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Evolution and geographic effects of high-speed rail in East Asia:

An accessibility approach

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Abstract: The rapid development of high-speed rail (HSR) is influencing regional development, regional structure, commuting, and regional integration. East Asia is the region with the world's first and largest current operating and planned HSR network. In this paper, we examine the evolutionary mechanism and impacts on the transport circle and accessibility of HSR in East Asia. The results indicate that the HSR network first follows a "core-core" model and then forms a corridor in Japan, South Korea, and China Taiwan, but then forms a complete network in China Mainland. The current operating HSR lines are mostly distributed in regions with developed economies and dense populations, and more than half of the population and GDP in China can be served by HSR within 1 hour's travel time. The planned HSR network will expand to the western region of China and Japan and the southern region of South Korea. The development of the current operating and planned HSR network considerably enlarges the transport circle of core cities, especially cities along trunk HSR lines. This 1 h transport circle of core cities has formed continuous regions in the Yangtze River Delta, the Pearl River Delta, Tokyo, Seoul, and along trunk HSR lines. The HSR network will bring about substantial improvement in accessiblity, but also increase the inequality of nodal accessibility in China Mainland. Spatially, the spatial patterns of the weighted shortest travel time of cities in China Mainland, Japan, and South Korea all present the "core-peripheral structure", taking Zhengzhou, Tokyo, and Seoul, respectively, as core cities, and cities located along the trunk HSR lines gain large improvement in accessibility.

Keywords: high-speed rail; East Asia; evolutionary mechanism; geographic effects; accessibility

1 Introduction

Since the first high-speed rail (HSR) route (Tokaido Shinkansen) opened in Japan in 1964, HSR has experienced a rapid development period, especially since 2000. Until 2013, there were 23,000 km HSR lines with the maximum speed greater than 250 km/h. Most of these

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lines were distributed in Europe (7303 km) and East Asia (14,538 km), accounting for 31.7% and 63.2% of the world capacity, respectively, according to the International Union of Railways (UIC, 2013). In 2010, the European Commission submitted a plan for the Trans-European Transport Networks (including the Trans-European HSR Networks), which aimed to improve the status of countries in HSR network, instead of being a measure to promote economic integration in Europe (Vickerman *et al*., 2013). However, some researchers found that the development of an integrated European HSR network would mostly promote economic integration in the continent (Gutiérrez *et al*., 1996; Vickerman, 1997). However, plans for an integrated HSR system in East Asia have not yet been proposed. According to the *Regional Plan of the Northeastern Region of China Open to Northeast Asia* submitted by the central government of China and the *East Asian Community* proposed by Japan, it is of vital importance to build an integrated transport network (especially an integrated HSR network) in East Asia (IA-PS, CASS, 2012).

As a result of the rapid development of HSR, research on the impacts of HSR networks has become a hot topic. At present, studies have concentrated mainly on the effects of HSR on accessibility (Jiang *et al*., 2010; Shaw *et al*., 2014), commuting behaviors (Hou *et al*., 2011; Wu *et al*., 2013), regional development (Hu and Shen, 1999; Wang, 2012), spatial structure (Wang and Ding, 2011; Wang and Lin, 2011), and competition and cooperation with other transport modes (Ding *et al*., 2013; Wang and Hu, 2013) at international, national, regional, and city levels. At the international scale, studies have concentrated mainly on two aspects: (1) The impacts of the European HSR network on the improvement of and disparities in accessibility. The development of integrated HSR network in Europe could generate uneven "time–space convergence" and "corridor effects", and enhance the "core–periphery" structure (Gutiérrez *et al*., 1996; Gutiérrez, 2001; Vickerman, 1997; Vickerman, 1999). (2) The effects of HSR on economic integration and regional specialization, taking the operating, planned or proposed HSR networks in the Pan-Asia region, China, and Europe as cases (Cheng *et al*., 2015; Ma *et al*., 2015). At the national scale, researchers focused on exploring the time saving for travel to the national capital or regional core cities from the other cities, or even between all cities, and the impacts on accessibility (Cao *et al*., 2013; Chen, 2012; Jiao *et al*., 2014; Kim and Sultana, 2015). Although some researchers have carried out work on the impacts of HSR networks separately in China Mainland and Taiwan, South Korea, and Japan, comparative studies about the effects of HSR networks in China, South Korea, and Japan and the potential implications of the proposed integrated HSR network in East Asia are rare. Thus, this paper tries to explore the spatial patterns, spatial impacts, and evolutionary mechanisms of current operating and planned HSR networks in China, South Korea, and Japan, and lastly the potential impacts of the proposed integrated HSR network are explored.

2 Study area, data, and methodology

2.1 Study areas and data

The uniform definition of HSR in East Asia has not formed. Japan, with the world's first HSR line, defines HSR as rail lines with a maximum speed of greater than 200 km/h (LNSR, 1971), which is broadly similar to the definition given by the UIC. The HSR network defined by the UIC in 2008 includes upgraded rail lines with a maximum speed of 200 km/h and newly-built HSR lines with a top speed of 250 km/h. In South Korea, there is no widely-accepted definition either. In this paper, both the current operating and the planned HSR networks in Japan and South Korea were digitized according to the map on the UIC website (www.uic.org). According to the Management Regulations of Railway Safety published by the State Department of China in 2014, HSR in China is defined as the newly-built passenger dedicated lines (PDLs) and intercity railways with maximum speeds of greater than 250 km/h and upgraded lines with maximum speeds of greater than 200 km/h (NRA, 2014). In China, the operating HSR network is digitized based on rail lines with G, C, and D prefix bullet trains running on, and the planned HSR network is digitized according to the 'Mid-to-long Term Railway Network Plan,' revised in 2008 by the Ministry of Railways (MOR).

The study area includes 333 prefecture-level divisions and four municipalities in China Mainland, seven cities and 16 counties in China Taiwan, 17 cities in South Korea (including eight provincial cities, six metropolitan cities, one city in a special self-governing province, one special city, and one metropolitan autonomous city), and 47 prefectural divisions in Japan. The administrative divisions were digitized according to the *2013 People's Republic of Administrative Divisions Booklet*, the *Japan Statistical Yearbook 2013*, and the *South Korea Statistical Yearbook 2013*. The total population and annual gross domestic product (GDP) of each study object were sourced from *China's Regional Economic Statistical Yearbook 2013*, the *China City Statistics Yearbook 2013*, the *Japan Statistics Yearbook 2013*, the *South Korea Statistics Yearbook 2013*, and the *Taiwan Statistics Yearbook 2013*. The GIS database of road and rail networks in China was obtained from the Thematic Database for the Human-Earth System of the Chinese Academy of Sciences and the 1:4 M Database of the National Fundamental Geographic Information System of China, while those for Japan and South Korea were from the Open Street Map (http://www.openstreetmap.org).

