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Prioritizing future funding and construction of the planned high-speed rail corridors of China – According to regional structure and urban land development potential indices

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ABSTRACT

This paper proposes two types of indices to prioritize the future funding and construction of the planned high-speed rail (HSR) corridors of China. The first index is the regional structure index that evaluates the performance of an HSR corridor from the perspective of spatial connectivity and accessibility, and it consists of regional structure factors (e.g., corridor length and buffer area) and coverage factors (e.g., the total number of HSR stations, cities, and people within the service domain of the HSR corridor). The second index is the urban land development potential index that assesses an HSR corridor depending on the corridor's potential effect on the promotion of urban land development. Following China's latest national railway network planning proposal, planned HSR corridors are prioritized using these two indices. The rankings obtained according to these two indices are presented and compared in this paper. The prioritization of results is then used to suggest patterns of future funding and construction for China's HSR corridors and, further, to suggest potential implications for HSR planning and development in other countries.

1. Introduction

As defined by Rodrigue (2007), a transport corridor is generally a linear belt area that consists of one or more transportation modes such as highways, railroads, or pipelines, which share a common course. The transport corridor is also closely linked with global or regional economic development because it is responsible for the heavy transportation of people and freight between service regions. Moreover, transport corridors often create linear agglomerations between the connected regions and bring out a linear form of neighborhood area development. In particular, the old Silk Road, which was developed to transport exquisite textiles, tea, and porcelain to faraway countries, has subtly linked China with the West since ancient times and has significantly affected the economic and cultural interactions of both Chinese and Western regions. From the perspective of service domain, transport corridors could be categorized as follows: (*a*) global transport corridor, (*b*) national transport corridor, and (*c*) urban transport corridor. Different types of transport corridors necessarily play different roles in promoting regional and urban development.

National transport corridors connect major cities across the extent of a country and feed passengers or freight to global transport corridors. In general, a national transport corridor has a dedicated transport mode, such as the national highway corridor (Forkenbrock and Foster, 1990), railway corridor (Karlson et al., 2016), pipeline corridor (Shroder, 2014; Vianello et al., 2014), or waterway corridor (Pant et al., 2015). Furthermore, a national transport corridor is associated with geographical constraints and the regional economic diversity of a country. As evidenced by Perl and Goetz (2015), a national railway corridor helps to reshape the economic structure while balancing regional development. Because railway corridors bring direct connections between the major cities of a country and play a vital role in regional development, many countries have deemed their railway corridors the backbone of their national transport system. In particular, a high-speed rail (HSR) corridor, which provides a fast, safe, and reliable connection between core cities, is expected to be an emerging transport mode that will stimulate the economy and promote regional integrity (Román et al., 2010).

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This paper first introduces the background of the rapid growth of China's HSR network. According to the latest national railway network planning proposal, a map and future picture of China's HSR corridors are presented. To assess the relative importance of HSR corridors, two types of indicators—the regional structure and the land development potential indices—are then introduced in the evaluation section of this paper. Following the methodology and findings of the paper, a reasonable funding plan and construction schedule for the world's largest bodies' (such as, China's) HSR construction could be identified; in addition, the paper provides a methodology supplementary to the existing literature regarding the priority assessment of national HSR corridors.

It must be pointed out that a similar research by Guirao and Campa (2014a) has scored a constructed HSR corridor using the indices presented in the existing literature. As such, this paper prioritizes future HSR corridors according to the newly created indices. Moreover, the new indices also highlight the real-world implications for national HSR corridor construction and funding arrangements. As a result, the proposed indices and ranking method in this paper could have extra guiding significance. HSR construction by China is being carried out on a large scale worldwide; 75% of the constructed HSR lines of the world are “Made in China”. Because of this, the theory of this paper can hopefully provide a valuable reference for the planning, construction, and introduction of HSR in other countries.

2. Literature review

The performance evaluation methods for national transport corridors used by Kamga (2015) mainly imposed a focus on implications for regional development promotion, and many indicators have been used to evaluate the effects of national transport corridors including cost and benefit balances (Nakagawa and Hatoko, 2007), spatial accessibility and connectivity improvements (Guirao and Campa, 2014b), environmental effects (Hanson, 1979), and safety issues (Thekdi and Lambert, 2015).

As proven by Todorovich and Hagler (2009), HSR can promote the development of a country's core region. As a result, many countries are committed to the construction of this large-scale transportation infrastructure to solve complex problems related to national or regional economic development. As pointed out by Levinson (2012), a wide divergence was found between different countries in prioritizing and selecting appropriate HSR facilities. For instance, the U.S. and European countries have established corresponding speed standards for their HSR lines. In 2009, the U.S. proposed the first national strategic plan, the well-known US-FRA-2009 Plan, which defined criteria for how to select and evaluate the HSR corridor. The indices used included those related to achieving public benefits, mitigating risks, and other criteria (Federal Rail Road Administration, FRA, 2009). According to the US-FRA-2009, the most important index for prioritizing an HSR corridor is the financial feasibility factor—because the debate over the cost and benefit of HSR has always been the biggest obstacle to the construction of HSR in the U.S. In the California High-Speed Rail Business Plan, five categories of indices, which covered population size, urban transit connections, origin–destination distance, economic vitality, and congestion, were used to score the San Francisco–Los Angeles HSR corridor (CHSRA, 2012). However, these five categories of indices were not examined using real-world data, as the California High-Speed Rail Authority unilaterally canceled the California High-Speed Rail project in 2016.

In Europe, little research has focused on methodologies for ranking HSR corridors; the related literature tends to use forecasted demand to evaluate the effect of new HSR lines (Campos and de Rus, 2009). In Guirao and Campa (2014a, b) and Guirao and Soria (2014)'s work, the indices for scoring the HSR corridors of Spain were adpoted from the U.S. experience. In Europe, related studies frequently reported that changing accessibility resulting from the construction of an HSR corridor could greatly impact regional economic development (Todorovich and Hagler, 2009; Cheng et al., 2015). Case studies in Spain, France, and the UK have shown that HSR corridors may also have a role in enhancing internal regional integration within a service region up to 200 km away (Garmendia et al., 2012).

In Asia, only three countries own operating HSR lines as of 2016. According to Nakagawa and Hatoko (2007), the Japanese HSR company has traditionally used cost–benefit indices to prioritize new HSR lines. These indices include reduction of traveling time, fare-based user benefits, and the ratio of HSR construction cost to the total project cost. Furthermore, the present work recognizes that political ramifications and technical feasibility issues should be addressed during the evaluation of HSR corridors. According to Sujith (2016), three categories of indices should be applied to the evaluation of new HSR projects in Korea: the social and political risk, the engineering (construction) risk, and the financial risk. However, no research has been carried out to evaluate HSR corridors in Korea. Because of China's vast territory, different kinds of transport means have been well developed. However, there is no systematic evaluation framework to evaluate existing transport corridors, let alone one that prioritizes newly planned HSR corridors.

As evidenced by many scholars, the regional structure (indexed as the mileage, buffer area, orientation, etc.) of the national transport corridor largely determines the “quality” of the transport corridor. Zhong et al. (2014) addressed that the regional structure of an HSR corridor, especially its operating distance, would largely affect the attraction of ridership. Sun (2016) pointed out that the regional structure of an HSR corridor should be consistent with the connection requirements of the hierarchical urban system; otherwise, the HSR corridor might be replaced by another type of national transport corridor, e.g., an air transport corridor. Furthermore, an urban development promotion potential function is another important indicator for evaluating the performance of an HSR corridor. Vickerman (2015) found that land development around intermediate HSR stations could drive the development of small cities within the HSR corridor. Similarly, Shen et al. (2014) found that whether the HSR line could play a dominant role in service hinterlands was mainly determined by the urban land coverage areas around HSR stations. Vickerman (2015) examined the way in which the growth of HSR in the London–Paris–Brussels–Amsterdam network had differential effects on the various intermediate places served. From the impact on intermediate areas between these major metropolitan areas and the creation of potential cross-border inter-regional services, Vickerman found that the levels of both service and potential economic impacts are much less pronounced in these intermediate areas. Similarly, many Chinese scholars have addressed the fact that the construction of HSR corridor lines could change the accessibility of the city networks of China, thereby improving the capacity and connectivity of the national rail network (Cao et al., 2013; Jiao et al., 2017; Shaw et al., 2014; Wang et al., 2016). However, a standard index system has not been used to evaluate the impact of HSR corridors or to guide how to determine the appropriate configuration of an HSR corridor to improve the spatial imbalance to the largest extent possible, for promoting urban development in China. Moreover, there is no regular method or index system for determining the “value” or future effect of HSR corridors.

Therefore, in this paper, two types of indices are proposed—a regional structure index (RSI) and an urban land development potential index (ULPI)—to prioritize the planned HSR corridors of China. Despite their remarkable importance, unfortunately, these two indices are missing from the most popular evaluation system for HSR corridors, the US-FRA-2009. Therefore, these two types of indices are used to prioritize the planned HSR corridors of China. Furthermore, the two types of indices are applied to determine the potential construction schedule and funding arrangement of China's planned HSR corridors.

