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An evaluation of the economic, social, and ecological risks of China-Mongolia-Russia high-speed railway construction and policy suggestions

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Abstract: The construction of China-Mongolia-Russia high-speed railways is a strategic move to promote transportation infrastructure inter-connectivity between these countries, which will accelerate the implementation of the China-Mongolia-Russia Economic Corridor. However, well-planned China-Mongolia-Russia high-speed railways demand accurately identifying construction risks, scientifically evaluating risk levels, and mapping the spatial distribution of these risks. Therefore, this study established the integrated risk evaluation model (IREM) to scientifically evaluate the economic, social, and ecological risks of China-Mongolia-Russia high-speed railway construction and determine their magnitude and spatial distribution pattern. Based on this analysis, we propose designs for the east and west China-Mongolia-Russia high-speed railways and policy suggestions to mitigate construction risks. Suggestions include developing innovative cooperation of the "high-speed railway for resources and market", strengthening communication and technology dissemination, and applying innovative engineering techniques and setting buffers; establishing collaborative prevention and control systems to mitigate the three major ecological risks in the China, Mongolia, and Russia trans-border areas; and promoting economic integration by improving strategic coordination. In summary, this study provides scientific support for designing the China-Mongolia-Russia high-speed railways minimizing construction risks.

Keywords: China-Mongolia-Russia high-speed railway construction; risk evaluation; designs of high-speed railways; policy suggestions; IREM

1 Introduction

As one of the six core corridors planned in "the Belt and Road (B&R) Initiative", the

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China-Mongolia-Russia Economic Corridor fits within the "Eurasian Economic Union" proposed by Russia and the "Prairie Road Program" proposed by Mongolia. This corridor is a key strategic area that China, Mongolia, and Russia are all dedicated to developing. In the "Plan for Construction of the China-Mongolia-Russia Economic Corridor", which was signed in 2016 by the governments of the three countries, "promoting the development and inter-connectivity of transportation infrastructure" is prioritized as a key cooperation area among the three countries. Furthermore, the plan has an explicit directive to "construct and develop international land transportation corridor and improve potentiality of railway and road transportation capacity" (NDRC, 2016). As one of the most important achievements of modern science and technology, high-speed railways are characterized by rapid transport, large capacity, high economic efficiency, low energy consumption, and reduced environmental pollution (Okada, 1994; Xu *et al.*, 2011, Ryder, 2012), which makes it the optimum selection for construction in the China-Mongolia-Russia international land transportation corridor. High-speed railways will both enhance communication and cooperation among the three countries, and remold the spatial distribution patterns of economies, cities, and tourism in areas along the railway corridor and promote their development (Xu *et al.*, 2011; Yu, 2015; Wang, 2014; Wang *et al.*, 2015a, 2015b). Therefore, constructing China-Mongolia-Russia high-speed railways will accelerate construction of the China-Mongolia-Russia Economic Corridor, which will have a significant impact on implementing the B&R Initiative. However, high-speed railway construction costs a huge investment and is often challenged by local economic, social, and ecological conditions. Furthermore, there are large differences in economic development, population scale and distribution, social system and development mode, and ecological environment in the trans-border areas of China, Mongolia, and Russia. While constructing high-speed railways in this corridor will have significant effects on local economic, social, and ecological conditions, there are multi-potential risks due to these above conditions. Therefore, accurately identifying the primary construction risks and scientifically evaluating their magnitude and spatial distribution are required to support the designs and mitigate risk during construction of the China-Mongolia-Russia high-speed railways.

At present, research on high-speed railways has primarily focused on the following aspects:

(1) High-speed railways for improving regional traffic accessibility (Givoni, 2006; Jiang, 2010; Chen, 2012; Preston, 2012; Shaw *et al.*, 2014; Zhong *et al.*, 2015; Mu, 2015; Jiang *et al.*, 2016). Chen (2012) studied the development of high-speed railway in China, and discovered that high-speed railway results in dramatic time-space shrinkage and mobility between cities. Shaw *et al.* (2014) analyzed changes in travel accessibility to cities in China caused by high-speed railways, and found that they improved travel time at the national scale. Preston (2012) observed high-speed railway operation in Britain, and arrived at that the benefit/cost ratio is greater than one, and the timesaving benefit is the largest among the many benefits.

(2) High-speed railways for remolding the economic, social, and urban spatial distributions and promoting regional development (Okada, 1994; EC, 1992, 1994; Xu *et al.*, 2011; Ryder, 2012; Yu, 2015). *The Treaty on the European Union* (EC, 1992) and *White Paper on Growth, Competitiveness and Employment* (EC, 1994) both claim that the development of the Trans-Europe Network is an essential element for both promoting economic development and improving the economic and social cohesion of the European Union. Okada (1994)

found that the Shinkansen bullet train has significantly influenced the commerce, economy, society, culture, and environment; it has brought direct economic effects, such as high profit and tax revenue and large external effects by remolding city allocation, improving energy efficiency, and reducing air pollution. Ryder (2012) highlighted that countries promoting high-speed railways are building them as part of broader regional economic projects or policies.

(3) Competitive interactions between high-speed railway and air transportation (Govoni, 2005; OECD, 2009; Ding, 2013). OECD (2009) discussed competitive interaction between airports, airlines, and high-speed railways, and reached the conclusion that in many circumstances, high-speed railways have potential as alternative transport to air transport. Givoni (2005) concluded that high-speed railways are a possible solution to congestion and environmental problems faced by air transport industry, and with planned cooperation, high-speed railway and air transport could integrate to realize benefits for both industries. Ding *et al.* (2013) studied the competitive relationship between high-speed railway and civil aviation based on the Beijing-Shanghai high-speed railway, and found that the impact of high-speed railway on airports in small cities is larger than that in large cities, and the impact on the airports of cities in the middle zone is greater than that of the both ends.

