J. Geogr. Sci. 2015, 25(6): 723-738
DOI: 10.1007/s11442-015-1198-3

© 2015 Science Press Springer-Verlag

Evolution of regional transport dominance in China 1910–2012

HU Hao[1], *WANG Jiaoe[2], JIN Fengjun[2], DING Nan[3]

1. Institute for Urban and Environmental Studies, CASS, Beijing 100028, China;
2. Key Laboratory of Regional Sustainable Development Modeling, Institute of Geographic Sciences and Natural Resources Research, CAS, Beijing 100101, China;
3. University at Buffalo, the State University of New York, New York 14260-1660, USA

Abstract: Transport infrastructure plays an important role in shaping the configuration of spatial socio-economic structures and influencing regional accessibility. Although China's transport infrastructure has been experiencing a rapid development in the last 100 years, there lacks a systematic examination of the complete evolution history of China's transport development, particularly with all kinds of transport modes. This paper first aims to clarify the history of China's transportation from 1910 to 2012, and divides its evolution process into five periods (1911, 1935, 1953, 1981 and 2012) whereby each period represents the preliminary development time for each transport mode. Second, the paper calculates the transport dominance and analyses its spatial distribution in each period, with county as the basic analysis unit. Transport dominance here is defined as an integrated indicator for evaluating regional transport conditions. The results demonstrate the following: (1) areas with relative good transport dominance have expanded from scattered dots such as Tianjin, Shanghai, Guangzhou in 1911 to extensive areas with each provincial city as cores in 2012; (2) transport development is improved by advances in transportation technology. The construction of modern transport infrastructures such as seaports, airports, high-speed rails (HSRs), and freeways lead the expansion of national territorial areas with good and excellent transport dominance and the increase of the value of transport dominance over time; (3) transport dominance is spatially unevenly distributed and exhibits resemblance with the expansion of transport network, which is closely related to China's socio-economic development and policies.

Keywords: transport dominance; transport infrastructure; spatial evolution; regions; history; China

Received: 2014-03-10 **Accepted:** 2014-10-30

Foundation: The Programme of Bingwei Excellent Young Scientists of the Institute of Geographic Sciences and Natural Resources Research, CAS, No.2011RC201; National Natural Science Foundation of China, No.41371143; No.41171107

Author: Hu Hao (1984–), PhD, specialized in regional development studies. E-mail: bsdhao@126.com

***Corresponding author:** Wang Jiaoe (1981–), Associate Researcher, specialized in transport geography and regional development studies. E-mail: wangje@igsnrr.ac.cn

1 Introduction

Historically, transport has always coevolved with civilisation. During the Industrial Revolution, the first modern highway appeared with the invention of horse-drawn vehicles and the first modern rail appeared in England in the 1820s, over 50 years earlier than that in China. The Wright brothers invented the first successful airplane and made the first sustained, controlled and powered flight in the U.S. in 1903. Seventeen years later the first air route in China (Beijing-Tianjin) was in operation. Western developed countries experienced water-oriented, railway-oriented transportation earlier and then built up a comprehensive modern transport system including ground transport, sea-based transport, air transport and underground transport in the mid-20th century. Meanwhile, the transport development of the United States also experienced the canal era, railway era, highway era, and then to a comprehensive transport era (Litman, 2003). This development process in the United States matched the needs of the nation's social and economic development in each era and efficiently prompted its economic development (Li *et al*., 2011). The research on the evolution of transport network was inspired by Taaffe (1963) who described the evolution of transportation networks of Ghana and Nigeria in six phases. Though China's transport system developed later than western countries, it grew fast, especially after the Chinese Revolution in 1911. During the last 100 years, China's transport technologies have been greatly improved. Railways, highways, airports and seaports have been built in a large scale, and the networks of freeway and high-speed rail (HSR) have been formed in the last 15 years. Today China owns a comprehensive transport system and the largest HSR network in the world (Zhang and Wang, 2008).

Transport development has a long-term impact on the economy. The quality of transport infrastructure is improved as well as the accessibility of places. As early as the 1960s, the effects of transport development had been studied from the perspective that how the reduction of travel cost or infrastructure service cost impacts the development of regional economy (Isard, 1960). Some other studies employed graph theory and related methods to analyze the location of individual nodes in transport networks (Leung, 1980), Fleming *et al*. (1994) firstly introduced factors which are related with transport development and transport network to evaluate regional transport dominance in 1994, and they made a good start to study the effects of transport development and transport patterns. In the early 21st century, some researchers paid more attention to the evaluation of the modern comprehensive transportation network. Bogart (2009) examined the co-evolution of highways, canals, and ports during the English Industrial Revolution and revealed noticeable interdependencies among different nodes and networks over time based on spatial and functional proximity. Ducruet and Notteboom (2012) found the complementarity between air and maritime networks in the formation of a global urban hierarchy. In China, as the relationship between transport investment and economic development had changed from transport investment lagging behind economic development, to maintaining a roughly equal pattern of development, to the point where transport investment growth outpaced that of the economy (Zhang *et al*., 2009), China's modern transportation has developed rapidly and attracted more researchers to study it, especially in the field of transportation development mechanisms and its historical evolution. Wang C J (2007) reviewed the transportation development pattern and the formation process of China's transport system; Zhu and Ma (2009) analyzed China's transportation

structure and the development of China's integrated transport system, while other researchers studied the mechanisms of transportation, such as railways and highways, and how they influenced regional economies and urban development (Jin *et al*.,2004; Ureña *et al*.,2009). Wang *et al.* (2009) contributed to the accessibility methods for studying the evolution of railway network in China and Jin *et al.* (2010) provided methods and references on the evaluation of transport dominance. Wang Q Y (2007) and Huang *et al*. (2011) did empirical studies on regional transport dominance and built an evaluation model, which applied the study of regional transport dominance in the spatial scale. However, most existing references have paid their attention to the comparison of different transport modes, rather than the spatial analysis of the comprehensive transport system (Wang *et al*., 2009). In addition, there was little literature on transport development and evolution before 1949. Furthermore, few existing literatures have studied how the comprehensive transport system of China involves from a spatio-temporal perspective and how it influences industrial development and urban growth. Zhang *et al*. (2005) argued that multi-layer infrastructure networks should be analyzed at various geographic levels with regard to the respective topology and functions of individual networks and the potential inter-modal shifts and mutual influence. Therefore, how to evaluate a comprehensive transport network is needed in the study of transport development in China.