3. Background and prioritization indices

3.1. Background of China's HSR corridors

At the end of 2016, China owned 20,380 km of HSR lines (in which the operating speed is more than 200 km per hour), thereby accounting for more than 70% of the global operating mileage. In 2015, China basically completed its "Four-vertical and four-horizontal corridors" national HSR network (Stanley, 2015).

According to China's latest national railway network planning proposal—"The Mid-to-Long-Term Railway Network Plan (Revised in 2016)," shortened to PLAN-2016 hereinafter, which was issued on July 20, 2016, China will continue to build more than 200 passenger-dedicated HSR lines, which are to formulate the "Eight-vertical and eight-horizontal corridors" national HSR network, to be constructed by 2025. The total mileage of the HSR tracks would be more than 30,000 km by 2020 and would exceed 38,000 km as of 2025. The existing and the planned HSR corridor maps of China are presented in Figs. 1 and 2, respectively.

As shown in Fig. 1, the "Four-vertical and four-horizontal corridors" network was specified in the "the Mid-to-Long-Term Railway Network Plan (Revised in 2008)," shortened to PLAN-2008 hereinafter. It can be found that about half of the land area of China is serviced with HSR corridors as of 2016. Moreover, as shown in Fig. 2, planned HSR corridors will connect all provinces of China except Tibet by 2025.

Because both the existing and the planned HSR corridors consist of "horizontal (from east to west)" and "vertical (from south to north)" itineraries, different numbers are used to classify the different types of HSR corridors in Figs. 1 and 2. Accordingly, when the first digit of a HSR corridor number is "4," it indicates that the line is a part of the Four-horizontal and four-vertical HSR corridors' network, and "8" refers to the Eight-horizontal and eight-vertical HSR corridors' network. For the second digit, "0" denotes a horizontal HSR corridor and "1" denotes a vertical HSR corridor. Finally, the third digit represents the sequence of the HSR corridor. For instance, as shown in Fig. 1, the HSR corridor numbered as "401" denotes the first horizontal HSR corridor of the existing "Four-vertical and four-horizontal HSR corridor" network. Further, the corridor numbered as "812" represents the second vertical HSR corridor of the future "Eight-vertical and eight-horizontal HSR corridor" network specified in PLAN-2016, which is shown in Fig. 2.

3.2. *Current evaluation system for HSR lines in China*

In China, the configuration and shape of an HSR line are specified in the Project Feasibility Study Report (PFSR). In a typical PFSR of an HSR line, an evaluation system that consists of specific indices is officially required. The evaluation system parameters used in the PFSR of the HSR line are presented in Table 1.

As shown in Table 1, it is clear that these comprehensive indices for evaluating a new HSR project in China focus more on the benefit/cost analysis, environmental impact, and potential risk. For an HSR corridor, there are possibly many HSR lines intersecting or connecting within its coverage domain. Consequently, if the performance of an HSR corridor is assessed according to these comprehensive indices, as in Table 1, the prioritizing result would be more or less inadequate. Although the selection of an HSR corridor would largely depend on the benefit/cost consideration of HSR lines within the linear belt of the corridor, the most important function of the HSR corridor is to fill a gap of spatial imbalance between the servicing cities or regions; as such, the indices presented in Table 1 are still insufficient. As a result, two kinds of additional indices are proposed in this paper that reflect how an HSR corridor could change spatial accessibility and to what extent urban land development would be promoted within the service area.

Other prerequisites in terms of the layout of an HSR corridor in China include, first, the inclusion of important provinces or cities requiring consideration based on economic integration, where connection to an HSR corridor would be inevitable; second, HSR corridors have been officially deemed a "national image", and to that end, political and economic centers such as Beijing and Shanghai would be selected as the start and end points of a corridor, and finally, second-tier cities of importance, such as Guangzhou and Wuhan, would be successively connected to the existing HSR corridors. In other words, the design of an HSR corridor in China would pay importance in advancing spatial integration and promoting regional economies from the nation-wide perspective.

After the 2000s, urban land development has gradually become the main driving force of China's economic development. Therefore, it would be essential to probe into how the HSR will change or promote urban land development in China in the future. As a result, in this paper, two attributes of an HSR corridor are emphasized: first, the spatial integration function through the RSI, and second, the economic promotion function through the ULPI. The two proposed indices would be supplementary to the indices of a PFSR for an HSR line in China; in addition, to align with the considered priorities of the central government of China to promote spatial integration and economic balance by using large-scale transport infrastructure, these two types of indices are applied by using both real-world and simulated datasets.

3.3. *Proposed prioritization indices for HSR corridors*

As stated in Section 3.2, this paper contributes to the limited literature on HSR corridor evaluation and ranking by developing two prioritization indices. The first index is referred to as a regional structure index (RSI) and the second is an urban land development potential index (ULPI). The RSI is equivalent to a regional configuration index and prioritizes HSR corridors from the physical structure perspective. However, the ULPI determines the degree of urbanization promoted by the HSR corridor. According to Rodrigue (2007), the higher the level of a transport corridor according to the RSI index, the broader is the extent of goods and services being transported within the corridor. For this to be considered, it is essential to rank planned HSR corridors according to the RSI index. However, one of the most important functions of a transport corridor is to balance regional development by promoting the urbanization process of "poor" cities by connecting them to "richer" cities (Vickerman, 2015). As such, the ULPI can reflect the degree to which the planned HSR corridor would balance regional development.

3.3.1. *Regional structure index*

The regional structure of the transport corridor refers to the spatial distribution of the transport nodes (e.g., stations or the serviced cities), transport routes, and transport network along the corridors (Rodrigue, 2007). The RSIs of a transport corridor incorporate the following factors: (*a*) geographical factors; (*b*) factors reflecting the distribution of HSR facilities, population, and natural resources being impacted, and (*c*) factors demonstrating the distribution of supporting infrastructures within the transport corridor, such as factories.

In this paper, the following RSI indicators are used for prioritizing the new HSR corridors of China:

S1: Transport corridor length (km);
S2: Number of cities above prefecture level within the service domain of an HSR corridor;
S3: Number of provincial cities within the service domain of an HSR corridor;
S4: Number of municipalities directly under the central government within the service domain of an HSR corridor;
S5: Number of counties within the service domain of an HSR corridor (as of 2030);
S6: Number of HSR lines within or intersecting with the service domain of an HSR corridor (as of 2030);
S7: Number of HSR stations within the service domain of an HSR corridor (as of 2030);
S8: Total urban population of cities within the service domain of an HSR corridor (as of 2015);
S9: Total GDP of cities within the service domain of an HSR corridor (as of 2015);

SI: Comprehensive evaluation index of the RSI, which is the sum of

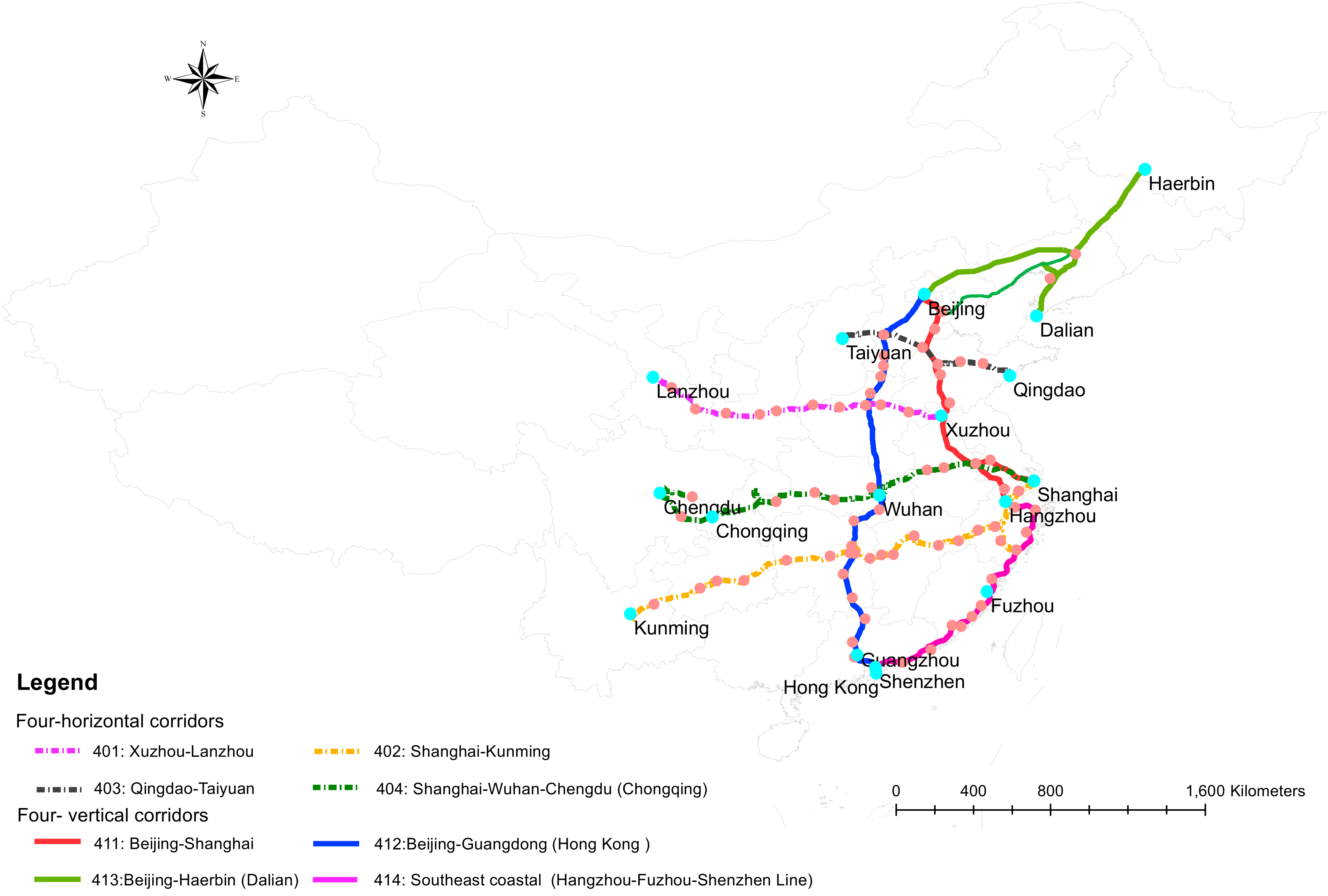

Fig. 1. The existing four-horizontal and four-vertical HSR corridors as of 2016.

