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Impacts of high-speed rail lines on the city network in China

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ABSTRACT

China's large-scale HSR network has a significant influence on both accessibility and connectivity, but little attention has been paid to its impacts on connectivity. Changes in connectivity largely affect the external relations among cities, thus influencing the structure of the city network. This paper examines the impacts of China's HSR network on the overall connectivity and nodal centrality of the city network, as evaluated by passenger trains from 2003 to 2014. This paper employs the graph index, average path length, clustering coefficient and three indicators of centrality, namely weighted degree centrality (WDC), weighted closeness centrality (WCC) and weighted betweenness centrality (WBC). The results show that the HSR network largely increased overall connectivity according to the increasing Beta index and clustering coefficient, and decreasing average path length. The HSR lines also increased the average centrality of the city network and the inequality of nodal centrality according to the WCC indicator, but they decreased the inequality of nodal centrality with regard to the WDC and WBC indicators. Meanwhile, the growing HSR network led to the centrality tended to intensify in large cities in terms of the WCC indicator, but intensify in small cities according to the WDC and WBC indicators. Spatially, the cities with HSR stations, population over 3 million and GDP over 100 billion RMB saw higher increases in centrality than the others; the cities with high values of WDC and WCC, especially the top 20 cities, tended to concentrate in the populous areas with well-developed economies (e.g., Yangtze River Delta), whereas the cities with high WBC values in 2014 were coupled with the hub cities of regional railway management administration.

1. Introduction

High-speed rail (HSR), the most significant technological breakthrough in railways since 1964, has not only generated an unprecedented shrinkage of time and space (Spiekermann and Wegener, 2006), it has also influenced connectivity among cities (Plassard, 1991). Both time-saving effects and changes in connectivity can influence external relations among cities, thus affecting the structure of city networks (Dupuy, 1991; Gallego et al., 2015). Yet, the impacts of HSR on social-economic development are still disputed (Chen and Hall, 2012).Previous studies have found that the development of HSR may enhance the dominant status of core cities by producing greater economic and employment growth than in peripheral cities (Sasaki et al., 1997). However, other studies have produced contrasting results: HSR lines may also catalyse the economic development of peripheral cities (e.g., Lyon and Lille) by increasing connectivity to core cities and improve the status of peripheral cities in the city network (Cervero and Bernick, 1996).

China has experienced a period of rapid HSR development in the last decade and now operates the largest HSR network in the world, covering 11,477 km of distance at the end of 2014 and accounting for 48% of the world's total (UIC, 2014). More and more Chinese can enjoy the convenience and accessibility improvements of HSR lines (Chen and Haynes, 2015). In China, approximately 74% of the population and 82% of the GDP is within a two-hour drive of the HSR network (Wang et al., 2015). The rapid development of HSR in China has generated obvious 'time-space convergence' and 'corridor effects' based on the indicators of accessibility(e.g. weighted travel time, daily accessibility and potential value) at the national scale (Cao et al., 2013; Shaw et al., 2014; Jiao et al., 2014) and the potential impacts on economic development caused by accessibility improvements (Chen, 2012). Meanwhile, HSR lines in China could powerfully affect the spatial interaction of cities by means of enhanced connectivity, which could be manifested in two ways: (1) Increasing train frequency between cities. For example, the opening of the Beijing-Tianjin intercity railway led to the number of bullet trains between these two cities increasing from 52 pairs daily in 2007 to 148 pairs daily in 2015, with an increase of 1.84 times. (2) Connecting cities without conventional rail stations by the HSR lines. For example, with the opening of the Shanghai-Shenzhen HSR line, two cities (Chaoshan and Shanwei) have been connected to the rail network.

However, little attention has been paid to the impacts of China's HSR that are due to enhanced connectivity in the previous studies. Some literatures had examined the structure of city network based on passenger trains that existed before 2007 (Li and Cai, 2007) and 2011 (Zhong et al.,

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2012), but their study could not yet reveal the impacts of the HSR network, which expanded rapidly after 2008. Thus, this paper aims to construct a network based on the passenger trains available from 2003 to 2014, thereby exploring the effects of HSR on the overall connectivity and hierarchy differences in the city network, according to the graph index and complex theory. This paper first briefly summarizes the existing literature, then outlines the study area, data processing approach and methodology; in the fifth section it explores the overall connectivity of the city network from 2003 to 2014;and then compares the overall characteristics, city hierarchy and spatial patterns of all three centrality indicators in the sixth section; and lastly summarizes conclusions.

2. Literature review

2.1. Theoretical and methodological framework of city networks

City networks have assumed an increasingly prominent role in theoretical interpretations in the context of globalization, as they can change the external relations of cities at global, national and regional levels (Capello, 2000). A city network is traditionally defined as a flow network that includes the external relations among cities (Camagni and Salone, 1993), taking the space of flows and the central flow theory as its theoretical bases (Wu, 2013). Among, space of flows, which is proposed by Castells in 1989, includes four components: networks (information systems, telecommunications, transportation etc.), nodes and hubs of these network, spatial organization of these network, and virtual places (Castells, 1999). As the complementary of central place theory, central flow theory is a matter of what is central, place or flow, which could describe external relation of cities (Taylor et al., 2010). The external relations of cities in the city network can be researched in two ways. The first arises from infrastructure systems including transport and communication networks, whereas the second considers the spatial interaction between cities from the perspective of urban areas, economic activities, and population, evaluated by the corporation approach and sociocultural approach (Camagni and Salone, 1993; Derudder and Witlox, 2008; Ma and Li, 2012). Transport infrastructure, along with the rapid development of transport technology, plays an increasingly important role in the formation and evolution of city networks (Wu, 2013). Moreover, the topological properties of transport networks can be used to study the spatial and functional economic processes that occur between cities (Reggiani and Nijkamp, 2007; Ma and Li, 2012). Complex network are widely used to explore the topological properties of transport network (e.g. connectivity and centrality), especially the airlines network (Wang et al., 2011; Wang et al., 2014), contain network (Ducruet, 2013), and train flow network (Fang and Sun, 2015), which could help us to understand the urban hierarchy concerning the external relations in the city network. Fig. 1 illustrates the theoretical and methodological research framework of city networks.

