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Measuring the spatiotemporal variation and evolution of transport network of China's megaregions

SONG Ge[1], YANG Jiawen[2]

1. School of Management, University of Science and Technology of China, Hefei 230026, China;
2. School of Urban Planning and Design, Peking University, Shenzhen Graduate School, Shenzhen 518055, Guangdong, China

Abstract: Megaregion has become a prominent feature of modern China. Reflecting upon China's recent path of transport infrastructure construction, this research examines the spatiotemporal characteristics of transport network development and its accessibility impacts in China's ten megaregions from 1982 to 2010. Using historical transport network data and multiple national censuses (1982, 1990, 2000 and 2010), we computed two levels of indicators of megaregional transport network: megaregion level and county level, and analyzed the intra-megaregion and inter-megaregion disparities of transport network of the ten megaregions of China. Transport networks at the megaregion level are measured by three indicators: 1) transport network density; 2) infrastructure endowment per capita; and 3) size of transport network's standard ellipse. Two accessibility indicators for measuring transportation network at the county level are calculated: weighted average travel time and potential accessibility. The research results show the following: 1) Road and rail network densities witnessed the greatest growth during the 2000–2010 period, and growth was more significant for railway network. 2) By 2010, average road endowments per capita in inland megaregions became higher than in coastal megaregions, while average rail endowments per capita in coastal megaregions became higher than in inland megaregions. 3) The sizes and directions of the standard deviational ellipses of road and rail network changed continuously during the study period. However the changes of road network ellipses were relatively small, while the changes of railway network ellipses were more significant. 4) Megaregions have all benefited significantly from transportation infrastructure improvement in the past few decades in terms of WATT and potential accessibility, but the three giant megaregions benefited most.

Keywords: China; megaregions; transport network; accessibility; GIS transport network model

1 Introduction

Megaregion has become a prominent feature of modern China. The increasingly linked

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Author: Song Ge (1983–), PhD and Associate Professor, specialized in urban and regional economics, transportation geography. E-mail: gsong@ustc.edu.cn

metropolitan areas and the increasingly regionalized nature of Chinese economy led the Central Government to promote megaregion as a key policy framework. A very important concept of 'megaregion' brings is its emphasis on flows, which captures the interdependencies between constituent cities of the entire system (Taylor, 2004; Taylor, 2005; Hall and Pain, 2006). Transport infrastructure is a crucial factor for the formation and development of megaregions, and also one of the important relationships that component cities within a megaregion share.

In China, extensive transport infrastructure construction and upgrade projects, including high-speed railways, highways, airports and other traditional transportation modes have been used to strengthen existing links and establish new connections between cities within megaregions and between megaregions (Figure 1). China's highway development started in the 1980s; by the end of 2014, China has constructed the largest highway system with a total length of 110,000 km (NBSC, 2015). Railway, particularly high-speed railway is being promoted as a new highly efficient alternative to road transportation. Since the operation of the first high-speed rail line in 2003, Qinhuangdao-Shenyang line, China's expanding high-speed railway network had a total length of 16,000 km in operation by the end of 2014 (NRAPRC, 2015).

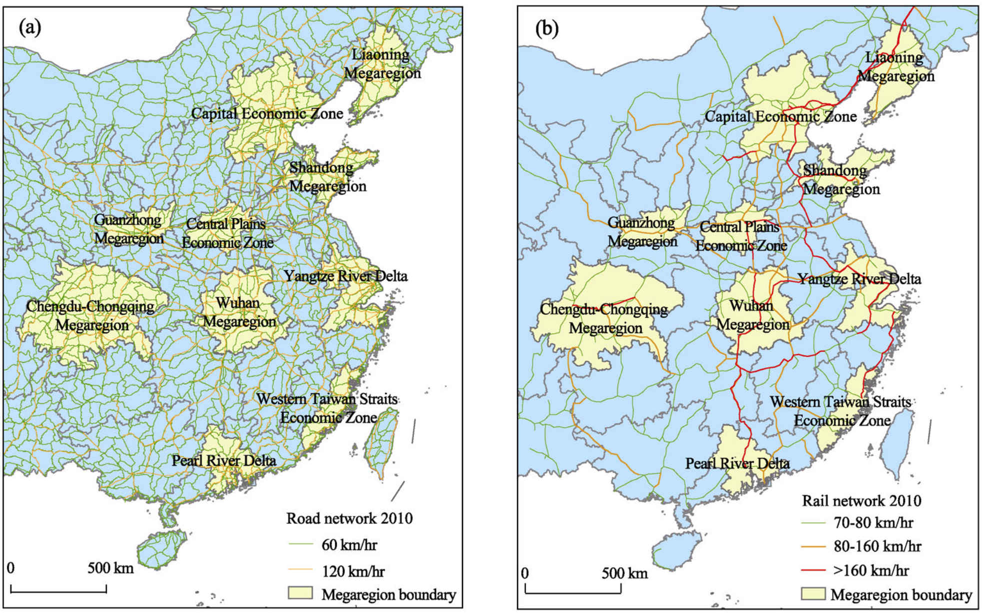


Figure 1 Road and railway network of China (2010)

The completion of megaregional transport systems strengthened connections and saved journey times between cities. With cities reached from each other within shorter travel time, regional barriers in terms of travel cost were reduced significantly during the past several decades. However, the impacts of China's transport infrastructure construction have been uneven, and disparities in the impacts of transport infrastructure are significant (Jiao *et al.*, 2014). These disparities exist not only between regions and megaregions, but also within megaregions.

Reflecting upon China's recent path of transport infrastructure construction, this research examined the spatiotemporal characteristics of transport network development and its accessibility impacts on China's ten megaregions from 1982 to 2010. Using historical transport-network data and multiple national censuses (1982, 1990, 2000 and 2010), we computed two levels of indicators of megaregional transport network: megaregion level and county level, and analyzed the intra-megaregion and inter-megaregion disparities of transport networks of the ten megaregions of China.

2 Literature review

A number of studies have examined the impacts of the recent highway development on accessibility. Li and Shum (2001) analyzed the impacts of China's National Highway System development program on the pattern of accessibility of 31 provincial capitals. They found greater improvements in nodal accessibility of the major coastal cities in the initial stage (1990–2000) of highway development, and argued that the highway system would bring more balanced development in the later stage (2000–2010). Cao *et al*. (2005) analyzed the spatial structure of accessibility of cities connected by the national highway system. Their results found the 'core-periphery' pattern with the top 50 most accessible cities concentrated in the middle of eastern China.