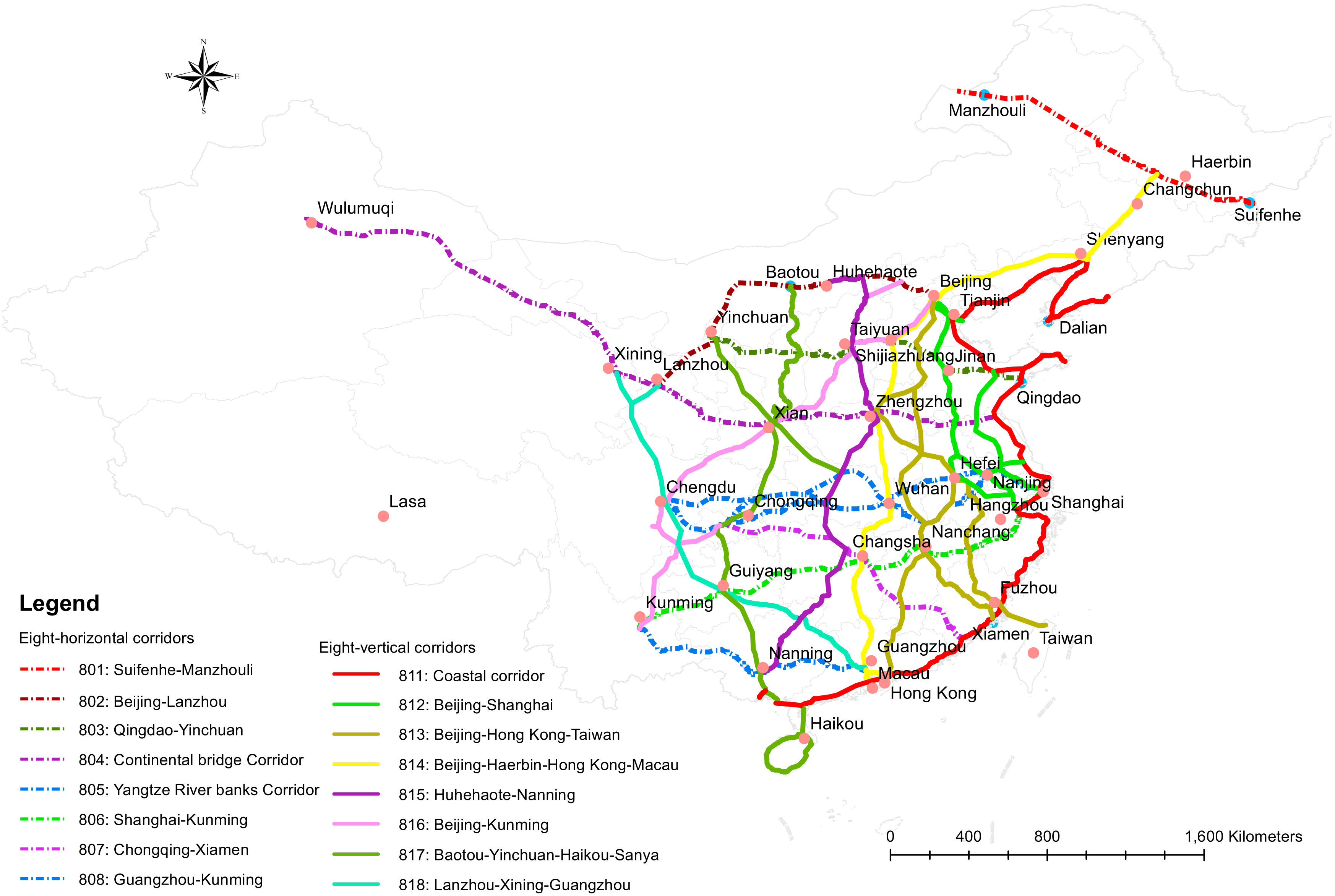

Fig. 2. The future Eight-horizontal and eight-vertical HSR corridors according to the latest national railway network plan of China.

Table 1
Current evaluation system of HSR line in the typical Project Feasibility Study Report in China.

Item	Including indices	Regularly required?	Remark
Project Content	Starting and ending location (city)	Yes	–
	Enterprise identity	Yes	National-owned/Private-owned
	Plan Mileage	Yes	–
	Planned investment scale	Yes	–
	Connected cities	No	–
	Economic feature of connected cities	No	Including the GDP, output of the tertiary industry
	Planned station number	Yes	–
	Design speed of the line	Yes	In km/h
Demand Forecast	Future service population	No	–
	Future passenger trips	Yes	In person-trip per year
	Future passenger turnover volume	No	In person * km per year
	The maximum daily passenger trips	Yes	In person-trip per day
Construction, maintenance and other cost	Unit mileage construction cost	Yes	In hundred million RMB per km
	Unit maintenance cost	Yes	In million RMB/km*year
	Accident cost	Yes	In million RMB/km*year
	Comprehensive cost	Yes	In million RMB/km*year
Economic benefit	Financial evaluation	Yes	Operating company's overall economic capacity
	Operational cost	Yes	In hundred million RMB per year
	Income	Yes	Including operational income, financial income, etc.
	Financial benefit	Yes	
	National economic benefit	Yes	the contribution to national economy under the certain capital investment conditions
Environmental impact assessment	Land use situation	No	Including areas of agriculture and urban land
	Water quality impact	Yes	–
	Noise emission	Yes	–
	Soil quality impact	Yes	–
	Ecological environmental impact	Yes	–
	Atmospheric environment impact	Yes	–
	Solid waste production	No	–
Capital estimation and fund raising	Total investment in fixed assets	Yes	In hundred million RMB per km
	Total working capital	Yes	In million RMB/km*year
	Funding sources	Yes	–
	Investment use plan	Yes	–
	Loan repayment plan	Yes	–
Financial and sensitivity analysis	Production cost estimation	Yes	–
	Unit cost	Yes	–
	Estimated sales revenue	No	–
	Financial evaluation	No	–
	National economic evaluation	No	–
	Financial uncertainty analysis	No	–
	Social and social impact	No	–
Risk analysis	Construction & development risks	Yes	–
	Market and operation risks	Yes	–
	Financial risk	Yes	–
	Political risk	No	–
	Environmental risk	No	–
	Technological risk	No	–

Note: the evaluation system is summarized from "The Project Feasibility Study Report of Beijing-Shanghai HSR line".

the normalized value of each RSI indicator, S1 to S9: SI $= \sum_{i=1}^{9} Si/\max Si$.

According to Stanley (2015), the service domain of an HSR corridor is a linear belt buffer area, in which the buffer radius is approximately 50 km. Accordingly, in this paper, the service domain of an HSR corridor is specified as the 50-km linear buffer belt area along the HSR corridor. Hereinafter, the service domain of an HSR corridor is equivalent to "the 50-km buffer belt."

Among the RSI indicators presented above, indicators S1–S7 belong to the geographical accessibility factors, and S8 and S9 are factors that reflect the distribution of HSR facilities, population, and natural resources being covered within the service domain of an HSR corridor. In practice, the decision-maker could further impose different weights to each indicator according to the need; however, for China's HSR corridor, no RSI indicators were weighted in this study. That is, all the RSI indicators are deemed to be of equal importance when prioritizing China's HSR corridor. When prioritizing the future transport infrastructure, multiple criteria decision-making problems with incomplete weighting information tended to lead to biased or subjective results. Consequently, an equal weighting for all indicators would be appropriate.

