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Abstract

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Keywords	China’s high-speed rail network, evolution process, Complex Network, network characteristics.

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China’s High-Speed Rail Network Construction and Planning over Time: a Network Analysis

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Keywords: China’s high-speed rail network, evolution process, Complex Network, network characteristics.

1. Introduction

In recent decades, as a large-scale passenger transport system, high-speed rail (HSR) has been widely introduced to many countries. Affordable prices, higher quality of service, and faster loading and unloading speed have made it competitive with other models of transport. The successful implementation of HSR systems in various countries all over the world has demonstrated the positive role of HSR in the economic development of countries. It has also proven that HSR is significant for strategic and regional development (Garmendia et al., 2012; Kim, 2000). Moreover, HSR networks may shape the socio-economic landscape (Laurino et al., 2015) and narrow the regional development gaps within a country (Hu et al., 2015; Wang et al., 2015). For example, South Korea's national planning policy has developed a balanced development strategy that uses HSR as a new point of development, with hopes that it will change the location-based roles of the national urban system (Kim et al., 2018). Similarly, the location of China's new HSR stations is also considered to be part of the national urban and economic growth strategy, especially for medium-sized cities (Yin et al., 2014). HSR also exacerbates accessibility inequalities between cities served by both high-speed and conventional trains (Kim and Sultana, 2015). In Europe, the HSR network has accelerated economic concentration in major cities, while negatively affecting the economic activities of small cities and neighboring cities in the network (Chen and Haynes, 2015; Gutiérrez, 2001; Jia et al., 2017; Monzón et al., 2013). Some studies also show that medium-sized cities in the HSR network suffer from inaccessibility and have limited success in attracting passengers compared with mega cities (Marti-Henneberg, 2015; Vickerman, 2015). In these cases, although HSR has a positive effect on the economy at the national scale, the uneven distribution of HSR stations has become an obstacle to balanced development (Moyano and Dobruszkes, 2017). Therefore, in order to better plan for city layouts and further the national social and economic development, it is necessary to study how a nation's HSR network is planned and constructed over time.

According to statistics, China's HSR operations have increased from 1,250 km in 2007 to 25,000 km in 2017, accounting for 48% of the global total (Jiao et al., 2017). At present, it can be seen that HSR in China is experiencing a peak period of high speed development. Therefore, studying the development process and evolution characteristics of China's HSR will help to gain an understanding of the problems and advantages of its development, and provide guidance and a planning basis for its future development.

Comparatively few studies have been done on the evolution of HSR networks at the national level (Li, 2017; Martí-Henneberg, 2017; Xu et al., 2014), largely because there is no publicly accessible database of when and how a country's HSR stations and railway lines have been built and put into operation. Thus, in this paper, the evolution of China’s high-speed rail network (CHSRN) between 2007-2017 is illustrated and the corresponding development characteristics are analyzed. Further, according to the latest Chinese national railway network plan, “The Mid- and Long-term Railway Network Plan”, issued in 2016, the future development and construction of CHSRN is expected between 2018 to 2030. The overall findings provide guidance for scheduling HSR construction in different tiers of cities.

As HSR networks are complex systems, they can be understood as complex networks for the purposes of analysis. Complex network analysis has widespread applications (Albert et al., 2000; Latora and Marchiori, 2001; Paul et al., 2005; Watts and Strogatz, 1998), especially in traffic networks, including railway networks and subway networks (Hong et al., 2015; Ouyang et al., 2010). As with railway networks, HSR networks can be understood abstractly as complex networks and, of course, can be investigated according to complex network measures. In this work, graph theory and complex network analysis are used to abstract the stations and tracks of CHSRN, where the nodes represent the stations and the links denote the rail tracks. Based on various complex network measures, the evolution process and development characteristics of the CHSRN are described through real-world data or plans.

The rest of this paper is organized as follows. Previous relevant work is reviewed in Section 2. Section 3 addresses the development process of the CHSRN. Section 4 describes the methodology and data for evaluating CHSRN over two periods, between 2007-2017 and 2018-2030. Section 5 summarizes the overall findings and discusses their policy and planning implications, and Section 6 concludes.

2. Literature review

2.1 HSR network and regional development

The impact of HSR on the national economy and society has attracted considerable attention and aroused widespread interest (Li et al., 2016). It was proven that HSR has significantly shortened intercity travel time, which directly improved regional accessibility and contributed to regional economic development (Wetwitoo and Kato, 2017). Many studies have addressed the significance of HSR from different perspectives. Ginés (2012) stated that the introduction of HSR travel can save time and bring direct benefits, improving economic productivity in the short-term; while in the long-term, it attracted new activities, leading to market expansion and improved productivity. Chen and Silva (2014) empirically examined the effects of HSR in Spain using the structural equation model approach. They concluded that HSR investment had a positive impact on the economic growth of Spanish provinces, such as stimulating GDP, raising employment levels, and leading to wider economic impact. In addition, Masson and Petiot (2009) provided evidence to support the positive impact of HSR on tourism. In this case, data from the southeastern line of the Train à Grande Vitesse (TGV), France's HSR, showed that the number of hotel visits and the number of meetings held increased after the introduction of HSR in the subject regions.

In contrast, many scholars have also claimed that the HSR system played a counterproductive role in regional economic development. Chen and Hall (2012) reported that the introduction of HSR had widened the economic gap in the Manchester region. This was primarily due to restructuring of the regional economy due to insufficient traffic volume in the areas connected to the HSR. Shen et al. (2014) found that if the HSR station was located at a significant distance from the central business district, the city would obtain lower returns from this large-scale infrastructure, and the speed of land development dependent on the attractiveness of the new HSR stations would also be accordingly low. Similarly, Givoni (2006) and Wetwitoo and Kato (2017), demonstrated that HSR was economically damaging to bypassed cities and reduced the travel demands of conventional railways, which aggravated vicious competition among different passenger transport modes.

2.2 HSR network and regional accessibility

Accessibility is a core measure for evaluating regional development, and the improvement of accessibility brought by HSR has been widely studied (Levinson, 2012). Many studies have found that the increase in regional accessibility from HSR depends upon the location of HSR stations and the quality of the transport network connecting the surrounding cities to the HSR stations (Hu et al., 2015; Ortega et al., 2012; Wang et al., 2015). Increased accessibility by HSR has also contributed to political and economic integration in the European region (Gutiérrez, 2001). Similarly, the integration of Chinese cities and provinces has also been strengthened by the rapid expansion of CHSRN (Cao et al., 2013; James Jixian et al., 2013; Jiao et al., 2017). Kim and Sultana (2015) found that since the accessibility of the cities along the HSR line near the Seoul area has improved, the spatial equity of South Korea has deteriorated, following the completion of the HSR extension in 2011. Hall and Pain (2008) pointed out that the increased accessibility between major cities linked by HSR may threaten the status of neighboring cities. Likewise, John and Pedro (2013) confirmed that the accessibility of major cities to surrounding cities has been significantly enhanced after the operation of HSR services in several European rail networks.

It has also been pointed out that HSR determines the regional connectivity and transport capacity between different areas. Zhang et al. (2016) used complex network theory to evaluate the structural vulnerability of HSR and found that Japanese HSRN had the best national connectivity, but CHSRN had the best local connectivity and the greatest transport capacity. Wang et al. (2009) detailed the expansion of China’s railway network and examined the ways in which it has influenced the spatial accessibility of different cities, local economic growth and urban systems, between 1906 and 2000. Martí-Henneberg (2017) showed that the railway network connects European regions and helps to integrate their national territories. Kim (2000) examined the effects of HSR upon location-based accessibilities in Japan and Europe, and pointed out that HSR could gradually change residents' residential locations and work patterns. Nakagawa and Hatoko (2007) and Sun et al. (2011) also put forward the same arguments. Cheng (2010) analyzed the potential impact of the future HSR network of Taiwan on improving accessibility, and Wang et al. (2016) studied the impacts of the present and proposed future HSR networks on accessibility at the provincial level in China: They all agreed that a high speed rail line could bring significant improvement to accessibility and convenience for passengers. There are, however, few studies that have analyzed the impact of the construction of an extensive high-speed rail network over time on the accessibility of different sized urban areas on a large scale.

2.3 Contribution of the paper

In summary, although many studies have analyzed the impact of HSR on regional development from different angles, these studies are limited to fixed time points and their research has been narrowly focused upon particular HSR lines or a limited number of stations with relatively narrow perspectives. From the perspective of transport geography, research on the impact of transport infrastructure on regional development needs to be established based on broader, longer time periods at the level of the entire transport network. However, over the past ten years, other countries have built relatively small-scale HSR systems. Sample sizes in previous studies about the impact of HSR lines on regional development were too small to give more than indication about the effects of general transport geography. Obviously, the impact of HSR on regional development also needs a comparative analysis based on different time periods. Fortunately, the construction of a large-scale HSR network in China during the past decade has provided an opportunity to more accurately examine the influence of the HSR network on the changes of spatial attributes in different construction stages and different regions. However, due to over-emphasis on the specific technological innovations of high-speed railway construction, analyses of its potential regional impact has been overshadowed.

Therefore, based on the datasets of CHSRN during different time periods, the evaluation measures of regional spatial accessibility and connectivity are established in this paper. Before-and-after impacts of the large-scale HSR network on the development of regional spaces are examined, and suggestions and references for further large-scale, high-speed railway construction are provided according to the related results.

3. Development process of CHSRN

3.1 Development stages of CHSRN

As one of the most advanced ground-based transportation modes, HSR can be operated at a speed of 250 km per hour or higher, hence inter-regional travel time can be greatly reduced. According to the well-known Chinese national railway planning guideline, *The Mid- and Long-term Railway Network Plan* (CGC, 2008; National Development and Reform Commission, 2008), the key objectives of the national HSR development plan for the Year 2020 were: *a*) to increase accessibility between major economic regions through an interconnected HSR network, and *b*) to promote coordinated and balanced regional development via improved regional transportation connectivity (Chen and Haynes, 2017). By summarizing the relevant information of China's HSR construction, it is found that the development of CHSRN can be divided into the following three stages, as shown in Table 1.

(Insert Table 1 Here)

3.2 CHSRN Plans

The planning of China's HSR system commenced in the early 1990s, with the proposal to build the HSR line between Beijing and Shanghai in 1990. After more than 10 years of preparation, the State Council of China approved the *Mid- and Long-term Railway Network Plan* in 2004 (PLAN-2004), and then revised the same plan in 2008. This plan is a long-term railway revision and guidance plan for the nation. It is approved by the State Council and issued by the National Development and Reform Commission, the Ministry of Transport, and the China Railway Corporation (Sun, 2016).

PLAN-2004 has guided the sixth plan of large-area railway enhancements, including adjustments to the network’s train operation diagram, which was successfully implemented. In addition, this plan promoted the construction of the Beijing-Tianjin Intercity Railway and Qinghai-Tibet Railway in 2007, which brought Chinese HSR into a new era (CGC, 2004).

Later in 2008, PLAN-2004 was revised and the *Mid- and Long-term Railway Network Plan (2008 revised)* (PLAN-2008) was formally enacted and implemented.

The new plan further expanded the scale of the network mileage and comprehensively improved the layout structure of the HSR network. It proposed that the total track mileage of CHSRN should expect to reach 160,000 thousand km by 2020 (CGC, 2008). In PLAN-2008, the revised national HSR corridors comprised eight HSR trunk lines, which are also known as the “Four Vertical” and “Four Horizontal” lines respectively; all the HSR lines planned in PLAN-2008 were realized by the end of 2015, five years ahead of schedule.

