a huge impact on accessibility and connectivity of cities. As the rise of "Flow space" theory, the impact of high-speed rail construction on urban network is more noteworthy. According to 2007-2014 HSR time schedule data, this paper analyses China's the development of urban network structure influenced by HSR networks. By calculating DIT, RSL, ODIc, ODII indexes, it tries to explore the urban networks structure and changes in the comprehensive Chinese HSR networks. The conclusions are: (1) with the spatial extension of HSR networks, the connectivity of cities was strengthen (2) China's urban system structure connected by HSR networks became more polycentric. (3) Compare to other regions, HSR networks are more completely developed in the Yangzi River Delta region.**

Keywords: *flow space, timetable, High speed railway (HSR), urban networks*

I. INTRODUCTION

In recent years, the reform of transportation technology has promoted the rapid expansion of high-speed railway transportation network. In the process of measuring traffic location, factors such as transportation convenience and timeliness have become more important [1]. As an emerging mode of transportation, high-speed railways have not only shortened the intercity travel time of passengers, but also strengthened the intercity connectivity [2]. China high speed railway is usually defined as a passenger train with a designed speed of more than 250km/h and an initial operating speed of not less than 200km/h. The success of Guang's trial operation in December 9, 2009 presents that the official entry of China into the "high-speed rail era". Since then, China's high-speed rail operation mileage has developed from 9356 km in 2012 to 22000 km in 2006.

Meanwhile, high-speed railways have played an increasingly important role in urban hierarchy and spatial reconstruction of urban agglomeration. Because high-speed railways can promote the rapid intercity flow of people, goods, capital, information, technology flow and other factors, they have become important carriers in the research for China's urban network structure, and "high-speed railway flow" has become an important mode of expression. By the end of 2017, the mileage of Chinese high-speed railways has accounted for more than 66.3% of the global total [3]. With the advance of the

construction progress, more high-speed railway nodes and lines have been opened, the network has covered more areas, and China's high-speed railways have a more accurate response to the urban network structure. In this context, "high-speed railway flow" becomes an important perspective for China's urban network hierarchy evolution [4].

Because it is hard to obtain the high-speed railway passenger flow data, data of high-speed railway train schedules are mostly adopted in the existing academic researches, and the social network analysis method is used to depict the high-speed railway train frequency network [5]. According to the findings, since the opening of high-speed railways, the trend of functional decentralization has appeared in some areas [6,7]. For example, Luo Zhendong et al. (2010, 2011) depicted the multi-centralization degree of the Yangtze River Delta region with high-speed railway train data [8,9] and found an ever-strengthening internal integration trend and the strongest connectivity between Nanjing and Shanghai. Based on that, Feng Changchun et al. (2014) measured the multi-centralization degree of the Pearl River Delta region with the same method, and found that the Pearl River Delta region was more dispersed than the Yangtze River Delta region [10]. However, due to the difficulty in data acquisition, the existing researches mainly focus on inside of the regions. At the national level, Liu et al. (2016) conducted a comparative research on train schedules, finding that the Pearl River Delta region had a more obvious urban network structure clustering than the Yangtze River Delta region [11]. Yang et al. (2018) made an analysis on China's high-speed railway passenger flow data, finding a multi-centralization development trend in the Pearl River Delta, the Yangtze River Delta, Beijing, Tianjin and Hebei [12]. Although these researches were made at the national level, cross-sectional data of only one year cannot dynamically measure the influence of the high-speed railway flow on the evolution of the urban network structure on a large scale. Although there have been attempts in dynamic research on the high-speed railway network of multiple years at the national level, Jiao et al. (2017) studied the urban network structure and connectivity through the national high-speed railway passenger data from 2003 to 2014 [13]. Jiao Jingjuan et al. (2016) discussed the influence of the high-speed railway construction on the hierarchical structure and clustering of urban network from the perspective of urban network based on railway passenger training schedules at 8 time sections [14]. However,

because there have been newly opened stations and lines every year, it is difficult to compare high-speed railway network structures with the unified standards, and previous studies have not unified standards as well.

In conclusion, the existing researches have focused on sectional data at the regional or national level [15], but lack of a dynamic evolution analysis on the high-speed railway flow at the national level. In this paper, with prefecture-level cities as basic units, high-speed railway nodes, line intensity and entropy index are calculated based on data of train schedules between 2007 and 2014 [16], so as to study the high-speed railway network structure at the national level. Besides, the standardization method is used to solve the inconsistency between the number of nodes and the number of node connection lines in different time dimensions [17], in a bid to explore the urban network structure evolvement rules based on the high-speed railway flow.