3.3.2. Urban land development potential index

To evaluate the land development potential for the planned HSR corridors specified in PLAN-2016, the situation of future urban land expansion for the cities within the service domain of each HSR corridor should be considered. In general, it is difficult to precisely predict the urban land expansion situation for all Chinese cities. Fortunately, relevant studies on large-scale urban land development predictions for Chinese cities provide the necessary data that reflect urban land expansion. In this paper, the scenario analysis approach of existing studies is adopted to incorporate the future urban land expansion of all Chinese cities. For the scenario analysis approach of urban development prediction, a new type of urbanization scheme (NTU) has been proven to be an efficient method and is recognized by several scholars (Tan et al., 2016; Zhou et al., 2015). The NTU is a national development roadmap of the future urban development of Chinese cities. It was issued as a national policy in the latest "Five-year" Plan of China, in 2015, and was expected to address the emerging issues in China's urbanization process. One of the key purposes of the NTU is to coordinate the development between differentsized cities through newly constructed transport infrastructure such as the HSR.

By using the NTU, a general urban simulation approach was developed; the cellular automaton (CA) model was used to predict the urban land expansion of each Chinese city for the 2016–2030 period. Since the prediction of urban land expansion is not the focus of this paper, the result of the CA model was taken directly from the previous work of Long et al. (2014) to simulate the urban land expansion process of Chinese cities over the next 15 years. The related fundamental dataset was downloaded from "https://www.dropbox.com/s/05id7nhn5i5qcwi/DT20.zip". In addition, it was assumed that the NTU scheme is to be implemented through policy over the next decade and that China's urban land footprint expands by 3% for every 10% economic growth (Long et al., 2014). It was also assumed that China would have a stable political and economic environment over the next 15 years, as it has for the past 30 years. To ensure the reliability of the simulated urban expansion, the simulated land parcels were validated by online browsers at CartoDB (an online WebGIS), in the manner of Wiki-map (Fritz et al., 2012). Wiki-map facilitates communication and comments between local and expert knowledge and simulates results. The comments from the online-GIS mapping were fed back to the authors for technical improvements, thus increasing the confidence of the generated land parcels.

For identifying the circumstances of urban land expansion of Chinese cities for the period 2016–2030, land use data for 623 cities in mainland China were collected from the 2012 Chinese City Construction Statistics Yearbook (MOHURD, 2013). As Chinese cities contain both rural and urban land uses, in this research, the amount of rural land around HSR stations (5-km-radius domain) within the planned HSR corridor to be developed into urban land was examined. The GIS data of the HSR network were collected from the database of the China Railway Corporation.

After incorporating the urban land expansion data for all Chinese cities, the following indicators were used to examine the urban land development potential of cities within the service domain of an HSR corridor:

L1: Urban land parcel size within the 50-km buffer belt of the HSR corridor in 2015; this indicator denotes the total of urbanized areas within the service domain of the HSR corridor in 2015;
L2: Rural land parcel size within the 50-km buffer belt of the HSR corridor in 2015; this indicator denotes the total of unbuilt areas within the 50-km buffer belt of the HSR corridor in 2015;
L3: Urbanization rate within the 50-km buffer belt of the HSR corridor in 2015: $L3 = L1/(L1 + L2)$;
L4: Expanded urban land parcel size, which denotes the total expanded urban areas (obtained by the CA simulation model) within the 50-km buffer belt of the HSR corridor in 2030, according to the recent national land-use planning under the NTU scenario (Long and Liu, 2016; Long et al., 2014);
L5: Absolute land expansion ratio within the 50-km buffer belt of the HSR corridor in 2030: $L5 = L4/(L1 + L2)$;
L6: Relative land expansion ratio within the 50-km buffer belt of the HSR corridor in 2030: $L6 = L4/(L2 - L4)$;
L7: Urbanization rate within the 50-km buffer belt of the HSR corridor in 2030: $L7 = 1 - L5/L6 = (L1 + L4)/(L1 + L2)$;
LI: Index showing urban land development potential ratio of the HSR corridor: $LI = 100{*}L7 + 100{*}L5/L3$

In interpreting LI, it could be determined that the larger the LI, the higher is the possibility of urban land development along the HSR corridor, i.e., the larger is the land development potential along the HSR corridor.

The reliability of the simulation results of future land parcels directly determines the accuracy of the ULPI. After determining the ULPIs of all HSR corridors, these indices should be validated against the territory plans of some essential cities within the HSR corridor.

To illustrate the calculation of LI value for the HSR corridor, an example is presented in Fig. 3. As shown in Fig. 3, many cities are located within the 50-km buffer belt of HSR corridor 811. The left side of Fig. 3 shows the regional configuration of 811 and the serviced cities within its 50-km buffer belt (otherwise known as the service domain). For simplification, only four representative cities were chosen within the service domain of HSR corridor 811: Shenyang, Tianjin, Shanghai, and Guangzhou. For these four cities, their 2015 urban and rural land parcels are shown in the four subplots of the right-hand side of Fig. 3. Moreover, for these four cities, the estimated expanded land parcels under the NTU urban development policy by following the method presented by Long et al. (2014) are also presented in the four subplots on the right-hand side of the figure. From the expanded land parcels, the ULPI indices presented above could be directly computed using the given equations.

4. Prioritizing the future HSR corridors of China

4.1. Prioritization according to the RSI

As stated above, the RSI value of an HSR corridor reflects the regional configuration, spatial connectivity, and coverage levels from the point of view of geographical feature distribution. Table 2 presents the RSI values and the resultant prioritization rank of the planned HSR corridors according to China's PLAN-2016.

As evidenced, corridor 813, the Beijing–Hong Kong–Taiwan corridor, has the highest SI value. Combining Table 2 with Fig. 2, it can be seen that, in the new round of HSR construction during the 2016–2030 period, China would pay the highest importance in strengthening the links between the urban agglomerations of the Beijing–Tianjin region, the middle reach areas of the Yangtze River (regions around Wuhan City), the west side of the Taiwan Straits (regions around Fuzhou and Xiamen Cities), and the Pearl River Delta region (regions around Shanghai). Most of these regions are located within the southeast coastal region of China; furthermore, they are the most economically developed and most populous areas of China. As a result of strengthening connections between these urban agglomerations with the HSR corridors, the economic vitality of the most prosperous regions in China would be further promoted. This intention is also reflected in the second- and third-ranked HSR corridors shown in Table 2. As shown, the second- and third-ranked HSR corridors are HSR corridor 812 (the Beijing-Shanghai corridor) and HSR corridor 814 (the Harbin–Beijing–Guangzhou corridor), respectively. These two HSR corridors are, respectively, located at the left (west) and right (east) sides of corridor 813. It would be fair to conclude that these three HSR corridors cover and connect essential cities or regions of China, such as Beijing, Shanghai, Guangzhou, Shenzhen, Harbin, and Dalian. From another perspective, for HSR corridors with relatively small SI values, it was observed that HSR corridors 801, 807, and 808 rank in the lowest three positions. From Fig. 2, HSR corridor 801 is the Suifenhe–Manzhouli corridor, which services the faraway cities in northeast China, and HSR corridor 807 is the Xiamen–Chongqing corridor, which connects the southwest region and Fujian Province. Further, HSR corridor 808 is the Kunming–Guangzhou corridor, which connects southwest China and Guangdong province. As demonstrated earlier, these three HSR corridors connect the relatively poorer areas with the relatively richer areas. It is hoped that these three new corridors could balance the regional development of the corresponding service domains.

Finally, by comparing the horizontal HSR corridors with the vertical HSR corridors, it can be found from Table 2 that almost all vertical HSR corridors have relatively higher SI values than horizontal HSR corridors. This circumstance reveals that China will pay more attention to the south-to-north (and vice versa) HSR connection than the east-to-west

