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Transnational Economic Connection Analysis Based on Railway Class Accessibility Between China and Russia

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Abstract: Under the background of 'the Belt and Road' initiative, the economic cooperation has great potential between China and Russia. The railway accessibility has an important influence on the economic connections of cities along the railway line. This paper studied the Sino-Russian transnational economic connection based on the railway class accessibility along Trans-Siberian railway (the transnational China railway branch line). The results are as following. First, the railway accessibility of the Chinese nodes is stronger than that of the Russian nodes, which in general displays a tendency of space attenuation from China to the Sino-Russian border, then to Russia. Spatially, the railway accessibility within the study area shows a 'High East, Low West' and 'High South, Low North' spatial pattern. The railway accessibility of the nodes, which are located at the beginning and end of the railway line, is weaker than those nodes located in the middle of the line. Second, the railway accessibility and external economic connection intensity summation of the nodes show a positive relationship along the railway line. The economic connection intensity summation of different nodes presents obvious regional differentiation. Finally, as economic connection network has evolved, the small world effect of Sino-Russian railway economic connection network becomes strong.

Keywords: railway class accessibility; economic connection intensity; spatial pattern; China; Russia

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1 Introduction

Accessibility is an important concept that is broadly used in the fields of economic geography, transport planning, and land-use planning, and it originates from the classical location theory. Hansen introduced the accessibility concept, which he defined as the interaction opportunity of each city within a transportation network (Hansen, 1959). Accessibility also refers to the ability to arrive at an appointed place at the appropriate time via a transportation facility. The level of the accessibility depends on the mobility of a person and the opportunity to achieve the purpose (Geertman and van Eck, 1995). The transportation facilities with high accessibility can improve the economic connection among the nodes in the transportation network. The details of transportation accessibility and economic connection analysis should reflect the needs of specific perspectives, contents and methods.

Research perspectives: Scholars have focused their studies on the accessibility of various transportation modes (Gutiérrez et al., 1996; Li and Shum, 2001; Kwan et al., 2003; Zhu and Liu, 2004; Condeço-Melhorado et al., 2011; Koopmans et al., 2013),

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spatial flow (Goetz, 1992; Russon and Vakil, 1995; O'Kelly, 1998; Weidlich and Haag, 1999; Djankov and Freund, 2002; Matsumoto, 2004; Zook and Brunn, 2005; Jin et al., 2010) and spatial spillover effect of traffic accessibility (López et al., 2009; Gutiérrez et al., 2010; 2011), *etc*. Research contents: Scholars have focused their studies on the accessibility of the transportation networks (Jin, 2003), the evolution of spatial patterns based on the accessibility improvement (Gutiérrez et al., 1996; Gutiérrez, 2001; Li and Shum, 2001; Kwan et al., 2003; Zhu and Liu, 2004; Condeço-Melhorado et al., 2011; Delmelle and Casas, 2012; Tribby and Zandbergen, 2012; Koopmans et al., 2013; Wang and Cheng, 2016; Chen et al., 2018), regional equity between congested central regions and poorer peripheral areas (Keeble et al., 1982; Monzón et al., 2013), the relationship between accessibility and economic growth (Linneker and Spence, 1996; Bunnell et al., 2002; Andersson et al., 2010; Jiao et al., 2016; Ma and Ma, 2016; Chu and Zhang, 2018; Wang et al., 2018), the reshape of urban system and its spatial structure from the perspective of spatial flow (Goetz, 1992; O'Kelly, 1998; Weidlich and Haag, 1999), urban spatial interaction and regional spatial reorganization (Djankov and Freund, 2002; Matsumoto, 2004; Dai and Jin, 2008; Jin et al., 2010; Jiang et al., 2018), *etc*. Research methods included accessibility model (Ma and Ma, 2016; Wang and Cheng, 2016; Chu and Zhang, 2018; Jiang et al., 2018), spatial interaction gravity model (Russon and Vakil, 1995; Shen, 2004; Khadaroo and Seetanah, 2008; Chen et al., 2018; Chu and Zhang, 2018; Jiang et al., 2018), potential model (Djankov and Freund, 2002), distance decay model (Dai and Jin, 2008), cumulative chance model (Wachs and Kumagai, 1973), and Pearson's correlation coefficient (Jiao et al., 2016), *etc*. More specifically, existing research on the transportation accessibility and economic connection analysis has mainly contained the following research context: change of accessibility, economic connection from the perspective of transportation accessibility, transportation network structure, economic connection and interactions from the perspective of spatial flow.

(1) Changes of accessibility. The weighted average time, economic potential and daily accessibility were adopted to analyze the accessibility impacts of the Madrid-Barcelona-France border high-speed rail (HSR). And Gutiérrez et al. (1996, 2010, 2011) and Gutiérrez (2001) evaluated the overall accessibility status of the HSR network in Europe. On these bases, he analyzed the spatial spillover effects of HSR accessibility. Gutiérrez et al. (1996; 2010; 2011) and Gutiérrez (2001) believed that the travel time was sharply reduced and the convergence of time and space was enhanced after the opening of HSRs. HSR accessibility within the scope of the national scale was universally improved. And HSR improved the economic connection between urban and regional areas. Wang and Cheng (2016) evaluated the evolution of China's expressway network accessibility in each period including connectivity, travel time and location coefficient.

(2) Economic connection from the perspective of transportation accessibility. Linneker and Spence (1996) thought that the accessibility improvement of the M25 Ring Road in London had played a positive role in promoting regional economic development. Sasaki et al. (1997) also found that there was a significant positive correlation between accessibility of Japan Shinkansen rail and the economic development along this line. Chu and Zhang (2018) studied the urban railway accessibility, the urban economic connections and their spatial differentiation along the Sino-Russian railway line of K19/K20 class train. Jiao et al. (2016) explored the relationship between accessibility and economic growth in China from 1990 to 2010. Dai and Jin (2008) studied the spatial interaction and network structure evolvement of cities in terms of China's rail passenger flows. Dong et al. (2018) believed that the construction of China-Mongolia-Russia HSRs is a strategic move to promote transportation infrastructure inter-connectivity, which will enhance communication and cooperation among the three countries, and remold the economic distribution patterns along the railway corridor.

(3) Transportation network structure. Goetz studied the aviation network and its hierarchical scale structure based on the perspectives of air passenger and freight flow (Goetz, 1992). O'Kelly (1998) and Weidlich and Haag (1999) analyzed the spatial structure of the urban system based on the urban transportation network. Jin (2003) discussed the transportation network and its development strategies of shipping centers in the Yellow Sea Rim based on the economic globalization tendency. Chen et al. (2018) explored the long-term evolutionary characteristics of land transportation network in the Beijing-Tianjin-Hebei.