II. DATA SOURCE AND ANALYSIS

Direct connection data can accurately reflect the intercity association. After the measurement of traffic flow and spatial information, passenger flow can be used to calculate the spatial connection strength, so as to analyze the spatial connection characteristics [18,19]. Transportation vehicles carry humans who serve as microscopic participants in spatial connection. Due to the functionality and popularity of passenger transportation, data of high-speed railway train schedules can replace the "flow data" of the spatial connection [20]. In this paper, the method framework of Limtanakool et al. (2007) is adopted to measure high-speed railway network in China [21]. According to 2007-2014 nationwide train schedule data at Jpskb.com, the two-way high-speed railway train operation frequency between two prefecture-level cities are summarized, and data of cities owning two and more high-speed railway stations are integrated to calculate the urban node strength and the high-speed railway line strength. As the offline program of the nationwide train schedule data at Jpskb.com has not been updated since September 2015, the data analysis covers only the national train schedule data from the beginning of 2007 to the end of 2014. By the end of 2014, the data covered 102 prefecture-level cities with high-speed railway stations and 1979 high-speed railway lines.

III. STUDY METHOD

In this study, in order to accurately describe the urban network structure based on the frequency of high-speed railway, this article mainly involved four indexes: dominance index DITi, relative strength index RSLij, and entropy indexes ODIc and ODIl. These indexes were used to define in two levels: one was the node of prefecture-level city linked by high-speed railway stations and the high-speed railway lines; the other was the whole high-speed rail network.

DITi and RSLij were used for the first level, which was to measure the node or line strength of specific prefecture-level cities. DITi (see Formula 1) was used to measure the node strength of cities linked by high-speed railway and to calculate the sum of frequency of high-speed railway related to City I, and the ratio of the mean of frequency of the high-speed railway related to other cities except City I. RSLij (see Formula 2) was used for the second level and to measure the strength of lines between two cities, that was to calculate the ratio of frequencies

of the high-speed railway between two cities to the total frequencies of nationwide high-speed railway.

$$DIT_i = \frac{T_i}{(\sum_{j=1}^{J} T_j / I)} \qquad (1)$$

$$RSL_{ij} = \frac{t_{ij}}{\sum_{i=1}^{I} \sum_{j=1}^{J} t_{ij}} \qquad (2)$$

Among them, Ti referred to the sum of frequencies of high-speed railway related to City I, of which $i \neq j$. The cities with a dominance index DITi of more than 1 were the mainstream cities, because in the high-speed railway network the importance of these cities were larger than that of others. Tij referred to the sum of frequencies of high-speed railway between City i and City j, of which $i \neq j$. The value of RSL_{ij} was 1; and the value range of specific line was 0-1; the smaller the value was, the weaker the strength became; in other word, the less important the line was in the total lines, the larger the strength of the line became, and the more important the line was in the total lines.

Entropy indexes ODIc and ODIl could be used for the second level, to measure the structure of the whole high-speed railway network. ODIc (see Formula 3) could be calculated to measure whether the prefecture-level cities in the high-speed railway network were distributed evenly. ODIl (see Formula 4) was the total distribution index based on lines and could be used to measure whether the lines in the high-speed railway network (the relationship between two cities) was even.

$$ODI_c = -\sum_{i=1}^{I} \frac{(Z_i) \ln(Z_i)}{\ln(I)} \qquad (3)$$

$$ODI_l = -\sum_{l=1}^{L} \frac{(Z_l) \ln(Z_l)}{\ln(L)} \qquad (4)$$

Among them, Zi referred to the percentage of total line number to all lines related to City I; I referred to the number of cities of the whole high-speed raiway network. The value range of ODI_c was 0-1. The value 0 implied the urban network system featured by the highest-level uneven development. Zl meant the percentage of frequency sum of Line I between two cities to total frequency of high-speed railway lines across the country. L meant the sum of total frequency number of the high-speed railway network. The value range of ODIl was 0-1. And the value 0 implied the highest level division of lines.