The recent large-scale rapid development of high-speed rail in China has been a focus of transportation research. Studying 49 major cities of China, Cao *et al*. (2013) found that central-eastern cities would gain more benefits based on the results of Weighted Average Travel Time (WATT) and daily accessibility measures, and cities along Beijing-Shanghai axis and in the Pearl River Delta region have high values of potential accessibility. Jiao *et al*. (2014) con-ducted a national study of 337 prefecture-level cities. Their results showed that high-speed rail network will lead to national time–space convergence, but it will also increase the inequality of nodal accessibility between eastern, central, and western regions, between cities of different sizes and at different distances to HSR stations. Shaw *et al*. (2014) employed a timetable-based accessibility evaluation approach to study the impacts of high speed rail on railroad network accessibility. Their study confirmed the 'corridor effect' of HSR network. Wang *et al*. (2009) studied the expansion of China's railway network from 1906 to 2000, and the evolution of its spatial accessibility. Their study revealed that accessibility contours showed a concentric pattern around North China, and Zhengzhou is the most accessible city of China. Jin *et al*. (2010) employed a multimodal approach integrating multiple transport modes including railway, highway, water and air to study China's regional transport network in 2006. Their study defined transport dominance at the county level including three components: transport network density, proximity to transport hubs or trunk roads, and accessibility. Their results showed that the three giant megaregions – Yangtze River Delta, Capital Economic Zone, and Pearl River Delta had the highest level of transport dominance.

A number of studies focused on individual megaregions and examined the accessibility impacts of recent transport infrastructure development. Wu *et al*. (2006) studied the accessibility impacts of highway development in the Yangtze River Delta from 1986 to 2005. Their study found that the evolution of regional spatial patterns of accessibility exhibited an inverted U-shaped trend, with regional accessibility level diverging during the 1986–1994 period, and converging during the 1994–2005 period. Hou and Li (2011) analyzed the accessibility implications of expressway and inter-city railway development in the Pearl River Delta during the period 1990–2020, measured by three indicators: average travel time, economic potential and daily accessibility. Their study found high unevenness in regional accessibility prevailed in the initial stages of expressway and inter-city railway development, which is followed by more balanced spatial accessibility pattern with the maturation of regional transport network. Wu *et al*. (2010) examined the evolution of transport accessibility in the Yangtze River Delta in 1986, 1994, and 2005. They calculated the Integrated Weighted Average Travel Time composing road, rail, water and air transport. Their results indicated that the improvement of accessibility from transport network development was faster in the period of 1994–2005 than 1986–1994, and Shanghai and the area surrounding Taihu Lake are the regions with the highest accessibility levels.

Most of the existing studies are nationwide analyses of transport network. Studies focusing on megaregions have been limited. The Pearl River Delta and the Yangtze River Delta are often the target areas for research on megaregions' transport network. Other megaregions are often neglected, and there has been no comprehensive study including China's ten megaregions. In addition, most studies are at the more aggregate prefecture level. The effects of spatial differentiation at the sub-regional level are hidden or lost in analyses at aggregated spatial scales. Therefore analyses of transport infrastructure at more detailed spatial scales are much needed, which are able to reveal the spatial differentiation patterns. Another major limitation of the existing literature is that studies on transport infrastructure tend to consider individual modes of transport, and the utilization of multi-modal transport network methodology has been limited. However, China's transport infrastructure network has developed into a modern, integrated stage, in which various transport modes have been developed comprehensively, and need to be coordinated (Jin *et al*., 2008; Jin *et al*., 2012). In addition, accessibility to the network is an important factor when analyzing rail and especially high-speed rail network, as stations on high-speed railway lines are usually at hundreds of kilometer distance from each other (Gutiérrez *et al*., 1996). This research tried to fill the gap in previous literature. Using county-level data at a much finer scale, this research employed a multi-modal approach integrating road and railway, and conducted a comprehensive study of the ten megaregions of China.

3 Methodology

In this research, the boundaries of China's ten mega-city regions follow the most commonly accepted definition given by the National Development and Reform Commission of China (Xiao and Yuan, 2007). The definitions of the ten megaregions are as follows:

- Capital Economic Zone: Beijing and Tianjin, surrounded by 8 cities from Hebei Pronvince, including Shijiazhuang, Baoding, Qinhuangdao, Langfang, Cangzhou, Chengde, Zhangjiakou and Tangshan.
- Central Plains Economic Zone: Zhengzhou and Luoyang, surrounded by 7 cities from Henan Province, including Kaifeng, Xinxiang, Jiaozuo, Xuchang, Pingdingshan, Luohe and Jiyuan.
- Chengdu-Chongqing Megaregion: Chongqing and Chengdu, surrounded by 13 cities

from Sichuan Privince, including Zigong, Luzhou, Deyang, Mianyang, Suining, Neijiang, Leshan, Nanchong, Meishan, Yibin, Guang'an, Ya'an and Ziyang.

- Guanzhong Megaregion: Xi'an, surrounded by Xianyang, Baoji, Tongchuan and Weinan.
- Liaoning Megaregion: Shenyang and Dalian, surrounded by Anshan, Fushun, Benxi, Dandong, Liaoyang, Yingkou, Panjin and Tieling.
- Pearl River Delta: Guangzhou, Shenzhen, and Hong Kong, surrounded by Zhuhai, Huizhou, Dongguan, Qingyuan, Zhaoqing, Foshan, Zhongshan, Jiangmen and Macao.
- Shandong Megaregion: Jinan, Qingdao, Yantai, Zibo, Weifang, Weihai, Dongying and Rizhao.
- Western Taiwan Straits Economic Zone: Fuzhou and Xiamen, surrounded by Zhangzhou, Quanzhou, Putian and Ningde.
- Wuhan Megaregion: Wuhan, surrounded by 14 cities from 3 provinces, including Huangshi, Ezhou, Huanggang, Xiantao, Qianjiang, Xiaogan, Xianning, Tianmen, Suizhou, Jingmen, Jingzhou, Xinyang , Jiujiang and Yueyang.
- Yangtze River Delta: Shanghai, surrounded by 6 cities from Zhejiang Province and 8 cities from Jiangsu Province. These cities include Hangzhou, Jiaxing, Huzhou, Shaoxing, Ningbo, Zhoushan, Nanjing, Yangzhou, Changzhou, Taizhou, Zhenjiang, Wuxi, Nantong and Suzhou.