The total track mileage of CHSRN has now reached 21,000 km. On July 20, 2016, the State Council of China proposed a revised national railway network plan, which was named PLAN-2016 (CGC, 2016).

According to PLAN-2016, the total mileage of railway tracks of China’s railway network should be expanded to 150,000 km by 2020, including 30,000 km of HSR. Working toward this target led to a 58% growth in track mileage for CHSRN in 2015. The trunk lines of HSR corridors were also redesigned in PLAN-2016: the “Eight Vertical” and “Eight Horizontal” HSR corridors were specified. Compared with PLAN-2008, PLAN-2016 proposed more HSR corridors across China. In addition to the existing corridors, PLAN-2016 outlined extra corridors that would form multiple trunk HSR lines between cities.

HSR network data as of 2017 is used in Figure 1, from 2017, to present the current HSR layout in China. It should be noted that this picture is the result of planning addressed in PLAN 2008 (network constructed during 2008 - 2015), and PLAN-2016 (network constructed during 2016-2017).

(Insert Fig.1 Here)

4. Methodology and Data

4.1 Complex network measures

There is extensive literature on the growth or evolution characteristics of different types of transportation networks based on complex network analyses (Wandelt and Sun, 2015; Yang, 2015; Badia et al., 2016; Ducruet, 2017). However, the scale of the HSR network in most countries is too small to be analyzed with the existing complex network measures. As a result, there has been little research on the

HSR network characteristics based on such measures. Nevertheless, the existence and expansion of CHSRN provides scholars with a golden opportunity to study the evolving processes of the huge HSR network with the complex network measures. In this study, CHSRN is presented during different time periods as an undirected graph, where links are different HSR segments and nodes are prefectures (cities) or above in the Chinese administrative hierarchy (Qiu et al., 2018).

Based on Borgatti and Everett (2006), Liu et al. (2018), and Zhang et al. (2018), the following complex network measures are used to examine the evolution characteristics and development prospects of the CHSRN during the two time periods (2007-2017 and 2018-2030):

(1) Degree (C1)

$$k_i = \sum_{j \in N} \alpha_{ij} \quad (1),$$

where

k_i denotes the degree of node i;

α_{ij} is a binary variable which denotes the state of connection between node i and node j. α_{ij} is equal to 1 if node i and node j connect to each other, otherwise, it is equal to 0;

N denotes the node set of the graph (i.e., the complex network).

(2) Eccentricity (C2)

$$c_i^{\mathrm{E}} = \max_{j \in N} \left\{ dist(i, j) \right\} \quad (2)$$

where

c_i^{E} is the eccentritiy of node i, which is the longest of all the shortest paths between node i and all other nodes in the graph;

$dist(i, j)$ denotes the shortest path between node i and node j.

The smaller the eccentritiy, the closer to the centre of the graph a node is (Shi and Zhang, 2011).

(3) Closeness centrality (C3)

$$c_i^{\mathrm{C}} = \frac{1}{\sum_{j \in N} dist(i, j)} \quad (3)$$

where

c_i^{C} is the closeness centrality of node i, which is defined as the sum of its "farness" (the average of the inverse of the shortest network distance) from all other nodes.

(4) Betweenness centrality (C4)

$$c_i^{\mathrm{B}} = \sum_{s \neq j \neq t} \frac{\sigma_{st}(i)}{\sigma_{st}} \quad \forall s,t \in N \tag{4}$$

where

σ_{st} is the total number of shortest paths between node s and node t;

$\sigma_{st}(i)$ denotes the number of those paths which pass through node i (Brandes, 2001).

(5) Pagerank (C5)

$$PR_i = \xi \sum_{j \in N} \alpha_{ji} \frac{PR_j}{k_j} + \frac{1-\xi}{\bar{N}} \tag{5}$$

where

PR_i reflects the contribution of node *i* to the mutual connection;

$\bar{N}$ is the total number of nodes on the graph;

ξ is a damping factor which can be set between 0 and 1. Usually, ξ is set equal to 0.85. If a node does not connect to any other node, its pagerank value would be $\frac{1-\xi}{\bar{N}}$ (Brin and Page, 1998).

(6) Clustering coefficient (C6)

$$C_i = \frac{2\left|\sum_{j \in N} \sum_{k \in N} \alpha_{jk}\right|}{k_i(k_i - 1)}, \forall j,k \in \{t \,|\, \alpha_{it} = 1\} \tag{6}$$

where:

C_i is the clustering coefficient of node *i*, which reflects the number of links connecting nodes within the neighborhood of node i (the neighborhood denotes a set of nodes connecting to node i) divided by the number of links that could possibly exist between all nodes within the neighborhood.

The following new measures are also used in this study:

(7) Average degree (C7)

$$\langle k \rangle = \frac{\sum_{i \in N} k_i}{\bar{N}} \tag{7}$$

(8) Average weighted degree (C8)

$$\langle k^w \rangle = \frac{\sum_{i \in N} \sum_j \beta_{ij}}{\bar{N}} \tag{8}$$

where

β_{ij} denotes the number of arcs connecting node i and node j.

(9) Graph diameter (C9)

$$D_i = \max_{i \in N} \left(C2_i \right) = \max_{i \in N} \left(\max_{j \in N} \left\{ dist\left(i, j\right) \right\} \right) \tag{9}$$

(10) Graph density (C10)

$$DE = \frac{2\bar{A}}{\bar{N}\left(\bar{N} - 1\right)} \tag{10}$$

where

$\bar{A}$ represents the total number of links in the graph.

The graph density evaluates how sparse or dense a graph is according to the number of connections between nodes (Lawler, 2001).

(11) Modularity (C11)

$$Q = \frac{1}{2\bar{A}} \sum_{i,j \in N} \left(\alpha_{ij} - \frac{k_i k_j}{2\bar{A}} \right) \delta\left(c_i, c_j\right) \tag{11}$$

where

c_i denotes the community node i belongs to;

$\delta\left(c_i, c_j\right)$ is a binary variable and is equal to 1 if node i and node j belong to the same community, and equals 0 otherwise (Blondel et al., 2008).

Each node is assigned to one of N_i communities with the modularity Q decomposition on the graph.

(12) Number of communities (C12)

$$g_i = \sum_{i \in N} c_i \tag{12}$$

(13) Average clustering coefficient (C13)

$$\langle C \rangle = \frac{\sum_{i \in N} C_i}{\bar{N}} \tag{13}$$

(14) Average path length (C14)

$$\langle l \rangle = \frac{\sum_{i \in N} \sum_{j \in N} dist(i, j)}{\bar{N}} \tag{14}$$

4.2 Data

As of 2016, there are 34 provinces, 361 prefectures (cities), and 2,089 counties in China. The provinces include four provincial level municipalities, Beijing, Shanghai, Tianjin and Chongqing, and five provincial level autonomous regions. Cities are divided into three grades: provincial level cities are categorized as Tier 1 cities; other cities with populations ranging from one to five million are Tier 2 cities; finally, cities with populations less than 1 million are Tier 3 cities (Qiu et al., 2018). The county is a smaller administrative division than the city.

Since China did not have any HSR until 2007, two time periods have been used in this paper: 2007-2017 and 2018-2030.The first period includes eleven years from the first implementation of China's HSR. In these years, China's HSR construction made outstanding achievements. Although there were only 193 stations and153 HSR-serving counties in China before 2010 (Victor and Ponnuswamy, 2012), new stations and 64 new HSR lines totaling 13,703.2 km have been added into the CHSRN since the planned “four-vertical and four-horizontal HSR corridors” were realized in 2015, bringing the total to 491 (National Development and Reform Commission, 2008). The second period represents the years from 2018 until the end of PLAN-2016. According to PLAN-2016, by 2020 the total mileage of CHSRN would be twice as much as that in 2015, reaching 30,000 km. By 2030, the total mileage of CHSRN will be over 38, 000 km (CGC, 2016).

Table 2 summarizes the network growth measures of CHSRN during different time periods. Correspondingly, Figure 2 shows the network growth process of CHSRN. Figure 3 depicts changes of HSR-serving counties (counties within the 20km buffer of an HSR station) over time.

(Insert Table 2 Here)

(Insert Fig.2 Here)

(Insert Fig.3 Here)

Regarding 2017, it can be seen from Table 2 that the mileage of the CHSRN grew to 33,594.8 km and there were 7.275 billion passenger trips across the whole network. Several cities, such as Beijing, Shanghai, and Guangzhou boasted more than two HSR lines. However, many prefectures were still not connected with HSR in this period, especially those in Ningxia and Inner Mongolia (see Figures 2 and 3).

However, by the end of 2030, the total mileage of CHSRN is to reach near 81,500 km if new lines planned in PLAN-2016 are completed. This would mean 2,350 counties, 453 prefectures, and 33 provinces would be serviced by the HSR network (see Figures 2 and 3), and that a land area of 6,915,000 km^2 would be covered within a 20km-radius of the HSR stations, and 1.155 billion people could take the HSR directly without the necessity for other long-haul transport options. Lastly, the total passenger trips are expected to reach 55.225 billion annually (see Table 2).

5. Results and Discussion

5.1 Evolving characteristics of nodes on CHSRN

Table 3 presents the complex network measures of the Tier 1 cities in the CHSRN. For all nodes, both C1 (Degree) and C2 (Eccentritiy) increase over time. This result reflects the fact that increasingly more HSR lines are constructed and added into the CHSRN in each period. As shown in the second column (2007-2017) of Table 3, Harbin has the largest C2 value at 32, which means that the "center" of the CHSRN between 2007-2017 was Harbin, which connected with 32 other cities via HSR.

(Insert Table 3 here)

The measure C3 denotes the sum of the "farness" from all other nodes to a single node. With the increased network scale of CHSRN, the C3 value of each city first increases and finally converges to a stable value. The returned value indicates that the farness from one city to all other cities by HSR decreases as more HSR lines are constructed. As the HSR network matures and its scale enlarges, the above farness would become a stable value.

The measure C4 denotes the sum of the proportion of the shortest path which passes through a node and reflects the “position” of a node in the graph. It was observed that some cities, such as Shanghai and Hangzhou, had a value of zero for C4 between 2007-2017. The reason is that these cities were the terminal nodes of HSR lines at the time, meaning no shortest path would pass through those nodes. Furthermore, as shown in Table 2, the C4 value of each city increases with time. During 2007-2017, Wuhan (the capital of Hubei Province) had the highest C4 value, but is overtaken by Beijing during 2018-2030.

The C5 value denotes the individual contribution of a node to the mutual connections of the HSR lines on the network. As shown in Table 3, the C5 values of almost all Tier 1 cities decrease from the first period to the second period. It shows that the contribution of the Tier 1 cities to the network connection becomes smaller over the total period from 2007 to 2030. Thus, as also shown in PLAN-2016, China will be paying more attention to HSR lines between cities lower than Tier 1 once HSR lines connect all Tier 1 cities.