Existing research has primarily focused on social and economic effects after high-speed railways are implemented, and little focus has been given on preliminary studies that evaluating risk prior to construction, which are urgently needed for construction of the China-Mongolia-Russia high-speed railways. Therefore, based on the strategic demands of the China-Mongolia-Russia high-speed railway construction, and our research group's long-term scientific and field research on local economic, social, and ecological conditions of the trans-border areas of China, Mongolia, and Russia, this study tries to meet this challenge. Here, we identify the primary risks of China-Mongolia-Russia high-speed railway construction by establishing the integrated risk evaluation model (IREM) and scientifically evaluate the magnitude and spatial distribution of risks. Then, we make targeted suggestions to mitigate construction risks, which are scientific support for rational designs of China-Mongolia-Russia high-speed railways, and is of great theoretical and practical significance.

2 Research area

National Development and Reform Commission of China has planned two corridors for the China-Mongolia-Russia Economic Corridor, the east and west corridor. The east corridor is from Northeast China-Manzhouli-Russia-Mongolia and the west corridor is from Jing-Jin-Ji area-Hohhot-Mongolia-Russia (CEH, 2015). The two corridors form the two China-Mongolia-Russia high-speed railways that most urgently to be constructed, aptly termed the east and west China-Mongolia-Russia high-speed railways. There are 11 regions along these corridors, Liaoning, Jilin, Heilongjiang, Inner Mongolia, Beijing, Tianjin, and Hebei in China; Zabaykalsky Krai, Republic of Buryatia and Irkutsk Oblast in Russia; and Mongolia. Among these regions, high-speed railways from Beijing-Tianjin, Beijing-Shijiazhuang, Dalian-Shenyang-Changchun-Harbin, Harbin-Qiqihar, were completed and officially began operating on August 1, 2008; December 26, 2012; December 1, 2012; and August 17, 2015, respectively. Their corresponding track lengths are 281 km, 120 km, 921 km, and 282 km.

Meanwhile, the high-speed railways for Beijing-Kalgan, track length 174 km, and Kalgan-Hohhot, track length 286.8 km, have been constructed, and completion and operation are expected in 2019 and 2018, respectively. The segment from Hohhot-Ulanqab has been finished and officially begun operating on August 3, 2017, with a length of 126 km. In addition, according to China's *Medium- and Long-term Railway Network Plan*, the Suifenhe-Manzhouli high-speed railway channel has been planned with a planned route of Suifenhe-Mudanjiang-Harbin-Qiqihar-Hailar-Manzhouli. Therefore, in the future, the east high-speed railway only needs to extend as Qiqihar-Manzhouli-Russia- Mongolia, and the west high-speed railway needs to extend as Beijing-Kalgan-Hohhot- Mongolia-Russia. Therefore, the research area for this study includes eight research units, Beijing, Hebei, Inner Mongolia, Heilongjiang, Mongolia, Zabaykalsky Krai, Republic of Buryatia, and Irkutsk Oblast, as shown in Figure 1.

Figure 1 Map showing the research area and locations of the proposed economic corridors

The research area is not only the core area of the China-Mongolia-Russia Economic Corridor, but also the strategic area that connects the trans-Siberian railway, linking vibrant East Asia with the well-developed Europe Economic Circle. Constructing the China-Mongolia-Russia high-speed railways and developing an international land transportation corridor is crucial to link the regions and boost common regional development.

By analyzing changes in railway passenger traffic volume for Chinese research units along the China-Mongolia-Russia high-speed railways over the last eleven years (Figure 2), we found out that high-speed railways obviously boosted railway passenger traffic volume. There were three peaks in growth of railway passenger traffic volume. The first occurred in 2008, with a growth rate of 9.55% when the first high-speed railway in China, the Beijing-Tianjin high-speed railway, began operating; this coincided with the 29th Olympic Games in Beijing, which brought a sharp rise of railway passenger traffic volume in Beijing and Tianjin with growth rates of 10.57% and 23.58%, respectively. The second occurred in 2013, one year after the Beijing-Shijiazhuang and Harbin-Dalian high-speed railways began operating, with a growth rate of 7.05%. Along these two high-speed railways, growth rates for Beijing, Tianjin, Hebei, Liaoning, and Jilin reached 12.33%, 12.85%, 11.67%, 8.20%, and 5.8%, respectively. The third peak occurred in 2016, one year after the Harbin-Qiqihar high-speed railway began operating; the growth rate for Heilongjiang increased by 6.23%, while prior to operation, railway passenger traffic volume in Heilongjiang had decreased successively for four years. Clearly, high-speed railway operation affects railway passenger traffic volume and boosts resident mobility. Therefore, constructing the China-Mongolia-Russia high-speed railways is important for promoting connection and cooperation between China, Mongolia and Russia. However, the research area includes eight regions from three countries, and passes through multiple geographical units, including the North China Plain, Northeast China Plain, Mongolian Plateau, and Eastern Siberian Plateau. The overall ecological environment is characterized by transitivity, diversity, complexity, vulnerability, and sensitivity (Dong *et al*., 2017). At the same time, there are large differences in economic, social, and ecological development within these regions, so constructing these high-speed railways will significantly affect economic, social, and ecological development of regions along the high-speed railways, but it also has many potential risks. Clarifying the sources of risk and scientifically evaluating their magnitude and spatial distribution will allow us to formulate targeted risk avoidance measures.

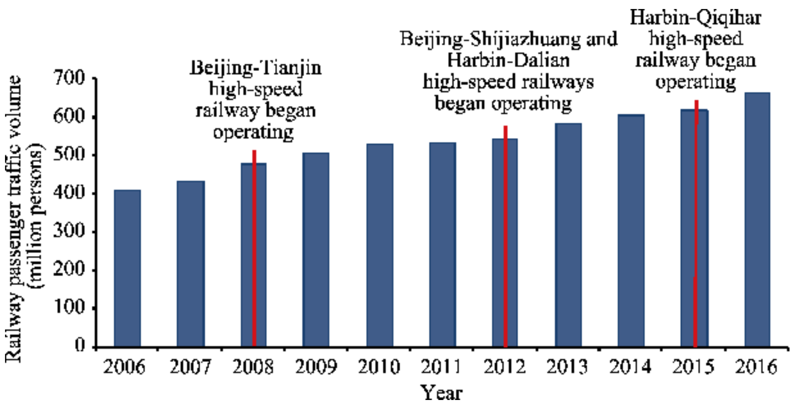

Figure 2 Railway passenger traffic volume for research units in China along the China-Mongolia-Russia high-speed railways from 2006 to 2016