Three scenarios were used to explore the potential impacts of both the currently operating and planned HSR networks on accessibility. Scenario 1 involved the transport systems with highway and rail networks in 2012; Scenario 2 contained all the transport networks in Scenario 1 and the operating HSR networks in 2012, and Scenario 3 included all the transport networks in Scenario 2 and the planned HSR networks. In addition, the change from Scenario 1 to Scenario 2 is defined as the first period, and the change from Scenario 2 to Scenario 3 as the second period.

2.2 Accessibility

Accessibility is traditionally defined as the potential opportunities for interaction (Hansen, 1959) and is widely used to explore the potential impacts of HSR (Vickerman *et al*., 1997). According to their function, the accessibility indicators can be divided into three types, including travel cost indicators (e.g. weighted average travel time (WATT)), daily accessibility (DA), and potential accessibility (Liu, 2007).This paper attempts to explore the impacts of HSR on accessibility from the inter-regional perspective, instead of building a new indicator. Therefore, DA and WATT are chosen in this paper to explore the impacts of HSR on the transport circle and "time–space convergence".

2.2.1 Daily accessibility (DA)

DA measures the total population or area of economic activity that can be reached from a node within a certain travel time limit (Gutiérrez *et al*., 2001). DA could be used to explore the impact of HSR on the transport circle of cities and the hinterland of HSR networks (Wang *et al*., 2015). The DA is calculated as:

$$Q_i = \sum_{T_{ij} \leqslant \alpha} q_j \tag{1}$$

where Q_i is the DA of node i and q_j is the population of node j. T_{ij} is the minimum travel time between nodes i and j (in hours), and α is the time limit, which is set as 2 hours in this paper.

2.2.2 Weighted average travel time (WATT)

WATT is an accessibility measure based on space separation. The WATT, which not only considers the relative locations of nodes but also the activities of the destinations (Gutiérrez, 2001), measures the time cost from one node to another. Nodes with a small value of WATT have good accessibility. The WATT of each node is calculated as:

$$T_i = \frac{\sum_{j=1}^{n} T_{ij} * M_j}{\sum_{j=1}^{n} M_j} \tag{2}$$

where T_i is the WATT of node i, T_{ij} is the shortest travel time between nodes i and j, and M_j is the attribute of node j, which could be GDP or population scale. In this paper, both population and GDP are chosen as the attributes of nodes, and then M_j equals the square root of population multiplied by GDP for node j.

3 Evolution of HSR

3.1 Overview of HSR network expansion

The first HSR route in East Asia, in the world even, opened in Japan in 1964. After that, HSR networks experienced a rapid development period. The extent of HSR lines with speeds of greater than 250 km/h increased from 515 km in 1964 to 12,777 km in 2012, a 24.8-fold increase (UIC, 2013). The development of HSR in East Asia can be divided into three eras, namely, the Japan period (1964–2002), the Transition period (2003–2007), and the China period (2008–) (Figure 1). The following sections discuss the overall characteristics of HSR network expansion.

(1) Japan period (1964–2002)

HSR networks in this period were all distributed in Japan, while China and South Korea had just begun to study the feasibility of HSR lines. Following the Tokaido Shinkansen, Japan then opened the Sanyo Shinkansen (1972–1975), the Tohoku Shinkansen (1982–2010), the Joetsu Shinkansen (1982), and the Hokuriku Shinkansen (1997). At the same time, South Korea completed its feasibility study on an HSR line between the largest city (Seoul) and the second largest city (Busan) in 1984 and began to build it in 1992. The MOR in China proposed the construction of an HSR line between Beijing and Shanghai in 1990, published the Preliminary Research Report of Economic and Technical Problems of the Beijing–Shanghai HSR line in1993, and finished the feasibility study report of the Beijing–Shanghai HSR line in 1998. Meanwhile, the MOR implemented the first, second, third, and fourth Railway

Speed Up Campaigns, which led to some rail lines upgraded into the lines with speeds of greater than 160 km/h, such as the Guangzhou–Shenzhen rail line and the Beijing–Shanghai rail line. By 2002 in Japan there was 2335 km of HSR lines with speeds of greater than 250 km/h (accounting for 30.8% of the world's total). During this period, the spatial expansion of HSR in Japan presented a "core-core" pattern and then formed a corridor in the east of the country.

(2) Transition period (2003–2007)

During this period, the HSR network was still mostly distributed in Japan, but both China and South Korea had begun to open their HSR lines. Japan continued to extend the corridor in the east by opening the Kyushu Shinkansen between Shin Yasuhiro and Kagoshima Chuo in 2004. In 2003, China opened its first HSR line between Shenyang and Qinhuangdao, which was followed by the opening of the HSR line between Taipei and Tsoying in China Taiwan. South Korea opened its first HSR route in 2004, which was one part of the full proposed HSR line. During this period, the MOR in China continued to implement the fifth and sixth Railway Speed Up Campaigns in 2004 and 2007. After that, train speeds reached 200 km/h on the main sections of the Beijing–Guangzhou, Beijing–Harbin, Beijing–Shanghai, Lianyungang–Lanzhou, Wuhan–Guangzhou, Jinan–Qingdao, Guangzhou–Shenzhen, and Hangzhou–Zhuzhou rail lines. By the end of 2007, the extent of HSR lines with speeds of greater than 250 km/h had increased to 2452 km in Japan, 750 km in China, and 330 km in South Korea. Spatially, these HSR networks presented a "core-core" pattern in China Mainland and South Korea, but a corridor pattern in Japan and China Taiwan.

(3) China period (2008–)

China replaced Japan as the country with the largest operating HSR network in East Asia, and also in the world. During this period, Japan had just opened the Kyushu Shinkansen (Hakata–Shin-Yatsushiro, 82 km), the Tohoku Shinkansen (New Hachinohe–Aomori, 130 km), and South Korea had opened the second part of the proposed HSR lines (Daegu–Pusan, 82 km), while the HSR network in China expanded rapidly. In 2008, China opened its first newly-built HSR line between Beijing and Tianjin with a maximum speed of 350 km/h. Following this, China opened Jinan–Qingdao, Wuhan–Guangzhou, Beijing–Shanghai, Hefei–Wuhan, Zhengzhou–Xi'an, Fuzhou–Xiamen, Shanghai–Nanjing, Nanchang–Jiujiang, Shanghai–Hangzhou, Dalian–Harbin, Beijing–Wuhan, and other HSR lines. By the end of 2013, there were 11,477 km HSR lines with speeds of greater than 250 km/h in China, 2664 km in Japan, and 412 km in South Korea. Spatially, the HSR network in China Mainland had formed a complete network in the eastern and central regions and began to expand westward, whereas those in Japan and South Korea continued to extend their HSR corridors. According to the HSR plans for East Asia, the extent of the HSR network could reach 41,000 km in China, 3622 km in Japan, and 708 km in South Korea by the end of the planning period. East Asia has become the region with the largest operating and planned HSR networks in the world.