The C6 measure, i.e., the clustering coefficient, measures the degree to which nodes in a graph tend to cluster together. As shown in Table 2, almost all the Tier 1 cities had a C6 value of zero between 2007-2017, meaning that the clustering degree of CHSRN before 2017 was weak. In other words, for different parts of the CHSRN, cities with more than one HSR line are more likely to have extra HSR lines. As a result, the mutual connections between any two Tier 1 cities would be strengthened between 2018-2030. Specifically, the C6 values of quite a few Tier 1 cities between 2018-2030 are larger than those in the previous time periods, e.g., Hefei, Lanzhou (the capital of Gansu Province) and Nanchang (the capital of Jiangxi Province). Thus, connections between Tier 1 cities would be intensified in the CHSRN between 2018-2030. It is therefore expected that urban agglomeration will emerge around Tier 1 cities between 2018-2030. Also, accordingly, cities around Tier 1 cities with a high C6 value would be better connected during the second period.

An interesting observation is that even though Beijing and Guangzhou are the two most important cities in China, they do not dominate any of the highest values of the six measures during the first period, as can be seen in Table 2. This implies that the CHSRN has equalized rather than polarized HSR connections among different tiers of cities. To prove this assertion, values of the six measures of 50 cities at Tiers 2 and 3 (including Shenzhen, Xiamen, Ningbo, etc.) are presented in Table 4.

(Insert Table 4 here)

As shown in Table 4, the trends of the six measures of the Tier 2 and 3 cities are consistent with those of their Tier 1 counterparts presented in Table 3. Compared with the Tier 1 cities in Table 3, the Tier 2 and 3 cities have relatively smaller index values in the first period, but in the second period (2018-2030), some Tier 2 and 3 cities have larger index values than almost all the Tier 1 cities. For instance, Shenzhen, Huangshan, Huizhou and Baoding would have eight HSR lines. Similarly, Langfang, Wuhu, Shaoxing, Yongzhou and Qinhuangdao would have high C6 values that are greater than 0.3, dwarfing all the Tier 1 cities. It could be inferred that HSR planners of China may have expected a larger share of passenger flows from the Tier 1 cities to Tier 2 and 3 cities in the future, which may explain why PLAN-2016 specified more HSR lines to or from the Tier 2 and 3 cities. The C6 values of all city nodes on CHSRN in different periods are presented in Figure 4.

(Insert Fig. 4 Here)

Figure 4 indicates that almost all city nodes have a C6 value of zero between 2007-2017. All cities except for those in the Yangtze River Delta region had fewer HSR lines and neighbors because of these lines. This changes for the period between 2018-2030 with significantly more HSR lines across east and central China. Due to these lines, there would also be more city-region clusters. In this period, the notable city-region clusters are: Beijing-Tianjin-Heibei Region, Yangtze River Delta Region, Xi'an Region, Urumchi Region and Chongqing-Chengdu Region. These city-region clusters have one or two Tier 1 cities and contain many adjacent Tier 2 and 3 cities. Figure 4 shows that China initially focused on HSR lines serving the Tier 1 cities, but will build more HSR lines to and from Tier 2 and 3 cities over time.

The changes of C6 values indicate that the multiple connections among cities could contribute to, or even result in, economic agglomeration, spillover or polarization. The denser the HSR network, the smaller the differences in the complex network measures between Tier 1, 2 and 3 cities. In fact, with an increased average clustering coefficient, Tier 2 and 3 cities would share more similarities with Tier 1 cities. It could be possible that Tier 1 cities would become more attractive and competitive because of the path dependence, economic agglomeration and polarization effects, as people become able to move more efficiently between them. It is also possible that Tier 2 and 3 cities will benefit more from the spillover effects of Tier 1 cities.

To determine whether Tier 2 and 3 cities always have better network measures than most of the Tier 1 cities, an independent samples t-test is applied to statistically examine inequalities of C6 values between different tiers of cities across the two periods. Table 5 shows the detailed results. In Table 5-a, there are two groups of cities that are denoted “1” and “O”. Here, “1” represents the Tier 1 cities and “O” denotes the other tiers of cities, including Tier 2, Tier 3 and other. According to Table 5-a, between 2007-2017 the mean C6 value for Tier 1 cities was much more than that of other tiers of cities, as well as the standard deviation, whereas in the second period the data reverses so that the mean of C6 values for other tiers is larger than that of Tier 1 cities and the standard deviation. The results demonstrate that between 2007-2017, the CHSRN planners focused on the connection between the Tier 1 cities, leaving the construction of HSR connecting the other types of cities for the period between 2018-2030. Table 5-b further confirms this result: for the first period, $T = 2.652$ and the significance (two-tailed), $P = 0.012$, is $P < 0.05$. This means there is a significant difference between the C6 values of Tier 1 and other cities. In other words, the planner prioritized Tier 1 cities in this period. Conversely, in the second period, $P = 0.73$, meaning there is not a significant difference between the C6 values for Tier 1 and other tiers during this period. This is evidence that the CHSRN planners are likely to adopt an egalitarian model to construct HSR routes between different tiers of cities in the next 15 years.

(Insert Table 5 Here)

5.2 Evolving characteristic of the entire network

The values of C7 - C14 can be used to evaluate the evolving characteristics of the entire CHSRN.

Figure 5 shows the evolution process of the CHSRN, which is treated as a complex network or graph, with cities as nodes and HSR line segments as arcs. The scale of the CHSRN is initially very small, but enlarges rapidly before the period 2011-2017. In Figures 5-a and 5-b, the size and depth of a circle represents the city's degree, and the thickness and depth of the line represents the origin city's weighted degree. In addition, the city names are given from large to small (or from deep to shallow) to represent their tiers.

(Insert Fig.5 Here)

By the second period, the scale is already so large that there are many large-degree nodes and large-scale communities (city-region clusters connecting by HSR lines). Specifically, Figure 6 summarizes measures that could be used to further examine evolving characteristics of the entire CHSRN during different time periods. In Figure 6, the average degree (C7), average weighted degree (C8), graph density (C10), modularity (C11), and average clustering coefficient (C13) use the primal vertical axis on the left. The network diameter (C9), number of communities (C12) and average path length (C14) use the secondary axis on the right.

(Insert Fig.6 Here)

Over time, the C7, C8 and C13 values for the CHSRN notably increase, but the graph density (C10) and modularity (C11) decrease. These reflect a denser CHSRN over time. C9 also increases, but the C12 and C14 values decrease from the first period to the second, meaning that the new HSR lines between 2018-2030 would dramatically change the structure of the CHSRN. As previously mentioned, in this period more HSR lines to and from Tiers 2 and 3 cities will be built. Because of this, the network diameter (C9) will increase, as well as modularity (C11), and the number of communities (C12) will see very significant growth after 2017. China is therefore expected to have a very dense, large-scale HSR network with a large number of communities and a long graph. Tiers 1 and 2 cities will be served by at least three HSR lines each. By 2030, passengers will be able to get to 34 other cities from any one of these cities solely by HSR lines.

5.3 Evolving network with population measures at the regional level

As a rail network grows, it is expected to serve a larger population. Since the relationship between the population and the growth of the network cannot be explained by the complex network index, a supplementary index is used to express how the CHSRN continues to evolve with population growth. Firstly, an index of “per capita HSR rail length” (= total HSR length / total population at the prefectural city level) is composed. The population data for prefectures in 2017 were obtained from the National Bureau of Statistics of the People's Republic of China. It is important to use the estimated projected population data for the different tiers of

Chinese cities for 2030, which comes from the World Bank (World Bank, 2017). In accord with this data, the uniform population growth rates of Tier 1 cities of China are set to 1.01, with other tiers set to 1.02 over the following seven years. It is predicted that after 2025 the population of Chinese cities will stop growing (World Bank, 2017). Consequently, the population of each city in 2030 is set equal to that of 2025 in the analysis. Further, HSR network datasets of 2017 and 2030 are used to calculate the "per capita HSR rail length" index.

Figure 7-a illustrates the spatial distribution of "per capita HSR rail length (in km per million capita)" during 2007-2017. The redder the area is, the higher the indicator is. Compared with the surrounding low-tier cities, the indexes of the Tier 1 cities seem to be more advantageous in this period, but this phenomenon changes in the second period. As shown in Figure 7-b, Tier 1 cities would not have any advantage on the "per capita HSR rail length" index between 2018-2030. Instead, some of the low-tier cities, such as Jiujiang, a Tier 3 city to the north of Nanchang, had larger "per capita HSR rail length" values than the surrounding cities.

(Insert Fig.7 Here)

The results show that the Chinese HSR network benefits the most populated cities first, and then gradually connects the less populated cities. To support this conclusion, the "per capita HSR rail length" is correlated with the population at the prefectural level for both periods. The related results have been presented in Figure 8. In Figure 8-a it is clear that for the first period there was no correlation between the "per capita HSR rail length" and the population across all tiers. This changes in the second period, where Figure 8-b shows a strong negative correlation between the "per capita HSR rail length" value and the population of first grade cities and the other low graded cities. Last is the calculation of the Pearson's coefficients for the four plots (a1, a2, b1 and b2) of Figure 8. The corresponding results are -0.05, -0.04, -0.823 and -0.854 respectively. Again, the relationship between "per capita HSR rail length" and population for lower-tier cities is stronger than for the Tier 1 cities. This provides further evidence that China's HSR planners would aim to link the more populated lower-tier cities in the next run of HSR construction.

(Insert Fig.8 Here)

6. Conclusions

As the third largest country and most populated developing country in the world, it is necessary for China to find efficient ways to transport its resources, goods and people. In recent years, HSR seems to have emerged as an efficient national solution, but at this point no publicly accessible, comprehensive dataset of built or planned HSR lines is available for China. This remains an obstacle for understanding China's experience with HSR and its implications for the outside world. This research aimed to build this dataset and then examine China's HSR growth based on the dataset. The study treats China's HSR network as a complex network and uses different existing complex network measures to uncover the growth patterns of China's HSR network.

This study brings new insights on the Chinese HSR network and related plans that are not obtainable from discrete maps or currently available documents on China's HSR network. Most notably, the following three insights can be highlighted:

First, the degree and eccentritiy of each Tier 1 city increases over time, which reflects the increasing number of HSR lines constructed and added onto the CHSRN in each period. Moreover, Harbin, a Tier 1 city in Northeast China, was the "center" of the CHSRN between 2007-2017, which means that the Chinese government did not only focus on megacities, such as Beijing and Shanghai, during the first stage of CHSRN construction. In addition, as the pagerank of almost all Tier 1 cities decreases from the first period (2007-2017) to the second period (2018-2030), this further indicates that the contribution of the Tier 1 cities to the network connection becomes smaller and smaller from 2007 to 2030. Thus, the Tier 1 cities did dominate the growth of China's HSR network initially, but despite the possibility that extra lines could be added to and from these cities in the future, those lines' contribution to the overall connection level (indicated by the pagerank) diminish over time. It indicates that China is adopting an equalizing model for constructing its HSR network in the long-term. The network benefits the most populated cities first, and later connects the less populated cities.

Second, compared with the Tier 1 cities, Tier 2 and 3 cities have relatively smaller index values in the first time period, however, the second period reverses this so that Tier 2 and 3 cities have larger index values than almost all of the Tier 1 cities. For instance, Shenzhen would have very high clustering coefficients that are greater than 0.3, dwarfing all the Tier 1 cities. It could be inferred that Chinese HSR planners may expect a larger share of passenger flows from the Tier 1 cities to Tier 2 and 3 cities in the future. This reveals that one or more of these cities may potentially become a “windfall” city due to HSR construction. These cities would obtain substantial HSR investment due to the construction of multiple HSR routes to, from, or through them. The way in which they could combine this with other advantages would greatly influence their respective futures. On the other hand, those cities that were well connected by regular railway lines but do not end up well-linked by HSR may suffer in the era of HSR.