Historical GIS transport infrastructure data from 1982 to 2010 is used in conjunction with China's county-level census data (1982, 1990, 2000 and 2010) to analyze spatiotemporal characteristics of megaregional transport networks and their accessibility impacts. Attribute information of transport infrastructure were coded based on data from multiple sources, including historic maps, documents and online records. Relevant attribute information includes construction time, upgrade/expansion time, roadway design speed and railway service speed. It should be noted that design speed adopted in this research may not reflect the actual travel speed, especially in some highly congested areas. However actual travel speed is not available at the nationwide level, and thus this research uses design speed to calculate travel time. This research develops two levels of measurements for transport network: megaregion level, and the county level.

3.1 Megaregion level

Transport networks at the megaregion level are measured by three indicators: 1) transport network density; 2) infrastructure endowment per capita; and 3) size of transport network's standard ellipse.

The most popular network measurement – network density measures the territorial occupation of a transport network in terms of length of links (L) per unit of land area (S). The higher the network density is, the more developed a transport network is. However this measure does not take into consideration the population served by the infrastructure network, and thus ignores the demand side of transport infrastructure. For this reason, road length per capita is also calculated. This research adopts the length of transport infrastructure as a proxy for regional infrastructure endowment instead of monetary indicators, because of, first, the constraints in terms of data availability and, second, its capacity to capture in a direct way the development of transport infrastructures. These two indicators are numerical indicators, which do not reflect the spatial dimension of transport network. Therefore, a third measurement is proposed – the size of transport networks' standard ellipse. It is calculated by GIS spatial statistics tool – Directional Distribution: Standard Deviational Ellipse. It measures the spatial distribution of transport infrastructures for the individual megaregions.

Simply taking physical numbers may disguise some important measurement. Infrastructure upgrades and speed increases, which are the major transport infrastructure improvements in the last two decades, are not reflected in these measures. In order to reflect infrastructure upgrades and speed improvements, the three measures are modified to include a weight factor for the network segments. The ratio of the designed speed to a standard speed is assigned to each road segment as the weight. In 1982, the average road and rail speed is 40 km/hour, and thus 40 km/hour is used as the standard speed to calculate the weight for each link. The designed/service speed in the following years is listed in Table 1.

Table 1 Road and rail minimum and maximum designed/service speed (km/hour)

Minimum/maximum speed	1990	2000	2010
Road	45–110	55–110	60–120
Rail	48–60	60–120	70–300

3.2 County level accessibility

There is a wide range of indicators of accessibility, reflecting the different approaches to the concept of accessibility (Gutiérrez and Urbano, 1996; Gutiérrez, 2001). This research selected two accessibility indicators for measuring transportation network at the county level: weighted average travel time and economic potential.

The first indicator adopts the travel cost approach. The most basic measures of travel cost include travel distance and travel time. Because the recent transportation projects were mainly speed-increasing, therefore this research measures travel time as the travel cost – the average travel time from one local unit to all the other destinations in the same megaregion. A modified approach of the simple travel cost measure–Weighted Average Travel Time (WATT) – is proposed: population weighted travel time (Gutiérrez *et al*., 1996). Population of the destination is assigned to the travel time for each origin-destination pair as the weight. The assumption is that connection to a destination of more activities (symbolized by a large population) is more important than the connection to a destination of smaller population. Therefore the WATT of one local unit is defined as:

$$\text{WATT}_i=\sum_j (\text{time}_{ij}*\text{population}_j) / \sum_j \text{population}_j \quad (1)$$

where i is the county of origin; j is all the other destinations within the same megaregion; Time_{ij} is the network travel time between i and j; population_j is the population of the destination, which functions as the weight for the travel cost.

The second indicator measures the potential megaregion accessibility of economic activities. As summarized by Handy (1993), accessibility has two components: a transportation element or resistance factor and an activity element or motivation factor. The transportation element reflects the ease of travel between locations as determined by the character and quality of service provided by the transportation system and as measured by travel distance, time or cost. The spatial element reflects the distribution of activities, characterized by both the amount and location of different types of activities (Handy, 1993; Handy and Niemeier, 1997). This research adopts the gravity model approach to calculate transport accessibility. It can be interpreted as the volume of activity opportunities that can be accessed from a given point after the travel impediment has been accounted for (Gutiérrez, 2001). Accessibility measurement combines the travel impediment to, and the attractiveness of the destinations in a single indicator (Geertman and Ritsema Van Eck, 1995). In this research, the travel impediment is measured by travel time, and the attractiveness is measured by total population of the destinations. The expression of the potential accessibility model is given as follows:

$$A_i = \sum_j M_j / T_{ij}^{\lambda} \quad (2)$$

where A_i is the potential accessibility of place i; M_j is the 'mass', in this research population of destination j; T_{ij} is the travel time or cost between origin i and destination j; λ is the distance decay or friction parameter, and in this research λ is set to 1. We realize that population is an imperfect measurement for the number of opportunities of destinations, but employment data at the county level is not available at the national scale.

Geographical scale is a very important issue when measuring accessibility, and in fact, results can be different depending on the geographical scale (Gutiérrez, 2001). Megaregion has emerged as the new, natural economic unit, and the underlying assumption is that cities within megaregions have stronger ties. In this paper, we are trying to investigate the accessibility impact of recent road and rail developments in China's megaregions. For this reason, it would seem reasonable to set the study scale within megaregions. However, it should be noted that the measured accessibility in this research is lower than the actual level, especially for the peripheral cities along the boundaries of megaregions. Therefore, the interpretation of the results must be carried out from a megaregion viewpoint: the indicators measure the potential accessibility of each place in the megaregion it belongs to.

Transport networks for the two travel modes considered in this research – by roadway and by railway, are built in ArcGIS 10.2. ArcGIS employs the classic Dijkstra's algorithm to solve the shortest-path problem using travel time of each segment as the weight. For the mode of road, the network only consists of roads. For the mode of railway, multi-modal transport networks consisting of both railway and road are built. Railway is the primary mode of transport, while roads serve as secondary mode. The multimodal network modal performs network analysis using a hierarchical approach that favors traveling on rail, which is the higher level of the hierarchy. The route solver begins by simultaneously traveling forward from the origin stop and backward from the destination stop. Roads are searched until the best transitions to rail are found. The solver then only searches railways, ignoring roads in the lower hierarchical classes, until the path from the origin meets the path going backward from the destination, thereby connecting the origin and destination and finding a route. Penalty times are added to account for boarding/alighting, waiting time and any extra time cost related to transfer between road and rail. An estimated 15-miniute penalty time is added as the transfer time between road and rail mode, and thus a total of 30 minutes is added for each trip. Utilizing ArcGIS network analysis tool, an origin-destination (OD) cost matrix is generated. For each county, the travel time to all the other counties in the same megaregion are calculated on the basis of the length of trip segments and the estimated design/service speed. County accessibility scores by road and by rail are then calculated.