3.2 Spatial patterns of the HSR service hinterland

To better understand the distribution patterns of HSR networks, in this paper we introduce the measure about the hinterland of HSR lines (Wang *et al*., 2015). The results are presented in Table 1 and Figure 2. The development of the HSR lines enlarged to a great degree the

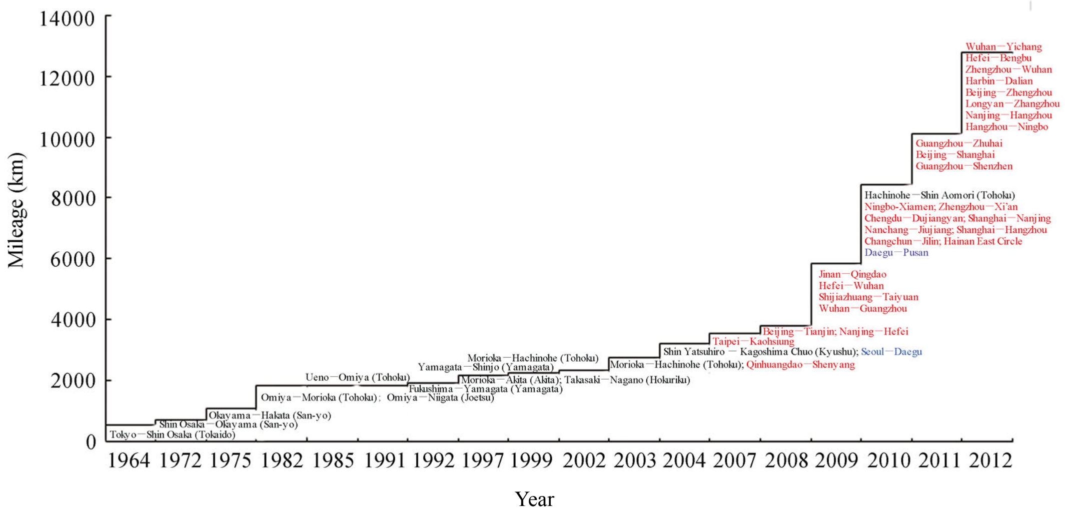

Figure 1 Chronology of High-Speed Railway (HSR) operation in East Asia

Note: HSR lines named in black are located in Japan, those in red are located in China, and those in blue are located in South Korea.

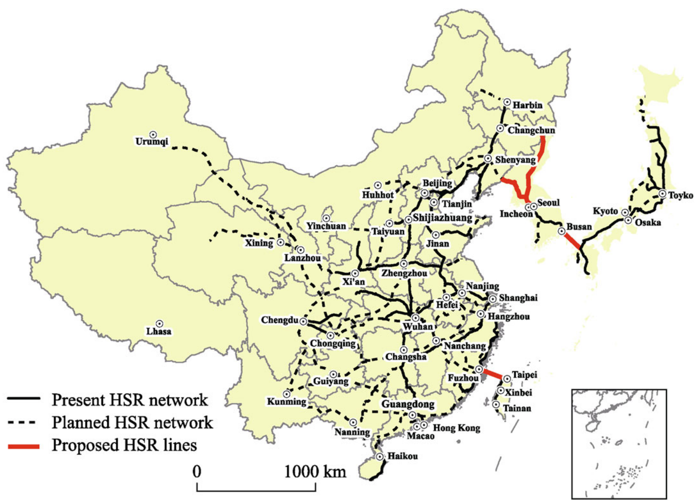

Figure 2 Spatial distribution of current operating, planned and proposed HSR networks in East Asia

service hinterland of the HSR network in East Asia, especially in China, while the service hinterland of the HSR network had higher coverage rates for cities, population, and GDP than that for the area. In 2012, 13.6% of areas, 50.1% of cities, 62.9% of population, and 75.2% of GDP in East Asia were accessible to HSR stations within 1 hour's travel time, which increased to 24.8%, 73.1%, 84.4%, and 83.8% with the opening of the planned HSR lines. A similar trend could be found for the 2 h service hinterland of HSR lines. At the country level, the 1 h service hinterland of operating HSR lines in Japan had the highest coverage rate compared with those in the other two countries, whereas China will eventually achieve the highest coverage rate in Scenario 3 on the number of cities, population scale, and GDP. Regarding the 2 h service hinterland, South Korea will achieve the highest coverage rate in Scenario 3. Overall, the development of the HSR network will lead to much larger areas, more cities, population, and GDP accessible to HSR stations, but the service hinterland of HSR still has a higher coverage rate for GDP and population than for area. China has the highest coverage rate of service hinterland concerning population and GDP, while South Korea ranks the highest with respect to area. The reason might be that the operating HSR network is distributed mainly in regions with developed economies and dense population (e.g., the eastern region of China), while the planned HSR network will begin to expand into the western region of China Mainland and Japan and the northern part of South Korea.

Table 1 Socioeconomic attributes of areas covered by operating and planned HSR stations within 1 and 2 hours

Travel time		East Asia		China		Japan		South Korea	
		Number	Percentage (%)	Number	Percentage (%)	Number	Percentage (%)	Number	Percentage (%)
1 h of operating HSR stations	Area (10^4 km^2)	135.8	13.6	111.3	11.7	19.8	53.0	5	47.0
	No. of cities	214	51.0	174	48.7	31	66.0	9	56.3
	Population (million persons)	967.7	63.0	829.4	61.0	101.6	79.0	36.6	74.0
	GDP (billion dollar)	12,066	75.2	6523	72.9	4685	79.3	858	71.9
2 h of operating HSR stations	Area (10^4 km^2)	257	25.9	224	23.6	26	69.1	8.1	80.7
	No. of cities	281	66.9	229	64.2	38	80.9	14	87.5
	Population (million persons)	1204.4	78.3	1047.4	77.0	110.5	86.3	46.5	93.4
	GDP (billion dollar)	13,901.8	86.6	7687.1	85.9	5097.8	86.3	1116.9	93.6
1 h of operating and planned HSR stations	Area (10^4 km^2)	247	24.8	219	23.1	23	61.2	5	47.0
	No. of cities	307	73.1	265	74.2	33	70.2	9	56.3
	Population (million persons)	1298.7	84.4	1158.3	85.1	103.9	81.1	36.6	73.6
	GDP (billion dollar)	13,447.8	83.8	7782.7	87.0	4789.3	81.1	875.8	73.6
2 h of operating and planned HSR stations	Area (10^4 km^2)	424	42.6	3867	40.7	30	79.2	8.1	80.8
	No. of cities	357	85.0	303	84.9	40	85.1	14	87.5
	Population (million persons)	1431.9	93.1	1268.2	93.2	117.2	91.5	46.5	93.4
	GDP (billion dollar)	15,044.5	93.7	8525.3	95.3	5405.7	91.5	1113.5	93.3

Note: The areas are 1 h or 2 h actual accessible areas surrounding the HSR by road traffic simulation.