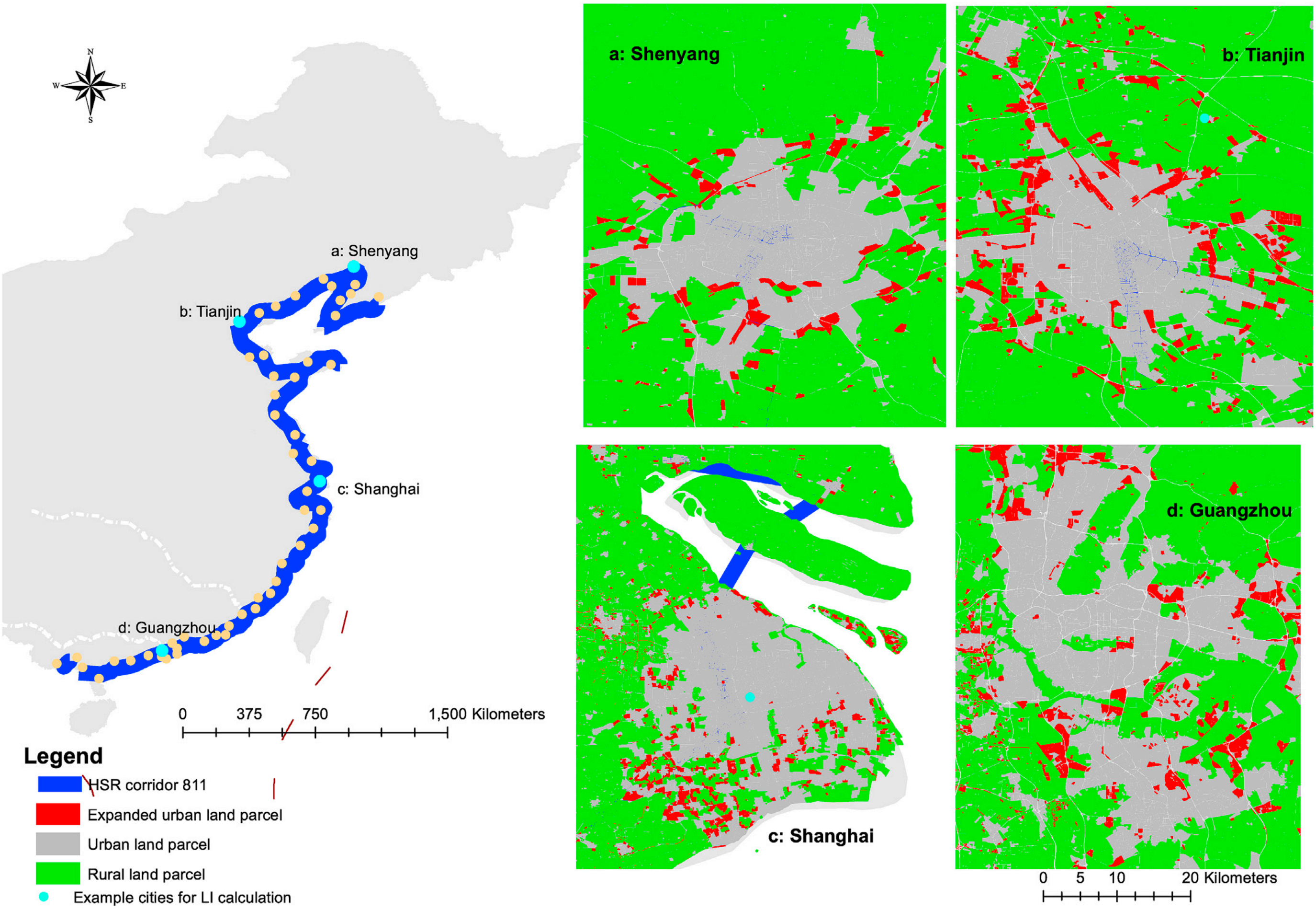

Fig. 3. Example of determining LI value for HSR corridor 811.

Table 2

Regional structural index value and the prioritizing rank of each HSR corridor of China in 2030.

Horizontal/Vertical	Corridor number	S1	S2	S3	S4	S5	S6	S7	S8	S9	SI	Prioritizing rank
Horizontal corridor	801	1851.11	6	1	0	56	11	31	953.00	14059.86	**0.79**	**16**
	802	1933.14	13	3	1	156	43	67	3250.20	38853.17	**1.98**	**13**
	803	1963.53	13	4	0	338	57	98	2451.90	42112.67	**2.09**	**12**
	804	4255.94	24	5	0	444	78	123	3674.44	39640.79	**3.05**	**10**
	805	4702.94	38	4	2	1270	206	369	11833.54	165797.10	**6.30**	**4**
	806	2526.92	24	4	1	735	104	148	5862.35	78109.47	**3.52**	**8**
	807	1668.76	11	1	1	360	56	92	3200.00	41027.17	**1.90**	**14**
	808	1364.33	11	2	0	228	38	85	3288.70	40767.64	**1.46**	**15**
Vertical corridor	811	6055.92	54	3	3	1238	187	355	13761.10	256942.82	**7.22**	**2**
	812	3464.45	30	3	3	1084	170	254	12272.30	168646.42	**5.53**	**5**
	813	**5669.76**	**38**	**4**	**3**	**1401**	**164**	**274**	**407623.66**	**151099.90**	**7.34**	**1**
	814	4343.14	39	7	2	1047	170	320	10939.16	200456.71	**6.35**	**3**
	815	3026.87	24	4	0	678	80	120	3392.80	50554.45	**2.92**	**11**
	816	3476.14	23	5	2	530	114	222	7345.40	83380.02	**4.26**	**6**
	817	6033.82	24	4	1	520	92	163	4096.60	52016.91	**3.82**	**7**
	818	1667.79	21	5	1	414	83	154	4360.15	57821.73	**3.06**	**9**

Notes:S1: Corridor Length (km); S2: Number of cities above prefecture level; S3: Number of provincial cities; S4: Number of municipalities directly under the Central Government; S5: Number of counties intersecting with the 20 km radius buffer of HSR stations (As of 2030); S6: Number of HSR lines within or intersecting with the HSR corridor (as of 2030); S7: Number of HSR stations within 50 km buffer belt of the HSR corridor (as of 2030); S8: Total urban population of the covered cities (as of 2015); S9: Total GDP of the covered cities (as of 2015); SI: comprehensive evaluating index, $SI = \sum_{i=1}^{9} S_i/\max S_i$.
The bolded row denotes the HSR corridor which ranks the 1st position according to the SI index.

(and vice versa) when constructing the future HSR corridors.

4.2. Prioritizing according to the ULPI

Table 3 presents the resultant ULPIs for the planned Eight-horizontal and eight-vertical HSR corridors' network of China.

In Table 3, indicators L1, L2, and L3 reflect the current land-use situation within each HSR corridor's 50-km buffer belt; that is, the land use status quo within the impact area or service domain of each HSR corridor. In particular, L3 denotes the urbanization rate within the

Table 3

Urban land development potential index value and the prioritizing rank of each HSR corridor of China in 2030.

Horizontal/Vertical	corridor number	L1	L2	L3	L4	L5	L6	L7	LI	Prioritizing rank
Horizontal corridor	801	1132.70	189017.42	0.60%	167.10	0.09%	0.09%	0.68%	15.44	**13**
	802	2296.72	143350.92	1.58%	399.45	0.27%	0.28%	1.85%	19.24	**6**
	803	2929.57	188786.3	1.53%	664.09	0.35%	0.35%	1.87%	24.54	**2**
	804	3595.42	554648.75	0.64%	606.35	0.11%	0.11%	0.75%	17.62	**8**
	805	10320.30	320955.08	3.12%	1 614.84	0.49%	0.51%	3.60%	19.25	**5**
	806	3939.46	232381.97	1.67%	647.99	0.27%	0.28%	1.94%	18.39	**7**
	807	1111.60	127630.27	0.86%	163.81	0.13%	0.13%	0.99%	15.73	**12**
	808	1992.72	138387.25	1.42%	354.79	0.25%	0.26%	1.67%	19.48	**4**
Vertical corridor	811	6147.69	232810.39	2.57%	1 217.96	0.51%	0.53%	3.08%	22.89	**3**
	812	**2739.78**	**101749.47**	**2.62%**	**712.43**	**0.68%**	**0.71%**	**3.30%**	**29.31**	**1**
	813	1407.1874	210118.25	0.67%	215.45	0.10%	0.10%	0.77%	16.08	**10**
	814	5824.82	237533.44	2.39%	713.16	0.29%	0.30%	2.69%	14.93	**14**
	815	1071.16	109529.68	0.97%	159.34	0.14%	0.15%	1.11%	15.99	**11**
	816	944.61	168306.08	0.56%	149.17	0.09%	0.09%	0.65%	16.44	**9**
	817	1206.56	251645.05	0.48%	144.46	0.06%	0.06%	0.53%	12.51	**16**
	818	268.34	175045.22	0.15%	34.96	0.02%	0.02%	0.17%	13.20	**15**

Notes: L1: in km^2; L2: in km^2; $L3 = L1(L1 + L2)$; L4: in km^2; $L5 = L4\ (L1 + L2)$; $L6 = L4(L2 - L4)$; $L7 = 1 - L5$ $L6= (L1 + L4)\ (L1 + L2)$; $LI = 100 \times L7 + 100 \times L5/L3$.
The bolded row denotes the HSR corridor which ranks the 1st position according to the LI index.

service domain of the HSR corridor, depending on the urban and rural land parcel sizes (Indicators L1 and L2, respectively).

As shown in Table 3, HSR corridor 805 has the highest current urbanization rate (L3). From Fig. 2, HSR corridor 805 connects cities within the Yangtze River Delta region with those in southwest China. This service region is the most unbalanced development area in China. However, the urbanization rate within the service domain of HSR corridor 805 is the highest. Moreover, HSR corridors 812 and 811 occupy the second and third rank according to the current urbanization rate. Accordingly, if a region's urbanization rate is higher, then the future urban land development potential of this region may be relatively smaller.

However, according to L4 and L5 values shown in Table 3, this situation does not occur. From indicator L4 in Table 3, it can be said that the increase in urban land area along HSR corridor 805 remains the largest. With regard to L5 indicator, HSR corridor 812 is highest ranked. As revealed, corridors 805 and 812 also have relatively higher urbanization rates. Following this, it can be confirmed that these two HSR corridors will have a larger basis for urban land development potential.

The L6 indicator indicates that the relative proportion of the land parcel sizes would change from the status of “rural” to “urban” during the 2016–2030 period. According to Table 3, HSR corridor 812 would have the largest L6 value by 2030. Further, L7 clarifies the future urbanization rate within the 50-km buffer belt of each HSR corridor in 2030. As demonstrated earlier, HSR corridors 805 and 812 occupy the first- and second-ranked places, according to the L7 indicator value presented in Table 3.