Considering the article focused only on the undirected frequency information and less on the direction vector of frequency, we only calculated the bidirectional frequency of the nodes between two cities. The analyses in this article didn't cover the symmetry of specific node cities and lines but merely the non-vector indexes related to the strength and structure. In order to unify the standard and compare the strength and structure of different node and different lines in different high-speed railway networks of different years, this article referred to Derudder and Witlox (2009) and van Nuffel et al.(2010) [22,23] for standardization processing. Briefly speaking, the article adjusted all indexes according to nodes and lines and then made transformation as per the annual order of

the node and line structure, to facilitate the unified comparison among sectional data in different years.

IV. RESULT ANALYSIS

At time of calculating RSLij, on basis of the original value, it was multiplied by 1,000 so as to convenient to mark. Meanwhile, in order to increase the readability, it only drew the lines, the strength of which (RSLij) was more than 1. Under the influence of high-speed railway, the nationwide urban network increasingly became weak in level and more polycentric in distribution. From the dynamic analysis, under the influence of high-speed railway network, China's urban network showed a homogeneous development, especially in the east and central part.

A. Node strength of high-speed railway

Since 2012, there were no longer the high-speed railway cities with node strength of more than 6 but more and more cities with small node strength on the map. The cities that had advantages in high-speed railway were mainly distributed in the east of China and less in northeast area. Moreover, such cities were mostly assembled in the densely-populated and economically-developed Bohai Bay Rim, Yangtze River Delta and Pearl River Delta and sparsely located in Chengdu-Chongqing City Group. Most of cities topped the list of node strength were distributed in the Yangtze River Delta or the Bohai Bay Rim. Except Beijing which ranked first in node strength in 2008, Shanghai won the first place for the remaining years. Furthermore, from 2007 and 2014, the top three cities were also located in the Yangtze River Delta. All indicated that compared with the Pearl River Delta and the Bohai Bay Rim, the Yangtze River Delta had more complete high-speed railway network. In term of the frequency of high-speed railway, the places where the urban station and lines of high-speed railway were most concentrated were Yangtze River Delta and the Bohai Bay Rim, followed by the Pearl River Delta. It was mainly because the high-speed railway projects led by the Ministry of Railways were inclined to the trans-provincial lines other than provincial lines. As Guangdong province was the richest province in China, the local government undertook 50% of high-speed railway construction fund for the Pearl River Delta. Comparatively speaking, in the Yangtze River Delta and the Bohai Bay Rim, the local governments undertook only 20%-30% of high-speed railway construction fund via self-financing [24]. Huge sums of high-speed railway construction fund also delayed the construction progress of high-speed railway project in the Pearl River Delta. Therefore, compared with the cities in the Yangtze River Delta, Guangzhou was backward in the improvement of node strength from 2007 to 2014.

Throughout the country, the mainstream cities in the high-speed railway network were basically Tier 1 cities, such as Guangzhou, Shanghai, and Beijing. And most of the top 20 prefecture-level cities, except Beijing, Shanghai and Guangzhou, belonged to provincial or sub-provincial cities, or the hub cities with outstanding GDP contribution or superior economic status within the area, such as Tianjin, Nanjing, Wuhan, Hangzhou and Suzhou. [25] The grade of high-speed railway, urban population and economic growth were complementary to each other. Guangzhou, Shanghai and Beijing, which were located in South China, East China and North China respectively, served as the representative city of the Pearl River Delta, the Yangtze River Delta and the Bohai Bay Rim separately, with the

characteristics of developed economy, large population and prominent location superiority. Nanjing, Hangzhou, Suzhou, Wuxi, Shenzhen, Wuhan, Tianjina and Changzhou, which served as the regional passenger transportation center cities of high-speed railway network, were also relatively large in population and developed in economy. Among them, as one important city of the Bohai Bay Rim, Tianjin was among the top 5 cities with highest node strength in 2008 and outside the top for in the remaining years. It was because that Tianjin was too close to Beijing, the national hub status of which brought competitive effect to Tianjin and weakened Tianjin's position in the whole transportation network [15]. In term of the node strength ranking, Beijing slid backward year by year, while Nanjing moved up gradually, indicating that the rapid growth of high-speed railway network in the Yangtze River Delta reduced the space-time distance of the Yangtze River Delta, fuel the rapid flow of talents, technology, information, fund, knowledge and experience among the cities linked by high-speed railway, accelerate the integrated growth of the Yangtze River Delta and promote it develop in breadth and depth.