4 Transport network: megaregion level

4.1 Transport network density

Road and rail network densities grew continuously from 1982 to 2010. Generally speaking, coastal megaregions have more connected road network measured by network density than inland megaregions (Figure 2). The average road network densities in coastal megaregions have been consistently higher than inland megaregions throughout the study period (Figure 3a). In 2010, road network densities of two of the coastal megaregions (Capital Economic Zone and Liaoning Megaregion) were below the average level for all the 10 megaregions. In 2010, Yangtze River Delta had the highest scores of both road network density and railway network density. Central Plains Economic Zone had the highest road network density among all inland megaregions, and was the only inland megaregion with road network densities higher than the 10 megaregions' average network density from 1982 to 2010. As for rail network density, the difference between inland megaregions and coastal megaregions had been small until after 2000 when railway network in coastal megaregions witnessed significant growths. Railway densities for inland megaregions were slightly higher than coastal megaregions before 2000, but this trend was reversed in 2010, with coastal megaregions' average rail network density significantly higher than inland megaregions' (Figure 3b).

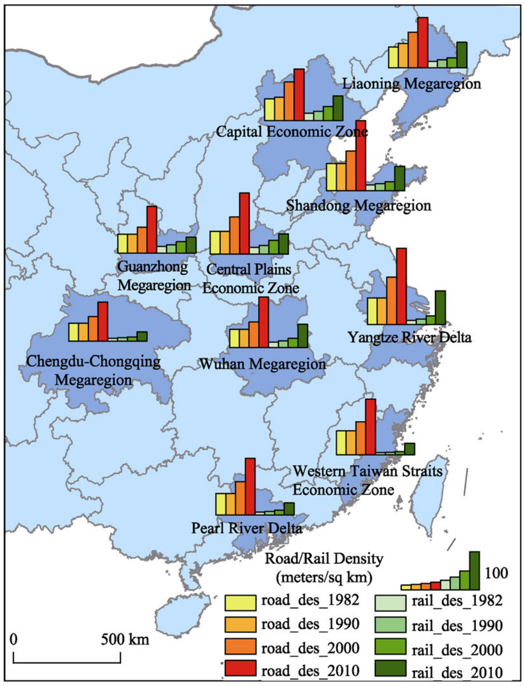


Figure 2 Road and rail network density 1982–2010

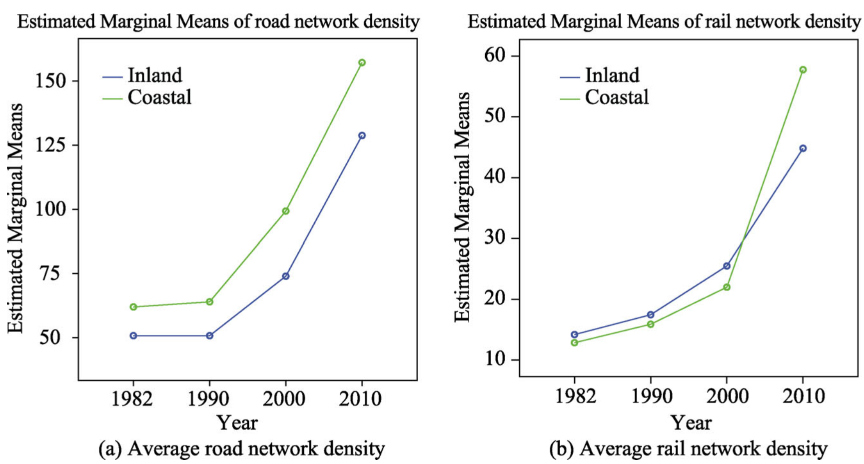


Figure 3 Average road and railway network density

The growth rates of road and railway network density further illustrated their growth trend from 1982 to 2010 (Figure 4). The most striking aspect of the data is that the growth rates of network densities accelerated during the 2000–2010 period, and this trend was more significant for railway network, reflecting the large-scale construction of high-speed rail network. Railway network density growths were more significant in the coastal megaregions, and this was due to the fact that large shares of the new high-speed railways were constructed in the coastal areas. Accordingly, rail network density growth rates for coastal areas skyrocketed during the 2000–2010 period, further confirming that the recent investments in railway and especially high-speed railway were strongly biased toward the coastal areas. These results reflected the biases of national transport development policies, which favor the already more developed coastal regions. Regional road infrastructure disparities remained between the coastal and inland regions, while rail network in coastal regions grew rapidly to outpace inland regions.

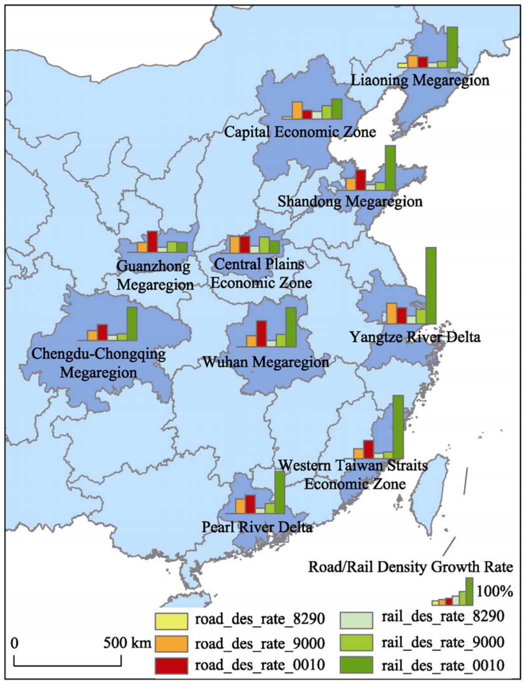


Figure 4 Growth rates of road and railway network density

4.2 Transport infrastructure endowment per capita

The statistics for road and rail infrastructure endowment per capita for the ten megaregions are presented in Figure 5. Generally speaking, coastal megaregions had more developed road network in terms of transport endowment per capita, but this trend was reversed in 2010, with the average road infrastructure endowment per capita in inland megaregions rose above coastal megaregions' (Figure 6a). It should be noted that during the 1982–1990 period, average road length per capita decreased for both inland and