Third, the expansion of the CHSRN is so fast that HSR is to connect almost all prefectural cities and billions of people in China during the next decade or so. This would be unprecedented in human history. The CHSRN then would not only be a mode of travel, but also a catalyst and a game changer, which could bring about a wide array of unimaginable changes in our lifetime such as mega-city regions (commuting sheds) consisting of a large number of cities of various sizes connected by HSR, HSR-oriented developments near or around HSR stations, and super commuters whose residences are up to 200 km away from their workplace.

All in all, this study evaluates characteristics of the CHSRN based on a complex network analysis. This research will help to better the understanding of different aspects of the network, in particular nodes and links in the CHSRN and their relationships. Such understanding tells us (a) how different HSR projects can and will change the network, (b) how we should determine HSR projects’ sequences, and (c) how we can maximize their respective utilities in years to come. The experience of the CHSRN has indicated that building an HSR network requires substantial capital investment, which comes with substantial opportunity costs. Inappropriate projects and sequences could mean a waste of precious resources. The evaluation method presented here provides another way for policy-makers to evaluate their projects and sequences. Unfortunately, due to data limitations and time constraints, this research has not been able to comprehensively assess the socioeconomic costs, benefits, risks, rationales, and consequences of HSR projects for different time periods, nor has it been able to quantify how HSR projects shape and reshape individual cities’ socioeconomic landscapes. These are questions we hope to be able to answer in the near future.

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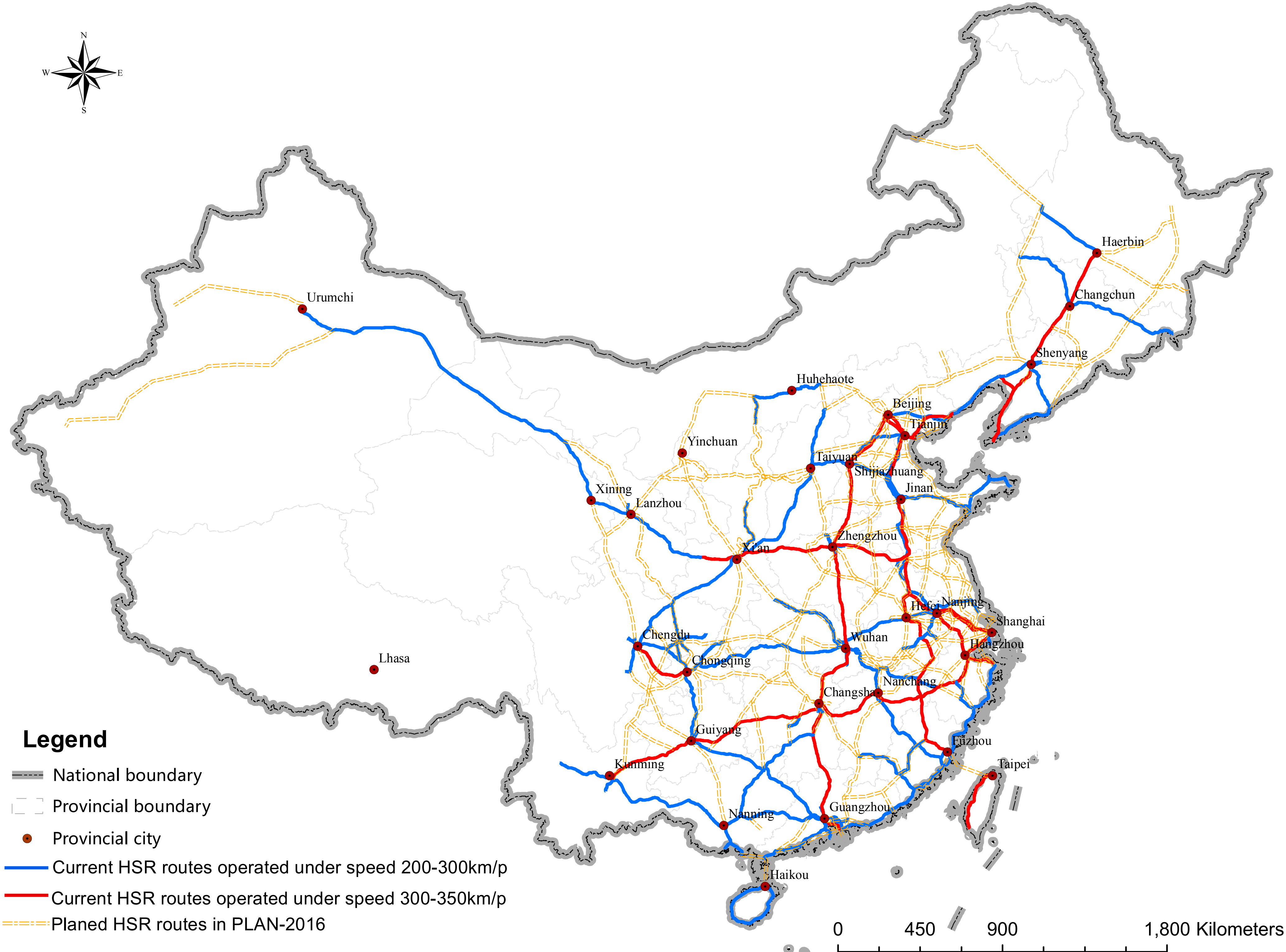


Fig.1 China's high speed rail network: current (as of Dec. 2017) and the planned in PLAN-2016

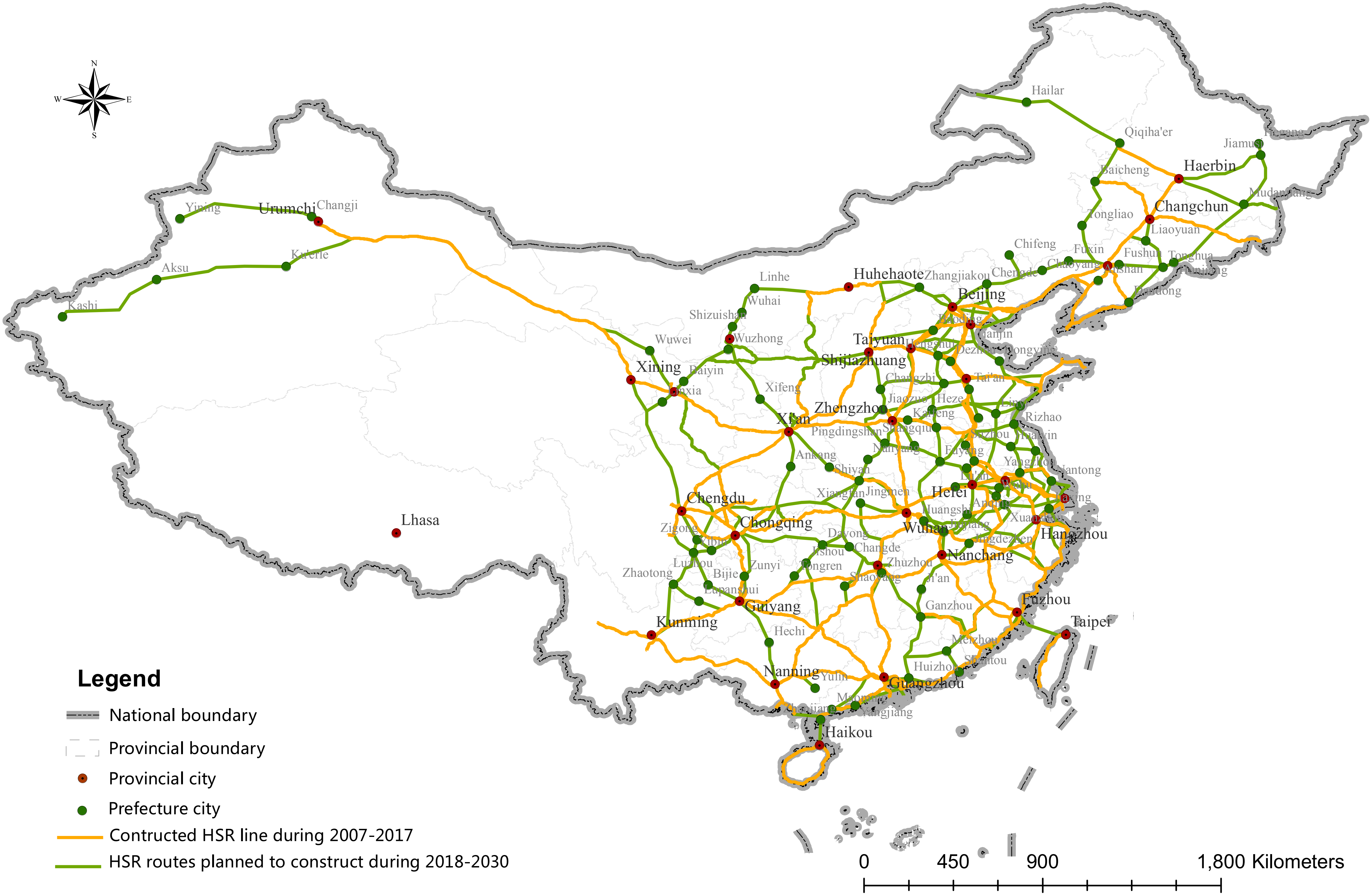


Fig.2 The contructed HSR networks and the planned HSR routes during diffierent time periods