From 2007 to 2017, among the top 20 cities, most of them were national and regional passenger transportation center cities of high-speed railway network. And most of cities were located in the Yangtze River Delta, then the Bohai Bay Rim and finally the Pearl River Delta. The cities in the central part were gradually increased in number, and their node strength also became stronger gradually. The Yangtze River Delta, the Bohai Bay Rim and the Pearl River Delta had the largest number of hub cities and thus, compared with other areas, were more prominent in polycentric feature.

B. Line strength of high-speed railway

According to the Top 20 high-speed railway between 2007 and 2014, after 2009, the high-speed railway lines with a line strength value of 8 no longer appeared on the map; the high-speed railway lines with a line strength value between 1 and 6 were greatly increased; there was no western line and few Cross-regional lines in rankings between 2007 and 2014. It indicated that the eastern areas of China had established the more mature high-speed railway network, while the western areas still lacked of high-speed railway lines; most lines were distributed in the Yangtze River Delta, the Bohai Bay Rim and the Pearl River Delta. For instance, in 2007, 2008 and 2009, Guangzhou-Shenzhen Line ranked the first; in 2010, 2011 and 2012, Nanjing-Shanghai Line ranked the first; in 2007 and 2010, Nanjing-Shanghai Line ranked the second; in 2008 and 2009, Beijing-Tianjin Line ranked the second; in 2013, Shanghai-Suzhou Line ranked the second. All showed that the high-speed railway advanced the geographical superiority and strengthen inter-city linkages. As the political and cultural center and the economic center separately, Beijing and Shanghai displayed the strongest linkage of high-speed railway flow between 2007 and 2014.

Take Guangzhou, Shanghai and Beijing as the representative of the Pearl River Delta, the Yangtze River Delta and the Bohai Bay Rim. The national high-speed railway passenger centers closely linked with their nearby regional high-speed railway passenger centers. The linkage was gradually decreased over time. Guangzhou mainly linked with Shenzhen in the southeast with strong line strength between 2007 and 2008, and inclined to focus on the north with weak line strength after 2009, indicating that since 2009, the

high-speed railway lines linked by Guangzhou showed a balanced regional development. Shanghai mainly linked with Nanjing between 2007 and 2012 and also showed a more balanced strength distribution in surrounding lines after 2012. Compared with Guangzhou and Shanghai, the high-speed railway centered on Beijing showed a more even distribution of space linkage with strong line strength in southeast and southwest areas, indicating a trend of balanced regional development. According to the network level evolution of high-speed railway, we can see that as the important high-speed railway passenger centers, Beijing, Shanghai and Guangzhou controlled other parts of the country and served respectively as the political and economic center, the most important engine of the economy, and a very dynamic region. The headquarters and chief offices of many companies in the three cities had become a contact center for both business and political circles and other elites.

Through making a comprehensive survey on Top 20 High-speed Railway in Line Strength, we found the lines in central areas and lines across areas started to stand out since 2009 and the number was gradually increased. To some extent, it also reflected the country's construction process of high-speed railway working on a wider coverage from eastern coastal areas to central inland area. This, to a certain extent, filled the gap in high-speed railway and established links between the Yangtze River Delta and the central area, the Yangtze River Delta and the coastal areas, and especially the Pearl River Delta and the central areas. Moreover, the backward linkage of high-speed railway between the economically-developed and densely-populated coastal areas and the Pearl River Delta was also a gap in high-speed railway planning in eastern areas [25]. In addition, most of western areas were rich in tourism resources. Tourism served as the service sector that was vital to fuel economic growth. Thus, the high-speed railway can promote the tourism and the economic growth of the western areas by strengthening the linkage among the three major areas and the central areas as well as the western areas [26].