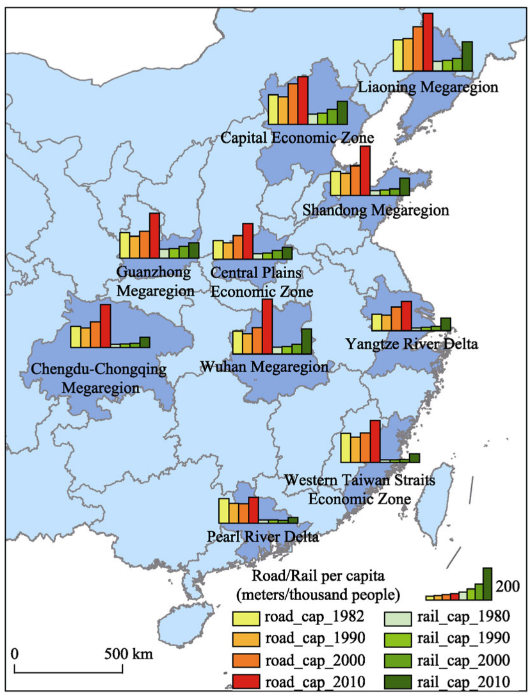
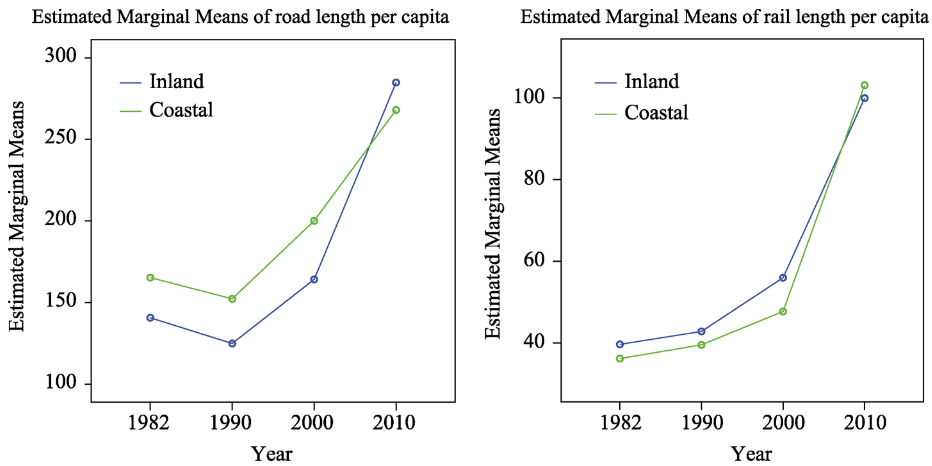


Figure 5 Stock of transport infrastructure per capita 1982–2010 (meters/ thousand people)



(a) Average road length per capita (b) Average rail length per capita

Figure 6 Average road and railway infrastructure stock per capita

coastal megaregions, reflecting that the construction of transport infrastructure did not keep pace with population growth during that time. The Yangtze River Delta and the Pearl River Delta were the two coastal megaregions with the lowest road infrastructure endowment per capita. Railway length per capita of inland megaregions was slightly higher than that of coastal megaregions from 1982 to 2000, but in 2010 coastal megaregions caught up with inland megaregions (Figure 6b). However, it should be noted that Western Taiwan Straits Economic Zones and Pearl River Delta are the two coastal megaregions with the lowest railway infrastructure endowment per capita, which is consistent with the results of network densities. Therefore, until 2010, railway network developments in these two coastal megaregions were still lagging behind.

Figure 7 presents information about the growth rates of road and railway endowment per capita for the periods 1982–1990, 1990–2000, and 2000–2010. The most striking fact about road endowment per capita is that during 1982–1990, all the ten megaregions had negative growth rates, which further indicated that the expansion or upgrade of road network is lagging behind the growth of population. During 1990–2000, most coastal regions experienced growth rates of road endowment per capita higher than the 10 megaregions' average level. This trend shifted during

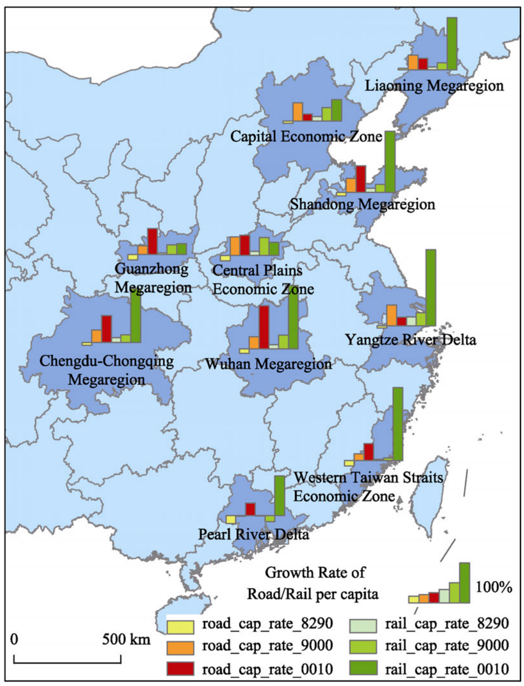


Figure 7 Growth rates of transport infrastructure per capita by megaregion

2000–2010, with three inland megaregions having growth rate of road endowment per capita higher than the 10 megaregions' average rate. Like the measurement of transport network density, the most striking aspect for transport endowment per capita is that the growth rates accelerated during the 2000–2010 period. This trend was more significant for railway, reflecting the large-scale construction of high-speed rail network.

4.3 Spatial structure of transport network

The sizes and directions of the standard ellipses (Tables 2 and 3) changed continuously during the period from 1982 to 2010. However the changes of road network ellipses were relatively small, while the changes of railway network ellipses were more significant.