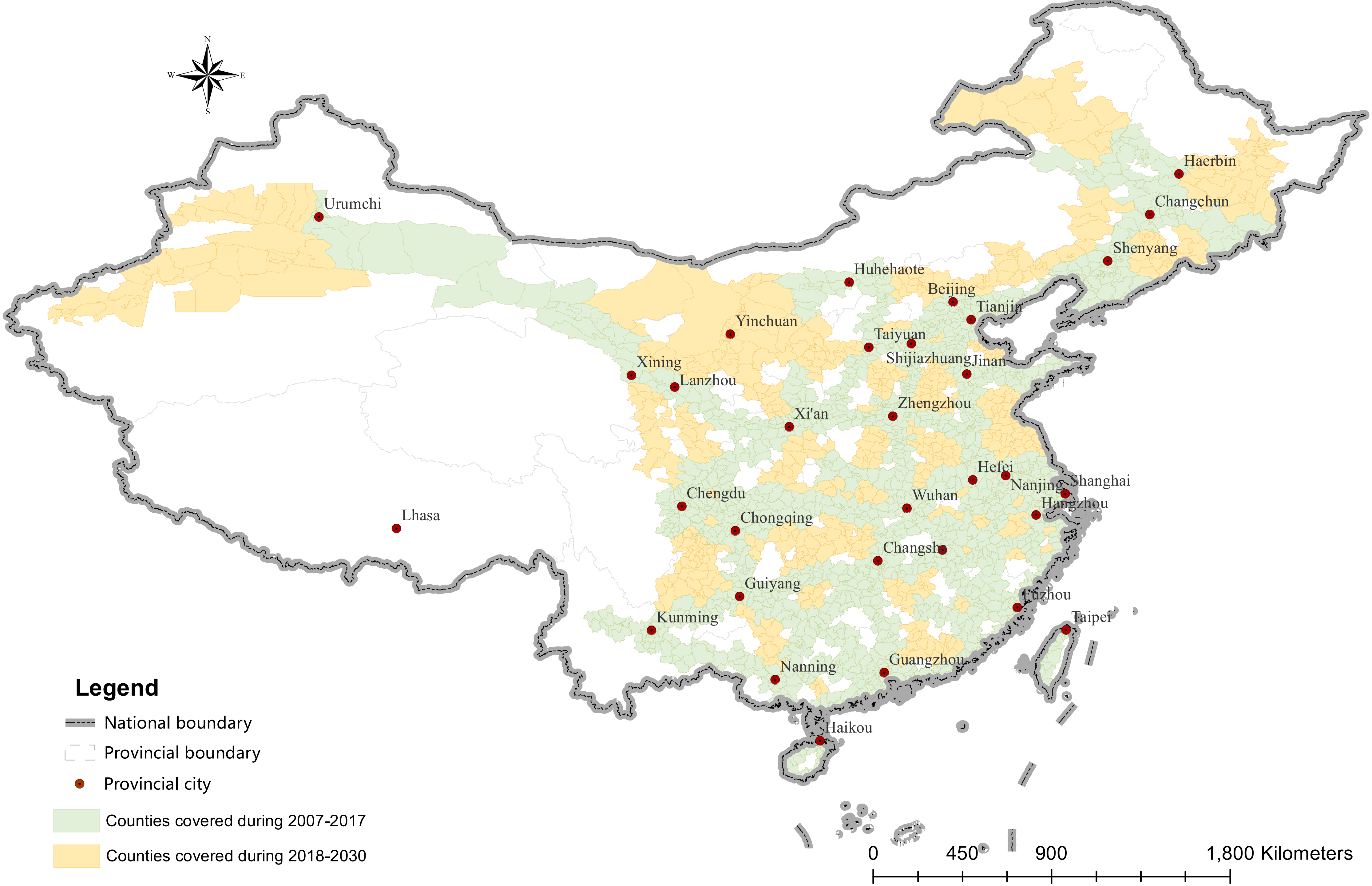


Fig.3 Counties covered by China's HSR stations within 20km radius during different time periods

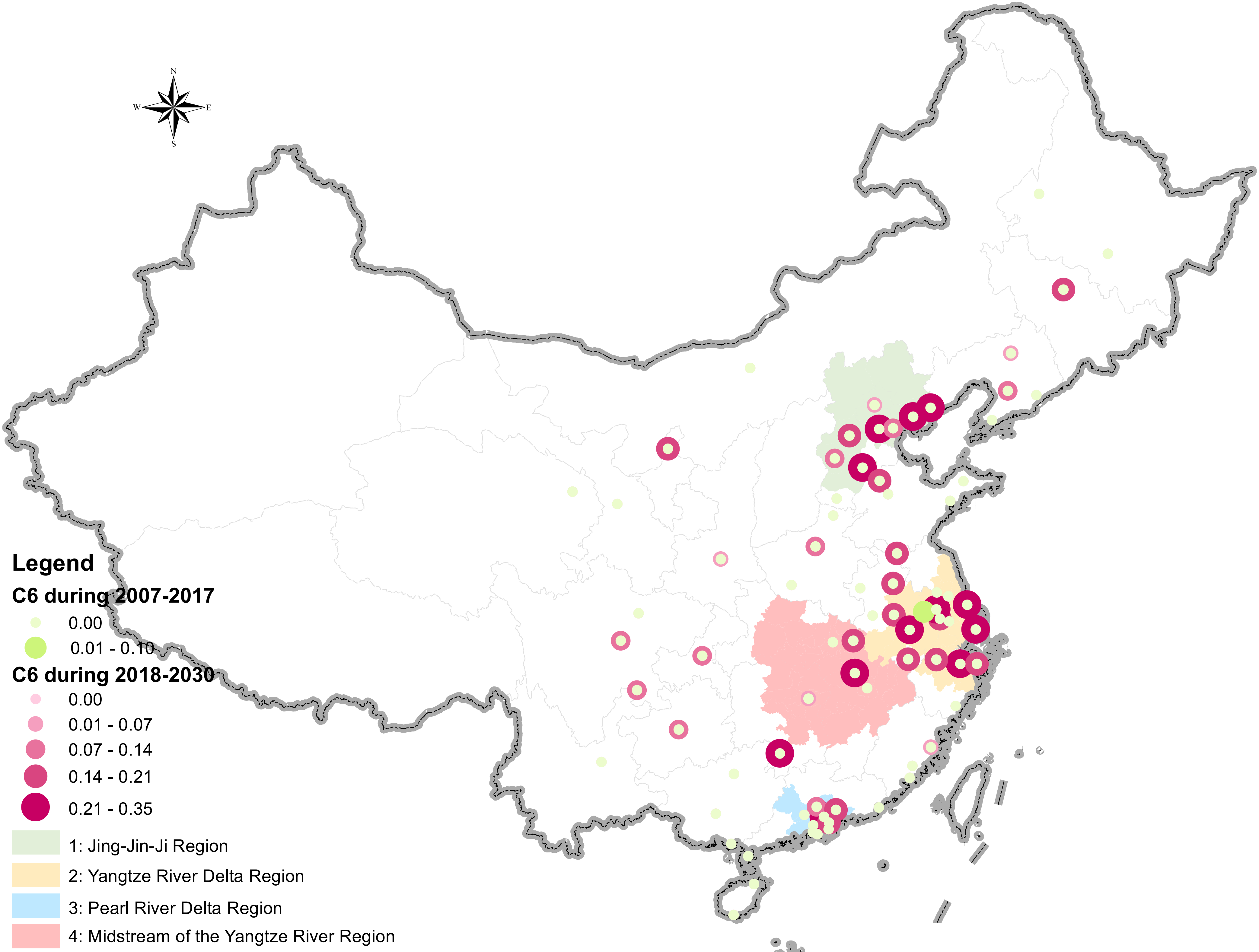


Fig.4 The evolving process of clustering coefficient of cities on CHSRN during 2007-2030