C. Feature evolution of network structure

To compare and analyze the nationwide urban network structures in time dimension and deduce the network structure features, this article worked out the SDN_DIT_i, the ODI_cN, SDN_RSL_{ij} and ODI_lN between 2007 and 2014. The results were shown in Figure 2:

Table 1 2007-2014 HSR cities and links SDN_DITi SDN_RSLij ODI$_c$N ODI$_l$N

	Cities			Links		
	SDN_DIT_i	ODI_cN	No.ciites	SDN_RSL_{ij}	ODI_lN	No.links
2007	0.282	0.516	52	0.365	0.512	222
2008	0.278	0.517	59	0.328	0.513	309
2009	0.201	0.529	76	0.188	0.522	594
2010	0.244	0.520	85	0.211	0.517	612
2011	0.261	0.518	90	0.179	0.521	726
2012	0.229	0.523	93	0.166	0.523	882
2013	0.202	0.529	101	0.146	0.525	1254
2014	0.175	0.535	102	0.127	0.527	1979

In Table 1, more nodes and more lines reflected the adjustment of nationwide high-speed railway strategy in term of supply. The high-speed railway speeded up the inter-city mobility of population, logistics and capital flows. Various

resources were reallocated in traffic nodes, arteries and circles. As the influence radius of high-speed railway, the intraregional linkage was also getting closer. In order to research the relationship among the number of the cities linked by high-speed railway and the high-speed railway lines, and the entropies of urban nodes and high-speed railway lines, Figure 1 took the number of cities and lines as the abscissa and the index value as the ordinate to make the analysis; in order to display the trend of various indexes in time dimension, Figure 2 took the year as the abscissa and SDN_DIT_i, the ODI_cN, SDN_RSL_{ij} and ODI_lN as the ordinates, and added the trend line on it.
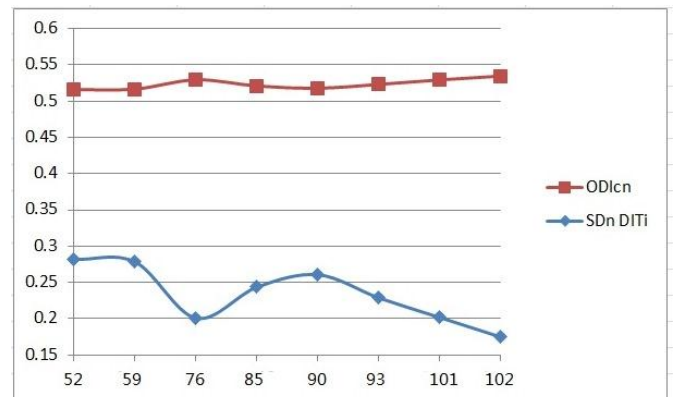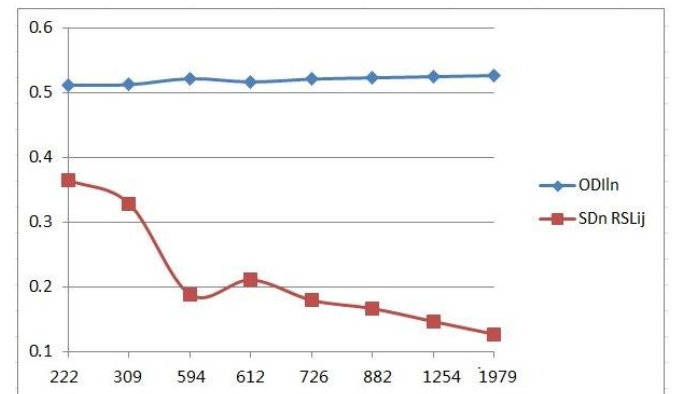

Fig 1(a) 2007-2014 city ODI$_C$N and SDN_DITi

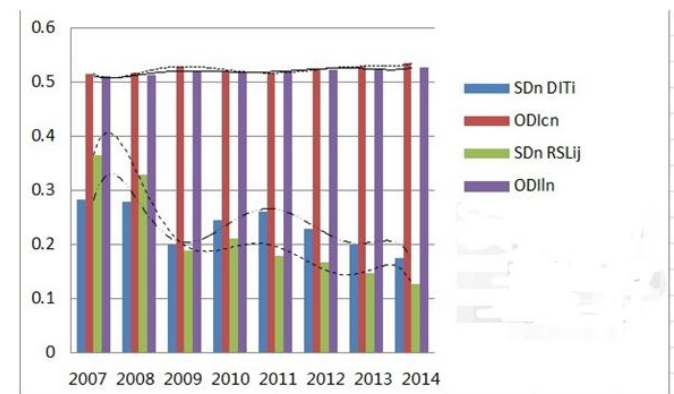Fig 1(b) 2007-2014 link ODI$_L$N and SDN_RSLij

Fig 2 2007-2014 HST network histogram

In comparison with previous researches such as Li Jing and others (2017), the greatest inconsistency features [27] lied in the indexes after the standardization treatment, and most of them showed a downward trend over time. It indicated that through the unified measurement and comparison across the country, though the high-speed railway network was well developed in

the areas of Yangtze River Delta and the Bohai Bay Rim, the homogeneous evolution of nationwide urban network level structure inclined to be more polycentric. Such feature was reflected not only among cities in an area but also among areas. The article hereby analyzed the feature from node structure and line structure respectively.