The paper aims to explore the role of transport development in shaping the configuration of spatial socio-economic structures, analyze its spatial distribution characteristics, and examine key factors which influence the spatial evolvement of regional transport dominance. Since the Chinese Revolution in 1911, transportation technology advances, economic development, urban systems, and policies have governed the uneven spatial distribution and hierarchical expansion mode of transport development and regional transport dominance in China. After an overview and a brief discussion of the evolution of transport development in China from the 1910s to the 2010s, five stages of China's transport development are identified and five years in each stage are selected for analyzing and mapping the spatial characteristics of transport dominance. Jin analyzed the spatial distribution of transport dominance in 2010 based on the traditional static and single indicator method (Jin *et al.*, 2010). Following the work of Jin *et al*. (2012), the paper establishes a more complicated evaluation system of transport dominance and examines how the transport dominance spatially evolves since 1911. Then the paper concludes by discussing the factors that influence the evolution of transport development and regional transport dominance of China. The paper provides some references for human influence simulative analysis in man-land relationship to territorial development, regional development and industrial distribution.

2 Study area, data processing and methods

2.1 Study area and data sources

The study area includes 3085 county-level units[1] in China (excluding Hong Kong, Macao,

[1]It includes county, county-level city, forest district, special zone, autonomous county, banners, autonomous banners, alliance autonomous cities and the union flag county in the ethnic minority autonomous region, municipal district of prefecture-level administrative unit, districts and counties of the municipality directly under the central government and municipalities directly under the central government at the provincial level.

and Taiwan), which are called counties for simplification in the following part of the paper. All transport networks are obtained from historical maps in 1911, 1935, 1953, and 1981. Historical data and statistical data related with selected years are abstracted from the Shun Pao New Map of China's Province in 1934, the Atlas of the People's Republic of China in 1958, the Atlas of China in 1979 which were published by map publishing house and China's key transportation in 1989, and transport planning promulgated by the Chinese central government. GIS data is derived from the remote sensing map at a scale of 1:250,000, supplied by the National Fundamental Geographical Information Center.

2.2 Transport dominance

Transport dominance is defined from three aspects: quality, quantity, and advantage, and measured by density, proximity, and accessibility indices respectively. The index is used to measure the development level of transport infrastructure network in a region, to reflect its supportive capacity for its socio-economic activities, and it is an integrated indicator for evaluating regional transport conditions (Jin *et al*., 2010). Based on the calculation method of transport dominance referred by Jin *et al*. (2010), this paper did several revisions: (1) including the HSR network for considering its large scale in 2012, where HSR stations instead of rail lines are used to measure the transport dominance; (2) combining double tracks and single tracks as one since there is no double-track in the early 20th century; (3) airports, seaports, and inland water harbors are used to measure transport dominance, but the difference between the feeder transport nodes and the hub transport nodes is ignored owing to the availability of historical data; (4) establishing the evaluation system varying in different transport modes and distances from central nodes (Table 1). Transport dominance and spatial autocorrelation of 3085 counties in China was evaluated by measuring the distance from each county to its nearest ground transportation (rail and highway) and non-ground transportation (airport and port) systems; (5) central nodes including all the capital cities of 31 provinces in China (excluding Hong Kong, Macao, and Taiwan) and 11 transport hubs such as Dalian, Datong, Lianyungang, Ningbo, Qingdao, Qinhuangdao, Qiqihar, Shenzhen,

Table 1 The index and weight of transport dominance evaluation

Class	Subclass	Distance (km)	Weight	Class	Subclass	Distance (km)	Weight
Transport mode	Conventional railway	<20	2	Transport mode	HSR	<30	2
		20–40	1.5			30–60	1.5
		40–80	1			60–120	1
		>80	0			>120	0
	Highway	<10	2		Airport	<30	2
		10–30	1.5			30–60	1.5
		30–60	1			60–120	1
		>60	0			>120	0
	Freeway	<20	2		Port	<30	2
		20–40	1.5			30–60	1.5
		40–80	1			60–120	1
		>80	0			>120	0
City nodes	Central city	<100	2	City nodes	Central city	300–600	1
		100–300	1.5			>600	0

Xiamen, Xuzhou, and Zhanjiang *et al*.; (6) due to the travel speed and capacity of each transport mode, the weight is set from 0 to 2 according to the distance from the counties to their nearest transport nodes, transport lines, and city nodes. In other words, the nearer the distance, the higher the weight; the faster the transport speed, the higher the weight. The detailed indicator system and the weight of each index are shown in Table 1.

3 Overview of China's transport development

Figure 1 summarizes the first events of China's transport development. As we all know, important historical events such as the Chinese Revolution in 1911, the War of Resistance Against Japan from 1931, the founding of the People's Republic of China in 1949, the implementation of the reform and opening-up policy in 1978, and the railway speed-up campaigns in the early 21st century, have profound influences on China's socio-economic development and transport construction. Based on the available data, the first appearance of each single transport mode in China and the important historical events, this paper divided China's transport development into five stages and selected the years of 1911, 1935, 1953, 1981 and 2012 for representing the transport dominance in each stage.