(4) Economic connection and interactions from the perspective of spatial flow. Bunnell et al. (2002) analyzed the influence of the spatial flow on the urban economic connection. Djankov and Freund (2002), Matsumoto (2004), Russon and Vakil (1995) studied the interaction intensity of air traffic flow, trade flow, passenger flow between origin and destination with the modified gravity model. Ma and Ma (2016) selected 286 Chinese cities at prefecture level or above as the search objects and they used principal component analysis method to get the cities' comprehensive economic connection and interactions. Jiang et al. (2018) explored HSR passenger spatial linkage pattern and its influence factors using national HSR services data based on the linkage density accessibility, rank-size rule and gravity model.

The research on transportation accessibility and economic connection has diversified locally and internationally, replacing the static description. However, integrated research of transportation accessibility and economic connection remain insufficient in view of multiple perspectives. Besides, scholars have focused more on surface linear distance or traffic distance to calculate economic connection intensity between urban and regional areas. In fact, with the rapid development and updating of the road network, there is no comparability to calculate economic connection intensity with surface linear distance or traffic distance between the regions with good traffic accessibility. What's more, there has been lack of exploration into economic connection analysis based on the influence of railway class accessibility on cross-border scale between China and Russia.

Due to the above mentioned reasons, this study improved and integrated existing research contents and methods. Under the background of 'the Belt and Road' and 'Economic Corridor of China, Mongolia and Russia' initiatives, this paper studies Sino-Russian transnational economic connection based on the railway class accessibility along the Trans-Siberian railway (the transnational China railway branch line). Firstly, the paper gave a definition to the railway class accessibility. Secondly, it tried to construct an exploratory framework of railway class accessibility, economic connection intensity and economic connection network characteristic along the railway line based on the three-dimensional perspectives of node, line and network. From the node perspective, the railway class accessibility of each node was measured along the railway line. From the line perspective, the economic connection intensity between any given nodes was measured along the railway line. From the network perspective, the economic connection network characteristics were explored in the Sino-Russian railway economic connection network. Finally, spatial interpolation function of geographic information system (GIS) was used to simulate the spatial pattern of accessibility and economic connection intensity summation to reveal their spatial differentiation characteristics. This study has some innovation in the economic connection analysis based on the influence of railway class accessibility. It provides a case reference to explore Sino-Russian transnational economic connection from the perspective of railway class accessibility. It provides suggestions for the future construction of Sino-Russian transnational HSRs, especially the transnational HSRs between Northeast China and Far East Russia. It also provides references to know Sino-Russian transnational economic priorities cooperation areas and potential development areas.

2 Materials and Method

2.1 Study area

Trans-Siberian railway is the longest railway line in the world with its length 9288 km (Richmond et al., 2016). It contains several branch lines, such as Baikal-Amur railway branch line, Ural railway branch line, transnational Mongolia railway branch line, and transnational China railway branch line. Among them, the transnational China railway branch line connects China and Russia. This railway branch line starts from Beijing in China and ends at Moscow in Russia. It connects Beijing, Tianjin, Hebei Province, Inner Mongolia Autonomous Region, Heilongjiang Province, Jilin Province, Liaoning Province, Primorsky Territory, Khabarovsk Territory, Zabaikalsk Territory, Republic of Buryatia, Irkutsk Region, Krasnoyarsk Territory, Kemerovo Region, Novosibirsk Region, Omsk Region, Tyumen Region, Perm Territory, Sverdlovsk Region, Republic of Udmurtia, Kirov Region, Nizhny Novgorod Region, Vladimir Region and Moscow (Fig. 1). In this study, Trans-Siberian railway (the transnational China railway branch line) is also called the Sino-Russian railway line. And forty-one nodes are included in the railway class accessibility and economic connection analysis along this line.