3 Methods and data

3.1 The integrated risk evaluation model (IREM)

Evaluating risks derived from constructing the China-Mongolia-Russia high-speed railways requires establishing a multi-layer and multi-objective comprehensive evaluation index system. At present, widely used methods for such a system include Comprehensive Scoring, Multivariate Statistics, Coordination Degree, Analytic Hierarchy Process (AHP), and Data Envelopment Analysis (DEA). Methods for determining weights include subjective methods, such as Expert Scoring and Delphi, and objective methods, such as Entropy, AHP, and Principal Component Analysis (Song *et al*., 2003; Chen *et al*., 2004; Peng *et al*., 2015). However, due to their own shortcomings, a single evaluation method has difficulty meeting the needs of a comprehensive evaluation. Therefore, comparing the advantages and disadvantages of these methods in detail, we created the IREM to scientifically evaluate risks from the China-Mongolia-Russia high-speed railway construction. The IREM consists of the following four steps.

Step 1: *Establishing a comprehensive evaluation index system.* According to research objects and subjects, we establish a multi-layer and multi-objective comprehensive evaluation index system.

Step 2: *Index screening*. Quantitatively screen the evaluation indices by applying Factor Analysis. According to the rotated component matrix, larger factor loading (as shown in equation 1) corresponds to a higher correlation between the index and factor, which means the index is more important. Applying the Factor Analysis guarantees the objectivity of the index system.

Step 3: *Weight determination*. The objective and subjective methods are combined. First, using Principal Component Analysis, the index's objective weight is obtained as shown in equations 2 and 3. Then, by applying Expert Scoring, the objective weights are revised to optimally reflect index information.

Step 4: *Risk evaluation*. The data are nondimensionalized using the Maximum Difference Normalization method shown in equation 4. After nondimensionalization, all data are transferred to [0, 1], where larger values indicate higher risk. Then, based on the determined index weights, the magnitude of the risks from constructing the China-Mongolia-Russia high-speed railways can be evaluated (equation 5).

$$a_{ij} = \frac{\mathrm{cov}(x_i, f_j)}{\sqrt{D(x_i)}\sqrt{D(f_j)}} \tag{1}$$

$$w_i = \frac{\sum_{j=1}^{m} a_{ij} \Big/ \sqrt{\lambda_j} \times \phi_j}{\sum_{j=1}^{m} \phi_j} \tag{2}$$

$$nw_i = \frac{w_i}{\sum_{i=1}^{n} w_i} \tag{3}$$

$$\begin{aligned} nx_i &= \frac{x_i - x_{\min i}}{x_{\max i} - x_{\min i}} \quad x_i \text{ for positive index} \\ nx_i &= \frac{x_i - x_{\max i}}{x_{\min i} - x_{\max i}} \quad x_i \text{ for negative index} \end{aligned} \tag{4}$$

$$D_o = \sum_{i=1}^{n} nw_i \times nx_i \tag{5}$$

In equations 1–5, x_i represents index i, f_j represents component j, and a_{ij} represents the factor loading. λ_j represents the characteristic root of component j. φ_j represents the variance contribution rate of component j, and w_i and nw_i are the weights of index i before and after normalization, respectively. $x_{\max i}$ and $x_{\min i}$ represent the maximum and minimum of index i, nx_i represents the value of index i after nondimensionalization, and D_o represents the magnitude of risk for research object o.

3.2 Comprehensive evaluation index system of risks for China-Mongolia-Russia high-speed railway construction based on the IREM

3.2.1 Primary risks derived from high-speed railway construction

The construction of high-speed railway is a complicated and systematic project that requires large investments, with a long payback period, and great potential construction difficulties that involves multiple industrial sectors and requires regional economic, social, and ecological contributions. Therefore, during high-speed railway construction and operation, construction risks must be fully considered, manifested from the following perspectives.

(1) *Economic risk*. Construction cost per km of high-speed railways that travel at a speed of 350 km/h is between 16.27 million and 20.35 million US dollars in China (Ou *et al*., 2014); the huge investment leads to high economic risk. Therefore, economic factors, such as economic development, passenger capacity, capacity to pay, and construction infrastructure in the regions along the high-speed railway, and particularly cities with planned railway stations, must be evaluated. However, most research units in Russia and Mongolia are sparsely populated and economically less developed. For example, in 2015, the population densities in Mongolia, Zabaykalsky Krai, Republic of Buryatia, and Irkutsk Oblast were all < 3.5 persons/km^2, and gross domestic product (GDP) per capita was < 4000 US dollars, excluding Irkutsk Oblast. Therefore, constructing high-speed railways in these regions may carry high risks from insufficient passengers and capacity to pay. In addition, China-Russia-Mongolia high-speed railways go through multiple regions with complicated geographic conditions. The east China-Mongolia-Russia high-speed railway goes through seven provinces; the construction distance is about 3100 km, covering a high proportion of hilly and mountainous terrain. The west China-Mongolia-Russia high-speed railway goes through five provinces and Mongolia; the construction distance is about 3000 km, with gobi as the main terrain. Excluding high-speed railways that are operating and under construction, the remaining construction distances for the east and west China-Mongolia-Russia high-speed railways are about 1891 km and 2251 km, respectively, while hilly and mountainous terrain accounts for nearly 70% of the former, and Gobi accounts for more than 80% of the latter. Here we use the Hohhot-Kalgan high speed railway for reference, which is with the most similar geographical conditions to the west China-Mongolia-Russia high-speed railway, whose construction per km was approximately 18.35 million US dollars, but consider the harsh terrain and weather conditions in regions along the China-Mongolia-Russia high-speed railways, the construction cost per km will be much more.

Furthermore, Mongolia and Russia have different rail gauges with China. To solve this problem, China has started to develop and build the next generation high-speed trains that suit gauges for China, Russia, and Mongolia. The new high-speed trains will be equipped with two sets of wheel rails, which can be used in all three countries. Therefore, although the gauge problem will no longer be a barrier to constructing China-Mongolia-Russia high-speed railways, it will increase construction complexity and cost. In conclusion, the China-Mongolia-Russia high-speed railways may face great economic risks from the inability to recover construction costs.