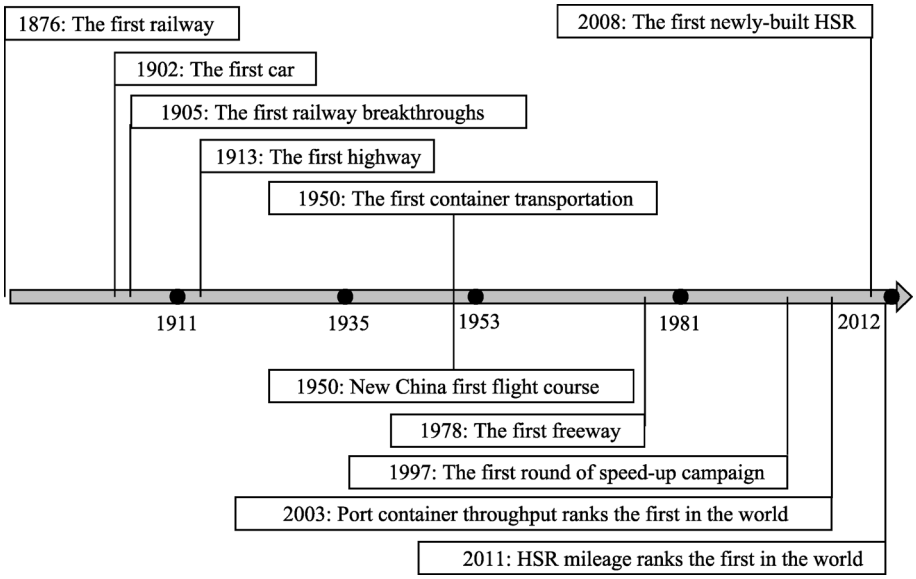

Figure 1 The first events of China's transport development in the last 100 years

(1) Rail construction in the late 19th century

In 1876, the construction of a 14.5-km long railway from Shanghai to Wusong represented the beginning of China's railway transportation (Wang, 1986). In 1905, the construction of Jing-Zhang Railway (from Fengtai in Beijing to Zhangjiakou in Hebei Province) represented a breakthrough in railway technology. By 1911, China had more than 9700-km long railway, including the busiest lines today, such as Harbin-Beijing rail, Beijing-Shenyang rail, Shanghai-Beijing rail, and Beijing-Hankou rail. However, the railway network in this stage was highly unevenly distributed, with 60.6% of railways located in

Northeast China and North China. The railway network in North China was constructed around the political city Beijing. This stage is related to the background of plundering history and military control by other countries, as well as the Qing Dynasty and local authorities' effort to stabilize their power. In this stage, the year of 1911 is chosen for analysis.

(2) Highway construction in the early 20th century

In the early 20th century, China's highway construction and automobile transportation started but stagnated later in the 1930s, due to the frequent outbreak of wars. In 1902, China imported the first car. In 1913, the Chang-Tan Military Highway (Changsha-Xiangtan, 50 km) in Hunan Province was built. It was the first paved highway in the mainland of China. By 1936, China had more than 95,000 km of paved highways. However, the subsequent wars destroyed all and China's highway construction entered into a temporary halt period. In this stage, the year of 1935 is chosen for analysis.

(3) Port construction during the 1930s–1970s

In this stage, China's transport development mainly focused on port construction, including airports, seaports, and inland harbors. The development of China's civil aviation was traced back to Air China, established by the father of Chinese commercial aviation (Kai Si) in 1928. The first 20 years of Chinese civil aviation was full of difficulties and challenges because of the turbulent confusion in the period of the Republic of China and the War of Resistance Against Japan. With the founding of New China in 1949, China's civil aviation development entered into a new stage. During the first and second five-year plan periods (1953–1962), China's air network expanded gradually and connected with 42 domestic and overseas cities, and Beijing was the air hub in this period. By 1957, the length of air routes in China was 26,000 km, 6.6 times greater than that in 1931. Though water transport had the longest history in China, port development before 1949 faced bottlenecks such as inadequate capacity and port construction. Meanwhile, the Republic of China could not provide stable environment for modern transport development because of the wars. China's port system achieved its real progress only after the founding of the People's Republic of China in 1949, especially after the implementation of the reform and opening-up policy in 1978. After that, ports in China were constructed rapidly. Not only did the inland harbors located around the "San Jiang Liang River" (i.e., the Yangtze River, the Heilongjiang River, the Pearl River, and the Huaihe River, the Beijing-Hangzhou Grand Canal) developed significantly, but also the seaports mostly located around the Bohai Bay Rim area and along the southeast coastal areas advanced rapidly (Wang C J, 2007). The container transport started in the 1950s also had a rapid development. In this stage, the year of 1953 is chosen for analysis.

(4) Freeway development (1980s–2010s)

After 1980, China has entered into a freeway era with increasing demand for ground transportation. Rapid economic development in this stage provided good conditions for constructing China's transport system at the end of the 20th century. China's freeway construction can be traced back to the early 1970s and gained its real growth in the 1980s and 1990s, which was an extensive construction period of freeway. By the end of 2008, 35,000 km of freeway, five vertical and seven horizontal, were opened 13 years ahead of schedule. By the end of 2010, China had over 65,000-km freeway, and became the second largest country by freeway length in the world only behind the United States. In this stage, the year of 1981 is chosen for analysis.

(5) High-speed rail stage since the 21st century

Besides the achievements in freeway construction in the 21st century, another important development that needs to be pointed out was the rapid growth of HSR network. In 1997, the beginning of six rounds of China railway speed-up campaign created an excellent platform for the development of HSR. In 2003, the first newly-built HSR (Qinhuangdao-Shenyang) with 250 km/h began its offline and operation. By the end of 2010, China had the world's largest HSR network with a mileage of 8358 km. Today, China has the world's most advanced HSR technology, the best integration skills, the longest operation routes, the highest railway speed, and the biggest HSR capacity. All of them greatly contributed to the development of China's HSR at the beginning of the 21st century. In this stage, the latest year 2012 is chosen for analysis.