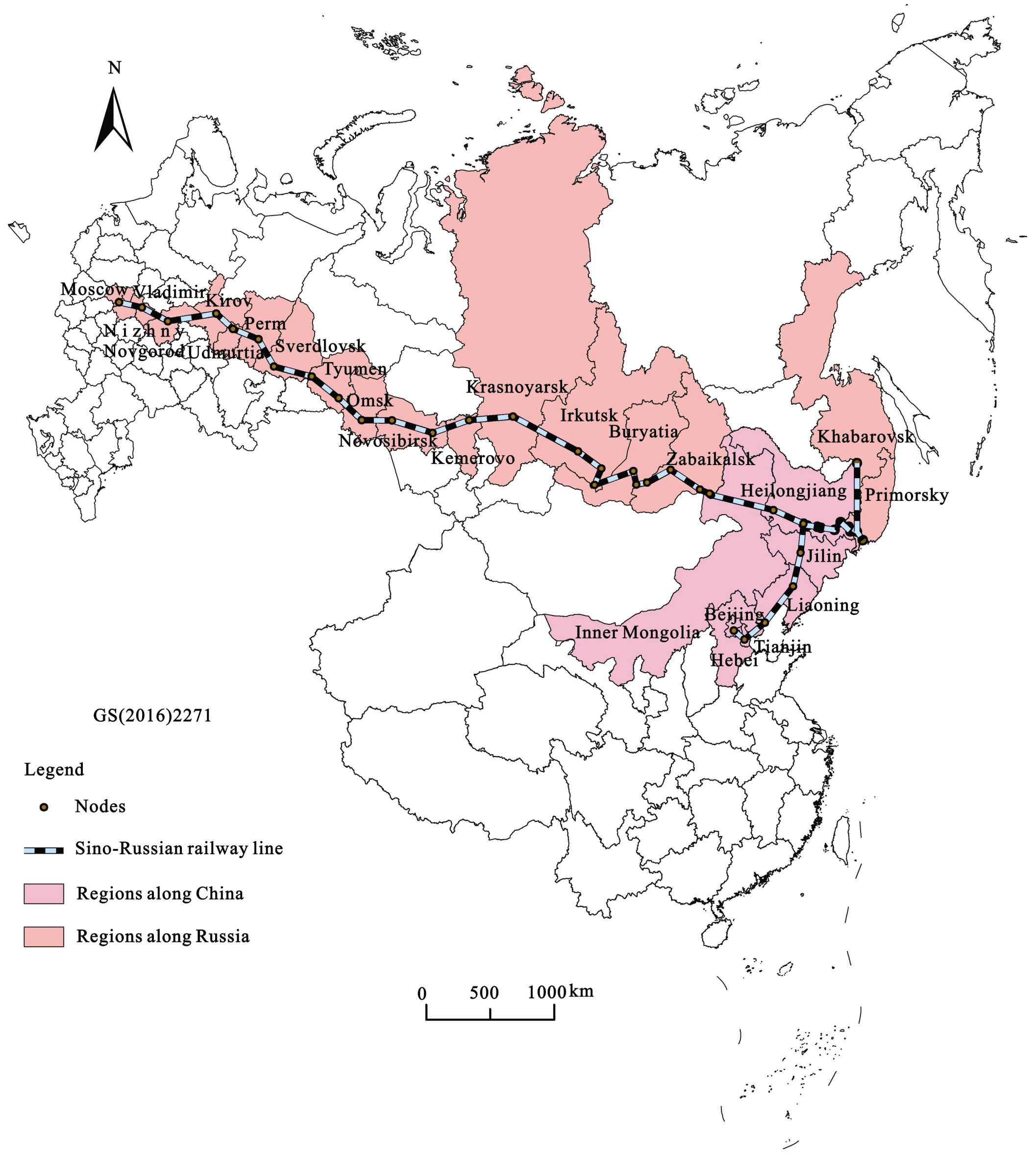

Fig. 1 Sketch map of the study area

2.2 Railway class accessibility

Accessibility is a relatively comprehensive system. This paper studies the external accessibility from the perspective of social-economy. At the same time, this paper defines this accessibility as the specific railway class accessibility. That is to say, the accessibility in this paper is the convenience degree which a traveler can travel from the origin train station to arrive at the destination train station by taking the specific class trains at a certain time along the Sino-Russian railway line. When calculating the accessibility, this study regards the quality of the city as '1'. It also regards the study area as closed and ignores urban openness and connectivity, only considering the city as a node.

2.3 Weighted average travel time

The weighted average travel time is the most commonly used indicator to measure the accessibility level of nodes. This study uses the weighted average travel time to measure the railway class accessibility of the nodes along the Sino-Russian railway line. The weighted average travel time (Gutiérrez et al., 1996; Bruinsma and Rietveld, 1998; Gutiérrez, 2001) emphasizes the point of space-time distance and cost saving to determine the level of railway class accessibility. It characterizes the physical sense of accessibility, which refers to the time measured from the established node city to other cities. This indicator is associated with several major factors of cities along the Sino-Russian railway line. These factors include: 1) urban spatial location, 2) the development degree of the transportation infrastructure, 3) the time from the established node city to other cities, 4) the degree of comprehensive competitive strength of the node city, such as node city's population and gross domestic product (GDP). Population and GDP can indicate the urban scale and economic development level of node city. The two indicators can also represent the attraction or radiation force of the node city to the surrounding areas, having an influence on travelers' wishes to reach this node city along Sino-Russian railway line. Then they can affect the node city's accessibility under the effect of Sino-Russian class trains. A higher value of weighted average travel time results in a lower city accessibility. This indicator is computed as follows:

$$A_i = \sum_{j=1}^{n}\left(T_{ij} \times M_j\right) \Big/ \sum_{j=1}^{n} M_j \qquad (1)$$

where A_i is the weighted average travel time of node i. T_{ij} is the average travel time when i reaches j by taking Sino-Russian class trains. Then the 41 × 41 origin-destination travel time matrix are thus derived. Population and GDP are important indicators for reflecting urban economic activities. In comparison with using one index, this study uses the approach for calculating M_j by the square root of the product of population and GDP to improve the rationality of the results. And n is the total number of the nodes except for i.

2.4 Economic connection intensity model

The modified economic connection intensity model in this study is used to analyze the economic interaction of forty-one nodes under the effect of Sino-Russian railway accessibility from the intercity railway travel time perspective. This model explores the economic radiation force of the centers such as Beijing, Moscow, as well as the economic acceptance force of other nodes along the Sino-Russian railway line. This paper only uses the average travel time between any given nodes by taking Sino-Russian class trains to measure economic connection intensity, not considering the average travel time by taking other class trains, such as HSRs class trains in Chinese territory. The modified economic connection intensity model is computed as follows:

$$R_{ij} = \frac{\sqrt{P_i \times G_i} \times \sqrt{P_j \times G_j}}{T_{ij}^{\ 2}} \qquad (2)$$

$$R_{iO} = \sum_{j=1}^{n} R_{ij} \quad R_{iD} = \sum_{j=1}^{n} R_{ji} \quad R_i = \sqrt{R_{iO} \times R_{iD}} \qquad (3)$$

where R_{ij} is the economic connection intensity between i and j along the Sino-Russian railway line. P_i and G_i are the population and GDP of i node respectively. P_j and G_j are the population and GDP of j node respectively. R_i is the summation of external economic connection intensity of i. R_{iO} refers to external economic connection intensity of summation i, when i reaches other cities, taking i as the origin city. R_{iD} refers to external economic connection intensity summation of i, when other cities reach i, taking i as the destination city. T_{ij} is the average travel time when i reaches j by taking Sino-Russian class trains. n is the total number of the nodes except for i.

2.5 Social network analysis

Social network analysis is the study of relationships between individuals in the economic or social network. With the modified economic connection intensity model, the economic connection intensity between each city-pair is calculated. The 41 × 41 economic connection intensity matrix is computed for the economic connection network analysis. The network analysis software, University of California at Irvine Network (UCINET), a visual analysis tool, is selected to study the spatial structure, shape and characteristics of Sino-Russian economic connection network from the perspective of railway class accessibility.

2.5.1 Network density

The network density in this study is used to analyze the agglomeration or diffusion trend of economic flow between any given pair of cities in the Sino-Russian economic connection network. This study uses the approach for calculating the network density by the ratio of practical economic connection number and theoretical economic connection number between any given pair of cities in the network. The higher the network density is, the closer the city's economic connection is. The network density is computed as follows:

$$D=\sum_{i=1}^{k}\sum_{j=1}^{k}R\left(i,j\right)/k\left(k-1\right) \tag{4}$$

where D is the density of economic connection network. R (i, j) is the economic connection intensity between i and j. k is the number of nodes in the economic connection network.

2.5.2 Small world effect

The small world effect in this study is used to analyze the urban accessibility degree of economic flow between each city-pair in the economic connection network. It mainly consists of two most commonly used indicators: the characteristic path length and the clustering coefficient. The longer the characteristic path length is, the greater the diffusion trend of the urban traffic economic elements in the network is, the slower the urban traffic economic flow from one node to another is, and the weaker the small world effect of economic connection network is. The higher the clustering coefficient is, the greater the agglomeration trend of the urban traffic economic elements in the network is, the more frequent of urban economic flow from one node to another is, and the stronger the small world effect of economic connection network is. The characteristic path length and the clustering coefficient are computed according to the following procedure on UCINET: Network → Cohesion → Distance and Network → Cohesion → Clustering Coefficient.