Depending on the indicators presented above, LI gives a comprehensive index value of the land development potential of the HSR corridors. It could be observed that HSR corridor 812 ranks at the number one position according to LI values in Table 3, and HSR corridors 803 and 811 take up the second- and third-ranked places depending on the index LI. It is clear from Table 3 that the expanded land parcel size (L3) of HSR corridor 803 is not as large as those of HSR corridors 805, 811, 812, and 814. However, corridor 803 still presents a relatively higher urban land development potential than other HSR corridors. The reason is that the index LI of an HSR corridor is the relative ratio of the increased urbanization rate to the existing urbanization rate (i.e., $LI = 100{*}L7 + 100{*}L5/_{L3}$). As shown, the existing urbanization rate within the 50-km buffer belt of HSR corridor 803 is relatively lower than those of HSR corridors 805, 811, 812, and 814. As a result, a moderate increase in urbanization rate would cause a relatively larger LI value. As such, the index LI objectively evaluates urban land development potential within the service domain of an HSR corridor according to not only the expanded urban land parcel sizes but also the relative ratio of urbanization rate increase based on the existing urbanization rate within the service domain of the HSR corridor.

Urban land development potential of HSR corridors owing to relatively larger LI values and higher prioritized ranks are not the only things to be considered. For those HSR corridors of which the LI values and prioritization ranks are lower, as shown in Table 3, such as HSR corridors 807, 814, 817, and 818, the reasons for their low urban land development potential are various. For HSR corridors 807, 817, and 818, the situation that the LI values of these HSR corridors are very low results from their relatively low L4 values for their expanded urban land parcel sizes within the service domain of the HSR corridors. For HSR corridors 807, 817, and 818, all the cities within their service domains are almost small, which are located in the southwest and northwest of China. As such, the potential for urban land developments to be promoted by the construction of HSR corridors is relatively smaller than for other HSR corridors. However, for HSR corridor 814, its low LI value is caused by its current high urbanization rate. From indicator L3 in Table 3, it is clear that HSR corridor 814 has a relatively higher L3 value. Further, from Fig. 2, HSR corridor 814 connects Harbin, Changchun, Beijing, Taiyuan, Zhengzhou, Wuhan, Changsha, and Guangzhou cities. All these cities within the service domain of HSR corridor 814 are almost the largest provincial cities of China. The current urbanization rates of these cities are already very high, and as a result, it might be very difficult to promote urban land development in these cities again in future. Inevitably, the HSR corridor connecting these cities has a relatively low LI value and urban land development potential rank.

In summary, from Table 3, HSR corridors 812, 803, and 811 would have the largest urban land development potential over the time span of 2016–2030. Conversely, HSR corridors 807, 814, 817, and 818 would have lower urban land development potential.

4.3. Comparison between the RSI and the ULPI

To further examine the importance of the planned HSR corridors of China, the resultant SI and LI values are presented in Fig. 4 and Fig. 5, illustrated by proportional symbols with graduated colors.

From the perspective of spatial location, it is clear from Fig. 4 that the most important HSR corridors mainly connect the eastern and central regions of China. Regarding the importance stressed by the RSI, the vertical HSR corridors have absolute advantages. From the perspective of the urban land development potential, it can be observed from Fig. 5 that the horizontal HSR corridors have a dominant urban land development potential over the vertical HSR corridors, although the highest urban land development potential is attributed to a vertical HSR corridor. To present the difference between the two indices in a more vivid way, Fig. 6 shows a radar chart based on the ranking of SI and LI values for each

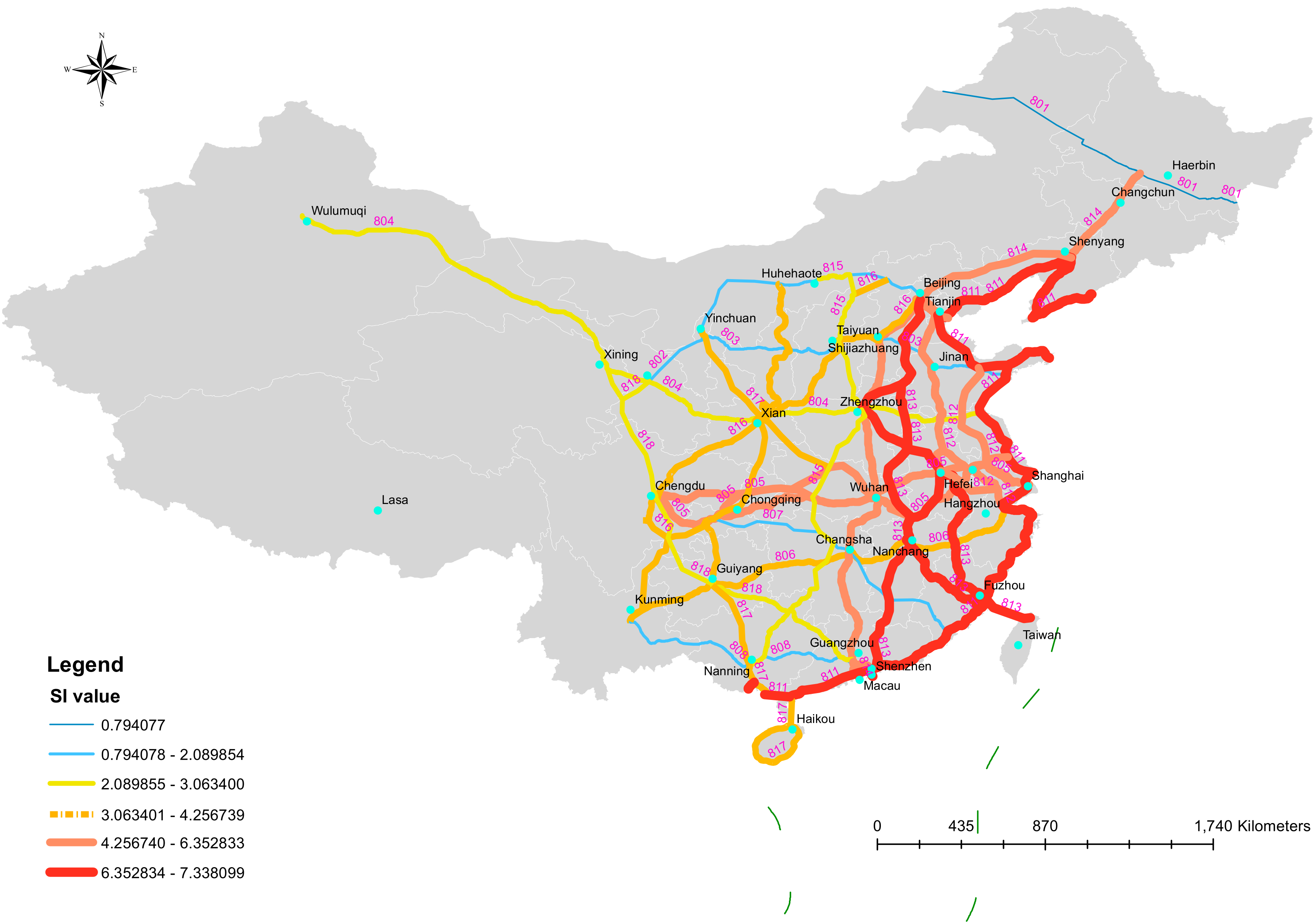

Fig. 4. Proportional symbols with graduated colors according to SI value of the eight-horizontal and eight-vertical HSR corridors. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