(2) *Social risk.* Because high-speed railway construction, especially trans-border high-speed railway construction has great influence on economic and social development, the ecology, and geo-environment, social factors, such as government and residential support,

and social stability along the high-speed railway, directly determines the feasibility of high-speed railway construction. Social risks need to be investigated accurately and thoroughly by field research and long-term interviews with local governments and residents.

(3) *Ecological risk.* High-speed railways require complex construction, which is significantly affected by local geological and ecological conditions, but also has a direct impact on the local ecological environment. Factors such as the geological status, the ecological environment, disasters, and biodiversity are also direct risk restraining factors (He *et al.*, 2009; Ozturk *et al.*, 2010; Popp *et al.*, 2017), even risks factors that must be avoided during high-speed railway construction. Thus, ecological risk is the most important risk that needs serious research.

3.2.2 Comprehensive evaluation index system of economic, social, and ecological risks from China-Mongolia-Russia high-speed railway construction

Based on the IREM, according to the described risks from high-speed railway construction, and combined with the indices selection principles of availability, typicality, and comparability, the following comprehensive evaluation index system was established.

(1) *Indices of economic risk*. To evaluate economic risk from China-Mongolia-Russia high-speed railway construction, we chose GDP per capita and GDP growth rate to reflect economic development; population density, population growth rate to reflect passenger capacity; transportation infrastructure to reflect high-speed railway construction foundation; and energy, mineral, tourism, and intellectual resources to reflect regional attractive power. Among these indices, transportation infrastructure was represented by the railway network density, where lower density results in higher costs for exploring and evaluating local geology, geomorphology, and the natural environment for construction planning, and corresponding greater economic risks. Tourism resources were represented by the proportion of international tourism revenue to export value, intellectual resources were represented by the number of students studying in colleges, universities and institutions of higher learning per 100,000 people, energy and mineral resources were evaluated by the abundance of strategic energy and mineral resources. Regions with backward economic development, sparse population, poor transportation infrastructure, and scarce resources have high economic risk.

(2) *Indices of social risk.* We chose government and residential support and social stability as the primary social risk indices. Data of government and residential support was obtained based on our group's long-term research with the governments and residents of trans-border areas of China, Mongolia, and Russia. Social stability was represented by unemployment rate. Lower government and residential support and social stability correspond to greater social risk.

(3) *Indices of ecological risk.* Disasters and ecological destruction are the two primary ecological risks faced by constructing high-speed railways; therefore, they were chosen as the ecological risk indices. For disasters, natural disaster was represented by forest fire, which is the most serious natural disaster in the trans-border areas of China, Mongolia and Russia; here, we used the area of forest fire per 10,000 km^2 as an index. Degree of geological disaster was represented by the number of geological disasters occurred. Ecological destruction risk was evaluated using regional forest coverage rate, number of natural reserves, and abundance of biodiversity. The greatest ecological risks correspond to the most serious disasters, best ecological environment, and richest biodiversity.

3.3 Data

As indicated previously, government and residential support was obtained by our group's long-term research in the trans-border areas of China, Mongolia, and Russia; we used a 10-point scoring system to evaluate the degree of support, where lesser support corresponded to greater social risk. Energy resources, mineral resources, and biodiversity were evaluated based on the reserves of strategic energy resources (oil and gas), mineral resources (iron and copper), and existing rare species respectively, and the evaluation results were divided into excellent, good, medium, and poor, with their corresponding scores as 8, 6, 4, and 2. For energy and mineral resources, lower scores indicate greater risk; for biodiversity, lower scores indicate lower risk. Other data were sourced from the "*2016 China Statistical Yearbook*, *2016 Mongolia Statistical Yearbook*, *2016 Irkutsk Oblast Statistical Yearbook*, *2016 Republic of Buryatia Statistical Yearbook*, *2016 Zabaykalsky Krai Statistical Yearbook*, and World Bank Open Data. All statistical indices are based on data for 2015.

According to the IREM, we screened the indices and determined their weights, as shown in Table 1.

Table 1 Comprehensive index system for evaluating economic, social, and ecological risks from China-Mongolia-Russia high-speed railway construction and their normalized weights

Object	Standard	Sub-standard	Index	Weight	Type
Comprehensive economic-social-ecological risk	Economic risk	Economic development	GDP per capita	0.0883	Negative indices
			Growth rate of GDP	0.0394	
		Passenger capacity	Population density	0.0743	
			Growth rate of population	0.0216	
		Transportation infrastructure	Railway network density	0.0282	
		Attractive power	Tourism resources	0.0120	
			Energy resources	0.0120	
			Mineral resources	0.0120	
			Education resources	0.0120	
	Social risk	Government and residential support	Government and residential support for high-speed railway construction	0.1015	
		Social stability	Unemployment rate	0.0985	Positive indices
	Ecological risk	Disaster	Area of forest fire per 10,000 km^2	0.1048	
			Number of geologic hazards	0.1497	
		Ecological destruction	Forest coverage rate	0.0934	
			Number of natural reserves	0.0751	
			Biodiversity	0.0770	

4 Results

Based on the IREM, the economic, social, and ecological risks from China-Mongolia-Russia high-speed railway construction were evaluated, as shown in Table 2.