2.5.3 Centralities

(1) Degree Centrality. The degree centrality is used in this study to analyze the economic connection intensity between any given each city-pair among the forty-one cities in the economic connection network. This indicator is intuitive, simple and commonly used to represent the urban location economic advantage. The importance of the degree centrality in a network depends on the economic connection intensity between a given node and other nodes. The higher the urban degree centrality is, the greater urban economic strength and competitiveness are, the more important node role the city plays in the whole network.

(2) Closeness Centrality. The closeness centrality is used in this study to analyze the urban controlling ability of the whole economic elements in the economic connection network. This indicator can express accessibility degree of economic flow between any given pair of cities among forty-one cities in the network. The higher the urban closeness centrality is, the stronger the urban economic core power is, the better the accessibility degree of the economic flow between a given node and all others, the closer the urban economic connection between a given node and all others, and the weaker the economic dependence degree on other nodes is.

(3) Betweenness Centrality. The betweenness centrality is used in this study to analyze the urban intermediary or bridge degree from a given city to another destination city by taking Sino-Russian class trains. The betweenness centrality, a ‘control force’ indicator, reflects urban ability to control other nodes’ economic development. In general, cities with high betweenness centrality nodes occupy the key economic positions in the economic connection network. And they are also located in the shortest path of the economic connection with other nodes.

Degree centrality, closeness centrality and betweenness centrality are computed according to the following procedure on UCINET: Network→Centrality→Multiple Measures.

2.6 Data sources

The data of intercity travel time are obtained from the international train schedules of Sino-Russian railway line. The data of Chinese city population and GDP are from the ‘China City Statistical Yearbook’ (National Bureau of Statistics of China, 2016). The data of Chinese county population and GDP are from the ‘Heilongjiang Statistical Yearbook’ (Heilongjiang Province Bureau of Statistics and Heilongjiang Province Bureau of Statistics, 2016). The data of Russian urban population are from the ‘Russia in Figures’ (Federal State Statistics Service, 2016). The data of Russian urban GDP are provided by the ‘Regions of Russia, the main characteristics of the subjects of the Russian Federation’ (ФЕДЕР АЛЬНАЯ СЛУЖБА ГОСУДАРСТВЕННОЙ СТАТИ СТИКИ (Federal Office for State Statistics), 2016).

3 Results

3.1 Accessibility analysis

3.1.1 Accessibility situations

Table 1 reports the urban weighted average travel time of the nodes along the Sino-Russian railway line. The average value of urban weighted average travel time is 39.59 h in China, much lower than that of 62.47 h in

Table 1 Weighted average travel time of nodes along Sino-Russian railway line

		A_i(h)		A_i(h)		A_i(h)		A_i(h)		A_i(h)		A_i(h)		A_i(h)
China	Beijing	48.41	Tianjin	43.48	Shanhaiguan	35.46	Shenyang	37.69	Changchun	37.13	Harbin	37.96	Ang'angxi	36.07
	Manzhouli	39.52	A'cheng	35.65	Shangzhi	36.92	Yimianpo	37.06	Mudanjiang	40.40	Muling	41.25	Suiyang	43.18
	Suifenhe	43.64	Average	39.59										
Russia	Ussuriysk	47.16	Vladivostok	49.58	Khabarovsk	56.10	Zabaikalsk	39.65	Borzja	40.52	Chita	43.39	Hilok	45.45
	Petrovsk	46.71	Ulan-Ude	47.63	Slyudyanka	49.97	Irkutsk	51.19	Zima	52.65	Krasnoyarsk	59.23	Anadyr	60.77
	Novosibirsk	66.26	Barabinsk	65.00	Omsk	67.40	Ishim	68.97	Tyumen	71.42	Yekaterinburg	74.85	Perm	77.75
	Glazov	80.13	Kirov	82.02	Nizhniy Novgorod	87.33	Vladimir	88.44	Moscow	104.72	Average	62.47		

Note: A_i is the weighted average travel time of node i.

Russia. In general, the railway class accessibility of the nodes in Chinese territory is stronger than that of the nodes in Russian territory along the Sino-Russian railway line. Chinese nodes are more accessible than Russian nodes. The weighted average travel time of the nodes along Sino-Russian railway line demonstrates obvious zone hierarchy and differentiation characteristics. The weighted average travel time of various railway sections is different, with the order of their weighted average travel time as follows: Shanhaiguan-Zabaikalsk and A'cheng-Mudanjiang (35–40 h) < Beijing-Tianjin, Borzja-Slyudyanka and Muling-Vladivostok (40–50 h) < Irkutsk-Krasnoyarsk (50–60 h) < Anadyr-Ishim (60–70 h) < Tyumen-Glazov (70–80 h) < Kirov-Moscow (more than 80 h). The areas with superior railway accessibility are concentrated in Shanhaiguan-Zabaikalsk and A'cheng- Mudanjiang.

The railway accessibility of the nodes which are located at the beginning and end of the Sino-Russian railway line is weaker than those nodes located in the middle of this railway line. Beijing and Moscow, where the economic development level is the highest and the people are the densest, have relatively low railway accessibility compared with some cities along the Sino-Russian railway line. This study regards the study area as closed and ignores regional openness and connectivity. Beijing and Moscow are located at the beginning and end positions of the railway line, respectively. One-way transmission of railway transport economic flow is pretty slow in Beijing and Moscow. Therefore, the railway accessibility of Beijing and Moscow is weaker than that of nodes, which are located in the middle of the railway line. However, Beijing and Moscow are respectively as the capital of China and Russia. Their potential accessibility advantages are enormous in the context of diversified traffic model and opening to the outside world.

3.1.2 Accessibility patterns

Spatial interpolation function of GIS was used to simulate the pattern of the railway class accessibility within the scope of study area along Sino-Russian railway line (Fig. 2). The railway accessibility pattern within the study area presents the spatial differentiation characteristics under the effect of Sino-Russian trains. The areas of most superior railway class accessibility are concentrated in Chinese territory. The railway class accessibility of the Chinese nodes is stronger than that of the Russian nodes, which in general displays a tendency of space attenuation from China to the Sino-Russian border, then to Russia along the Sino-Russian railway line.

