Journal of Transport Geography 70 (2018) 40–54

Contents lists available at ScienceDirect

Journal of Transport Geography

journal homepage: www.elsevier.com/locate/jtrangeo

China's high-speed rail network construction and planning over time: a network analysis

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ARTICLE INFO

Keywords:
China's high-speed rail network
Construction and planning
Evolution process
Complex Network
Network characteristics

ABSTRACT

Based on the construction scale of China's high-speed rail network (CHSRN) between 2007–2017, this paper presents the evolution process and network characteristics over this period. Additionally, according to China's latest national railway planning proposal - "The Mid- and Long-term Railway Network Plan" issued in 2016, the development prospects and impacting factors of future CHSRN from 2018 to 2030 are analyzed. The evolutionary process and regularity of CHSRN development is evaluated with various complex network measures. It is found that the degree and eccentricity of each Tier 1 city increase over time, but the pagerank of almost all Tier 1 cities decreases from 2007–2017 to 2018–2030, and that the contribution of the Tier 1 cities to the network connections decreases from 2007 to 2030. The Chinese government would be adopting an egalitarian model to construct the CHSRN in the long-term. Moreover, during the second period, the CHSRN would form increasingly more connections between more populated Tier 2 and Tier 3 cities. From 2018–2030 the clustering coefficients of some Tier 2 and Tier 3 cities would be greater than those of Tier 1 cities. The HSR planners of China may have expected a larger share of passenger flows from the Tier 1 cities to Tiers 2 and 3 cities in the future.

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 1250 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

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https://doi.org/10.1016/j.jtrangeo.2018.05.017
Received 1 September 2017; Received in revised form 15 May 2018; Accepted 21 May 2018

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 and 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 purpose 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 meetings 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 the restructuring of regional economy caused by 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 depending on the attractiveness of the new HSR stations would also be accordingly low. Similarly, Givoni (2006) and Wetwitoo and Kato (2017) demonstrated that HSR caused economic damage to the 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 connected European regions and helped 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