C.1 Node structure

We can see from Figure 1(a) that since 2007, as more and more cities joined in the high-speed railway network, the distribution of urban node strength became increasingly even, the SDn_DIT_i became gradually small, resulting in an obvious difference in SDn_DIT_i between 2007 and 2014.In view of the decreasing trend of SDn_DIT_i, the number of node cities exerted increasingly small influences on the SDn_DIT_i, the differences among urban network levels also become smaller and smaller, and the distribution of cities linked by high-speed railway became more and more even. The flat fitting trend line of SDn_DIT_i in Figure 3 also reflected the above-mentioned phenomena.

In Figure 2, the trend line of SDN_DIT_i also showed that there were level differences of node cities among the network structures of high-speed railway in 2007. The fluctuation of SDN_DIT_i trend line in 2009 can be explained due to the rapid growth of high-speed railway network in the Yangtze River Delta, attracting more cities with large economic weight, for instance, Shanghai, Nanjing and Suzhou, which were always at the top of the Node City List, which also caused certain level differences of urban network system in 2009. From 2007 to 2014, affected by the high-speed railway, the urban network across the country became increasing weak in urban level and more polycentric in distribution, and the traffic reachability and homogeneous growth within area were slightly improved. As the frequency of high-speed railway was gradually increased, the cities with the newly-opened stations were mostly located in the Yangtze River Delta which had a robust economic position in China, and became increasingly influential in population, social and economic growth.

C.2 Line structures

From the perspective of high-speed railway lines, we can see from Figure1(b) that as there were more and more lines, the SDN_RSL_{ij} were gradually decreased, and its distribution also flatten out. In general, the more the lines joined in the high-speed railway network, the smaller the line structure level among cities would become, and the more the homogeneous urban network system developed. The flat fitting trend line of SDN_RSL_{ij} in Figure 2 also reflected the above-mentioned phenomena.

And the year featured with highest line level difference was the year of 2007. The fluctuation since 2009 can be explained due to the robust line involvement of more trains. For instance, Nanjing-Shanghai and Shanghai-Suzhou lines made the urban network level more obvious. At large, the fitting trend line of SDN_RSL_{ij} indicated the homogeneous development of network distribution. The newly-opened lines were mostly located in the economically-developed Yangtze River Delta.

D. Overall analysis

Overall, nationally, the frequency data of high-speed railway between 2007 and 2014 showed a network growth, broader rural and urban coverage, more hub nodes and link lines in the

distribution of high-speed railway traffic transportation system, and obvious agglomeration characteristics in spatial distribution of high-speed railway, particularly in the areas centered on Guangzhou, Shanghai and Beijing. The high-speed railway closely linked with each other in urban agglomerations, while the sparsely-linked high-speed railway l across areas and in central and western areas caused big differences in high-speed railway linkage among urban agglomerations. The high-speed railway linked closely in Beijing-Shanghai lines and Beijing-Guangzhou lines but linked relatively sparsely in Shanghai-Guangzhou lines. Thus, to narrow the gap between the eastern and western areas of China in the development of high-speed railway traffic network has become an issue worthy of further attention.

V. CONCLUSIONS

This article uses the sample data of nationwide high-speed railway frequencies between 2007 and 2014 to reflect the urban functional network structure of a country in a dynamic way and make a study on the effected exerted by space allocation of Chinese cities. This article aims to explore the dynamic effects exerted by high-speed railway flow on urban network through the distribution of nationwide nodes and lines in different years.