Table 2 The magnitude of economic, social, and ecological risks from China-Mongolia-Russia high-speed railway construction

Research units	EN	ED	PC	TI	AP	S	SGP	ST	EC	D	EDT	CESE
Mongolia	0.2237	0.1002	0.0743	0.0282	0.0211	0.1662	0.0677	0.0985	0.3203	0.2545	0.0658	0.7102
Republic of Buryatia	0.2498	0.1158	0.0879	0.0273	0.0187	0.1422	0.1015	0.0407	0.2191	0.0733	0.1459	0.6111
Zabaykalsky Krai	0.2672	0.1255	0.0944	0.0266	0.0207	0.1586	0.1015	0.0571	0.1765	0.0507	0.1259	0.6024
Irkutsk Oblast	0.2122	0.0744	0.0920	0.0274	0.0183	0.1184	0.0677	0.0507	0.1660	0.0213	0.1447	0.4966
Heilongjiang	0.2224	0.0753	0.0913	0.0236	0.0323	0.0500	0.0000	0.0500	0.1700	0.0000	0.1700	0.4425
Inner Mongolia	0.1738	0.0367	0.0882	0.0249	0.0241	0.0371	0.0000	0.0371	0.1390	0.0171	0.1219	0.3499
Hebei	0.1907	0.0712	0.0644	0.0152	0.0399	0.0355	0.0000	0.0355	0.0746	0.0171	0.0576	0.3009
Beijing	0.0467	0.0023	0.0097	0.0000	0.0347	0.0000	0.0000	0.0000	0.1144	0.0748	0.0396	0.1611

Abbreviations: EN for economic risk, ED for economic development, PC for passenger capacity, TI for transportation infrastructure, AP for attractive power, S for social risk, SGP for government and residential support, ST for social stability, EC for ecological risk, D for disaster, EDT for ecological destruction, CESE for comprehensive economic-social-ecological risk.

4.1 Economic risks from China-Mongolia-Russia high-speed railway construction

According to the IREM results, the economic risks in some regions along China-Mongolia-Russia high-speed railways primarily manifested as follows:

(1) *Some regions are characterized by backward economic development and slow even negative economic growth, which suggests poor profitability for high-speed railways in the short-term.* Zabaykalsky Krai, Republic of Buryatia, and Mongolia have the highest economic development risks among the research units, 0.1255, 0.1158, and 0.1002, respectively. In 2015, GDP per capita for these three regions were all < 4000 dollars, GDP growth rates were < 2.5%. The GDP growth rate for Zabaykalsky Krai and Republic of Buryatia even showed negative growth, –5.8% and –1.7%, and were the least developed and most serious regions of economic downward. The backward economic development and economic downturn pressure may result in local residents not having enough capacity nor desire to pay for high-speed railways; the profitability of high-speed railways is difficult to guarantee (Table 2).

(2) *Populations are sparsely distributed and have negative growth; therefore, the local passenger capacity may not be high enough.* Zabaykalsky Krai, Irkutsk Oblast, and Heilongjiang face high passenger capacity risk, with magnitudes of 0.0944, 0.0920, and 0.0913, respectively (Table 2); these are the highest of the research units. In 2015, population densities of Zabaykalsky Krai, Irkutsk Oblast, and Heilongjiang were 2.5 persons/km^2, 3.1 persons/km^2, and 82 persons/km^2, respectively, i.e., all < 1% of Beijing. Concurrently, the population in these regions showed negative growth, –3.7‰, –0.8‰, and –5.4‰, respectively. Low population density and declining population may lead to high risk of insufficient passenger capacity for high-speed railways.

(3) *Transportation infrastructures is poor*, *and the foundation to construct high-speed*

railways is weak. Transportation infrastructure in Mongolia, Irkutsk Oblast, Republic of Buryatia, and Zabaykalsky Krai is poor. In 2015, the railway network densities of these four regions were 11 km/10,000 km^2, 32 km/10,000 km^2, 35 km/10,000 km^2, and 56 km/10,000 km^2, while that of Beijing was 783 km/10,000 km^2. Poor transportation infrastructure may require more comprehensive geology, geomorphology, and ecology exploration and evaluation to construct high-speed railways in these regions, which will result in higher construction costs and a longer construction period. The transportation infrastructure risks for these regions are 0.0282, 0.0274, 0.0273, and 0.0266, respectively.

(4) *Scarce resources lead to weak regional attractive power.* Tourism and intellectual resources are important indices that reflect regional attraction for tourists and talent. Tourism and intellectual resources in Hebei and Heilongjiang have been poor. In 2015, international tourism revenue only accounted for 1.5% and 4.9% of export value in Hebei and Heilongjiang, which was less than 1/3 of Inner Mongolia. The number of students studying in colleges, universities and institutions of higher learning per 100,000 people was 2141 and 2518, less than 1/2 of Beijing and Mongolia. Furthermore, the relatively scarce energy and mineral resources in Hebei and increasing number of resource-exhausted cities in Heilongjiang exacerbates their risks in attracting people and logistics. These poor characteristics may result in these two regions having high risks in sustaining attracting passengers.

In summary, the magnitudes of the economic risk in the research units decrease in order Zabaykalsky Krai, Republic of Buryatia, Mongolia, Heilongjiang, Irkutsk Oblast, Hebei, Inner Mongolia, and Beijing, as 0.2672, 0.2498, 0.2237, 0.2224, 0.2122, 0.1907, 0.1738, and 0.0467, respectively (Table 2). According to the principle of "equal interval", we divide the economic risks into high risk, medium risk and low risk, as shown in Table 3. Zabaykalsky Krai, Republic of Buryatia, Mongolia, Heilongjiang, and Irkutsk Oblast are regions with high economic risk. During high-speed railway planning and construction, investment and profit guarantee mechanisms should be established to mitigate economic risk.

Table 3 Categories of economic, social, ecological, and comprehensive risks from China-Mongolia-Russia high-speed railway construction

Risk category	Economic risk	Social risk	Ecological risk	Comprehensive risk
Low risk	[0.0467, 0.1202]	[0, 0.0554]	[0.0746, 0.1565]	[0.1611, 0.3442]
Medium risk	(0.1202, 0.1937]	(0.0554, 0.1108]	(0.1565, 0.2384]	(0.3442, 0.5272)
High risk	(0.1937, 0.2672]	(0.1108, 0.1662]	(0.2384, 0.3203]	(0.5272, 0.7102]

4.2 Social risks from China-Mongolia-Russia high-speed railway construction

Social risks of some regions along China-Mongolia-Russia high-speed railways are primarily manifested as:

(1) *High unemployment rate and low social stability.* In 2015, the unemployment rate in Mongolia reached 7.5%, which exceeded the international warning line of unemployment rate; this high risk to social stability in Mongolia is quantified with a risk magnitude of 0.0985, the highest among research units. In addition, Mongolia also has large income disparity, high crime rate, and poor social security, which aggravate the social stability risk in Mongolia.