Table 2 Area of road network ellipse (km^2)

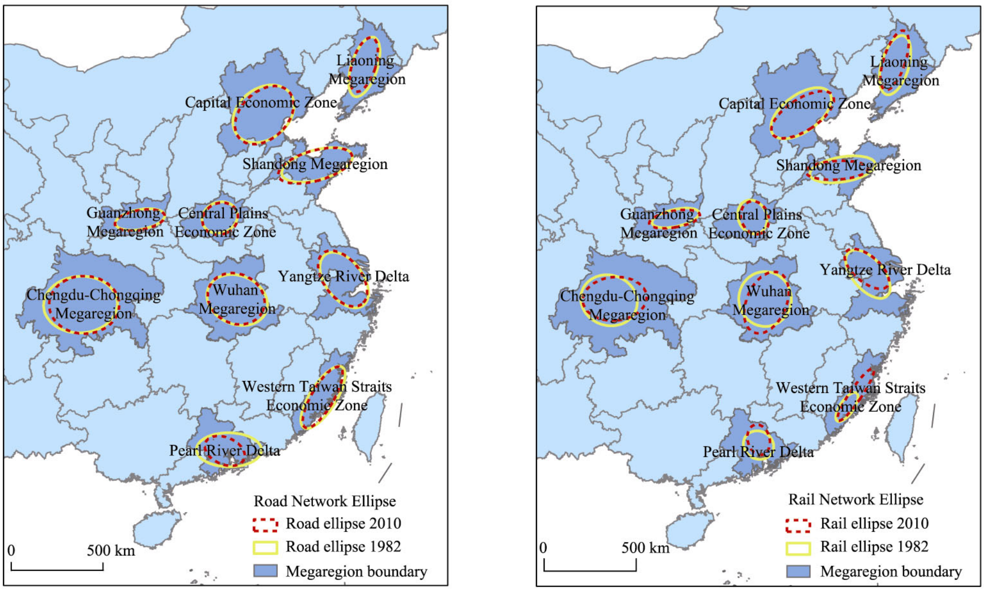
Megaregion	1982	1990	2000	2010	1982–2010
Capital Economic Zone	78585	77326	70149	73707	–6.21%
Central Plains Economic Zone	25588	25488	25552	26102	2.01%
Chengdu-Chongqing Megaregion	96753	96425	96753	93500	–3.36%
Guanzhong Megaregion	22797	22716	22797	23073	1.21%
Liaoning Megaregion	37579	35789	34454	30525	–18.77%
Pearl River Delta	51210	28247	47557	26113	–49.01%
Shandong Megaregion	50535	50732	55417	53478	5.82%
Western Taiwan Straits Economic Zone	43954	43797	43954	35742	–18.68%
Wuhan Megaregion	70286	70377	73264	66920	–4.79%
Yangtze River Delta	55482	55482	52186	55735	0.46%

Table 3 Area of rail network ellipse (km^2)

Megaregion	1982	1990	2000	2010	1982–2010
Capital Economic Zone	59597	58956	59528	52518	–11.88%
Central Plains Economic Zone	22848	22718	21874	21254	–6.98%
Chengdu-Chongqing Megaregion	66580	66580	65915	64259	–3.49%
Guanzhong Megaregion	18910	18910	19952	19565	3.46%
Liaoning Megaregion	38814	39451	42391	31197	–19.62%
Pearl River Delta	19898	19898	19961	15622	–21.49%
Shandong Megaregion	38220	39207	41852	26774	–29.95%
Western Taiwan Straits Economic Zone	10692	10692	10692	17399	62.73%
Wuhan Megaregion	66629	66647	69434	59458	–10.76%
Yangtze River Delta	41385	40230	39292	32230	–22.12%

Figure 8a shows the Standard Deviational Ellipses for road network at the beginning and end of the study period (1982 and 2010). The ellipse sizes of the six of the ten megaregions decreased from 1982 to 2010, and this indicated a tendency toward strengthening the existing core corridors and concentrating transport investment in the core areas. The most significant shrinkage happened in Pearl River Delta, the ellipse size of which decreased to nearly as half as it original size in 1982.

The trend for railway network (Figure 8b) was more significant, with the ellipse sizes of eight megaregions exhibited decreases. The shapes and directions of the ellipses also revolved, which reflected the formation and development of the new major corridors. Only Guanzhong Megaregion and Western Taiwan Straits Economic Zone showed increases of ellipse sizes. With a 60% increase in size, Western Taiwan Straits Economic Zone's standard ellipse of railway network became more resembling of the shape of the megaregion boundary.



(a) Road network (b) Rail network

Figure 8 Transport network ellipse: 1982 and 2010

5 Transport network: county level

This section assesses transport network at the county level through two measurements: Weighted Average Travel Time (WATT) and potential accessibility. It should be noted megaregions are of different sizes ranging from 52,000 km^2 to 267,000 km^2. The differences of the 10 megaregions' geographical span make the comparison between megaregions less meaningful. Therefore the analyses focus on the cross-sectional comparisons of the local units within each megaregion and between megaregions of similar sizes, and the longitudinal comparisons from 1982 to 2010, which will provide more meaningful information about the differentiations and changes of regional connectivity of the ten megaregions.

5.1 Weighted Average Travel Time (WATT)

Figures 9 and 10 illustrate the evolution of county accessibility to megaregional activities