Spatially, the railway class accessibility within the study area shows a 'High East, Low West' and 'High South, Low North' spatial pattern along railway line. The railway accessibility in the southeastern part of the study area is obviously stronger than that in the western and northern parts. The marginal railway accessibility

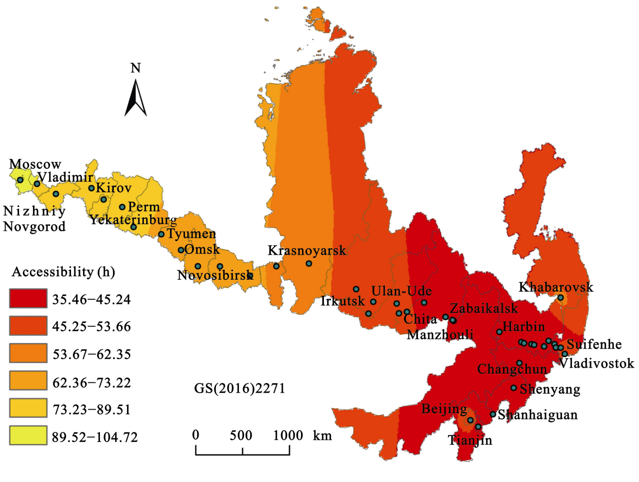

Fig. 2 Spatial pattern of accessibility

areas are mainly concentrated in the western part of Russia. Because the southeastern part of the study area has formed a complex railway network, which consists of Harbin-Manzhouli, Harbin-Suifenhe, Harbin-Dalian, Shenyang-Shanhaiguan, Siping-Qiqihar, Shenyang-Jilin, Changchun-Tumen, Harbin-Jiamusi, Beijing-Shenyang, Beijing-Tongliao, Beijing-Chengde-Jinzhou, Tongliao-Ranghulu and more than thirty railway lines. This complex railway network cover many economic and transportation centers in China, resulted in spatial agglomeration and scale effects of core elements, such as population and economy in these centers. And the scale effects have changed into the spatial spillover effects of railway accessibility, expanding to the western and northern parts of the study area along railway line. But the spatial spillover effects of railway accessibility show an obviously weakened tendency in Suifenhe (Sino-Russian border city) and Zima. Urban approaches, high population density, and highly developed economies in the southeastern part of the study area promote the flow of people, logistics, and other various elements. The western part of the study area has not opened HSRs. The railway accessibility ability of Moscow, Yekaterinburg, Nizhniy Novgorod has the weaker dominant forces, whereas those of other cities in China are significantly stronger. Thus, the degree of railway network connection in the southeastern part of the study area is relatively closer than that in the western and northern parts along railway line.

3.2 Economic connection intensity

3.2.1 Intercity economic connection intensity

Fig. 3 shows the economic connection intensity map between any given each city-pair among the forty-one cities along Sino-Russian railway line. In the economic connection intensity map, this study raises the color standards of green, yellow and red to classify into the economic close, compact and loose connection intensity between each city-pair under the effect of Sino-Russian trains. The results show that the number of city-pairs in intercity economic compact and loose connection intensity account for a larger proportion, compared with that in intercity economic close connection intensity. The economic connection intensity of Beijing-Tianjin is the highest, appearing the economic close connection intensity. Beijing, Tianjin, Shenyang, Changchun and Harbin

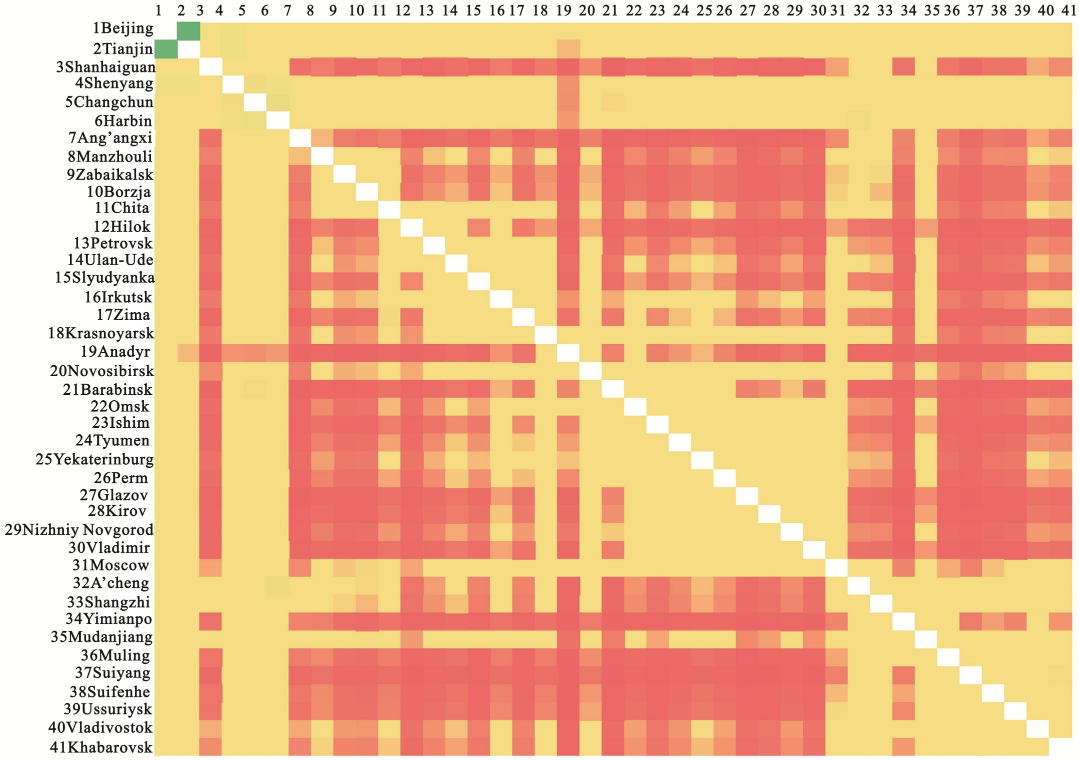

Fig. 3 Intercity economic connection intensity map. Green, yellow and red refer to the economic close, compact and loose connection intensity respectively between each city-pair

are the regional economic centers, forming the economic compact connection intensity map with the other nodes along railway line. The economic membership of the nodes along the railway line presents obvious tendency of spatial directivity and economic-centers' proximity. In Chinese territory, Beijing, Tianjin, Shanhaiguan, Shenyang, Changchun and Harbin have formed an internal economic compact connection intensity group. In Russian territory, Tyumen, Yekaterinburg, Perm, Glazov, Kirov, Nizhniy Novgorod, Vladimir and Moscow have formed an internal economic compact connection intensity group. Mudanjiang, Muling, Suifenhe, Ussuriysk, Vladivostok and Khabarovsk have also formed an internal economic compact connection intensity group in Sino-Russian transnational territory.

3.2.2 Economic connection intensity summation

The average value of the external economic connection intensity summation of nodes in the Russian territory is 4.66, much lower than that of 681.18 of nodes in the Chinese territory along Sino-Russian railway line. In general, the comprehensive railway accessibility of the nodes in Chinese territory is stronger than that of the nodes in Russian territory. The nodes with high railway accessibility level also have relatively high external economic connection intensity summation. So railway accessibility and external economic connection intensity summation show a positive relationship under the effect of Sino-Russian trains. The stronger the urban railway accessibility is, the higher the urban external economic connection intensity summation is. In other words, urban external economic connection intensity summation can be increased by the means of improving urban railway accessibility along Sino-Russian railway line (Table 2).