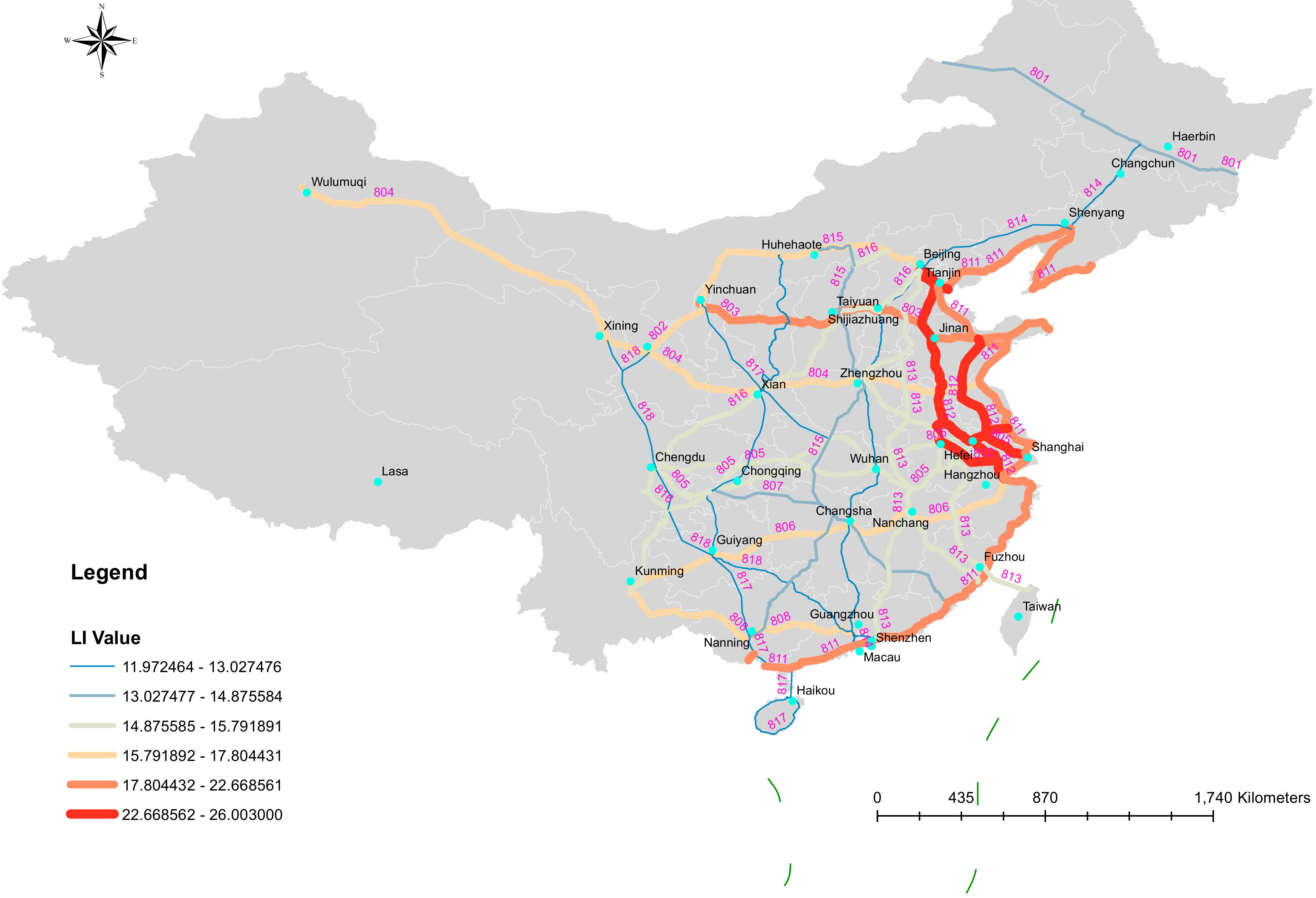

Fig. 5. Proportional symbols with graduated colors according to LI value of the eight-horizontal and eight-vertical HSR corridors. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

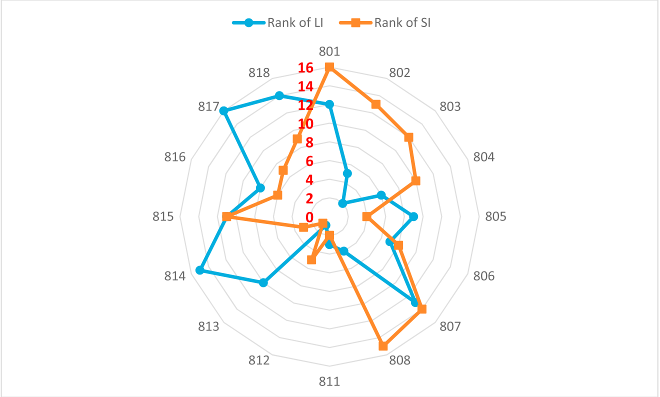

Fig. 6. The radar map of LI and SI ranks for each HSR corridor.

HSR corridor.

As shown in Fig. 6, each HSR corridor has a different rank according to the two indices. The results imply that each HSR corridor would play different roles in reshaping the geographical structure of the passenger transport network or promoting the urban development of China. As shown in Fig. 6, HSR corridor 808 responds to the largest difference between the ranks of LI and SI, thus indicating that the main purpose of constructing HSR corridor 808 is to promote the development of the city in the service domain, rather than to increase the connectivity/accessibility of the future HSR network of China. As evidenced, HSR corridors 814 and 817 would also play different roles. As shown in Figs. 4–6, the following conclusions can be drawn:

1. The vertical HSR corridors of the eastern coastal areas of China are mainly constructed to advance the regional performance of China's planned HSR network. Accordingly, HSR corridors 811, 812, and 813 occupy the first three places of the SI rank.
2. The horizontal HSR corridors connecting the central and western regions of China are constructed to promote future urban land development of cities within these regions, as it has been shown that HSR corridors 802, 803, 804, and 806 have relatively larger urban land development potential.
3. Some vertical HSR corridors are proven to be equivalently important irrespective of the evaluating index they are subjected to, for example, HSR corridors 811 and 812, which have the relatively higher SI and LI ranks. As such, these HSR corridors should be constructed as soon as possible.
4. Some horizontal HSR corridors are proven to be relatively "unimportant"—regardless of whether the RSI or the ULPI index is used, the ranks of these HSR corridors are in the lowest position. For instance, corridors 801 and 807.

4.4. *Implications for future funding and construction*

From the prioritization results shown above, it could be suggested and urged that a reasonable HSR construction schedule and funding arrangement scheme be decided upon.

From Figs. 4 and 5, it can be found that two vertical HSR corridors 812 and 813 always take up the dominant positions, regardless of the index they are subjected to. As shown in Fig. 2, it can be seen that HSR corridors 812 and 813 service China's most important cities, including Beijing, Shanghai, Guangzhou, Nanjing, and Hangzhou. According to the latest national railway network planning proposal of China, corridor 813 has not yet been constructed. As such, proceeding with construction along this corridor should be sped up as soon as possible. However, some horizontal HSR corridors, such as corridor 801 and corridor 807, always rank lower, according to both indices. Furthermore, these HSR corridors could not be deemed "dispensable," As shown in Fig. 2, HSR corridor 801 would open up the gateways between North Korea, China, and Russia. Further, it is a newly added HSR corridor in the latest stage of the national railway network planning. As a result, although it seems that this HSR corridor is not as essential as the others, it might create an opportunity for adding a fast connection between North Korea, China, and Russia. That is, the importance of the HSR corridors with lower rankings could be evaluated from another perspective, e.g., from the position of international, global connectivity, key material resource, or population transport purposes.

To clarify where the HSR corridors should be constructed in advance, the existing HSR corridor network is overlapped with the graduated color map of the average LI and SI value of each HSR corridor. The corresponding results are shown in Fig. 7.

As illustrated, Fig. 7 shows which unconstructed HSR corridor has the relatively higher normalized average value of SI and LI. Accordingly, some sections of HSR corridor 811 between Jinan and Shanghai, HSR corridor 812 between Jinan and Hefei, and HSR corridor 803 between Yinchuan and Taiyuan have the highest normalized average prioritized rankings. Therefore, these sections of the corresponding HSR corridor should be constructed first, as soon as possible. At the same time, a large number of HSR corridor sections that connect the Midwest China have the second-most prioritized rankings. If these HSR corridors were constructed at the same time (i.e., constructed in the next 5 years), a large volume of funding and careful budgeting would be required. This would possibly also affect the future budget allocation of the whole country. Finally, HSR corridors 801, 817, and 807 have relatively lower average prioritized rankings. As a result, from the point of view of a construction schedule, these HSR corridors could be postponed, to be constructed within a 5- to 10-year timeframe—i.e., with construction commencing between 2020 and 2025.

To further demonstrate the funding demand and the suggested construction schedule, the unconstructed mileage and the future funding demand are presented in Table 4. According to the statistical data of the China Railway Corporation (2013), the construction cost per kilometer of China's HSR is approximately 0.12 billion RMB Yuan. Since HSR corridors in particular have been focused on in this study, a relatively large construction cost should be budgeted for the planned HSR corridor network. Thus, the construction cost per kilometer of the planned HSR corridor of China is estimated at 0.15 billion RMB Yuan. Moreover, from the existing HSR corridor shown in Fig. 1, the unconstructed mileage of each HSR corridor and the estimated funding demand can be determined, as shown in Table 4.

On the basis of the estimated funding demand and the prioritized ranking of each HSR corridor, a suggestion on the construction time of each HSR corridor can be made. Since the Chinese government will allocate a 600 billion RMB Yuan per year for the construction of HSR infrastructure, a suggested schedule to start the construction of each HSR corridor is provided in Table 4. As shown in the table, it is suggested that China's government start construction of HSR corridors 803 and 811, followed by HSR corridors 808 and 815, then HSR corridors 804, 805, and 813, and so forth. Of course, the suggested construction schedule is provided based on the assumption that other policies for HSR construction remain the same as those of recent decades. Once the government has other considerations or must confront some unexpected policy change on HSR development, the construction schedule could be flexibly adjusted according to the circumstance.