(2) *Despite the overall support for high-speed railway construction*, *some regions still*

have concerns. According to our long-term and comprehensive investigation in the trans-border areas of China, Mongolia, and Russia, local governments and residents generally support constructing the China-Mongolia-Russia high-speed railways. However, due to their potential ecological and geopolitical impacts, some officials and residents still have some concerns, and their attitudes toward the high-speed railway construction may be influenced by some unexpected incidents. For example, China's enterprises intended to build a bottled water plant near Lake Baikal, which was opposed by Irkutsk residents because of the potential damage to Lake Baikal. As major engineering project, high-speed railway construction will have significant impact on local ecological environment, which leads to relatively high social risks in the Republic of Buryatia, Zabaykalsky Krai, Mongolia, and Irkutsk Oblast, which are 0.1015, 0.1015, 0.0677, and 0.0677, respectively.

The magnitudes of social risks from constructing China-Mongolia-Russia high-speed railways were calculated as decreasing in the order of Mongolia, Zabaykalsky Krai, Republic of Buryatia, Irkutsk Oblast, Heilongjiang, Inner Mongolia, Hebei, and Beijing, with values of 0.1662, 0.1586, 0.1422, 0.1184, 0.0500, 0.0371, 0.0355, and 0, respectively (Table 2). Dividing the social risks into high, medium, and low risk (as shown in Table 3), it shows that regions with high social risks are distributed in Mongolia, Zabaykalsky Krai, Republic of Buryatia, and Irkutsk Oblast. During the planning and construction of high-speed railways, emergency prevention and control mechanism should be established to avoid social stability risk, and efforts to eliminate concerns from officials and residents should be made.

4.3 Ecological risks from China-Mongolia-Russia high-speed railway construction

The ecological risks of some regions along the China-Mongolia-Russia high-speed railways are primarily manifested as:

(1) *Ecological destruction risk to the world natural heritage site "Lake Baikal".* Lake Baikal is located in territory of Irkutsk Oblast and Republic of Buryatia. The total volume is about 23.6 trillion m^3, and the deepest point reaches 1637 m. It is the largest and deepest fresh water lake in Eurasia, and one of the most famous natural heritage sites, with a good ecological environment, rich biodiversity, and valuable ecological resources, along the China-Mongolia-Russia Economic Corridor. Because the high-speed railway construction and operation will have significant impact on the ecological environment and ecosystem patterns, it may lead to the ecological destruction of Lake Baikal, which needs to be highly emphasized during high-speed railway construction.

(2) *Ecological and biodiversity destruction risk.* The ecological environment of Heilongjiang, Republic of Buryatia, Irkutsk Oblast, and Zabaykalsky Krai are excellent, with high forest coverage rates and rich biodiversity. In 2015, forest coverage rates for these four regions were 43.2%, 63.7%, 83.6%, and 68.3%, respectively, far above the world average. Meanwhile, the world natural heritage site of Lake Baikal and more than 250 national natural reserves are located in these four regions, which are also important habitats for rare animals, such as moose, muskrat, sable, tiger, and red-crowned crane. However, high-speed railway construction may damage surface vegetation and ecosystems, fragment animal communities, and destroy ecosystem service function and biodiversity. Therefore, these four regions face high ecological destruction risk, calculated as 0.1700,

0.1459, 0.1447, and 0.1259, respectively (Table 2). During the planning of high-speed railways, the designs of high-speed railways should avoid core ecosystem areas, advanced engineering technology, buffer zones, and bridges and tunnels should be applied to minimize ecological damage from construction.

(3) *Natural and geological disaster risks.* The natural and geological environment in Mongolia is fragile, desertification and soil erosion are serious, disasters occur frequently, which will directly determine the feasibility and safety of high-speed railway construction. In 2015, Land degradation area of Mongolia reached 95,754 km^2, accounted for 6.1% of the territory of Mongolia. Nearly 80% of land in Mongolia has been subject to differing desertification intensities, and desertification is expanding to grassland in Dornod aimag and Khentii aimag (XNA, 2017). Meanwhile, the forest fire area in Mongolia reached 415 km^2/10,000 km^2, which was more than 1000 times that in China, and there were 44 disasters. Therefore, the disaster risk in Mongolia is the highest among the research units, 0.2545, and far beyond the risk in other regions. Construction of high-speed railways in Mongolia should avoid disaster prone areas, and disaster prevention and control mechanisms should be established.

In summary, the magnitudes of the ecological risks were found to decrease in the following order: Mongolia, Republic of Buryatia, Zabaykalsky Krai, Heilongjiang, Irkutsk Oblast, Inner Mongolia, Beijing, and Hebei, with values of 0.3203, 0.2191, 0.1765, 0.1700, 0.1660, 0.1390, 0.1144, and 0.0746, respectively (Table 2). Dividing the ecological risks into high, medium, and low risk, as shown in Table 3.

4.4 Comprehensive economic-social-ecological risks from constructing the China-Mongolia-Russia high-speed railways

Integrating the economic, social, and ecological risks from the China-Mongolia-Russia high-speed railway construction, the comprehensive risk magnitudes decrease in the order of Mongolia, Republic of Buryatia, Zabaykalsky Krai, Irkutsk Oblast, Heilongjiang, Inner Mongolia, Hebei, Beijing, which are 0.7102, 0.6111, 0.6024, 0.4966, 0.4425, 0.3499, 0.3009, and 0.1611, respectively (Table 2). Dividing the comprehensive risks into high, medium, and low risk (see Table 3), there are clear spatial distribution differences in risk. Regions with high comprehensive risk are primarily located in research units in Russia and Mongolia, while medium and low risks are mainly located in research units of China.

Based on our research, both the east and west China-Mongolia-Russia high-speed railways are confronted with great construction risks. The high construction risk from the east China-Mongolia-Russia high-speed railway is found in Zabaykalsky Krai and Republic of Buryatia, represented by high economic, government and residential support, and ecological destruction risks. The region with high construction risk from the west China-Mongolia-Russia high-speed railway is Mongolia, represented by high economic, social stability, and disaster risks. Therefore, designs for the China-Mongolia-Russia high-speed railways need to be scientifically regulated. Concurrently, targeted measures and advanced engineering techniques must be applied to minimize the construction risk from the China-Mongolia-Russia high-speed railways. The spatial distribution of economic, social, ecological, and comprehensive risks from the China-Mongolia-Russia high-speed railway construction is shown in Figure 3.