As the high-speed railway network covered more and more cities, the reachability in the area and among areas became increasingly strong. More cities and railway lines had joined China railway network, thus the urban network level structure realized the homogeneous development, with a coverage extending to broader urban and rural areas. Affected by the high-speed railway network, China's urban network became more polycentric. Based on the node strength value and line strength value of specific cities in this article, between 2007 and 2014, Beijing, Shanghai and Guangzhou, as the most important cities with the advantage of high-speed railway in the Bohai Bay Rim area, the Yangtze River Delta and the Pearl River Delta respectively, interacted with the surrounding cities functionally in term of high-speed network in an effective way. The mainstream cities and main lines of high-speed railway urban network are usually in the Bohai Bay Rim area, the Yangtze River Delta and the Pearl River Delta. Compared with other areas, the eastern area showed a more homogeneous growth under the influence of high-speed railway network, while the western area still lagged behind, thus there are differences between the central area and the western area of China in its high-speed railway traffic network. The reachability among cities in eastern, central and western areas can be strengthened through the development of high-speed railway, while the high-speed railway can also play an important role in the integrated development of eastern, central and western areas [28]. To open more cross-region high-speed railway, particularly to intensify the building of high-speed railway network in the western area can strengthen the linkage between the three major areas and the central and western areas to a certain degree. Due to its high reachability brought by high-speed railway, the eastern area had, to the greatest extent, changed the travel habits of people in a social economy and also promoted the development of agglomeration economy at the same time. By contract, the Pearl River Delta was less developed in the homogeneous development of high-speed railway network in three major economically-developed eastern coastal areas. Its high-speed railway linkage was relatively weak in the area or across areas, because its high-speed railway construction had lagged behind by the end of 2014 [29] and thus

the number of both nodes with high reachability strength and railway lines is relatively small in the Pearl River Delta. In term of geographical position, the Pearl River Delta is closer to the central-west area, so to increase the investment in the high-speed railway construction in the Pearl River Delta can more effectively improve the construction of high-speed railway network in the western area [30].

Though the time cost of high-speed railway was relatively low due to its high speed, its money cost was higher than that of traditional railway transportation due to its high ticket price, thus the low-income population, such as migrant workers, hadn't taken the high-speed railway into the consideration of their regular travel modes. Therefore, the high-speed railway flow inclined to represent the travel structure of the middle and upper-middle-income population. Furthermore, in view of the limited coverage of high-speed railway network, the high-speed railway flow cannot fully capture the functional interaction among cities and only focus on the urban network level of its users, such as civil servants, businessmen and so on. The statistics showed a high correlation between the distribution of high-speed railway and population, and the high-speed railway frequency was positively correlated to the city levels [31]. China's high-speed railway displayed the obvious agglomeration characteristics in spatial distribution, thus the high-speed railway flow also inclined to reflect the higher-level links among cities. In the light of these conditions, more perfect high-speed railway network can more fully and definitively reflect the actual urban network structure of China. Due to limited data, this article cannot make an analysis or research on the effects of high-speed railway network on Chinese cities. However, for the high-speed railway, which served as a traffic network to be constantly developed and improved, the research objective of this article for the next step was to collect the frequency data of nationwide high-speed railway after 2014 and explore the spatial network structure evolution of future cities.

REFERENCES

[1]Castells M. Centrality in the space of flows[J].Built Environment,2007,33(4):482-485

[2] Wang Jiao'e, Jing Rui. Comparison of spatial structure and organization mode of inter-city networks from the perspective of railway and air passenger flow. ACTA Geographica Sinica. 2017, 72(8):1508-1519.

[3] Wang Jiao'e, Jiao Jingjuan, Huang Jie, Jin Fengjun. Theory and methodology of transportation development and location measures. ACTA Geographica Sinica. 2018,73(04):666-676

[4] Zhu Hui-bin. The Chinese City Function Network Based on Aviation PassengerFlow. Economic Geography Journal 2014(34)

[5]Babuster,D.&M.Givoni(2013),High-speed Rail in the EU27:Trends,Time, Accessibility and Principles. Built Enviornment,39,pp.324-338

[6] Completion and operation of "Four vertical and four horizontal" HSR network, total 3038km in 2007. Building structure.2018(2).

[7] Zhu Qiushi. Explore for the social-spatial restructuring under HSR "flow space" effect. China Institute of urban planning. 2014:11.

[8]Hall P. New trends in European urbanization [J]. Annals of the American Academy of Political and Social Science,1980,451(1):45-51

[9] Garmerda,M.&V. Romero(2012),High-speed Rail Opportunities around Metropolitan Regions:Madrid and London.Journal of Infrastructure Systems,18,pp.305-313

[10] Verma,A.,H.-S. Sudhira, S.Rathi, R.King & N. Dash(2013),Sustainable urbanization using high speed real(HSR) in Karnataka, India. Research in Transportation Economics,38,00.67-77

[11]Luo Zhendong. Primary exploration for the functional polycentric in Yangtze river delta. International urban planning, 2010,25(01):60-65.