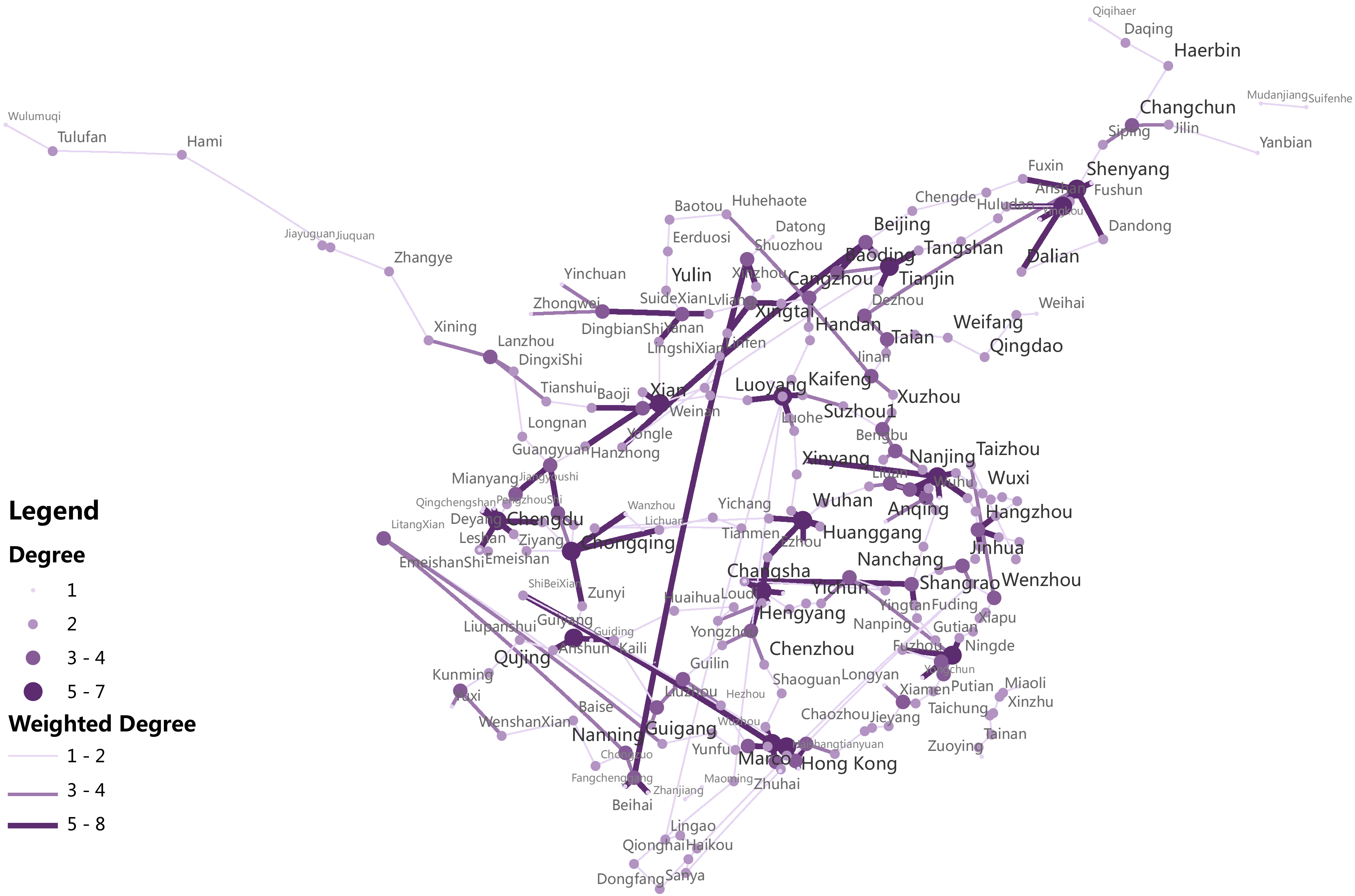


Fig.5-a Complex network representations CHSRNs during 2007-2017

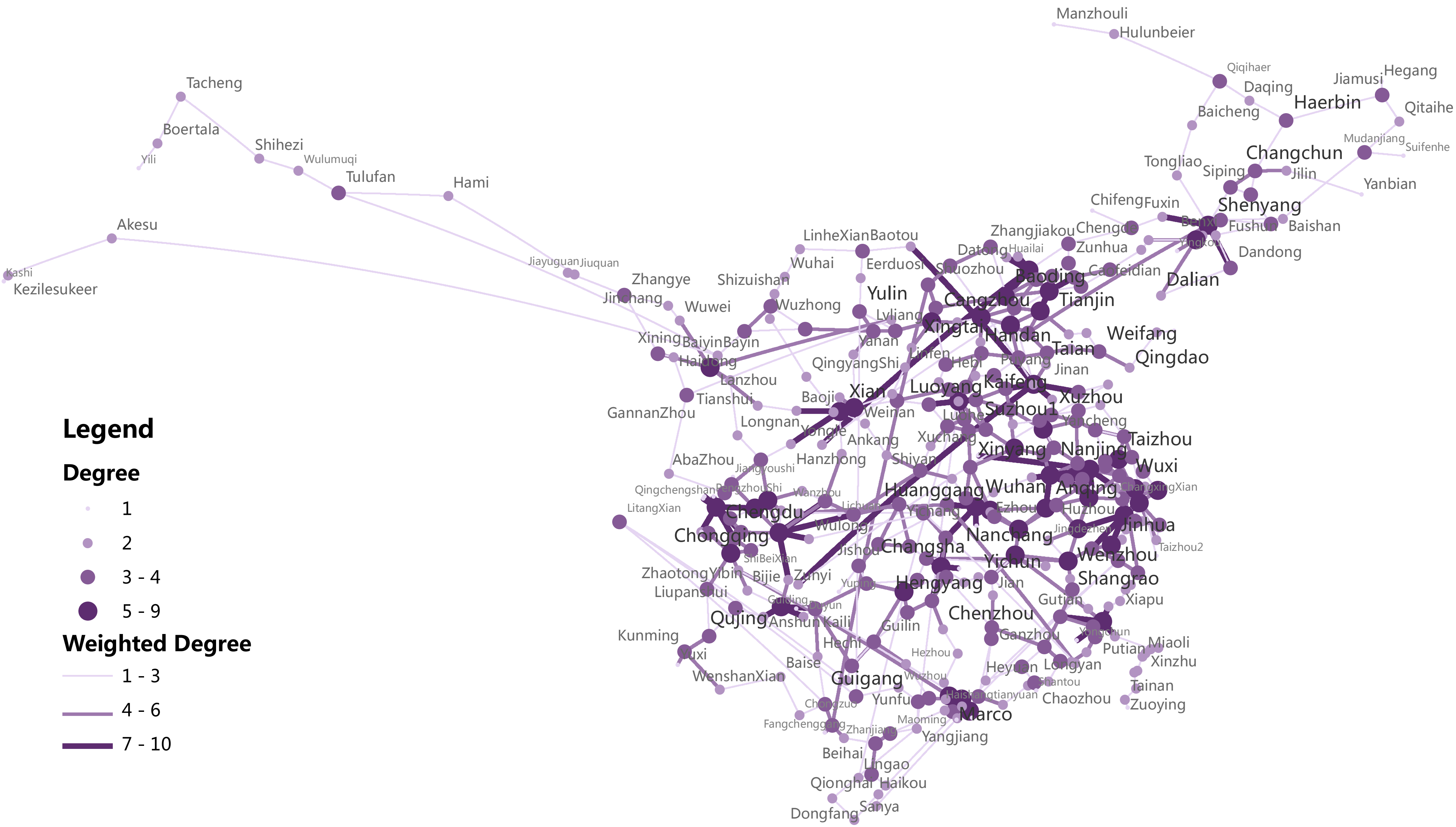


Fig.5-b Complex network representations CHSRNs during 2018-2030

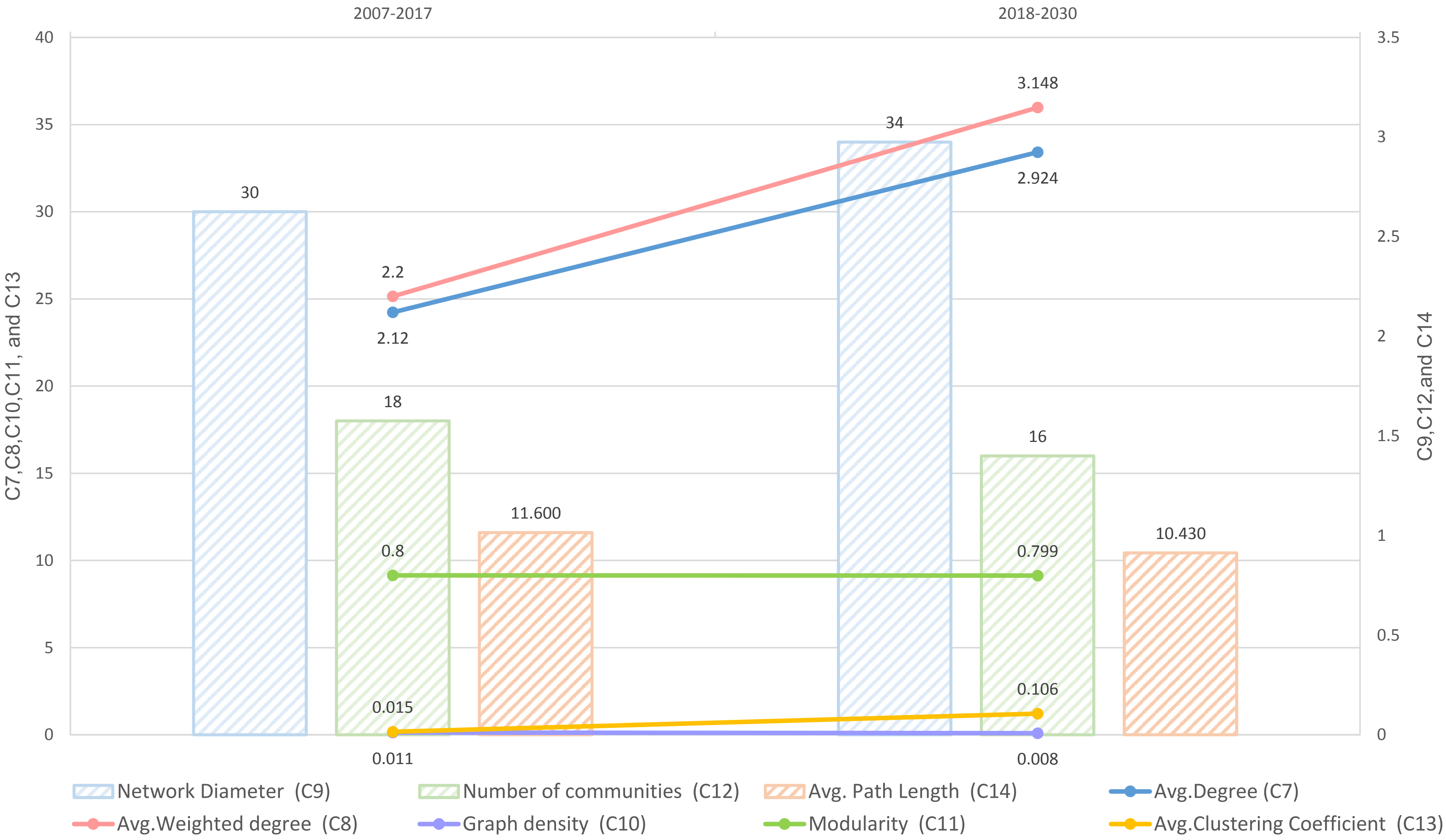


Fig. 6 Indexes of the entire Complex Network which is built based on CHSRNs during different time periods