The HSR network has covered most of the megacities and very large cities in municipal districts with a population of more than 3 million persons (see Table 2). The 1 h service hinterland of operating HSR lines covers all cities with a population of more than 10 million (including Tokyo, Osaka, Beijing, Shanghai, and Chongqing) and between 3 and 10 million except for Shanwei in Guangdong Province, 60% of cities with a population between 1 and 3 million, 50.74% of cities with a population between 0.5 and 1 million, and 19.61% of cities with a population below 0.5 million. A similar trend could be found for the 2 h service hinterland of the operating HSR network. As the HSR network in East Asia develops further, the coverage of the 1 h service hinterland in Scenario 3 will increase considerably, in particular for cities with a population below 0.5 million. The percentage of cities with a population below 0.5 million in Scenario 3 has risen to 47.06%, which is still the lowest coverage, compared with the other categories by population size.

Table 2 Percentage of socioeconomic attributes of cities covered by current and planned HSR stations within 1 and 2 hours (%)

Population (10^4 persons)			<50	50–100	100–300	300–1000	>1000
Current HSR stations	1 h	No. of cities	19.61	50.74	63.33	96.30	100
		Population	29.06	53.80	63.44	97.52	100
		GDP	53.75	57.10	82.45	96.79	100
	2 h	No. of cities	35.29	67.65	81.33	96.30	100
		Population	49.49	71.25	82.70	97.52	100
		GDP	78.65	80.55	90.99	96.79	100
Planned HSR stations	1 h	No. of cities	47.06	73.53	86.00	96.30	100
		Population	62.65	80.62	88.64	97.52	100
		GDP	65.88	72.43	90.02	96.79	100
	2 h	No. of cities	63.73	86.76	96.00	96.30	100
		Population	77.99	91.36	97.04	97.52	100
		GDP	90.15	91.90	95.36	96.79	100

Note: The numbers of cities with populations less than 0.5 million persons, between 0.5 and 1, between 1 and 3, between 3 and 10, and greater than 10 million are 102, 139, 147, 27, and 5, respectively; the units of population and GDP are the same as Table 1.

3.3 Evolutionary patterns

Similar to the evolutionary and spatial patterns of HSR in East Asia, the common patterns can be summarized as the “corridor model”, the “hybrid model”, and the “network model”, as found in a previous study by Perl and Goetz (2015) (Figure 3).

(1) The corridor model. The HSR lines in the corridor model tend first to be distributed among core cities with large populations and then to continue to expand along trunk corridors. Commonly, the evolutionary patterns of HSR lines are first influenced by increasing demand between core cities or between core cities and secondary cities in the same administrative divisions, such as the HSR lines between Zhengzhou and Xi’an, between Shijiazhuang and Taiyuan, between Wuhan and Guangzhou, between Beijing and Shanghai, between Tokyo and Osaka, between Seoul and Busan, and so on. Following on from this, the smaller cities along these HSR lines tend to receive a large boost to their economies, which promotes the formation and development of economic belts.

(2) The hybrid model. The HSR lines in this model tend to connect core cities with other cities surrounding them, which spatially forms the “hybrid model”. This model is mostly located in urban agglomerations, such as the Yangtze River Delta, the Pearl River Delta, the Wuhan Megalopolis, and the Central Plains Economic Region, which enhances the economic linkages between cities and promotes regional integration in these regions.

(3) The network model. Influenced by national areas, the equalization of transport infrastructure, and national strategy, the HSR lines tended to form a complete network in some countries. China would build an HSR network with four horizontal and four vertical PDLs according to the ‘Mid-to-long Term Railway Network Plan (revised in 2008)’. There is a large scale of planned HSR to be constructed in the western region of China, although the western region has high construction costs of HSR, lack of passenger demand, a poor economy, and low population density.

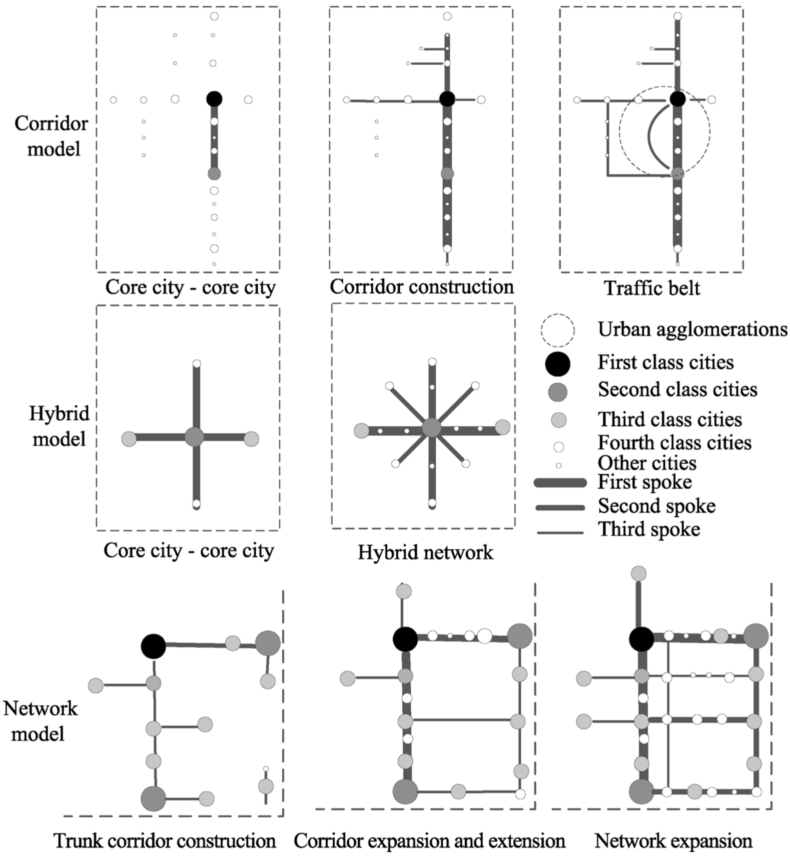

Figure 3 Spatial development model for the HSR networks in East Asia

Overall, the evolutionary patterns of HSR lines in Japan, South Korea, and China Taiwan all present the "corridor model", while that in China Mainland shows the "network model" at the national scale, the "corridor model" at the regional scale, and the "hybrid model" in some urban agglomerations.