From the first events of China's transport development and the different phase characteristics in history, it is easy to notice the importance of transportation innovations in our daily life. The major transportation innovations have exhibited profound and prolonged interdependencies with the growth patterns of national or regional urban systems (Goetz, 1992); the utilization of recent major transportation innovations has related with the growth patterns of urban areas. As transport policies are taken as the approaches and underlying principles adopted by governments to fulfill their responsibilities in the transport sector (Bray *et al*., 2011), it provides a decision-making framework to balance the relationship between economic growth, environmental protection, safety, mobility, accessibility and social services (Delbosc,2012). Just as Rau *et al*. (2012) remarks, accessibility levels of transport development do not depend solely on the choices that individual members of society make, but also reflect wider social, economic, and political factors. Economic development, political decisions, the expansion of urban areas, transport policies, historical wars and terrorisms, all have a strong impact on transport development and its pattern evolvement in China.

4 Results

The transport dominance of all the 3085 counties in the years of 1911, 1935, 1953, 1981 and 2012 were calculated with the methods mentioned above. The data normalization with a minimum value of 0 and a maximum value of 10 was done to compare the results in different years. Meanwhile, the spatial distribution of transport dominance was analyzed by employing the Inverse Distance Weighting method. Finally, all the counties are classified into five types referring to relative research (Dey and Fricker, 1994). The transport dominance value of 4, 6, 7.5 and 8 are selected as the criterions for each type and respectively represents very poor, poor, fair, good, and excellent levels of transport dominance. All analyses are completed with the 3D Analyst tool in ArcGIS 9.3.

4.1 Statistical analysis

The overall transport dominance of China has been improved over time. Though wars, natural disasters and economic crisis in the last 100 years have destroyed or blocked the development of transportation in China, the overall system is constantly improved and finally well developed. In 1911, the overall transport dominance in China is 4959, and the average value is 1.61. Twenty years later, China's transport dominance nearly doubled and reached

8542 in 1935. Due to the damages of the War of Resistance Against Japan (1937–1945) and the liberation war (1946–1950) to transport infrastructures, China's transport dominance was highly reduced in this period. However, three to four years later after the founding of New China in 1949, the transport dominance gradually bounced back to the prewar level. The overall transport dominance was 9604 in 1953, almost the same as that of 1935. Meanwhile, the average value of transport dominance in 1953 increased from 2.77 in 1935 to 3.11 in 1953. In 1981, China's overall transport dominance reached 12540, and the average value of all counties was 4.07, over 2.5 times of that in 1911. In 2012, China's overall transport dominance was 17,810, an increase of 42.03% compared with the year 1981, and the mean value was 5.77, 3.58 times of that in 1911.

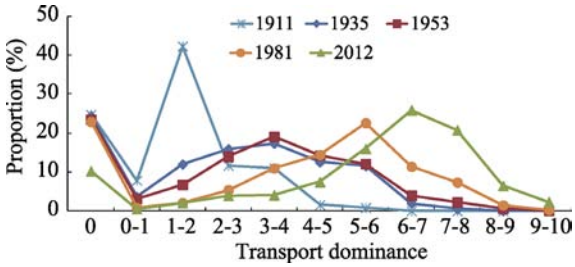

Figure 2 Proportion of counties with different transport dominance values, 1911–2012

Transport dominance range has gradually converged for all counties, as shown in Figure 2. All the proportions of counties in each transport dominance range were less than 30% (excluding the range of 1–2 in 1911). Meanwhile, the proportion difference between the five groups of transport dominance range was reduced. The curve of transport dominance proportion changed little between 1935 and 1953. From 1981 to 2012, the proportion of transport dominance rose and fell between 0.1% and 25.9%. What's more, the peak value of transport dominance gradually increased from 3–4 in 1935, to 5–6 in 1981, and finally reached 6–7 in 2012. Therefore, China's transport dominance has been improved, and its spatial distribution has become more balanced in the last 100 years.

Only a few counties had good transport infrastructure and excellent or good transport dominance in the last 100 years. From the late 19th century to the early 20th century, seaport was an important transport mode influencing transport dominance value. The areas with poor transport dominance accounted for 0.92% of national territorial areas in 1911. In 1935, before the outbreak of the War of Resistance Against Japan, the number of counties with very poor transport dominance value decreased to around 750, with 84.82% of national territorial areas. Meanwhile, areas with poor transport dominance value increased from 0.92% of the whole country in 1911 to 14.05% in 1935. Areas with fair dominance value in 1953 increased by 2.6 times compared to that of 1935. In the same year, 34 counties with good transport dominance and 15 counties with excellent transport dominance covered an area of 35,235 km^2 and 11701 km^2 respectively. The areas with very poor transport dominance dropped from 98.08% in 1911 to 59.41% in 1981. On one hand, areas with good transport dominance expanded from 35,235 km^2 in 1953 to 131,394 km^2 in 1981 (Figure 3). On the other hand, the percentage of areas with good and excellent transport dominance was still very low – less than 0.15% both in 1911 and 1935, less than 1.5% both in 1953 and 1981. In 2012, areas with good and excellent transport dominance only accounted for 6.9% and 4.01% respectively. Therefore, China's transport infrastructures still have enough space for improvement in the future.