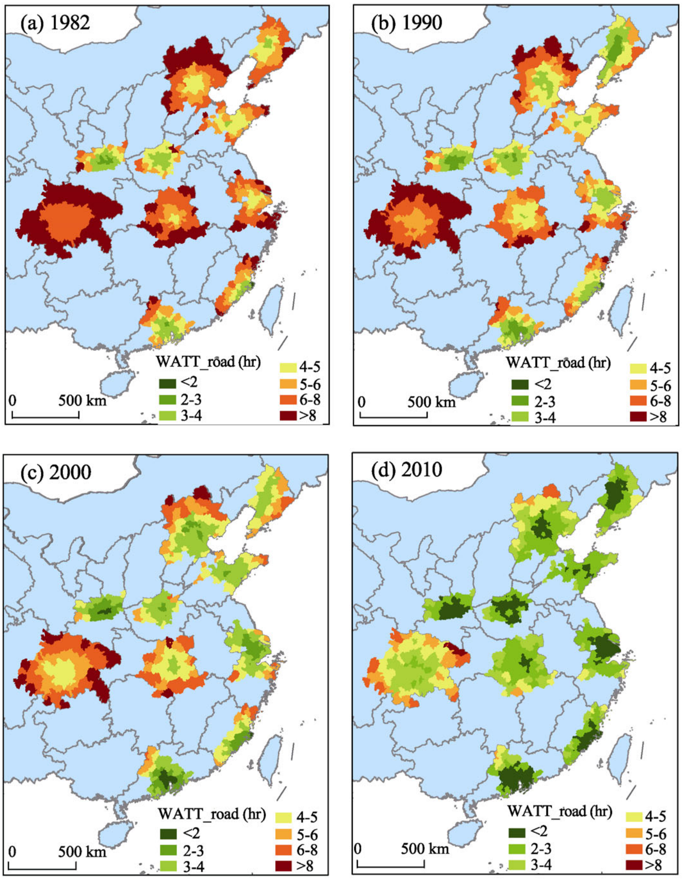


Figure 9 WATT by road network 1982–2010

measured weighted average travel time by road and by rail. The WATT measures of the two modes are generally consistent with each other. Chengdu-Chongqing Megaregion is the largest megaregion, and in 1982, the entire megaregion's WATT was higher than 6 hours. In 1982, in the other large megaregions (Capital Economic Zone, Yangtze River Delta and Wuhan Megaregion), only the central areas had high connectivity levels, and the peripheral areas all exhibited long WATTs. Large areas of the remaining small megaregions had WATTs below 5 hours, and only the peripheral areas had WATT larger than 6 hours. During the past three decades, the accessibility levels of all megaregions have risen continuously. Consistent with the previous analysis, the most significant change happened between 2000 and 2010. By 2010, the within-megaregion accessibility for most megaregions became below 3 hours by both road and rail. Chengdu-Chongqing Megaregion still showed longer travel times due to its large territory, but it nevertheless exhibited significant improvement in terms of accessibility from 1982 to 2010.

Further analyses comparing the WATT by road and railway reveal the modal and spatial disparities (Figure 11). In 1982, almost the entire Yangtze River Delta had shorter travel time by rail, and the time saved by rail compared to road was more than 30 minutes for large areas within the Yangtze River Delta. Wuhan Megaregion and Liaoning Megaregion exhibited a clear pattern of 'corridor effect', with cities along major railway axes had shorter WATT by railway. For the rest of the ten megaregions, large areas showed shorter travel times by road, though the differences were not very significant (lower than 15 minutes) for the majority of them.

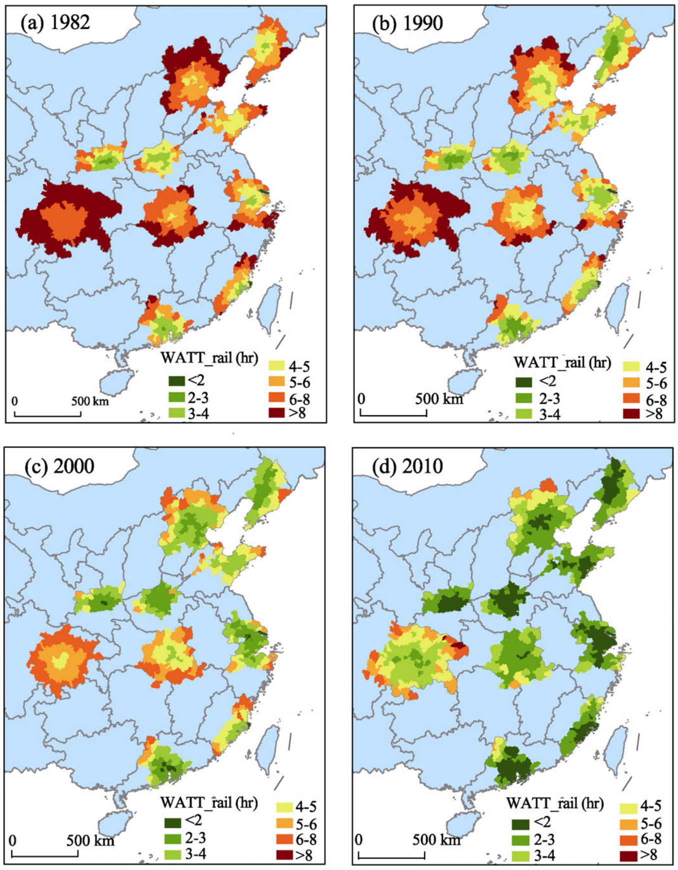


Figure 10 WATT by railway network 1982–2010

During the 2000–2010 period, both high-speed railways and expressways have developed rapidly. By 2010, the net effects are that WATT by rail became shorter than WATT by road for large areas of the ten megaregions. The differences were only moderate for most areas, with the WATT saved by rail was smaller than 15 minutes. Some peripheral areas exhibited substantial difference, and the WATT by road was more than half hour longer than WATT by rail. As mentioned in the methodology section, a total penalty time of 30 minute is added to account for the transfer between road and rail for each regional trip by rail. The addition of penalty time makes the effects of high-speed rail development for travel time saving and accessibility improvement seeming less significant, especially at the megaregion level where the actual travel time is only a few hours at most. On the other hand, no penalty time is added for trip by road, and the assumption applied when calculating travel time by road is