Transport infrastructure has been widely used to identify the topological properties of city networks at international, national and local scales (Derudder and Witlox, 2008; Wu, 2013). A number of scholars have examined the structure of city networks at the international scale based on air passenger flows and aviation timetables (Smith and Timberlake, 2001; Derudder and Witlox, 2008;Derudder et al., 2007), concluding that New York, Paris, London, Tokyo etc. played a dominate role in the hierarchy of world city network (Derudder and Witlox, 2008;Derudder et al., 2007), while the major megacities in Asia (e.g., Hong Kong)greatly improved their positions in the city network from 1977 to 1997 (Smith and Timberlake, 2001). At the national scale, the city network in Canada, as based on air passenger flows, has evolved into a stable hierarchical structure (Murayama, 1982). Beijing, Zhengzhou and Harbin ranked at the top of China's city network, as measured by train flows (Zhong et al., 2012), while Shanghai and Guangzhou climbed into the top three cities based on aviation timetables (Li and Dawood, 2016). According to Li and Cai (2007), China's city network follows a scale-free distribution as measured by train timetables; similar results are found evaluated by commuting flows at the local scale (Laan, 1998; Limtanakool et al., 2009) and train timetables at the megacity scale (Hall and Pain, 2007).

2.2. High-speed rail and urban hierarchy

HSR generates short-term impacts on accessibility and connectivity, and it inevitably has long-term impacts on the relocation, agglomeration and diffusion of economic activities (Chen and Hall, 2011; Ureña et al., 2009). Changes in connectivity caused by HSR lines played a more important role in economic development than that time saving (Dupuy, 1991). HSR lines increased the connectivity of cities alongside, mostly enlarged their market areas, as such it was much easier for producers in peripheral cities to transport their products to core cities (Spiekermann and Wegener, 2006). Meanwhile, the increasing connectivity of cities with HSR stations can lead to the redistribution of economic activities among regions, especially between the core and peripheral areas. For instance, the deployed HSR lines have led to the concentration of high-level specialized activities in core cities, whereas land- and labour-consuming activities moved to peripheral areas (Ureña et al., 2009). Additionally, the HSR lines might catalyse the economic development of peripheral areas following their increasing connectivity to core cities (Thompson, 1994).

The development of HSR lines can generate either a concentrated or a dispersal hierarchy in the city network, as shown in various case studies (Garmendia and Romero, 2012; Bonnafous, 1995). The Shinkansen, deployed in Japan, has generated a concentrated hierarchy in the city network, with the major cities (e.g., Tokyo and Osaka) showing strong increases in employment, economic activities and land values (Sasaki et al., 1997; Albalate and Bel, 2012). A similar result can be found with regard to the HSR network in Spain (Garmendia and Romero, 2012). Some monitoring studies have also concluded that the development of HSR led to both population and employment concentrating in Seoul, South Korea (Kim, 2000) and London, the UK (Sánchez-Mateos and Givoni, 2012). However, case studies in France found that the development of HSR lines largely promoted the development of small cities along them (Cervero and Bernick, 1996). For example, the operation

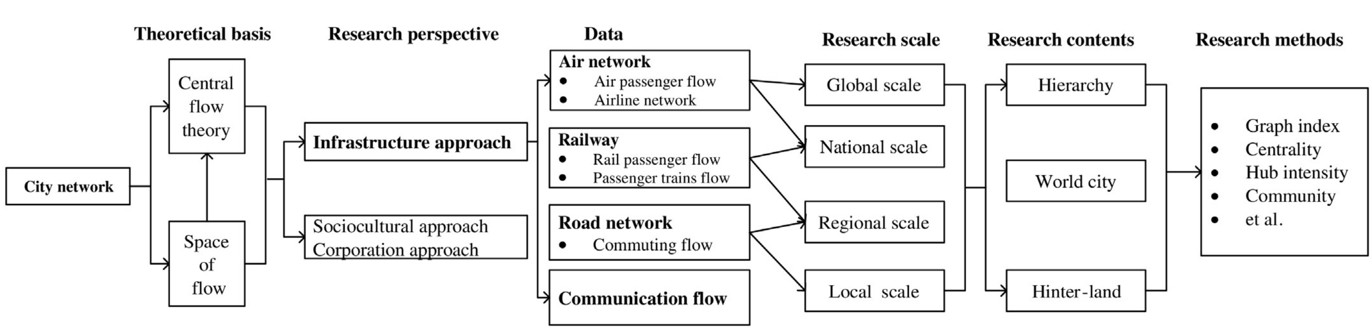

Fig. 1. Outlines of the theoretical and methodological research framework of city network.