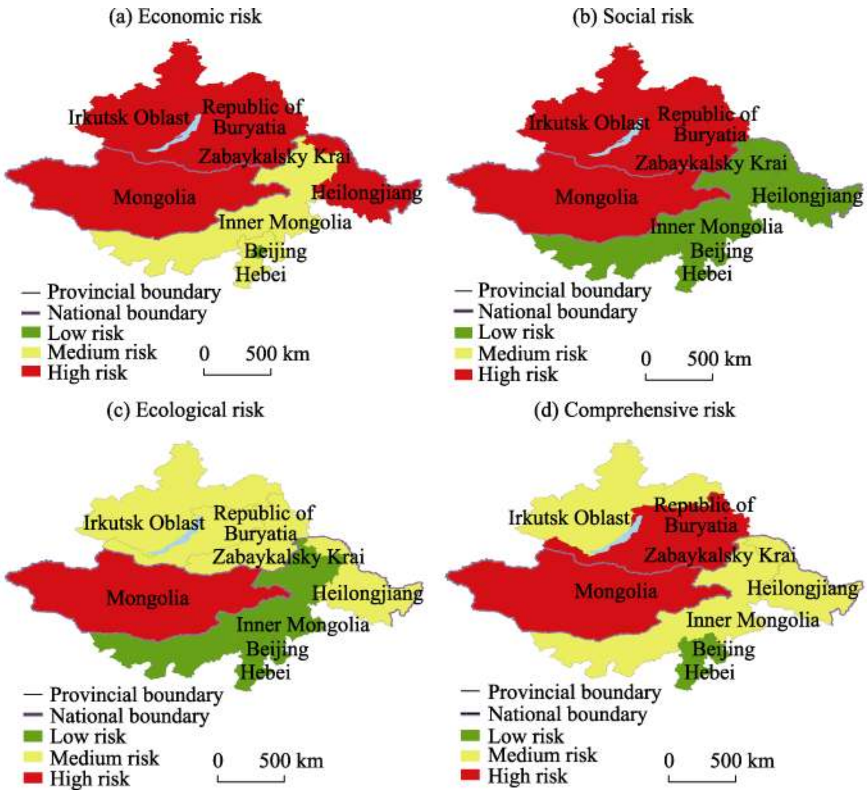

Figure 3 Map of the research area showing the spatial distribution of construction risks arising from the China-Mongolia-Russia high-speed railways

5 Policy suggestions

According to the magnitudes of risk and their spatial distribution, we propose the following suggestions to mitigate construction risks.

5.1 China-Mongolia-Russia high-speed railway designs need to be scientifically regulated

According to the distribution of risks, regions with good economic, social, and ecological conditions should be chosen as node cities for the high-speed railway, and regions with high risk factors should be avoided. For instance, in Mongolia, high-speed railway designs should avoid the disaster-prone area of western Mongolia. For Republic of Buryatia, Irkutsk Oblast, Zabaykalsky Krai, and other regions with good ecological environment, high-speed railway designs should avoid zones with dense forests, rich biodiversity and good ecological environments. Meanwhile, metropolitan cities, such as Ulan Bator and Irkutsk, and important border cities, such as Erenhot and Manzhouli, with good economic development, large population density, strong regional attracting power, and good transportation infrastructure should be selected as the node cities for the China-Mongolia-Russia high-speed railways. After comprehensively analyzing the economic, social, transportation infrastructure conditions of the research units, we suggest the following designs for the China-Mongolia-Russia high-speed railways (Figure 4).

The east China-Mongolia-Russia high-speed railway: Dalian-Shenyang-Changchun-

Harbin-Qiqihar-Hailar-Manzhouli-Chita-Ulan-Ude-Irkutsk.

The west China-Mongolia-Russia high-speed railway: Shijiazhuang/Tianjin-Beijing-Kalgan-Ulanqab-Hohhot-Erenhot-Zamyn-Uud-Sainshand-Choyr-Ulan Bator-Darkhan-Sukhbaatar-Altanbulag-Kyakhta-Ulan-Ude.

Figure 4 Map showing the proposed east and west China-Mongolia-Russia high-speed railway routes

5.2 Innovative cooperation can be developed to reduce economic risk

For regions with high economic risks in Russia and Mongolia, although they support the construction of high-speed railways, they are short of investment funds. Innovative cooperation based on "high-speed railway for resources and markets" can be established to reduce economic risk. Namely, China can provide investment funds, technology, equipment, technicians, and the labor force to construct and maintain the high-speed railways, while Russia and Mongolia can transfer development rights for mineral and energy resources and transport resource-based and high-tech products to China as payment for high-speed railway investment. By developing comparative advantages, the three countries can co-develop and reduce economic risk.

5.3 Communication and technology dissemination can be strengthened to reduce social risk

For regions that have geopolitical and ecological destruction concerns for high-speed railway construction, governmental and non-governmental communication should be strengthened to show China's friendly cooperation policy toward the world; this can improve China's international image and eliminate the concerns and prejudices some Mongolian and

Russian residents have toward China. In addition, high-tech dissemination activities, such as hosting high-speed railway technology exhibits, making promotional videos, should be provided, to expand residents' knowledge of the features of high-speed railways and improve their acceptance of high-speed railways.

5.4 Advanced engineering techniques and buffer zones can be applied to reduce ecological risk

For regions with high ecological risk, such as Irkutsk Oblast, Republic of Buryatia, and Zabaykalsky Krai, high-speed railway designs should avoid zones with dense forests, rich biodiversity, and excellent ecological environment. For dotted forests, grassland, lakes, wetlands that high-speed railway construction cannot avoid, advanced engineering techniques, such as viaducts, tunnels, bridges, ramp transitions, and noise barriers, can be applied to minimize ecological damage. For Lake Baikal and other natural reserves, buffer zones should be designated, and the high-speed railway should be located outside the buffer zones, thus minimizing the disturbances from high-speed railway construction and operation on ecological systems.