3.2.3 Economic connection intensity patterns

Spatial interpolation function of GIS was used to simulate the pattern of the urban external economic connection intensity summation within the scope of study area along Sino-Russian railway line (Fig.4). The spatial distribution of the urban external economic connection intensity summation shows large disparities. Spatially, the external economic connection intensity summation within the study area shows a 'High East, Low West' and 'High South, Low North' spatial pattern along railway line, appearing an increasing trend from west to east, and from north to south. In general, the pattern of the urban external economic connection intensity summation within the study area is similar with that of the railway accessibility, displaying a tendency of space attenuation from China to the Sino-Russian border, then to Russia. This also suggests that there is positive relationship between the railway accessibility and external economic connection intensity summation within the study area under the effect of Sino-Russian trains.

Table 2 External economic connection intensity summation of nodes along Sino-Russian railway line

	City	R_{iO}	R_{iD}	R_i	City	R_{iO}	R_{iD}	R_i	City	R_{iO}	R_{iD}	R_i	City	R_{iO}	R_{iD}	R_i
China	Beijing	4436.50	4326.58	4381.19	Tianjin	4326.29	4431.14	4378.40	Shanhaiguan	5.84	5.99	5.91	Shenyang	283.67	301.65	292.52
	Changchun	412.78	413.02	412.90	Harbin	490.87	502.85	496.82	Ang'angxi	1.20	1.07	1.13	Manzhouli	3.32	3.26	3.29
	A'cheng	181.95	160.43	170.85	Shangzhi	30.76	29.98	30.36	Yimianpo	5.87	5.83	5.85	Mudanjiang	34.98	32.91	33.93
	Muling	2.26	2.22	2.24	Suiyang	0.73	0.84	0.78	Suifenhe	1.52	1.36	1.44	Average	681.24	681.28	681.18
Russia	Ussuriysk	1.24	1.24	1.24	Vladivostok	3.70	3.40	3.55	Khabarovsk	1.71	1.64	1.67	Zabaikalsk	2.59	2.57	2.58
	Borzja	0.37	0.35	0.36	Chita	0.80	0.77	0.78	Hilok	0.11	0.11	0.11	Petrovsk	0.55	0.55	0.55
	Ulan-Ude	0.87	0.87	0.87	Slyudyanka	0.63	0.69	0.66	Irkutsk	1.95	1.86	1.91	Zima	0.54	0.55	0.54
	Krasnoyarsk	2.22	2.51	2.36	Anadyr	0.15	0.16	0.15	Novosibirsk	6.52	7.17	6.84	Barabinsk	1.15	0.98	1.06
	Omsk	3.93	3.40	3.65	Ishim	1.94	1.77	1.85	Tyumen	4.26	4.16	4.21	Yekaterinburg	6.46	6.99	6.72
	Perm	4.56	4.41	4.48	Glazov	1.47	1.38	1.42	Kirov	2.29	2.25	2.27	Nizhniy Novgorod	14.08	18.59	16.18
	Vladimir	16.24	20.46	18.23	Moscow	41.75	32.65	36.92	Average	4.70	4.67	4.66				

Note: R_i is the summation of external economic connection intensity of *i*. R_{iO} refers to external economic connection intensity of summation *i,* when *i* reaches other cities. R_{iD} refers to external economic connection intensity summation of *i*, when other cities reach *i*. The higher the values in the Table 2, the stronger the external economic connection intensity of *i*

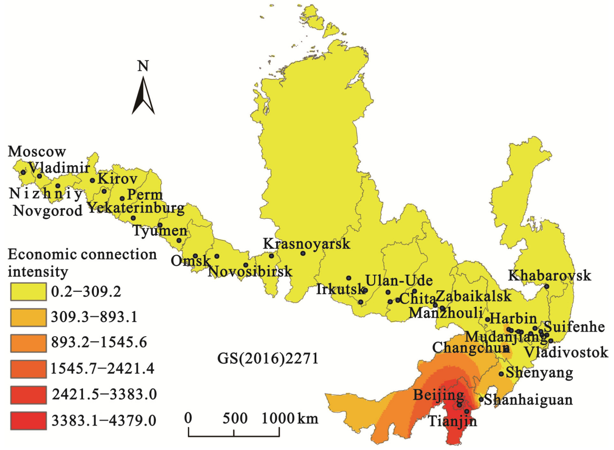

Fig. 4 The pattern of external economic connection intensity summation

The cities with high external economic connection intensity summation are mainly located in the Chinese territory. The spatial advantage distribution of external economic connection intensity summation presents a decreasing trend from Beijing, Tianjin to Northeast China, then to the Sino-Russian border and Russia along the Sino-Russian railway line. Beijing and Tianjin are the economic development polar cities, with strong economic polarization effects. The strong economic polarization effects have both positive effects and negative effects. 1) Positive effects. Spatial agglomeration and scale effects of core elements, such as population and economy are prominent in Beijing and Tianjin. The expansion of railway economic flow has a profound effect on the re-allocation of core elements, enhancing the supply and demand efficiency of core elements from Beijing and Tianjin to other cities along the Sino-Russian railway line. 2) Negative effects. Beijing and Tianjin are located at the origin position of Sino-Russian railway line. It is difficult for the terminal Russian cities with poor accessibility to receive the effective expansion of railway economic flow from Beijing and Tianjin due to the long distance restriction. This phenomenon leads to the imbalanced and uncoordinated economic development along the Sino-Russian railway line. But with Sino-Russian HSRs opening, high time-space compression can gradually reshape urban and regional economic form, function, and development mode in the future. With high speed, large capacity, security, and developed accessibility, HSRs must improve the economic connection between urban and regional areas along Sino-Russian HSR lines (Dong et al., 2018).

4 Economic connection network characteristics

4.1 Network density and small world effect

The economic connection intensity between each city-pair is calculated. The 41 ´ 41 economic connection intensity matrix were constructed for the analysis of economic connection network. Here, the network density measured by the UCINET is 0.7232 of Sino-Russian economic connection network. Cities are constructed in a crisscross pattern to form a complex economic connection network, which apparently improves intercity spatial connections and accessibility (Fig.5). The city-pairs with high economic connection intensity are concentrated in Beijing-Tianjin (4272.43), Harbin-hangchun (217.95), Harbin-A'cheng (156.91), Changchun-Shenyang (127.52), Tianjin-Shenyang (55.14), Beijing-Shenyang (53.59), Beijing-Changchun (25.38), Tianjin-Changchun (23.65), Beijing-Harbin (20.34) and Tianjin-Harbin (18.12) in the Chinese territory. And in the Russian territory, Moscow-Vladimir (16.58), Moscow-izhniy Novgorod (13.62), Yekaterinburg-Tyumen (2.02), Yekaterinburg-Perm (1.76), Vladimir-Nizhniy Novgorod (1.51), Novosibirsk-Omsk (1.48), Moscow-Perm (1.10), Moscow-Yekaterinburg (1.03), Novosibirsk-Krasnoyarsk (1.02) and Moscow-Kirov (1.01) are the city-pairs of superior economic connection intensity, whereas other city-pairs exhibit poor economic connection intensity.