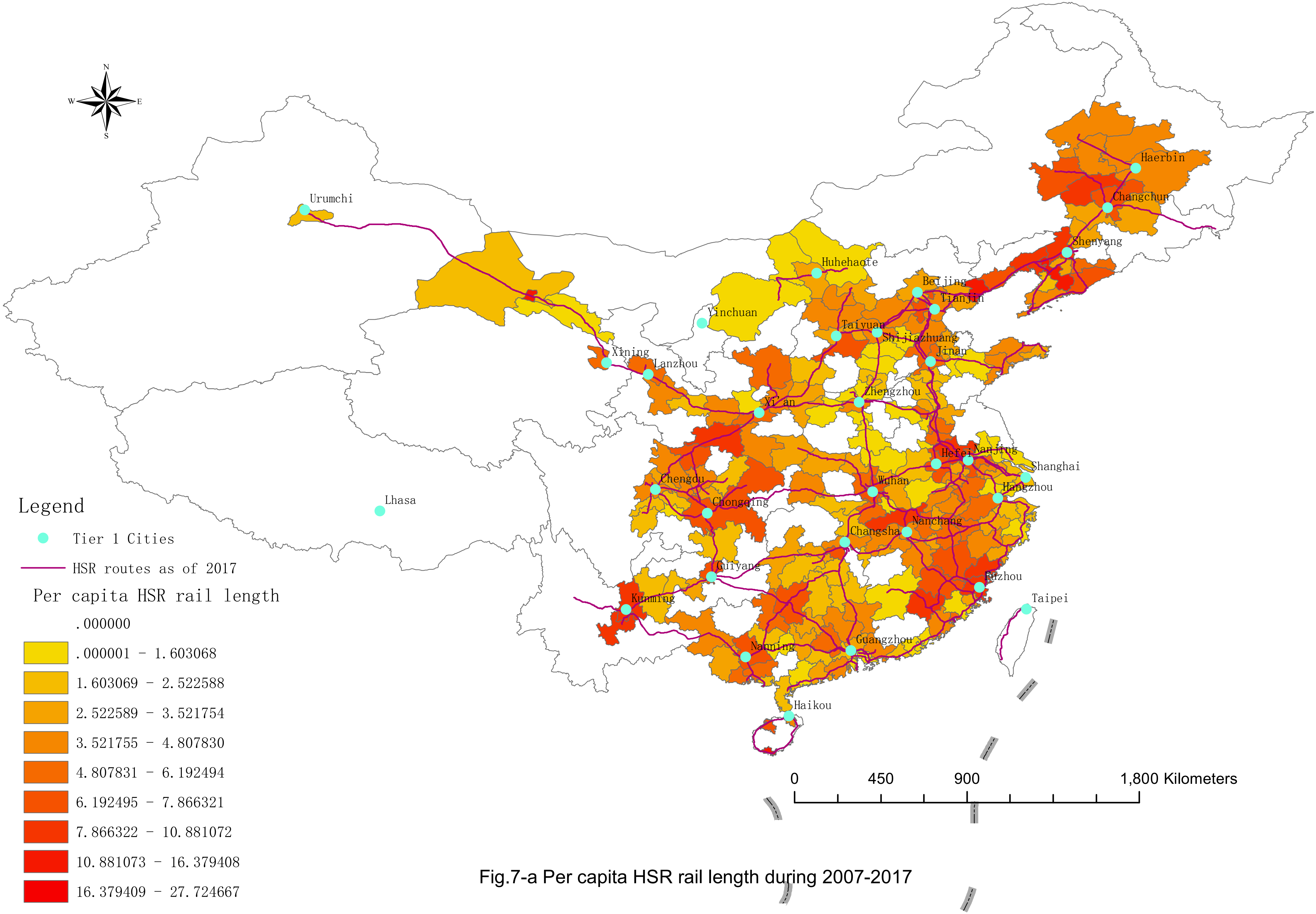


Fig.7-a Per capita HSR rail length during 2007-2017

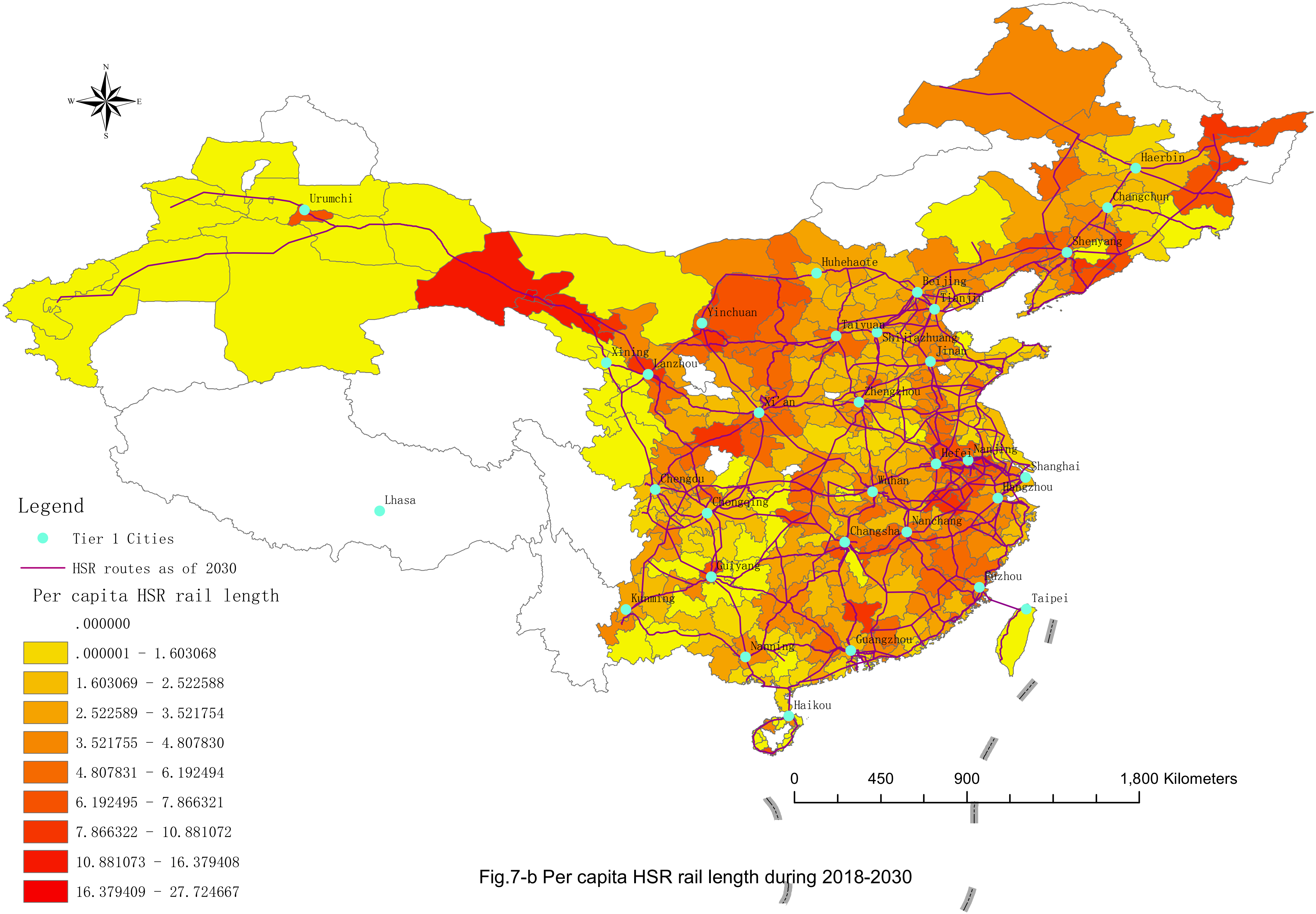
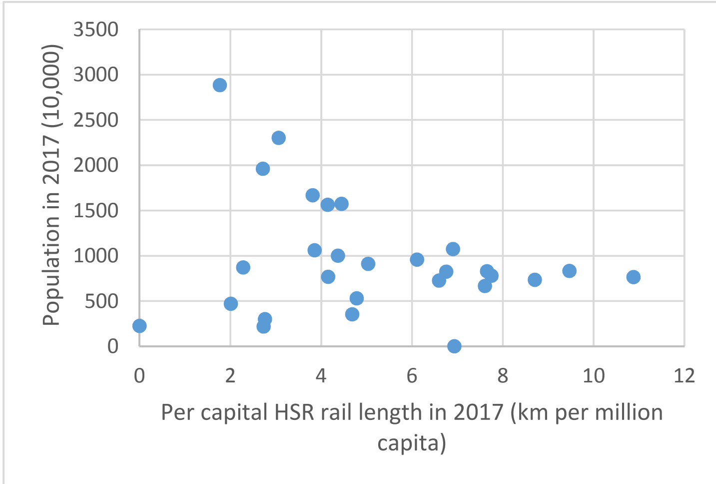
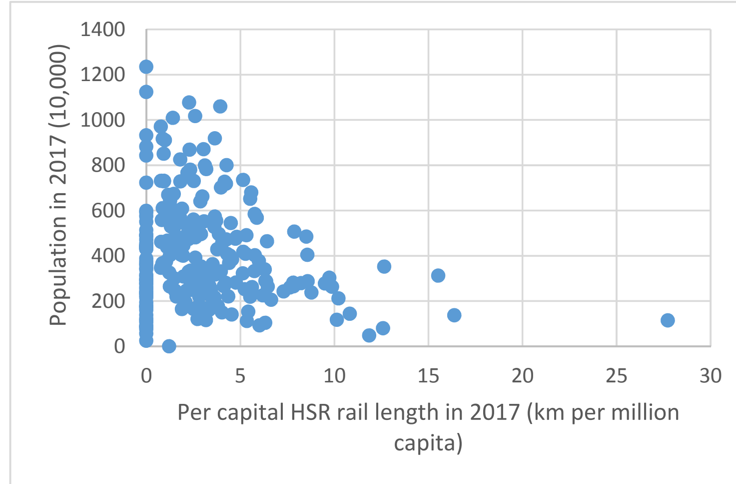


Fig.7-b Per capita HSR rail length during 2018-2030

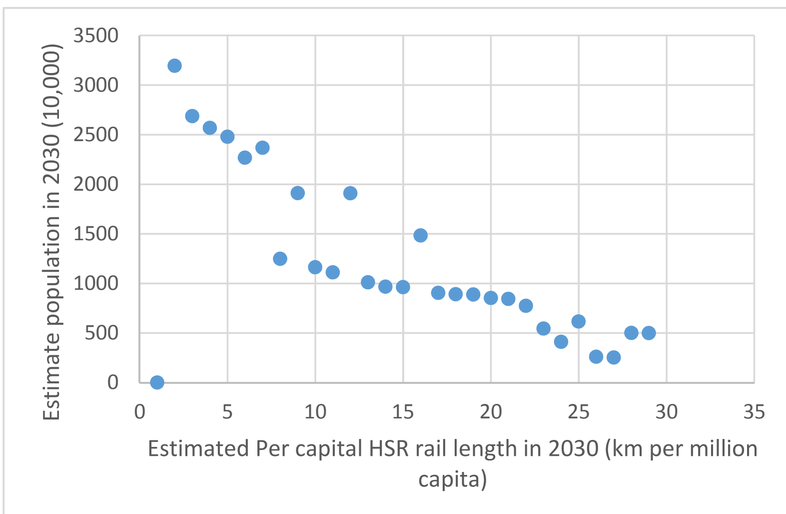


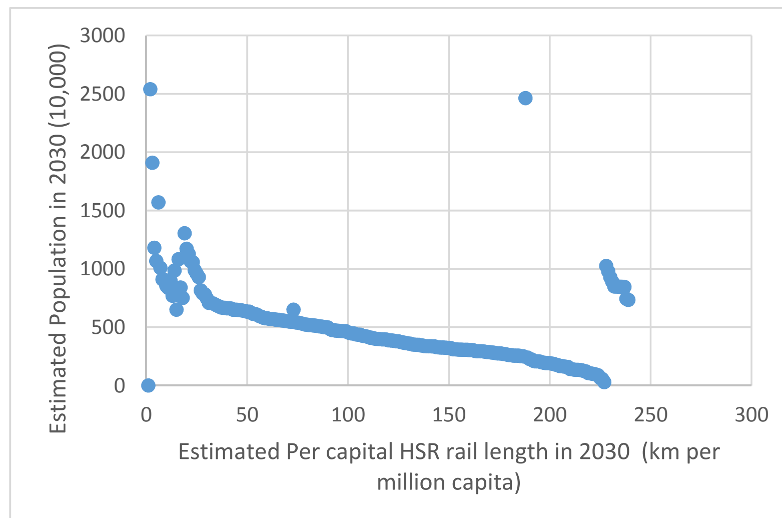


a1) Tier 1 cities

a2) Other classes of cities

a) Per capital HSR rail length vs Population in 2017





b1) Tier 1 cities

b2) Other classes of cities

b) Per capital HSR rail length vs Population in 2030

Fig.8 Per capital HSR rail length vs Population in 2017 and 2030

Table 1 The development stages of CHSRN

Stages	Years	Major events	Operation effects
Initial	2004 - 2007	• In April 18, 2004, the fifth plan of large area railway speed-up and train diagram adjustment began to be implemented. • The State Council of China approved the first national railway plan: " The Mid- and Long-term Railway Network Plan (2004) " (The Central Government of China, 2004). • In April 18, 2007, the sixth plan of large area railway speed-up and train diagram adjustment began to be implemented.	• Trains ran at a speed of 160 km/h, and the mileage of tracks reached 7,700 kilometers. • The mileage of tracks that has the highest speed of 200 km/h was 1,960 kilometers. • The " four-vertical and four-horizontal HSR corridors" were formed. • The total passenger volume of China's HSR had reached 300 million trips one year. • Many HSR lines ran at a speed of 350 km/h, i.e., Beijing-Tianjin line, Wuhan-Guangzhou line, and Zhengzhou Xi'an line. • The "D" series HSR lines were added.
Rapid development	2008 - 2015	• In 2008, "The Mid- and Long-term Railway Network Plan (2008 revised)" (The Central Government of China, 2008) was proposed. • In 2011, the Wenzhou HSR train accident happened (Mu et al., 2015). • The four-vertical and four-horizontal HSR corridors specified in PLAN-2008 have been materialized.	• The " four-vertical and four-horizontal HSR corridors " were outlined, and a goal of completing 33 passenger-only HSR lines by 2011 was set up. • The Ministry of Railway in China had to suspend all the new railway project approvals and reduced the speed of "D" series HSR lines from 250 km/h to 200 km/h, and, the speed of "G" series trains from 300 km/h (or above) to 250 km/h (Mu et al., 2015). • The speed of Beijing - Shanghai HSR line reduced from 380 km/h to 300 km/h. • The total mileage of China's HSR had exceeded 19,000 kilometers. The cumulative ridership since the introduction of China's HSR had reached 5.0 billion in the end of 2015.
International prominence	2016 - Today	• In 2016, the "13th Five-Year" plan (2016 to 2020) began (Hu, 2016).	• By 2020, the mileage of HSR lines will reach 30,000 km, covering more than 80% of mega-cities. • Foreign countries expressed their respective interests on Chinese HSR-related technologies and services.

* China carried out six-time plans of large area railway speed-up and train diagram adjustment, from April 1, 1997 to April 18, 2007. After six-time plans, China entered the era of HSR, and explored the technology of China's HSR (Mu et al., 2015).
* The "13th Five-Year" plan (2016 to 2020) is the thirteenth five year plan, that is, " the 13th five-year plan for economic and social development of the People's Republic of China "(Hu, 2016).

Table 2 The network growth indexes of CHSRN during different time periods

Periods	AHS	AHL	EHM (km)	THM (km)	PT (million)	ACHS	TCHS	APHL	TPHL	PHL	LAHS (km^2)	TPHS (million)
2007-2017	849	114	23019	33594.8	7275	1316	1755	201	300	31	1278000	426
2018-2030	791	170	47896	81490.0	55225	1855	3307	236	597	33	6915000	1155

Notes: AHS: Number of HRS stations added; AHL: Number of HSR lines added;
EHM: Extended HSR line mileage; THM: Total HSR line mileage;
PT: The total number of annual passenger trips; ACHS: Number of added counties within 20km around HSR stations
TCHS: Number of total counties within 20km around HSR stations; APHL: Number of added prefectures serviced by HSR lines;
TPHL: Number of total prefectures serviced by HSR lines; PHL: Number of Provinces owning HSR lines;
LAHS: Land areas covered by 20km radius buffer area of HSR station TPHS: Total Population covered by 20km radius buffer area of HSR station.