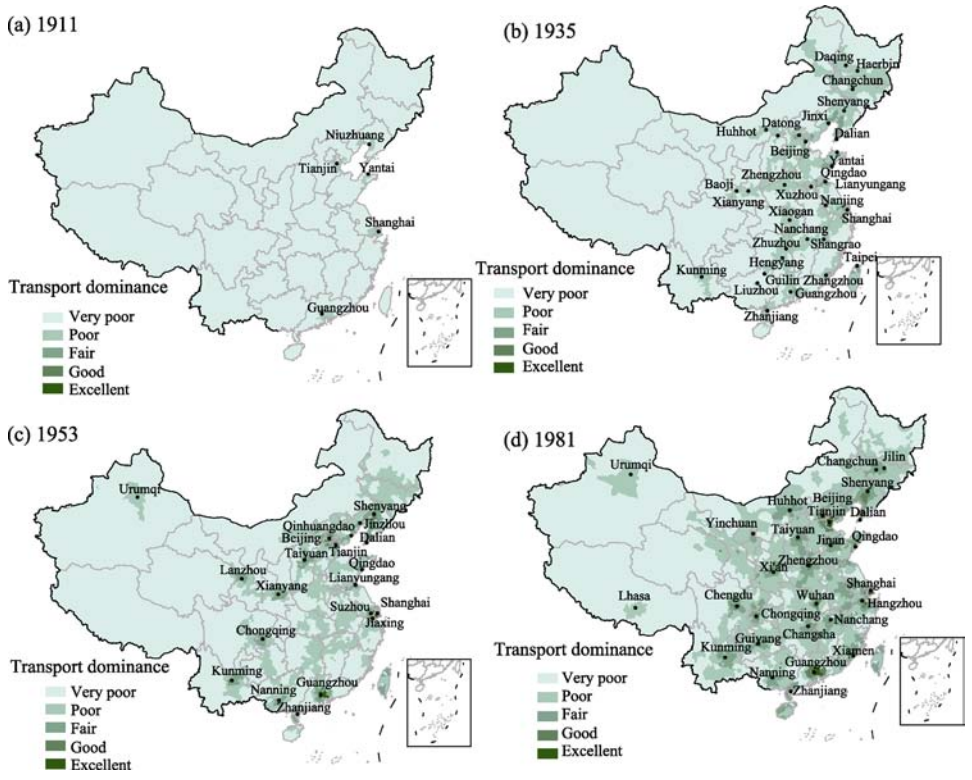

Figure 3 Spatial distribution of transport dominance 1911–1981

4.2 Spatial evolution

Not only the value of transport dominance rose substantially during the last 100 years, but also the spatial pattern and its regional divergence have changed significantly. From the late 19th century to the early 20th century, areas with very poor transport dominance mainly distributed in Northeast China, the greater Beijing area, and coastal areas. Political, economic centers and military spots in inland areas also had comparative advantages. However, there were few areas with railway access or no trading ports during this period in Northwest China and Southwest China. In this period, transport dominance was obviously affected by the limitation of transportation types. As railway construction just started in Northeast China, most of the inland areas, including that along the Yangtze River had no railway access at that time. Limitation of transportation types led these areas with very poor transport dominance. Due to the difference of geographical location and historical conditions, some areas gained good transport dominance while others did not. Relied on central cities such as Tianjin, Shanghai, Guangzhou, and Jiaozhou Bay in Shandong Province, the Bohai Bay Rim area, the Yangtze River Delta and the Pearl River Delta gained good transport dominance. Because of the construction of new ports including Niuzhuang (near the Yingkou seaport in Liaoning Province), Tianjin, Yantai (in Shandong Province), Shanghai and Guangzhou (in Guangdong Province), some dispersed areas along the coast lines gained great improvements of transport dominance in this period.

From the early 20th century to the 1930s, with the expansion of railway network and the

initial construction of highway, areas with good transport dominance were obviously distributed along the major transport lines. The organization effect and the spatial effect of railways built in Northeast China were increased during this period of time, and the spatial pattern of areas with good transport dominance was turned into linear distribution along the railways from sporadic areas in the coastal areas. Areas with poor transport dominance had grown by nearly 15 times, increasing from 88,093 km^2 in 1911 to 1,295,412 km^2 in 1935, and areas with fair transport dominance reached 11,212 km^2 in 1935 (Table 2). Large areas in North China and south of the Yangtze River, such as Hunan, Hubei and Jiangxi, were greatly improved by transport dominance and were followed by areas in West China, such as Guangxi, Yunnan, Shanxi and Gansu provinces where sporadic areas or block-shaped with poor transport dominance appeared in the period. Particularly in the Bohai Bay Rim, the Yangtze River Delta, and the Pearl River Delta, these areas had good transport dominance with much influence from the coastal treaty ports of the western coercion and aggression activities in this period. Compared with the spatial pattern in 1911, areas with very poor transport dominance decreased, while areas with fair transport dominance increased. Besides Northeast China, North China and East China were turned into the new-growth points of transport dominance. Areas with fair transport dominance shifted from major central cities to a much larger scale in Central China and East China. With the construction of highways, railways' effects on regional transport dominance have been decreased. Compared with railways, highways have advantages in agility and high-density service network. The spatial pattern of China's transport dominance has changed gradually from linear structure to block-shaped structure in this stage.

Table 2 Statistics of areas by transport dominance during the last 100 years

Transport dominance		Year				
		1911	1935	1953	1981	2012
Very poor	Number of counties	3011	2261	2052	1303	644
	Area (km^2)	9,415,732	8,061,029	7,645,895	5,703,774	2,957,907
	Area percentage (%)	98.08	84.82	79.64	59.41	30.81
Poor	Number of counties	74	744	816	1145	521
	Area (km^2)	88,093	1,335,486	1,547,199	2,873,956	2,143,983
	Area percentage (%)	0.92	14.05	16.12	29.94	22.33
Fair	Number of counties	0	75	168	504	1262
	Area (km^2)	0	101,539	263,795	767,331	3,354,976
	Area percentage (%)	0.00	1.07	2.75	7.99	34.95
Good	Number of counties	0	5	34	99	384
	Area (km^2)	0	5771	35,235	131,394	662,020
	Area percentage (%)	0.00	0.06	0.37	1.37	6.90
Excellent	Number of counties	0	0	15	34	274
	Area (km^2)	0	0	11701	27369	384940
	Area percentage (%)	0.00	0.00	0.12	0.29	4.01