The characteristic path length and the clustering coefficient in this study were adopted to analyze the small world effect in the Sino-Russian economic connection network. The small world effect is a comprehensive index of urban economic agglomeration trend, economic development potential, economic connection degree with other nodes in the network. The network has the small world effect, with the condition that the characteristic path length of city-pairs is less than 10 and the clustering coefficient of the network is close to 1. In the Sino-Russian economic connection network, the characteristic path length of city-pairs is 1.277. That is to say, the ratio of establishing economic connection of city-pair through one node and two nodes is 86.2% and 13.8% respectively. In general, economic connection could happen through one or two nodes between

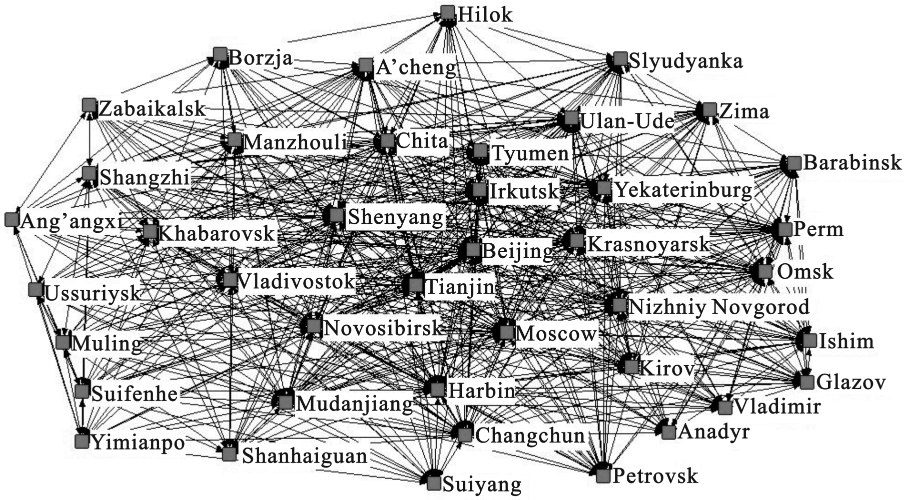

Fig. 5 Visualization structure of Sino-Russian economic connection network

any given pair of cities in economic connection network under the effect of Sino-Russian trains. Besides, the clustering coefficient is 0.867. The cities with high clustering effect and strong cohesion force are mainly located in the Sino-Russian economic connection network. The specific characteristic of the small world effect is quite significant in the Sino-Russian railway economic connection network.

4.2 Centralities

Table 3 reports the degree centrality, closeness centrality and betweenness centrality of the nodes in the economic connection network. The centralities of different cities in the network are uneven. The three kinds of centralities of Beijing, Tianjin, Shenyang, Changchun, Harbin, Mudanjiang in Chinese territory and Moscow, Novosibirsk, Irkutsk, Krasnoyarsk, Vladivostok, Chita, Yekaterinburg, Ulan-Ude, Khabarovsk in Russian territory are higher than that of other cities. Beijing, Tianjin, Moscow, Novosibirsk, *etc.* are the regional centrality centers with the other high centrality cities, thereby forming the economic development mode of multiple centers

Table 3 Centralities of nodes in the Sino-Russian economic connection network

	City	Degree (%)	Closeness (%)	Betweenness (%)	City	Degree (%)	Closeness (%)	Betweenness (%)	City	Degree (%)	Closeness (%)	Betweenness (%)
China	Beijing	100.000	100.000	2.074	Tianjin	100.000	100.000	2.074	Shanhaiguan	45.000	64.516	0.000
	Shenyang	100.000	100.000	2.074	Changchun	100.000	100.000	2.074	Harbin	100.000	100.000	2.074
	Ang'angxi	50.000	66.667	0.064	Manzhouli	82.500	85.106	0.773	A'cheng	87.500	88.889	1.079
	Shangzhi	82.500	85.106	0.812	Yimianpo	45.000	64.516	0.024	Mudanjiang	97.500	97.561	1.807
	Muling	55.000	68.966	0.112	Suiyang	40.000	62.500	0.000	Suifenhe	55.000	68.966	0.112
Russia	Ussuriysk	55.000	68.966	0.125	Vladivostok	87.500	88.889	1.067	Khabarovsk	82.500	85.106	0.812
	Zabaikalsk	52.500	67.797	0.029	Borzja	55.000	68.966	0.076	Chita	85.000	86.957	0.842
	Hilok	45.000	64.516	0.013	Petrovsk	67.500	75.472	0.147	Ulan-Ude	82.500	85.106	0.680
	Slyudyanka	65.000	74.074	0.092	Irkutsk	95.000	95.238	1.555	Zima	70.000	76.923	0.210
	Krasnoyarsk	92.500	93.023	1.369	Anadyr	40.000	62.500	0.000	Novosibirsk	100.000	100.000	2.074
	Barabinsk	55.000	68.966	0.062	Omsk	75.000	80.000	0.377	Ishim	65.000	74.074	0.195
	Tyumen	75.000	80.000	0.377	Yekaterinburg	82.500	85.106	0.709	Perm	75.000	80.000	0.377
	Glazov	50.000	66.667	0.000	Kirov	57.500	70.175	0.055	Nizhniy Novgorod	75.000	80.000	0.377
	Vladimir	50.000	66.667	0.000	Moscow	100.000	100.000	2.074				

in the Sino-Russian economic connection network. The regional centrality centers have strong economic core power, located at the key economic positions with high accessibility degree of the economic flow. Besides, the regional centrality centers are the important intermediary from a given city to another destination city by taking Sino-Russian trains, controlling other nodes' economic development.