Table 3 Complex Network indexes of Tier 1 city on CHSRN in different time periods

indexes / City	2007-2017						2018-2030					
	C1	C2	C3	C4	C5	C6	C1	C2	C3	C4	C5	C6
Nanjing	8	19	0.106	2108.77	0.01	0.1	10	23	0.109	2337.05	0.01	0.14
Hefei	8	19	0.113	2760.71	0.01	0	10	22	0.117	3696.10	0.01	0.21
Chongqing	8	5	0.350	14.00	0.01	0	10	19	0.117	7437.62	0.01	0.08
Chengdu	8	3	0.583	76.00	0.02	0	10	21	0.099	2127.85	0.01	0.08
Fuzhou	7	24	0.0941	2572.493	0.01	0	9	24	0.106	6918.88	0.01	0.07
Wuhan	7	18	0.118	4364.60	0.01	0	9	20	0.125	6606.19	0.01	0.14
Changsha	6	20	0.114	4238.60	0.01	0	9	21	0.118	5814.79	0.01	0.13
Tianjin	6	28	0.074	751.03	0.01	0	9	22	0.109	3562.29	0.01	0.10
Beijing	6	28	0.070	81.17	0.01	0.1	8	23	0.103	12188.99	0.01	0.29
Zhengzhou	6	22	0.092	2144.10	0.01	0.1	8	18	0.128	4459.49	0.00	0.13
Shenyang	5	29	0.071	1725.00	0.01	0	8	22	0.101	9486.24	0.01	0.11
Xian	4	26	0.069	141.00	0.01	0	8	20	0.119	6758.68	0.01	0.15
Guiyang	3	26	0.069	141.00	0.01	0	8	20	0.113	3992.07	0.01	0.10
Shanghai	3	23	0.077	85.00	0.00	0.3	7	26	0.092	592.23	0.00	0.30
Guangzhou	3	25	0.077	397.00	0.01	0	6	22	0.100	1677.01	0.00	0.10
Jinan	3	27	0.078	1867.90	0.00	0.1	6	21	0.113	6488.00	0.00	0.21
Shijiazhuang	3	26	0.077	799.10	0.00	0	6	21	0.115	4058.85	0.00	0.15
Lanzhou	2	7	0.250	0.00	0.00	0	6	23	0.098	6493.63	0.01	0.24
Nanchang	4	23	0.100	2355.79	0.01	0	5	23	0.115	9496.72	0.00	0.22
Taiyuan	3	29	0.058	141.00	0.01	0	5	22	0.117	4382.59	0.00	0.08
Hangzhou	3	21	0.088	331.00	0.00	0	4	24	0.102	886.25	0.00	0.17
Changchun	4	31	0.063	555.00	0.01	0	4	24	0.085	1900.17	0.00	0.17
Kunming	3	1	1.000	0.00	0.01	0	4	24	0.090	660.17	0.00	0.05
Nanning	3	27	0.068	417.00	0.01	0.1	4	21	0.114	5282.38	0.00	0.11
Yinchuan	1	0	0.000	0.00	0.00	0	4	23	0.104	861.68	0.00	0.17
Haerbin	3	32	0.059	280.00	0.01	0	3	25	0.079	910.17	0.00	0.00
Haikou	2	5	0.360	8.00	0.01	0	3	23	0.092	3113.00	0.00	0.00
Xining	2	6	0.318	6.00	0.01	0	3	24	0.091	4951.02	0.00	0.00
Taipei	1	7	0.250	0.00	0.00	0	2	27	0.082	2429.00	0.00	0.00
Huhehaote	1	0	0.000	0.00	0.00	0	2	19	0.118	2585.52	0.00	0.00
Urumchi	1	7	0.250	0.00	0.00	0	2	30	0.060	1400.00	0.00	0.00
Hong Kong	1	1	0.001	0.00	0.00	0	1	25	0.088	0.00	0.00	0.00
Macau	0	0	0.000	0.00	0.00	0	1	31	0.006	0.00	0.00	0.00
Lasa	0	0	0.000	0.00	0.00	0	0	0	0.000	0.00	0.00	0.00

Table 4 Complex network indexes of Tier 2 and 3 cities on CHSRN during different time periods

Indexes	2007-2017						2018-2030					
city	C1	C2	C3	C4	C5	C6	C1	C2	C3	C4	C5	C6
Shenzhen	3	34	0.05	0.00	0.003	0.01	8	24	0.10	2619.10	0.010	0.20
Huangshan	3	20	0.10	1089.08	0.005	0.01	8	24	0.10	1882.12	0.004	0.20
Huizhou	4	33	0.05	281.00	0.009	0.01	8	24	0.10	3365.91	0.004	0.17
Baoding	4	27	0.08	782.76	0.006	0.01	8	22	0.11	6397.81	0.004	0.20
Jiujiang	1	0	0.00	0.00	0.000	0.01	7	22	0.12	8344.34	0.004	0.30
Suzhou	3	23	0.08	115.00	0.005	0.01	7	26	0.09	271.06	0.004	0.30
Taizhou	3	25	0.08	261.32	0.005	0.01	7	25	0.10	2045.89	0.004	0.00
Huanggang	2	19	0.11	0.00	0.003	0.01	7	21	0.13	10448.55	0.004	0.20
Bengbu	4	21	0.10	2341.65	0.007	0.01	6	22	0.11	242.92	0.003	0.17
Fuyang	1	0	0.00	0.00	0.000	0.01	6	20	0.13	7537.64	0.004	0.00
Xuzhou	3	23	0.09	2133.90	0.005	0.01	6	22	0.11	1529.26	0.003	0.17
Yibin	1	0	0.00	0.00	0.000	0.01	6	21	0.10	1951.17	0.004	0.10
Handan	3	24	0.08	946.10	0.005	0.01	6	19	0.12	3566.65	0.003	0.00
Hengshui	1	0	0.00	0.00	0.000	0.01	6	20	0.12	6159.61	0.004	0.30
Langfang	3	29	0.07	18.82	0.004	0.01	5	22	0.11	300.83	0.003	0.33
Dongguan	2	34	0.05	0.00	0.003	0.01	5	23	0.10	841.92	0.005	0.30
Anshan	5	31	0.06	557.00	0.010	0.02	5	23	0.09	913.40	0.005	0.10
Wenzhou	3	25	0.08	263.48	0.005	0.00	4	26	0.09	1058.81	0.003	0.00
Ningbo	4	23	0.08	347.32	0.005	0.00	4	27	0.09	317.28	0.003	0.17
Wuxi	3	22	0.08	210.50	0.005	0.00	4	25	0.10	793.61	0.003	0.00
Wuhu	4	18	0.10	1305.91	0.007	0.00	4	23	0.11	634.26	0.003	0.33
Changzhou	3	21	0.09	331.00	0.005	0.00	4	24	0.10	886.25	0.003	0.17
Zhenjiang	3	20	0.10	463.00	0.005	0.00	4	24	0.10	202.81	0.002	0.33
Quanzhou	3	26	0.08	1320.00	0.004	0.00	4	26	0.09	181.94	0.002	0.00
Xiamen	3	27	0.08	1197.00	0.005	0.00	4	26	0.09	107.87	0.002	0.00
Dezhou	4	28	0.08	2153.90	0.007	0.00	4	21	0.11	9877.56	0.003	0.17
Mianyang	3	5	0.32	13.00	0.006	0.00	4	21	0.10	907.99	0.004	0.00
Anyang	3	5	0.32	13.00	0.006	0.00	4	21	0.10	907.99	0.004	0.00
Foshan	3	26	0.07	277.00	0.005	0.00	4	21	0.10	1266.94	0.002	0.00
Tangshan	1	0	0.00	0.00	0.000	0.00	4	23	0.10	453.48	0.003	0.33
Zhongshan	1	0	0.00	0.00	0.000	0.00	4	23	0.10	3238.22	0.004	0.00
Zhanjiang	2	1	1.00	0.00	0.005	0.00	4	22	0.10	5099.26	0.003	0.00
Liuan	3	19	0.11	2339.00	0.005	0.00	3	22	0.11	571.87	0.002	0.00
Shaoxing	1	0	0.00	0.00	0.000	0.00	3	27	0.09	40.72	0.002	0.33
Yangzhou	1	0	0.00	0.00	0.000	0.00	3	24	0.10	321.04	0.003	0.00
Nantong	1	0	0.00	0.00	0.000	0.00	3	26	0.09	428.42	0.003	0.33
Yongzhou	3	22	0.10	1273.00	0.005	0.00	3	22	0.11	1655.35	0.003	0.33
Qinhuangdao	1	0	0.00	0.00	0.000	0.00	3	24	0.09	348.93	0.003	0.33
Liuzhou	3	24	0.08	1033.00	0.005	0.00	3	20	0.11	2378.83	0.003	0.00
Dandong	2	33	0.06	0.00	0.003	0.00	3	23	0.09	511.00	0.003	0.00
Beihai	2	29	0.06	0.00	0.003	0.00	3	21	0.10	3768.67	0.002	0.00
Qiqihaer	2	34	0.05	0.00	0.003	0.00	3	25	0.08	880.33	0.004	0.00
Baotou	1	0	0.00	0.00	0.000	0.00	3	20	0.12	2771.84	0.003	0.00
Nanyang	1	0	0.00	0.00	0.000	0.00	2	18	0.12	1265.95	0.002	0.00
Qingdao	2	2	0.67	0.00	0.004	0.00	2	24	0.09	704.00	0.003	0.00
Dalian	3	32	0.06	141.00	0.006	0.00	2	24	0.08	5.00	0.002	0.00
Yantai	3	1	1.00	1.00	0.008	0.00	2	25	0.08	353.00	0.003	0.00
Zhuhai	1	0	0.00	0.00	0.000	0.00	2	24	0.09	353.00	0.003	0.00
Sanya	3	5	0.36	8.00	0.005	0.00	2	28	0.06	8.00	0.003	0.00
Shantou	1	0	0.00	0.00	0.000	0.00	1	27	0.08	0.00	0.001	0.00

Table 5 Independent sample t test of C6 values in the two periods between two tiers of cities

a) **Group Statistics**

	City Tier	N	Mean	Std. Deviation	Std. Error Mean
C6 (2007-2017)	1	34	.0300	.0580	.001
	O	50	.00360	.00525	.000
C6 (2018-2030)	1	34	.1087	.0872	.0150
	O	50	.1177	.136	.0192

b) **Independent Samples Test**

		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
									Lower	Upper
C6 (2007-2017)	Equal variances assumed	37.503	.000	3.214	82	.002	.0264	.00823	.0101	.04281
	Equal variances not assumed			2.652	33.369	.012	.0264	.00997	.006161	.04671
C6 (2018-2030)	Equal variances assumed	20.630	.000	-.328	82	.744	-.00865	.0264	-.06121	.0439
	Equal variances not assumed			-.355	81.768	.723	-.00865	.0244	-.05711	.0398