4 Spatial impacts of the HSR networks

4.1 Daily accessibility

The development of the HSR networks enlarges the 1 h and 2 h transport circle of cities, and the 2 h transport circle has formed continuous regions along the trunk HSR lines in Scenario 2 and will expand to much larger areas in Scenario 3 (Figure 4). Cities being located in the 1 h transport circle of a particular city means that the city can reach the particular city within 1 hour. And 1 hour is commonly regarded as the maximum time limit for commuters traveling between work place and home. The development of operating HSR lines has led to the number of city pairs within a 2 h round trip increasing from 159 (0.28% of the total) to 349 in China Mainland, from 25 (14.6% of the total) to 40 in China Taiwan, from 3 (0.3% of the total) to 7 in Japan, and from 9 (8.57% of the total) to 15 in South Korea. Spatially, the 1 h transport circle of cities distributed discretely in Scenario 1 and had formed continuous regions in the Yangtze River Delta, the Pearl River Delta, the Chengdu-Chongqing

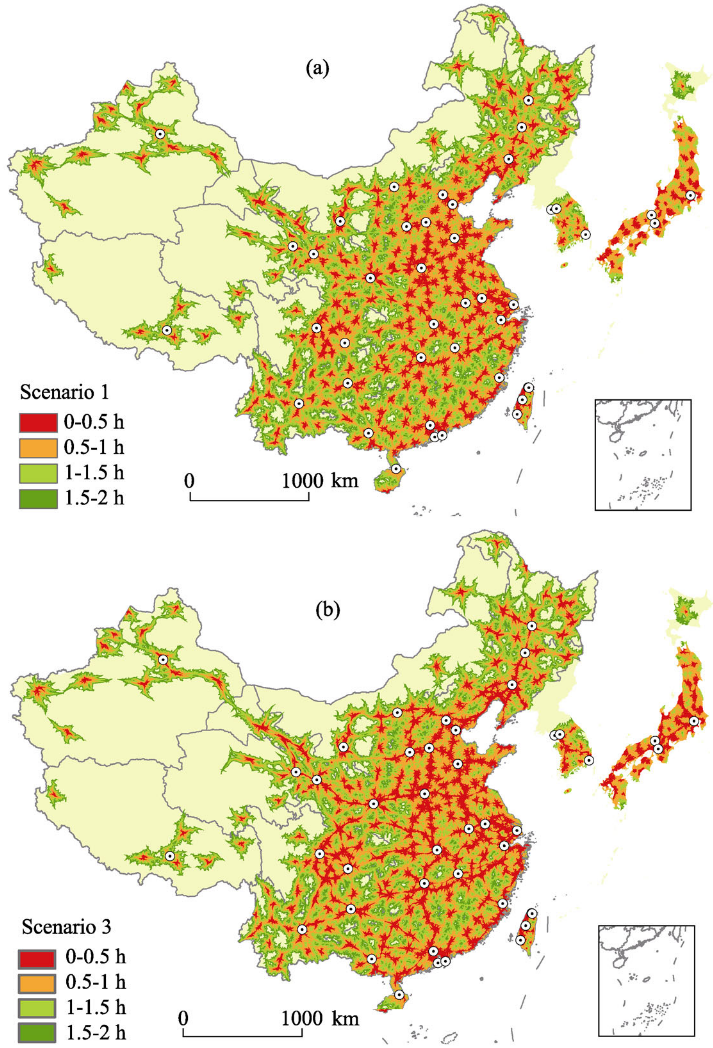

Figure 4 Spatial distribution of transport circles of cities in East Asia

Economic Zone, the Wuhan City Circle in China's Mainland, or around Tokyo or the southern region of South Korea and the east of China Taiwan in Scenario 2. Cities being located in the 2 h transport circle of a particular city means that the city pairs can be reached each other within 2 hours, which is commonly accepted as the maximum time limit for traveling to engage in recreational activities or short vacations. The 2 h transport circle of cities has formed continuous regions in the east of China Mainland and Japan, in China Taiwan, and the northern part of South Korea in Scenario 2, and will expand to the west of China Mainland and Japan, and the southern part of South Korea in Scenario 3. Cities being located in the 4 h transport circle of a particular city means that the city pairs can be traversed within 8 hours, which could allow for possible day trips between cities. All of the city pairs in South Korea and China Taiwan could be traversed within 8 h. Comparing with Scenario 1, the city pairs could reach each other within 4 h increasing from 349 to 476 in China Mainland, from 7 to 14 in Japan, from 15 to 17 in South Korea in Scenario 3.

The development of the HSR networks primarily increases the DA of cities in China

Mainland and Taiwan, Japan, and South Korea, but increases the nodal disparity of daily accessibility in China Mainland and decreases that in Japan, South Korea, and China Taiwan (Table 3). As a result of the deployed HSR network, South Korea saw the greatest increase in DA (65.2%), followed by Japan (63.5%), China Mainland (54.59%), and China Taiwan (39.03%), while China Mainland will be the largest beneficiary in terms of DA under Scenario 3 compared with Scenario 1. Overall, DA was improved much more in the first period than in the second period, and China Mainland saw the greatest increase in DA. Meanwhile, the coefficients of variation (CVs) of DA in China Mainland rose from 0.8 in Scenario 1 to 0.91 in Scenario 2, but then decreased to 0.81 in Scenario 3, whereas those in Japan, South Korea, and China Taiwan decreased in both the first and second periods. Spatially, the cities with high DA were mostly located in Chongqing, Henan, Shandong, Hebei, Jiangsu and Sichuan provinces in Scenario 1 and most of these regions had high population density. In Scenario 3, the cities with high DA will expand to the Chengdu–Chongqing Economic Zone and the regions along the trunk HSR lines, especially the Beijing–Guangzhou and Beijing–Shanghai PDLs. The cities with a greater increase in DA (Sce nario 3/1) are located at the intersection of the trunk HSR (e.g. Zhengzhou) lines or around cities with large populations (e.g. Beijing, Chengdu, Shanghai, and Tokyo) (Figure 5).