5. Discussion and conclusions

Today, HSR has been proven to be a popular transport means for reshaping the economic landscape of a country. However, in many countries, the attitude to the development of HSR is still not very firm. Because of long construction periods, large-scale impact, high cost, and difficult maintenance, many countries will always conduct a most comprehensive evaluation when considering the introduction of HSR. However, for the evaluation of an HSR corridor, the method used can be

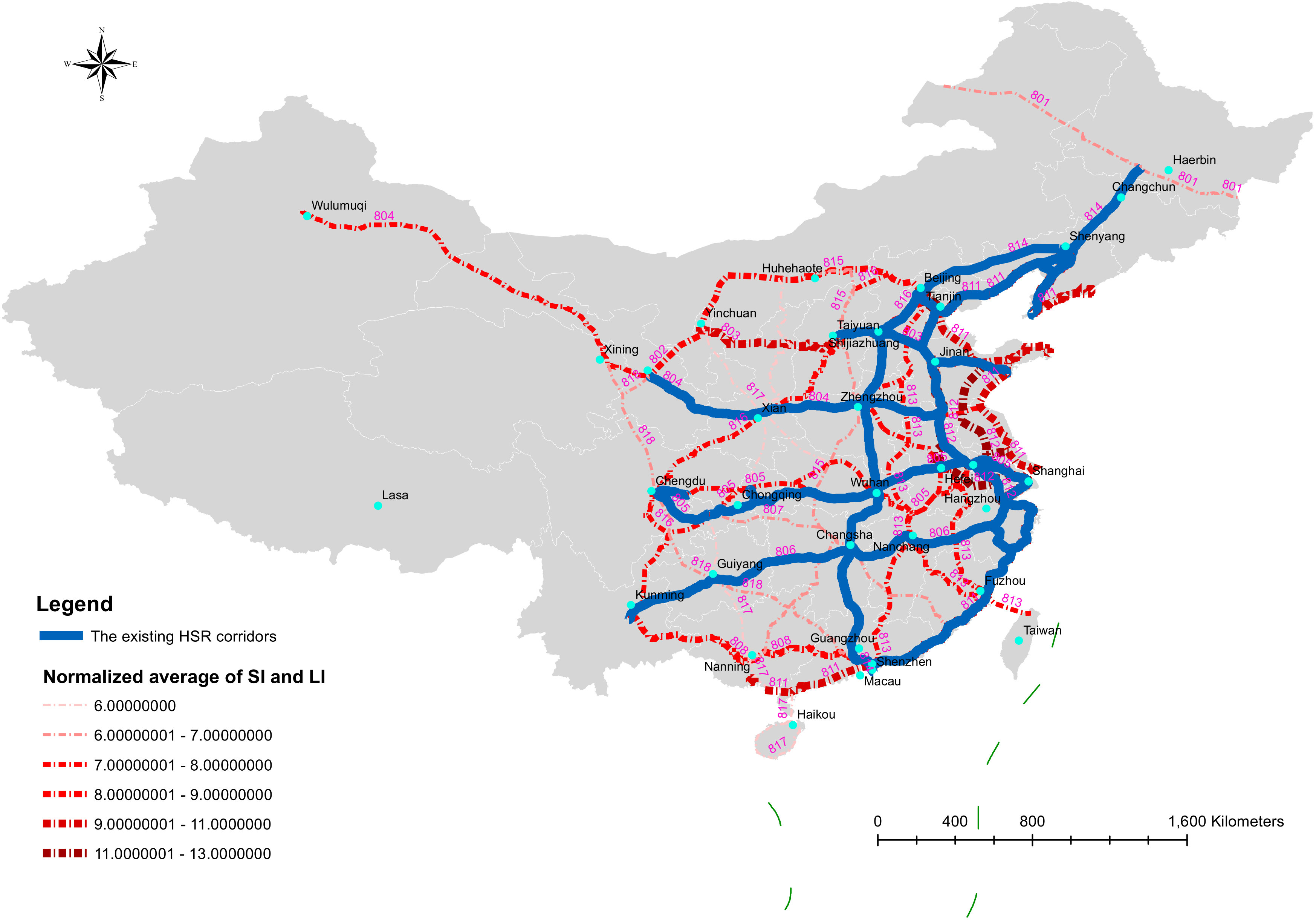

Fig. 7. Average prioritizing values of HSR corridors for future funding and construction directions.

Table 4

The estimated funding demand and the suggested time schedule to start the construction of China's planned HSR corridors.

Horizontal/ Vertical	Corridor number	Planned mileage (km)	Constructed mileage (km)	Unconstructed mileage (km)	Estimated funding (billion RMB)	Average prioritizing rank (normalized)	Suggested construction year (start from)
Horizontal corridor	801	1851.11	0.00	1851.11	277.67	5	2024–2025
	802	1933.14	0.00	1933.14	289.97	4	2020–2021
	803	1963.53	733.87	1229.66	184.45	1	2016–2017
	804	4255.94	1745.50	2510.44	376.57	3	2018–2019
	805	4702.94	1963.04	2739.90	410.99	3	2019–2020
	806	2526.92	0.00	2526.92	379.04	4	2021–2022
	807	1668.76	0.00	1668.76	250.31	5	2024–2025
	808	1364.33	0.00	1364.33	204.65	2	2017–2018
Vertical corridor	811	6055.92	1671.69	4384.23	657.63	1	2016–2017
	812	3464.45	1963.04	1501.41	225.21	4	2020–2021
	813	5669.76	2253.49	3416.28	512.44	3	2018–2019
	814	4343.14	2683.19	1659.95	248.99	4	2021–2022
	815	3026.87	0.00	3026.87	454.03	2	2017–2018
	816	3476.14	0.00	3476.14	521.42	4	2022–2023
	817	6033.82	0.00	6033.82	905.07	5	2025-
	818	1667.79	0.00	1667.79	250.17	4	2022–2023

Notes: The average prioritizing rank of the HSR corridor is categorized based on the value of normalized average value of LI and SI, as shown in Fig. 7. The larger of the normalized average value of SI and LI, the lower the average prioritizing rank of a HSR corridor is.

very simple, as seen in the United States' experience (Federal Railroad Administration, FRA, 2009). According to the consensus, the prioritization of HSR corridors should be based on real-world data and the practical experience of building construction. As a result, in this study, two types of indices are proposed to prioritize China's planned HSR corridors. These indices are computed according to the real-world data of China and explain the importance of China's future HSR corridors from different angles. The first angle is the regional or geographical position of importance of the HSR corridor. The related indicators comprise the spatial configuration and the service coverage indicators of a planned HSR corridor. From the second angle, the urban land development potential within the service domain of an HSR corridor is identified. The related indicators mainly include the urbanization rate changes within the service domain of the HSR corridor.

In particular, the indices are computed depending on the real situations of HSR construction and planning in China. Featuring a unique development path, China has undergone dramatic changes in the HSR network during the past 15 years. Unfortunately, because of these rapid changes, the detailed empirical data on how the HSR network was constructed could not be obtained. As a result, it offers rare opportunities to examine the impact of the HSR on the social and economic development of China. As revealed in existing research, the HSR corridor plays a critical role in promoting regional development balance. However, there lacks a comprehensive examination of how China's HSR corridor would bring change to the city, economy, and even the culture. In particular, the ways to shape the national HSR network with HSR corridors are also worth considering. Undoubtedly, proposing reasonable prioritization indices for ranking HSR corridors would also offer an instructive contribution to other countries, especially in bringing tangible benefits to developing countries, which urgently need to add one or more HSR corridors to stimulate the economy and bridge regional gap divergence. According to Guirao and Campa (2014a), both the evaluation systems for HSR corridor selections of the U.S. and of Europe were also developed to assess which corridors across the respective nation have the greatest potential demand for HSR. The evaluation indices consist of the transportation demand and related cost, economic, and social benefits. As a result, the RSI indicators presented in this paper are well suited to HSR corridor evaluation for the European countries where the real-world application of the whole of Europe HSR network is gradually being built. The ULPI proposed in this paper might be inapplicable to developed countries such as the U.S. or Europe because of their reduced need for urbanization. However, it is still hoped that the ULPI indicators in this study could be additionally supportive for national transport corridor evaluation and ranking for developing countries, which long to promote urban development via HSR infrastructure.

Limitations and insufficiencies remain for the HSR corridor prioritization methods used in this study. Presently, only China has such a large number of HSR routes to be built. Whether the experience or index, which is “Made in China,” could be applied to other countries is questionable. Moreover, the regional and land use potential indices might be unconvincing for HSR corridor evaluation, especially for countries where the urbanization rate has been very high. The shaping of regional structures and land use development promotion are not necessarily the eventual goals of an HSR network. This research provides only one framework for evaluating HSR corridors, but other considerations, such as inter-regional equality and transport network effects, were ignored. Furthermore, the spillover and agglomeration effects of HSR corridors were neglected. In its current format, these effects were not addressed in this paper, as it relies on the simulated urban land-use dataset of previous work, and this could largely affect the RSI and ULPI. For instance, if an HSR corridor is constructed, the cities it service would attract more people from other places, thus changing their urban forms, without doubt. Relatively, other places would then have fewer people and thus less opportunity for urbanization. The input data for a next round of RSI and ULPI analysis should therefore be adjusted; otherwise, the RSI and ULPI values would be biased. For probing into the spillover and agglomeration implications of an HSR corridor, panel analysis based on the RSI and ULPI within a fixed period (commonly a 5-year period would be appropriate) is required. However, the specifications in this paper were made only in terms of a cross-sectional analysis.

It is still hoped that the indices presented in this paper could supplement the existing evaluation indices in the HSR evaluation literature and, in turn, help China to establish a reasonable funding arrangement and construction schedule for the planned HSR corridors over the next decade.

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