The centrality is associated with several major factors of cities along the Sino-Russian railway line. These factors include: urban geographical location, urban economic strength, and the development degree of urban transportation infrastructure. 1) Urban geographical location. Novosibirsk and Harbin are located in the middle of railway line. In general, the accessibility of the nodes, which are located in the middle of the railway line is stronger than those nodes, located at the beginning and end of the lines. High time-space compression has gradually brought the two-way faster transmission of economic elements in Novosibirsk and Harbin. Novosibirsk and Harbin have controlled the agglomeration and diffusion of other nodes' economic flows along railway line. 2) Urban economic strength. Beijing, Tianjin and Moscow are located at the beginning and end of railway line. One-way transmission of railway transport economic flow is pretty slow in Beijing, Tianjin and Moscow. However, Beijing, Tianjin and Moscow are the regional economic radiation and transport service centers, with high external economic connection intensity summation. Besides, the economic polarization effects of Harbin have transited to A'cheng and Shangzhi, promoting the urban centrality of A'cheng and Shangzhi. 3) Development degree of transportation infrastructure. Beijing, Tianjin, Shenyang, Changchun, Harbin, and Moscow have experienced significant increases in transportation infrastructure investment and expansion of their transport networks. They are the important regional transportation centers of railway network, highway network, HSR network, expressway network and aviation network. They have broken the administrative division barrier, promoting the intercity, interregional and international economic flows along the railway line.

5 Discussion

This study constructed an exploratory framework of urban railway class accessibility, economic connection intensity and economic connection network characteristics along Sino-Russian railway line based on the three-dimensional perspectives of node, line and network. However, some contents still have many limitations. Firstly, this study regards the study area as closed and it ignores regional openness and connectivity. When calculating the weighted average travel time, this study regards the quality of the city as '1', and the result of accessibility is also relative. Once the cities' number or the regional scales change, the railway class accessibility of the cities is affected. Secondly, although the economic connection intensity model in this study takes into account of major factors, such as urban population, GDP and railway class accessibility, this study should construct a comprehensive economic connection intensity model involving into multi-factor flow in the long term. Finally, researches on railway class accessibility and economic connection intensity on transnational scale are still at the early stage. Data limitations of different countries make further researches difficult. Thus, the data collection through a variety of channels is necessary. Other subjects' methods must be introduced to prevent accessibility differences of the same city in different spatial scales. With the introduction of GIS support, this study will fully explore the evolution trends, mechanisms, and internal motivations of railway transportation network both in and beyond the study area.

Under the background of 'the Belt and Road' and 'Economic Corridor of China, Mongolia and Russia' initiatives, the Sino-Russian transnational railway has important practical significance to the economic connection of the cities and regions along the railway line. The accessibility central cities are the important growth poles of regional economic and social development. Firstly, from the node perspective, the centralities of Beijing, Tianjin, Shenyang, Changchun, Harbin, Mudanjiang in Chinese territory and Moscow, Novosibirsk, Irkutsk, Krasnoyarsk, Vladivostok, Chita, Yekaterinburg, Ulan-Ude, Khabarovsk in Russian territory are higher than that of other cities. So China and Russia should cultivate these central cities as the economic growth poles along the Sino-Russian transnational railway lines. Secondly, from the line perspective, China and Russia should construct more railway lines, including HSR lines in the east-west and south-north directions and strengthen the economic trade communications. For example, the Sino-Russian costal HSR (Beijing-Tianjin-Shanhaiguan-Shenyang-Changchun-Hunchun-Vladivostok- Ussuriysk-Khabarovsk) will strengthen the trade cooperation in mineral resources and fresh agricultural products between China and Far East Russia. The northeast China-Siberian Federal District HSR (Beijing-Tianjin-Shanhaiguan-Shenyang-Changchun-Harbin-Daqing-Qiqihar-Hulun Buir-Manzhouli-Chita-Ulan Ude-Irkutsk-Krasnoyarsk-Novosibirsk) will promote the trade communication in iron, copper, nickel and other metal resources between China and Siberian Russia. The prairie HSR of Russia, Mongolia and China (Beijing-Hohhot-Ulan Bator-Ulan Ude-Irkutsk-Krasnoyarsk-Novosibirsk) will strengthen the trade cooperation in wood, coal, oil, and other mineral resources. And China and Russia can jointly create Sino-Russian coastal economic belt, Sino-Mongolian-Russian grassland economic belt, Sino-Russian Eurasian urban economic belt, Sino-Russian cross-border railway economic belt, and Sino-Russian border port economic belt. Finally, from the network perspective, Beijing-Tianjin-Shanhaiguan-Shenyang-Changchun-Harbin, Tyumen-Yekaterinburg-Perm-Glazov-Kirov-Nizhniy Novgorod-Vladimir-Moscow, Mudanjiang-Muling-Suifenhe-Ussuriysk-Vladivostok-Khabarovsk have formed economic compact connection intensity groups under the effect of Sino- Russian trains. So relying on these economic growth pole cities, three HSR trunk lines and five economic belts, the China's Northeast HSR Key Area, Russia's Western Europe HSR Key Area and Sino-Russian Transnational Port Key Area will further promote the maturity of Sino-Russian economic connection network.

6 Conclusions

In general, the railway class accessibility of the nodes in Chinese territory is stronger than that of the nodes in Russian territory, which in general displays a tendency of space attenuation from China to the Sino-Russian border, then to Russia along the Sino-Russian railway line. Spatially, the railway class accessibility within the study area shows a 'High East, Low West' and 'High South, Low North' spatial pattern along the railway line. The areas with superior railway accessibility are concentrated in Shanhaiguan-Zabaikalsk and A'cheng-Mudanjiang. The railway accessibility of the nodes, which are located at the beginning and end of the Sino-Russian railway line is weaker than those nodes, located in the middle of the railway line.

The railway accessibility and external economic connection intensity summation of the nodes show a positive relationship under the effect of Sino-Russian trains. The number of city-pairs in intercity economic compact and loose connection intensity account for a larger proportion, compared with that in intercity economic close connection intensity. The external economic connection intensity summation within the study area also shows a 'High East, Low West' and 'High South, Low North' spatial pattern along Sino-Russian railway line. And Beijing-Tianjin-Shanhaiguan-Shenyang-Changchun-Harbin, Tyumen-Yekaterinburg-Perm-Glazov-Kirov-Nizhniy Novgorod-Vladimir-Moscow and Mudanjiang-Muling-Suifenhe-Ussuriysk-Vladivostok-Khabarovsk have formed economic compact connection intensity groups under the effect of Sino-Russian trains.

Cities are constructed in a crisscross pattern to form a complex economic connection network, which apparently improves intercity spatial connections and accessibility. The specific characteristic of the small world effect is quite significant in the Sino-Russian railway economic connection network. The economic connection could happen through one or two nodes between any given pair of cities in economic connection network under the effect of Sino-Russian trains. The centrality is associated with several major factors of cities. These factors include: urban geographical location, urban economic strength, and the development degree of urban transportation infrastructure. The three kinds of centralities of Beijing, Tianjin, Shenyang, Changchun, Harbin in Chinese territory and Moscow, Novosibirsk, Irkutsk, Krasnoyarsk in Russian territory are higher than that of other cities.

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