Table 3 Statistical characteristics of daily accessibility and weighted shortest travel time in East Asia

Indicators	Regions	Mean (10^4 persons (DA) or hours (WATT))			Change (%)			Coefficient of variation		
		Without HSR network	Current HSR network	Planned HSR network	Without/current HSR network	Current/planned HSR network	Without/planned HSR network	Without HSR network	Current HSR network	Planned HSR network
Daily accessibility	China Mainland	3,364	5,200	6,684	54.59	28.52	98.68	0.800	0.910	0.810
	China Taiwan	1,065	1,481	1,481	39.03	0.00	39.03	0.451	0.447	0.447
	Japan	1,865	3,051	3,595	63.6	17.82	92.76	0.830	0.674	0.673
	South Korea	1,678	2,772	3,295	65.2	18.86	96.35	0.598	0.531	0.429
Weighted shortest travel time	China Mainland	16.19	11.28	9.39	−30.31	−16.78	−42.00	0.410	0.570	0.520
	China Taiwan	1.92	1.45	1.45	−24.78	0.00	−24.78	0.270	0.380	0.380
	Japan	7.57	4.35	3.81	−42.48	−12.50	−49.67	0.361	0.360	0.340
	South Korea	1.99	1.59	1.52	−20.28	−4.51	−23.88	0.200	0.240	0.220

4.2 Time–space convergence

The development of the HSR lines leads to an uneven "time–space convergence" in China Mainland and Taiwan, and South Korea, with accessibility decreasing and its disparities increasing (Table 3). During the first period, Japan saw the greatest decrease (42.5%), followed by China Mainland (30.3%), China Taiwan (24.78%), and South Korea (20.28%), whereas China Mainland will get the largest decrease in WATT, followed by Japan, South Korea, and China Taiwan. Compared with that in Scenario 1, the country with the greatest decrease in WATT is Japan, which is different from that in terms of DA in Scenario 3. The development of HSR lines will increase the disparities of WATT in China Mainland, China Taiwan, and South Korea, but decrease that in Japan. The CVs of WATT in China Mainland, South Korea, and China Taiwan increased largely during the first period and decreased slightly during the second period, but rose overall, whereas that in Japan fell during both the first and second periods. Specifically, the CVs of WATT in China Mainland increased from 0.41 in Scenario 1 to 0.57 in Scenario 2, and then decreased to 0.52 in Scenario 3. At the same time, the CVs in Japan fell from 0.361 to 0.36, and then to 0.34.

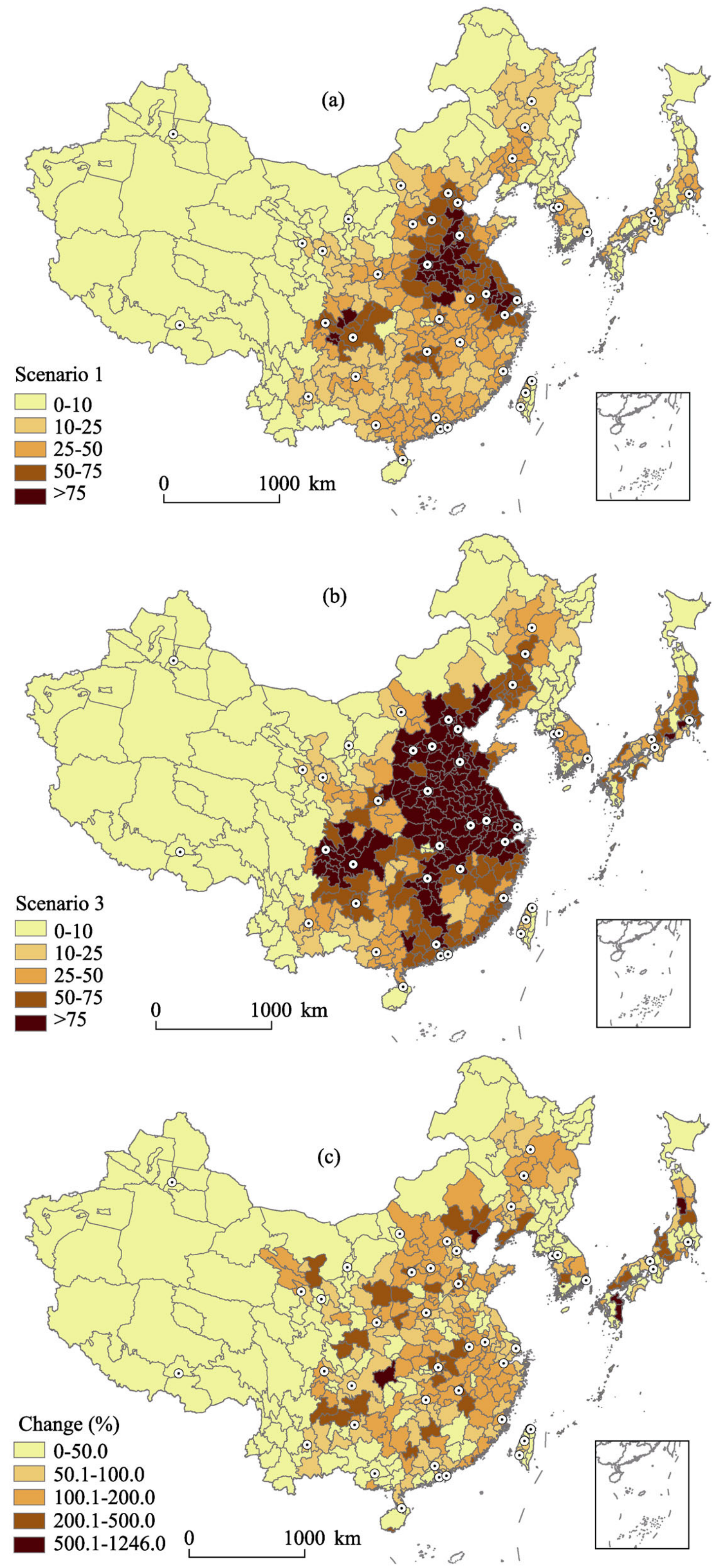

Figure 5 Spatial distribution of daily accessibility and its increase in East Asia

Spatially, the cities with the lowest WATT in China Mainland, South Korea, and Japan were mostly located around the geometric center of transport network, while those in China Taiwan were located mostly along the corridor between Taipei and Tainan (Figure 6). The