From the 1930s to the 1950s, the characteristics of transport construction before new China showed a slow progress in constructing highways and airports. The evolution of spatial pattern of transport dominance in this period was highly correlated with the location of node cities, such as Lanzhou, Nanning and Chongqing. These areas gained more advantages and regions with poor transport dominance extended to West China. As the civil aviation entered into China, the transport dominance value has increased significantly at the national level. However, the construction of airports in Southwest China was relatively slow and the transport dominance value there lagged behind other regions. This also explains why regions in Southwest China had very poor transport dominance in the 1930s. While highways and airport construction were relatively slow in Northeast China compared to Central and East China, and original transportation advantages in these areas brought by railways declined significantly. In addition, compared to the spatial pattern of transport dominance in 1935, the distribution of areas with good transport dominance became more fragmented in 1953. During the 1930s to the 1950s, not only areas with poor transport dominance, but also areas with fair and good transport dominance expanded quickly. More and more regions in Northwest China gained fair transport dominance. Areas with good transport dominance in the north of the Bohai Bay Rim, Yangtze River Delta, and Pearl River Delta expanded in a much larger scale than before. The spatial evolution trend that areas with good transport dominance had been moving from Northeast China to the rest areas of China became increasingly clear.

After the implementation of the reform and opening–up policy in the late 1970s, areas with very poor transport dominance shrunk rapidly, and areas with poor transport dominance expanded in a large scale. In East and Central China, most areas with good, fair, and poor transport dominance were located around central cities, but part of them began to expand to remote cities. Central cities' spatial organization and aggregation effect on transportation construction emerged gradually. Around 1981, with the construction of airports and freeways all over China, areas with fair and good transport dominance became more fragmented. Transport dominance in Beijing, Tianjin, and the Pearl River Delta continued to step forward. And areas with excellent transport dominance appeared in Beijing, Tianjin, Yangtze River Delta, and Pearl River Delta in this period.

In 2012, the overall transport dominance in China was much better than that in the late 1970s, the areas with very poor transport dominance were much less, and most of them only located in West China and the border areas, such as the Qinghai-Tibet Plateau and remote areas in Xinjiang, Inner Mongolia, and Heilongjiang provinces (Figure 4). Although the Chinese government implemented a lot of preferential policies in border areas and ethnic minorities living areas, the transport infrastructures in those areas still developed slowly because of the unfavorable topography and severe natural conditions. Meanwhile, the transport dominance in southeastern coastal areas and Central China was improved greatly owing to the rapid concentration of population and economic development. Areas with very poor transport dominance no longer existed in these areas, and areas with good transport dominance continuously expanded along the railway and highway extension directions, and effectively reflected the spatial organization effects of interactive development of cities and transport, especially in the Bohai Rim, the Yangtze River Delta, the Pearl River Delta, and the Chengdu-Chongqing region. Areas with excellent transport dominance had spread gradually to the urban agglomerations regions or along the urban belt regions. The construc-

tion of transport infrastructure and spatial organization always started from hub cities first, then gradually expanded to transport axis, and finally evolved to polygons which were driven by the Hub-and-Spoke System effect.

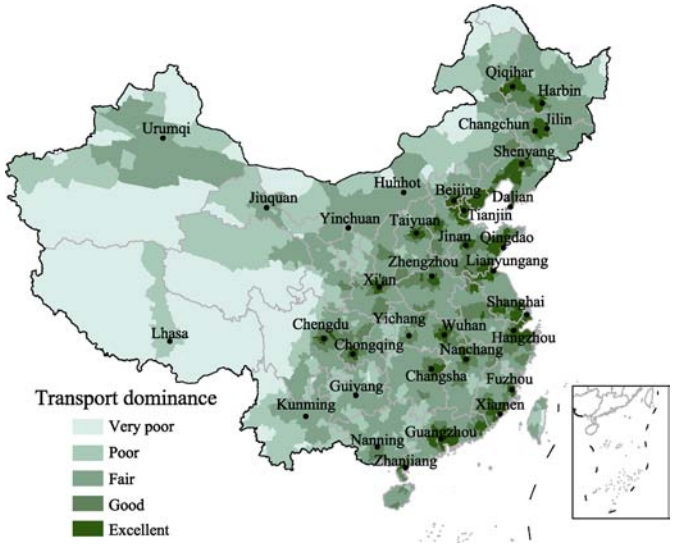

Figure 4 Spatial distribution of transport dominance in 2012

In conclusion, the last 100 years since the Chinese Revolution in 1911 were the most impressive years in China for both modernization development and social civilization progress. Transport technology innovations, socio-economic development and national policies have changed the development and spatial expansion of transport infrastructures in China, which is reflected by the unique historical characteristics in each time period. The crux of transport development was not only the change and evolution of the transport dominance value, but also its influences on the spatial organization and spatial efficiency of socio-economic development. In the early 20th century, the first railway designed by Chinese, from Beijing to Zhangjiakou, was constructed. In the 1930s, highway construction became a big issue in national transport planning. Twenty years later, China's Military Civil Aviation Bureau explored new routes, and promoted the new progress of Chinese civil aviation. In 1988, the freeway from Shanghai to Jiaxing brought the first freeway in the mainland of China. Each step of the above process was a remarkable milestone in the endless effort that China's transport system had been attempted to overtake the highest transportation technologies and skills in the world. One hundred years ago, China's transport system was too weak to benefit the Chinese nation. All the seaports were controlled by foreigners. But today, China owns the largest transport system, the longest HSRs, and the most advanced transport technologies of HSR in the world. Historically, "south China take boat and north China take carriage" was an active description for China's transportation. Today, China's transportation has progressed through the railway era, highway era, high-speed rail era which includes freeway, HSR and air transportation. The whole progress brought obvious effects on time-space convergence. People living in two cities such as Beijing and Tianjin, feel closer than ever before. With the improvement of transport infrastructures, more and more people could enjoy a bet-

ter life style and improved welfare.