5.5 Establishing collaborative prevention and control systems for the three major ecological risks in the China, Mongolia and Russia trans-border areas

According to the distribution of risks from China-Mongolia-Russia high-speed railway construction, collaborative prevention and control systems for three major ecological risks should be established. They are the prevention and control system for forest fire in the China, Mongolia and Russia trans-border areas, the prevention and control system for geological disasters, such as soil erosion, desertification, and sandstorms, in the China and Mongolia trans-border areas, and the prevention and control system for vegetation and biodiversity destruction in the China and Russia trans-border areas. By establishing real-time ecological environment monitoring and information-sharing platform between China, Mongolia, and Russia trans-border areas, real-time warnings and the prevention of ecological risk during construction and operation of China-Mongolia-Russia high-speed railway can be achieved.

5.6 Strategic coordination should be improved to promote economic integration between China, Mongolia and Russia

By enhancing strategic coordination among China, Mongolia, and Russia, economic integration of the three countries can be promoted, which will boost the construction of China-Mongolia-Russia high-speed railways. Thus, the following aspects can be enhanced. First, strengthen the strategic coordination for the China-Mongolia-Russia Economic Corridor with the "Eurasian Economic Union" and the "Prairie Road Program". Second, accelerate construction of the China-Mongolia-Russia Free Trade Area and China-Mongolia-Russia cross-border economic cooperation zone. Third, promote trade facilitation and cooperation on major projects. Fourth, strengthen cooperation for the production capacity and strategic resources and increase trade dependence. Fifth, enhance communication and cooperation for talent, science and technology, education resources and implement a visa exemption policy in China, Mongolia, and Russia to promote population flow and improve regional vitality.

6 Conclusions and outlook

6.1 Conclusions

(1) *The economic, social, ecological and comprehensive risks of China-Mongolia-Russia high-speed railway construction and their spatial distribution were evaluated.* Economic risk along the China-Mongolia-Russia high-speed railways is due to undeveloped economies, slow even negative economic growth, sparse and declining populations, poor transportation infrastructure, and scarce resources. Regions with high economic risk include Zabaykalsky Krai, Republic of Buryatia, Mongolia, Heilongjiang, and Irkutsk Oblast. Social risk is due to high unemployment rate, low social stability, and government and residential concerns despite the overall support for high-speed railway construction. Regions with high social risks are Mongolia, Zabaykalsky Krai, Republic of Buryatia, and Irkutsk Oblast. Ecological risk is due to the potential for ecological destruction in such areas as Lake Baikal and regions with excellent ecological environment, high forest coverage rate, and rich biodiversity. Furthermore, regions with fragile ecological environment and high frequency of disasters are also at high ecological risk. Regions with high ecological destruction risk are Heilongjiang, Buryat Republic, Irkutsk Oblast, and Zabaykalsky Krai. The region with the high disaster risk is Mongolia. Regions with high comprehensive risk are Mongolia, Republic of Buryatia, and Zabaykalsky Krai.

(2) *According to the risk distribution pattern and characteristics, the suggested designs for the east and west China-Mongolia-Russia high-speed railways were proposed.* The proposed design for the east China-Mongolia-Russia high-speed railway is: Dalian-Shenyang-Changchun-Harbin-Qiqihar-Hailar-Manzhouli-Chita-Ulan-Ude-Irkutsk, and for the west China-Mongolia-Russia high-speed railway: Shijiazhuang / Tianjin-Beijing-Kalgan-Ulanqab-Hohhot-Erenhot-Zamyn-Uud-Sainshand-Choyr-Ulan Bator-Darkhan-Sukhbaatar-Altanbulag-Kyakhta-Ulan-Ude.

(3) *Targeted policy suggestions to avoid construction risks were proposed*. Developing innovative cooperation of the "high-speed railway for resources and market", strengthening communication and technology dissemination, applying innovative engineering techniques and setting buffers; establishing collaborative prevention and control systems to mitigate the three major ecological risks in the China, Mongolia, and Russia trans-border areas; and promoting economic integration by improving strategic coordination.

(4) *The application of the IREM.* The IREM established in this paper can scientifically evaluate the economic, social, and ecological risks from the China-Mongolia-Russia high-speed railway construction, and can also be applied to evaluate risks for other trans-border high-speed railways and other field.

6.2 Outlook

China, Mongolia and Russia have profound historical contacts. China and Russia have a comprehensive strategic partnership of coordination, and China and Mongolia have a comprehensive strategic partnership. In 2016, trade value between China and Russia, and between China and Mongolia reached 69.5 billion US dollars and 4.61 billion dollars, the average annual growth rate was up to 14% and 18% since 2000, respectively (UN Comtrade

Database, 2017). Furthermore, with the implementation of the China-Mongolia-Russia Economic Corridor, Eurasian Economic Union, and Prairie Road Program, relationships between China, Mongolia, and Russia are growing increasingly close. In the future, cooperation among the three countries will be more intensive. To accelerate the construction of the China-Mongolia-Russia Economic Corridor and strengthen cooperation among the three countries, other high-speed railways also need to be studied. According to our research, in addition to the east and west Russia-Mongolia-China high-speed railways, another three railways can be considered. They are the coastal high-speed railway, Changchun (Jilin, China)-Hunchun (Jilin)-Vladivostok (metropolis of Primorsky Krai, Russia)-Khabarovsk (metropolis of Khabarovsky Krai, Russia); the northeast high-speed railway, Harbin (Heilongjiang, China)-Heihe (Heilongjiang)-Blagoveshchensk (metropolis of Amur Oblast, Russia); and the northwest high-speed railway, Urumqi (Xinjiang Uygur Autonomous Region, China)-Altai (Xinjiang)-Barnaul (metropolis of Altai Krai, Russia)-Novosibirsk (metropolis of Novosibirsk Oblast, Russia). Together with the east and west China-Mongolia-Russia high-speed railways, this would make five high-speed railways connecting China, Mongolia, and Russia from five directions, which would greatly expand the international land transportation corridor and promote implementation of the China-Mongolia-Russia Economic Corridor. In the future, we will continue to study the construction of the potential coastal, northeast, and northwest high-speed railways.

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