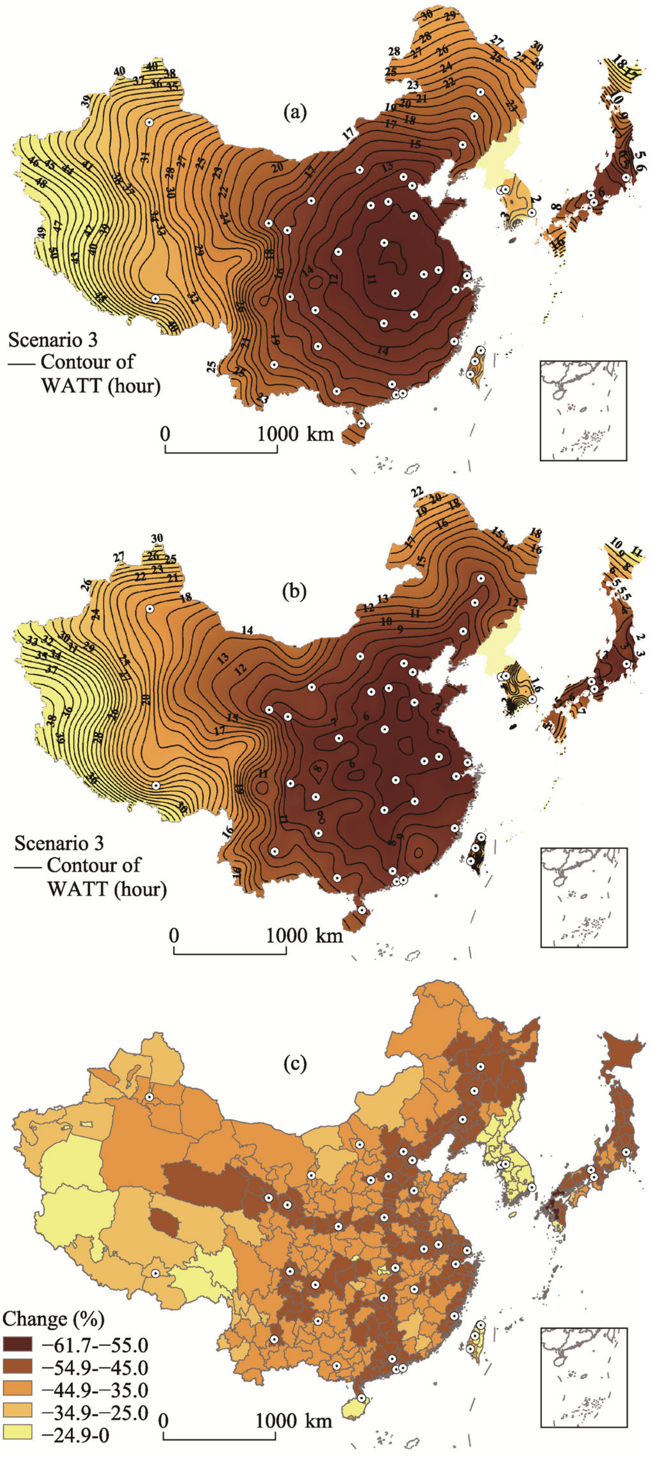

Figure 6 Spatial distribution of WATT and its increases in East Asia

WATT contours in China Mainland, South Korea, and Japan revealed a concentric pattern around Zhengzhou in China Mainland, around Seoul in South Korea, and around Tokyo in Japan, whereas those in China Taiwan presented a spatially banded structure in Scenario 1. Along with the devleopment of the current operating and planned HSR network, the WATT contour will stretch along the trunk HSR lines, such as the Beijing–Shanghai, Beijing–Guangzhou, and the Beijing–Harbin PDLs in China Mainland, the Tokyo–Osaka Shinkansen HSR lines in Japan, and the Seoul–Pusan HSR line in South Korea. In other words, cities located along the trunk HSR lines saw a greater increase in accessibility than other cities, which could be defined as "corridor effects" (Shaw *et al*., 2014). Compared with Scenario 1, cities whose WATT decreased by more than 55% in China Mainland were located mainly along the Beijing–Shanghai, Beijing–Guangzhou, Beijing–Harbin, Lianyungang–Lanzhou, and Shanghai–Shenzhen PDLs in Scenario 3. Those in Japan are located mainly along the Tokyo–Osaka Shinkansen HSR lines. Although cities in South Korea and China Taiwan see a low decrease in WATT, the decrease in WATT also reveal the "corridor effect," with cities along the HSR lines experiencing greater deduce.

4.3 Impacts of integrated HSR networks

In the 'going global strategy' of HSR, proposed by the Chinese Government in 2009, the central government planned to invest in a series of trans-continental HSR lines throughout Asia and Europe, including the Eurasian HSR line, the Central Asia HSR line, and the Pan-Asia HSR line, which would connect most of the countries in Europe and Asia. Meanwhile, some experts also proposed the HSR lines connecting North Korea, South Korea, and Japan (termed East Asia HSR lines in this paper). The East Asia HSR lines include the HSR lines between Fukuoka, Japan and Busan, South Korea (about 210 km), between Seoul, South Korea and Dandong, China, passing by Pyongyang, North Korea (about 400 km), between Pyongyang, North Korea and Yanji, China, and between Taipei in Taiwan and Fuzhou in Fujian province (about 210 km). In this section, we try to explore the impacts of the potential integrated HSR network on accessibility.

The development of an integrated HSR network will substantially shorten travel time between core cities in different countries of East Asia and promote regional integration (Figure 7). Integrated HSR lines make it possible to travel by rail between Shenyang, China, and Seoul, South Korea within 3 h, between Seoul and Tokyo, Japan within 4 h, and between Shenyang, China and Tokyo, Japan within 7 h. Meanwhile, the opening of integrated HSR lines will also substantially improve accessibility and connectivity, especially of the "gateway cities". In general, the integrated HSR lines could largely promote the passengers and goods traveling via integrated HSR lines concentrating in gateway cities, thus catalyzing the economic development of gateway cities. Also, the development of integrated HSR lines would enhance the social, economic, and cultural exchanges among China, Japan and South Korea. Specifically, all the passengers and goods by Seoul-Dandong HSR lines should be transferred at the gateway cities, such as Dandong and Yanji in China, Busan in South Korea, and Fukuoka in Japan. In addition, the development of an integrated HSR network will lead to the 2 h transport circle forming a continuous region in South Korea, Japan, and the north-eastern region of China.

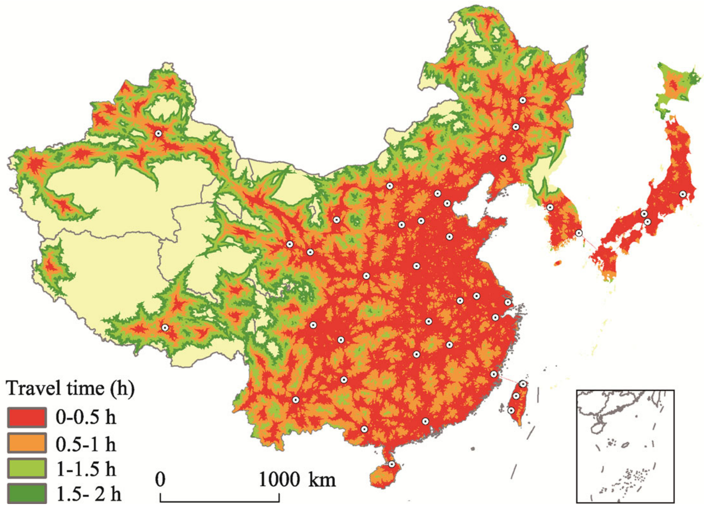

Figure 7 Spatial distribution of the transport circle of cities in the scenario with an integrated HSR network

5 Evolutionary mechanism of HSR

The expansion and impacts of HSR are mostly influenced by natural environmental conditions, by socioeconomic conditions, and by development strategies and plans. Regional natural environmental conditions mainly affect the costs of HSR's construction and technology; socioeconomic conditions influence other expenses (especially land acquisition costs) and the supply of passengers for HSR lines; development strategies and plans mostly affect the construction scheme and fund sources of HSR's construction.