5 Conclusions

5.1 Improvement of transport development by advances in transport technologies

The spatial evolution of China's transport dominance has a close relationship with the construction of transport infrastructures. Advancements in transport technologies have played an important role in driving the development of transport infrastructures and the expansion of transport network. Firstly, seaports, airports and short-distance transport drive the distribution of transport dominance into sporadic areas or punctuated patterns; Secondly, railways, highways, freeways and HSRs push these spots and sporadic areas into linear areas or zonal areas; new seaports, airports and short-distance transport reshape the above pattern into a new round of change and development. Based on this process, the spatial organization of China's transport dominance evolved from point driving axis, axis radiating the point and points driving axis in return. It was in this way that China's transport infrastructure contributed to regional development with high efficiency.

Based on transport innovations and transport development history since the Chinese Revolution in 1911, China's transport development and the evolvement pattern went through five stages with the emergence of railway, highway, voyage, freeway, and HSR in the last 100 years. In the five stages, the appearance of a new transport mode always affected the spatial distribution of transport dominance in earlier stages. For instance, the construction of ports changed the former pattern formed by railways, and airports improved the former pattern formed by highways. These two transport modes led to a relatively rapid expansion of areas with fair and good levels of transport dominance in East China and Central China. The overall transport dominance of China increased from 4959 in 1911 to 17810 in 2012, and the average value in 2012 was 3.58 times of that in 1911. China's transport dominance improved a lot and became more even distributed in the last 100 years. Not only the percentage of areas with good and excellent transport dominance increased from less than 0.15% in 1911 to more than 10.91% in 2012, the percentage of areas with very poor transport dominance reduced by 68%, but also the peak value of transport dominance gradually increased from 3–4 in 1935, to 5–6 in 1981, and finally reached 6–7 in 2012. In a word, the spatial evolution of transport dominance is closely related to the appearances and improvements of modern transport modes. It is the combination of time dimensionality, space dimensionality, technology dimensionality that drove the evolvement of regional transport dominance in the last 100 years. As the percentage of area with good and excellent transport dominance is still very small, e.g. the latter equals to 4.01%, there is still great potential for improving China's transport infrastructures in the future.

5.2 Uneven and hierarchical expansion mode of transport dominance from scattered plots to line corridors, and then to continuous areas

Areas with better transport dominance in East and Central China exhibited a point - line - polygon spatial expansion model. From the late 19th century to the early 20th century, with

the pressure of foreign governance and limited transport modes, the spatial distribution of transport dominance was mainly affected by coastal ports. In the 1930s, with the progress of rail technologies and the stable construction of highways, China's transport dominance obviously presented a linear pattern along the trunk railways and highways. What should be pointed out particularly was that areas with poor transport dominance in Northeast China turned from pieces or block-shaped structures in the Bohai Bay Rim to linear patterns along railways. In the 1950s, with the expansion of rail network and highway network, areas with good transport dominance were expanded to the north of the Bohai Bay Rim, the Yangtze River Delta, and the Pearl River Delta. After the 1980s, areas with very poor transport dominance decreased a lot in East China and Central China, especially in the greater Beijing area, the Yangtze River Delta and the Pearl River Delta. With the development of transport modes in the five stages, transportation advantages of central cities began to emerge because of their spatial location and aggregation. Today, China is covered by different levels of transport dominance and brings out the spatial distribution of hierarchical areas with different transport dominance.

In conclusion, areas with comparative advantages of transport dominance in the last 100 years firstly showed dotted patterns in coastal areas, and turned into a linear pattern with the construction of rails in Northeast China and North China. Secondly, areas with comparative advantages of transport dominance gradually expanded into East China, Central China and West China with the expansion of highway network and the construction of new airports. Lastly, areas close to transport hubs and transport lines always have advantages in transport dominance. The evolving pattern of transport dominance in China not only shows the characteristics of spatial distribution, but also follows the rule of "point - line - polygon spatial expansion model".

5.3 Economic development, urban systems, and policies governed China's transport development and its spatial distribution

Analyzing the evolvement of transport dominance in China from 1911 to 2012, the following conclusions can be drawn: (1) Although China's transport dominance is unevenly distributed, the spatial disparity is gradually decreased. Areas with advantages in transport dominance expanded to Central China and West China from East China during the five stages of transport development. (2) The spatial evolution of China's transport dominance had a close relationship with economic development and national policies. The change and spatial distribution of China transport dominance in the last 100 years cannot be separated from the historical background and government policies in each period. For example, the Chinese Revolution in 1911 caused the Qing government to sell the right of railway construction. Sun Yatsen proposed the grand comprehensive railway construction plan in the Constructive Scheme, where 200,000 km railways and 3 trunk lines were designed to connect the whole China. The War of Resistance Against Japan inflicted serious damage to the construction of highways in China, while the founding of People's Republic of China brought the airport construction and laid a solid foundation to the development of China's civil aviation. The reform and opening-up policy had brought the first freeway of China and pushed the development of China's transport infrastructures into a high-speed period. What