[12]Luo Zhendong, He Heming, Geng Lei.The research of Yangtze river delta functional multicenter structure based on transformational passage flow. Urban planning journal,2011(02):16-23.

[13]Feng,C., D. Xie, X. MA& L. CAI(2014),Functional Polycentricity of the Urban Regional in the Zhujiang River Delta Based on Intercity Rail Traffic Flow. Scientia Geoographica Sinica,34,pp.276-284.

[14]Liu,X.,B.Derudder&K.Wu(2016),Measuring Polycentric Urban Development in China: An Intercity Transportation Network Perspective. Regional Studies,50,pp.1302-1315

[15] Yang H, Dijst M, Witte P, et al. The Spatial Structure of High Speed Railways and Urban Networks in China: A Flow Approach[J]. Tijdschrift Voor Economische En Sociale Geografie, 2017.

[16]Jiao, J., J. Wang, and F. Jin, Impacts of high-speed rail lines on the city network in China. Journal of Transport Geography, 2017. 60: p. 257-266

[17]Jiao,J.,Wang J.,Jin F.,Wang H.,Impact of high-speed rail on inter-city network based on the passenger train network in China,2003-2013. ACTA Geographica SINICA,2016,71(02):265-280]

[18] Jiao J, Wang J, Jin F, et al. Impacts on accessibility of China's present and future HSR network ☆ [J]. Journal of Transport Geography, 2014, 40(40):123-132.

[19]Green, N.(2007),Functional Polycentricity:A Formal Definition in Terms of Social Network Analysis.Urban Studies,44,pp.2077-2103

[20]Limtanakool, N.,T. Schwanen& M. Dijst(2007),A Theoretical Framework and Methodology for Characterizing National Urban Systems on the Basis of Flows of People: Empirical Evidence for France and German. Urban Studies,44,pp.2123-2145

[21]Jiang Yong, The spatial connection of Zhejiang Province Based on the County Traffic Flow Perspective. Economics Geography, 2012,32(12):73-78.

[22]Wu W.,Dong Z.,Zhang W., Spatio-temporal Evolution of the China's Inter-urban Organization Network Structure: Based on Aviation Data from 1983 to 2006. ACTA Geographica SINICA, 2011,66（4）：435-445

[23]Liu Z.,Liu J.,He X., The Spatial Connection and Network Feature of Zhongyuan Economic District Base on Intercity Traffic Flow. Economic Geography,2014,34（7）：58-66

[24]Derudder,B.&F. Witlox(2009),The Impact of Progressive Liberalization on the Spatiality of Airline Networks:A Measurement Framework based on the Assessment of Hierarchical Differentiation .Journal of Transport Geography,17,pp.2371-2388

[25]Nathalie Van Nuffel. Measuring hierarchical differentiation: connectivity and dominance in the European urban network.Transportation Planning and Technology. Vol.33, No.4,June 2010,343-366

[26]Li Q.,Ren F.,Zhu Y.,Zhang H.,Analysis of the City rank and Spatial Contact Pattern Based on High-speed Rail Frequency Statistics. Journal of Geomatics. 2017, 42(3):83-87.

[27]Zhu Yong, HSR forced the speeding of Yangtze River Delta integration, Oriental Morning Post,2015.11.10

[28]Song W.,Li X.,Xiu C.,Patterns of spatial interaction and hierarchical structure of Chinese cities based on intercity air passenger flows. Geographical Research 2008, 27(4):917-926

[29]Luo Z.,Zhu C.,Xue W.,The analysis on spatial structure of Yangtze River delta based on Passenger flow of High-speed railway.Shanghai Urban planning, 2015(4):74-80.

[30]Wang J.,Jiao J.,Jin F.,Spatial effect of high-speed rails on interurban economic linkages in China. ACTA Geographica SINICA. 2014, 69(12):1833-1846

[31] Wang,J.J.,C.Rong,J.Xu& S.W.O OR(212), The funding of hierarchical railway development in China, Research in Transportation Economics,35,pp.26-33.