5.1 Natural environmental conditions

Natural environmental conditions directly affect the construction of HSR networks, especially the types, scale, technology hierarchy, and spatial patterns of HSR networks (Jin, 2013).

(1) The construction costs of HSR networks are widely influenced by the design speed, track standard, terrain, weather conditions, land acquisition costs, the need for viaducts instead of subgrades, the need for large river-crossing bridges, the construction costs of HSR stations, etc. The construction costs in regions with excellent natural conditions are lower than those of other regions. Thus, the construction costs of HSR in the east of China might be lower than that in the western region, just considering the natural environmental conditions.

(2) The curve radii and limiting grades of HSR lines, which are mainly influenced by natural conditions, have quite different requirements in HSR technology. Regarding the natural environmental conditions in East Asia (Figure 8), the terrain is mostly rugged and mountainous in Japan and the western region of China, which requires quite different HSR's technology with the other places.

5.2 Socioeconomic conditions

The socioeconomic factors influencing the expansion and impacts of HSR systems in East Asia include the following two types.

(1) Population scale and economy of cities along HSR lines. The areas with developed economies and dense populations usually require high land acquisition costs. Some local

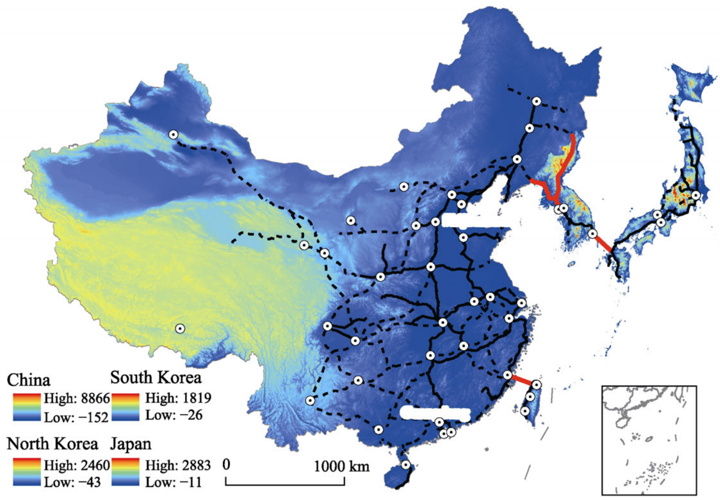

Figure 8 Distribution of HSR networks and natural conditions

governments choose to build viaducts instead of subgrades to reduce the demand for land use, which would influence the technical costs of HSR lines. Both the high land acquisition costs and the extra technical costs would increase the total construction costs of HSR lines in the areas with developed economies and dense population. However, these areas could also provide enough passengers for HSR networks, which might be greater than the minimum demand to generate a profit. For example, the three profitable HSR lines in 2011, including the HSR lines between Paris and Lille, between Beijing and Shanghai, and the Tokaido Shinkansen, are all located in areas with developed economies and dense population. In other words, it might be much more profitable to build HSR lines in eastern and central China than in western China.

(2) Competition and cooperation between HSR and other modes of transport. Commonly, HSR lines could serve as regional feeders for airports rather than as intercity services, which might increase the passengers of HSR lines. Also, the HSR lines could be competitive with other modes of transport, especially the air transport. The development of low-cost Airlines might accelerate the competition between HSR and air transport for passengers.

5.3 Development strategies and plans

Government-oriented and market-oriented development strategies of HSR lines are also important influencing factors in the expansion of and profits made by HSR networks. Government-oriented development strategies are intended to ensure that it is much easier to raise sufficient funds for the construction of HSR lines at a short time. Under the guidance of market-oriented development strategies, the operating timetable of HSR network could be adjusted according to market demand, which mostly improves the efficiency of the network and increases HSR profits. In other words, it is important to follow government-oriented development strategies during the construction period and market-oriented development strategy during the operating period. In Japan, the building of HSR lines was first guided by government-oriented policies before 1988 and then by market-oriented development strategy. The development of an HSR network in China Taiwan obeys the rules of a transit-oriented development (TOD) model during both the construction and operation periods, whereas that in South Korea obeys the public-private partnership (PPP) model. Most of the HSR lines in China Mainland, except for the HSR line between Qingdao and Jinan, are guided by government-oriented development strategies during both the construction and operating periods, which could be the main reason for the rapid expansion of HSR. The Chinese Government plays an important role in the rapid development of HSR by submitting some active financial strategies and plans. For example, in the "stimulating economic development by investment" strategies, the Chinese Government invested 660 billion yuan during 1998–2002 and a 4 trillion yuan in 2009–2010 to combat the Asian financial crisis of 1998 and the global financial crisis of 2007–2008. About 40% of the 4 trillion yuan was used to construct transport infrastructure.

6 Conclusions

East Asia not only boasts the world's first HSR line, but also the largest current operating and planned HSR network in the world. This paper has examined the impacts of HSR in East Asia from the perspective of accessibility and transport circle. The results are summarized as following:

(1) The evolution of the HSR network in East Asia presented a "core-core" pattern in the early years, followed by a "core-network" model more recently. The HSR lines first tended to be located in regions with developed economies and dense population and then expanded to other regions, such as western China. The evolution of the HSR networks can be divided into three periods: the Japan period (1964–2002), the Transition period (2003–2007), and the China period (2008–). During the latter period, China replaced Japan as the country with the largest operating HSR network in the world.

(2) The rapid development of HSR lines in East Asia substantially enlarges the transport circle of core cities and promotes the transport circle of some core cities from contiguous regions. Spatially, the 1 h transport circle of core cities formed the beaded regions in Scenario 1 and then formed contiguous regions in the Yangtze River Delta, the Pearl River Delta, and the Beijing–Tianjin–Hebei region in Scenario 2.

(3) The development of the HSR network generated uneven time–space convergence,with the uneven improvement in accessibility. Cities located along the trunk HSR lines saw a greater increase in WATT, while cities with developed economies and dense population saw greater increases in DA. The accessibility gets higher increase as for the development of current operating HSR network than that for the planed HSR network. The HSR network would increase the inequality of nodal accessibility in China Mainland, but decrease that in Japan, China Taiwan and South Korea.

(4) The development of the integrated HSR lines in East Asia could largely shorten the travel time between the core cities in China, Japan and South Korea, but also enlarge the transport circle of cities in South Korea, Japan, and Northeast China. However, the impacts of the integrated HSR network in East Asia are smaller than those of the HSR network at national scale. Also, there are many challengers for the integrated HSR network, such as the factors for geopolitics and cost-benefit rate of the HSR lines. Thus, further studies are needed for the integrated HSR network in East Asia.

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