is more, China's central government released various plans after the financial crisis in 1997 and 2008 such as the Medium and Long-term Railway Network Plan, the National Expressway Network Plan, China's Western Development Strategy, and Revitalization of Old Industrial Base of Northeast China, etc. These plans spurred the rapid development of transport network especially in freeways, airports and HSRs. In conclusion, policies in different historical periods had played a strong role in promoting and guiding the development of transport infrastructures development and profoundly impacted the scale and spatial distribution of each transport mode (Jin *et al*., 2012). (3) The uneven distribution of transport dominance was closely related to the socio-economic development and urban systems. Areas with advantages transport dominance were mainly concentrated in Tianjin, Shanghai, and Guangzhou in 1911, and then expanded to the greater Beijing area, the Yangtze River Delta, the Pearl River Delta, and Northeast China in 1935. Areas with good transport dominance emerged in transport hubs in 1953 and then further spread to provincial capitals and well-developed areas in East China, Central China and West China in 1981. As the socio-economic development level is better than West China, comprehensive transport systems with higher transport dominance value have been gradually formed in East China and Central China in nowadays. The uneven distribution of transport dominance reflects the spatially unbalanced development of economy and cities as well. Usually the higher the transport dominance, the better the economy and cities develop, and vice versa. However, the spatial coupling analysis between regional transport dominance and socio-economic development such as urban agglomeration, industrial layout, economic growth, are not researched in the paper due to the lack of data. The relevant issues and in-depth discussion need to be addressed in the future.

Acknowledgement

All the authors gratefully thank the reviewers and editor for their insightful and constructive comments. We especially thank Xi Hu at Environmental Change Institute, University of Oxford in the United Kingdom for editing the manuscript.

References

Bogart D, 2009. Inter-modal network externalities and transport development: Evidence from roads, canals, and ports during the English industrial revolution. *Networks and Spatial Economics*, 9(3): 309–338.

Bray D J, Taylor M A P, Scrafton D, 2011. Transport policy in Australia: Evolution, learning and policy transfer. *Transport Policy*, 18(3): 522–532.

Delbosc A, 2012. The role of well-being in transport policy. *Transport Policy*, 23(9): 25–33.

Dey S S, Fricker J D, 1994. Traffic impact analysis and impact fees in state departments of transportation. *Journal-Institute of Transportation Engineers*, 64(5): 39–44.

Ducruet C, Notteboom T, 2012. The worldwide maritime network of container shipping: Spatial structure and regional dynamics. *Global Networks*, 12(3): 395–423.

Fleming D K, Hayuth Y, 1994. Spatial characteristics of transportation hubs: Centrality and intermediacy. *Journal of Transport Geography*, 2(1): 3–18.

Goetz A R, 1992. Air passenger transportation and growth in the US urban system, 1950–1987. *Growth and Change*, 23(2): 217–238.

Henrike R, Amaya V, 2012. Spatial (im)mobility and accessibility in Ireland: Implications for transport policy. *Growth and Change*, 43(4): 667–696.

Huang X Y, Cao X S, Li T, 2011. The relationship between regional transport superiority and regional economic performance in Hainan. *Geographical Research*, 30(6): 985–999. (in Chinese)

Isard W, 1960. Methods of Regional Analysis: An Introduction to Regional Science. Cambridge, MA: MIT Press.

Jin F J, Ding J X, Wang J E *et al*., 2012. Transportation development transition in China. *Chinese Geographical Science*, 22(3): 319–333.

Jin F J, Wang C J, Li X W *et al*., 2010. China's regional transport dominance: Density, proximity, and accessibility. *Journal of Geographical Sciences*, 20(2): 295–309.

Jin F J, Wang F H, Liu Y, 2004. Geographic patterns of air passenger transport in China 1980–1998: Imprints of economic growth, regional inequality, and network development. *Professional Geographer*, 56(4): 471–487.

Leung C K, 1980. China: Railway patterns and national goals. The University of Chicago Department of Geography Research Paper. Chicago: University of Chicago Press.

Li W G, Bai Q L, 2011. The evolution analysis China's comprehensive transportation system in the last 30 years. *Future and Development*, (1): 28–32. (in Chinese)

Litman T, 2003. Measuring transportation: Traffic, mobility, and accessibility. *ITE Journal*, 73(10): 28–32.

Taaffe E J, Morrill R L, Gould P R, 1963. Transport expansion in underdeveloped countries: A comparative analysis. *Geographical Review*, 53(4): 503–529.

Urea J M, Menerault P, Garmendia M, 2009. The high-speed rail challenge for big intermediate cities: A national, regional and local perspective. *Cities*, 26(5): 266–279.

Wang C J, 2007. Evolution and developing mechanism of port distribution system in China. *Acta Geographica Sinica*, 62(8): 809–820. (in Chinese)

Wang C X, Wang G F, Liu R C *et al*., 2010. Empirical research on evaluation model of transport superiority degree: A case study of Shandong Province. *Human Geography*, 25(1): 73–76. (in Chinese)

Wang D R, 1986. The Distribution of China's Transportation. Beijing: Science Press, 78–86. (in Chinese)

Wang J E, Jin F J, Mo H H *et al*., 2009. Spatiotemporal evolution of China's railway network in the 20th century: An accessibility approach. *Transportation Research Part A: Policy and Practice*, 43(8): 765–778.

Wang Q Y, 2007. The evolution process and thinking of China's transportation development. *Journal of Transportation Systems Engineering and Information Technology*, (1): 1–11. (in Chinese)

Zhang P C, Peeta S, Friesz T, 2005. Dynamic game theoretic model of multi-layer infrastructure networks. *Networks and Spatial Economics*, 5(2): 147–178.

Zhang W C, Wang J E, 2008. Changes on layout of transportation and traffic in China since reforming & opening-up. *Economic Geography*, (5): 705–710. (in Chinese)

Zhang W C, Wang J E, Jin F J *et al*., 2009. 60 years of new China: Development and change of transportation. *Economic Geography*, (11): 1770–1776. (in Chinese)

Zhu W Y, Ma T S, 2009. The history of China's transportation structure development. *Transportation Enterprise Management*, (5): 62–63. (in Chinese)