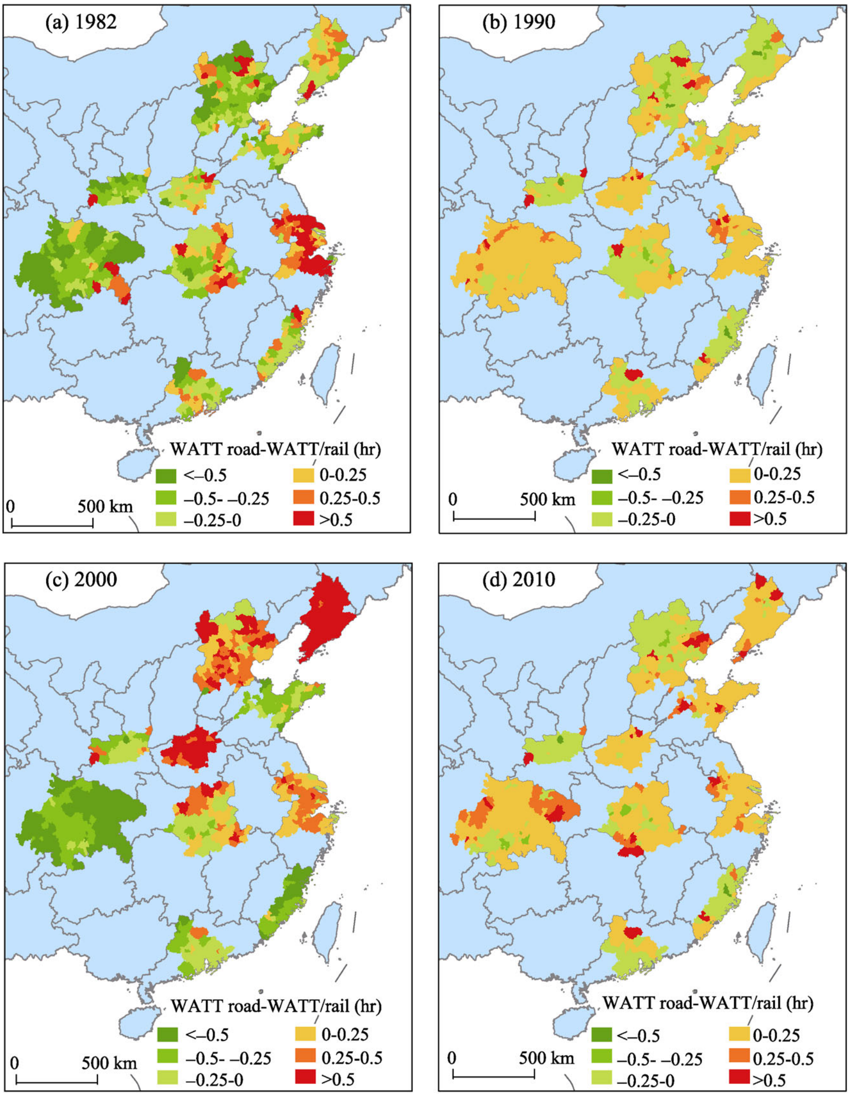


Figure 11 Difference between WATT by road and by railway 1982–2010

that people drive themselves. However, in reality, a lot of people do not own vehicles, and even for people with private vehicles, rail is still their primary choice for travel at the megaregion scale. Therefore, although the magnitude of travel time saved by rail is only at a modest level, its actual beneficial effects are nevertheless strong for passenger transport.

5.2 Potential mega-regional accessibility

Figures 12 and 13 illustrate the evolution of local accessibility to megaregional activities by road and by rail from 1982 to 2010. In 1982, all megaregions had relatively low accessibility levels, while only the central areas of Yangtze River Delta had relatively high accessibility levels by road and by rail. Between 1982 and 1990, the changes for most megaregions were

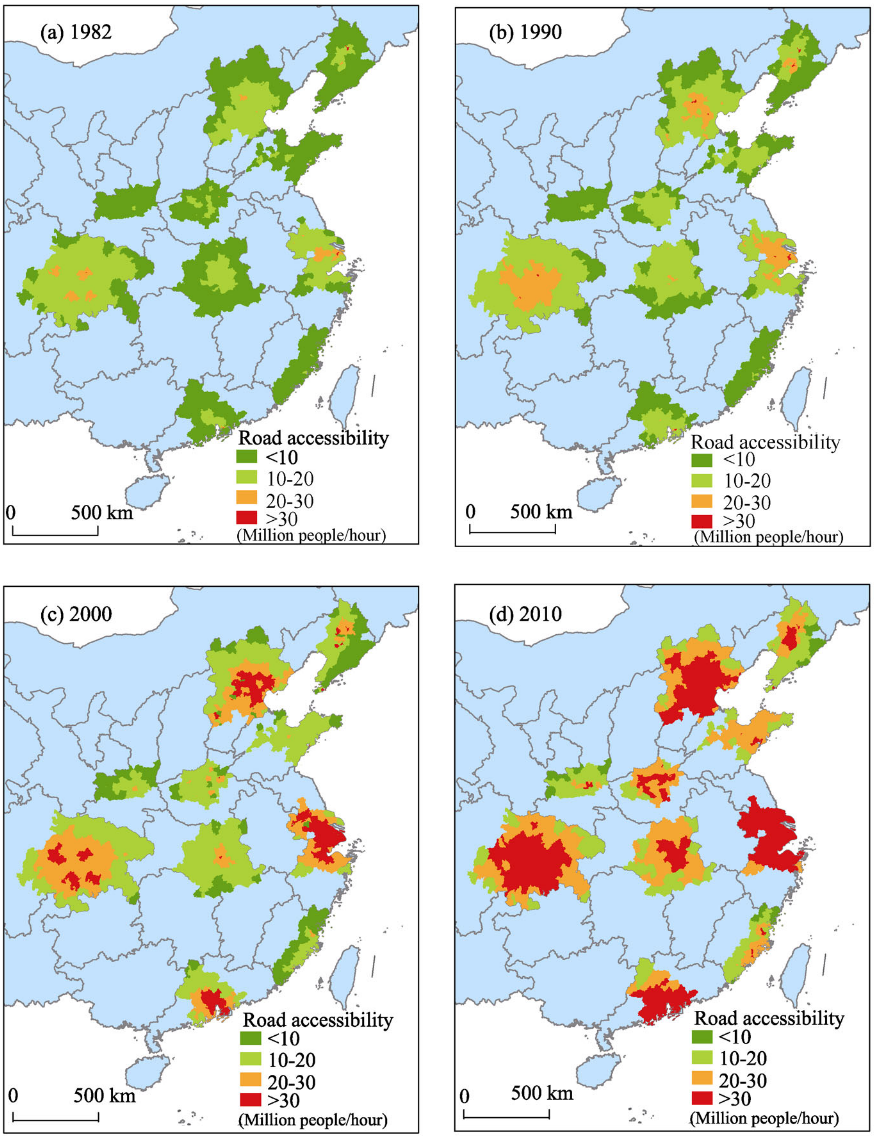


Figure 12 Road accessibility 1982–2010

not significant. In 2000, large areas of Capital Economic Zone and Yangtze River Delta, and the central areas of Pearl River Delta showed high levels of accessibility. Consistent with the previous analysis, the most significant change occurred between 2000 and 2010. In 2010, Yangtze River Delta had the highest level of accessibility by both road and rail, and almost the whole megaregion's accessibility level area was above 30 million people/hour. Capital Economic Zone and Pearl River Delta also had high accessibility levels.

Further analyses comparing accessibility levels by road and railway reveal the modal and spatial disparities (Figure 14). In 1982, apart from Yangtze River Delta, most areas' accessibility levels by road were higher than accessibility by rail. This trend of disparities became

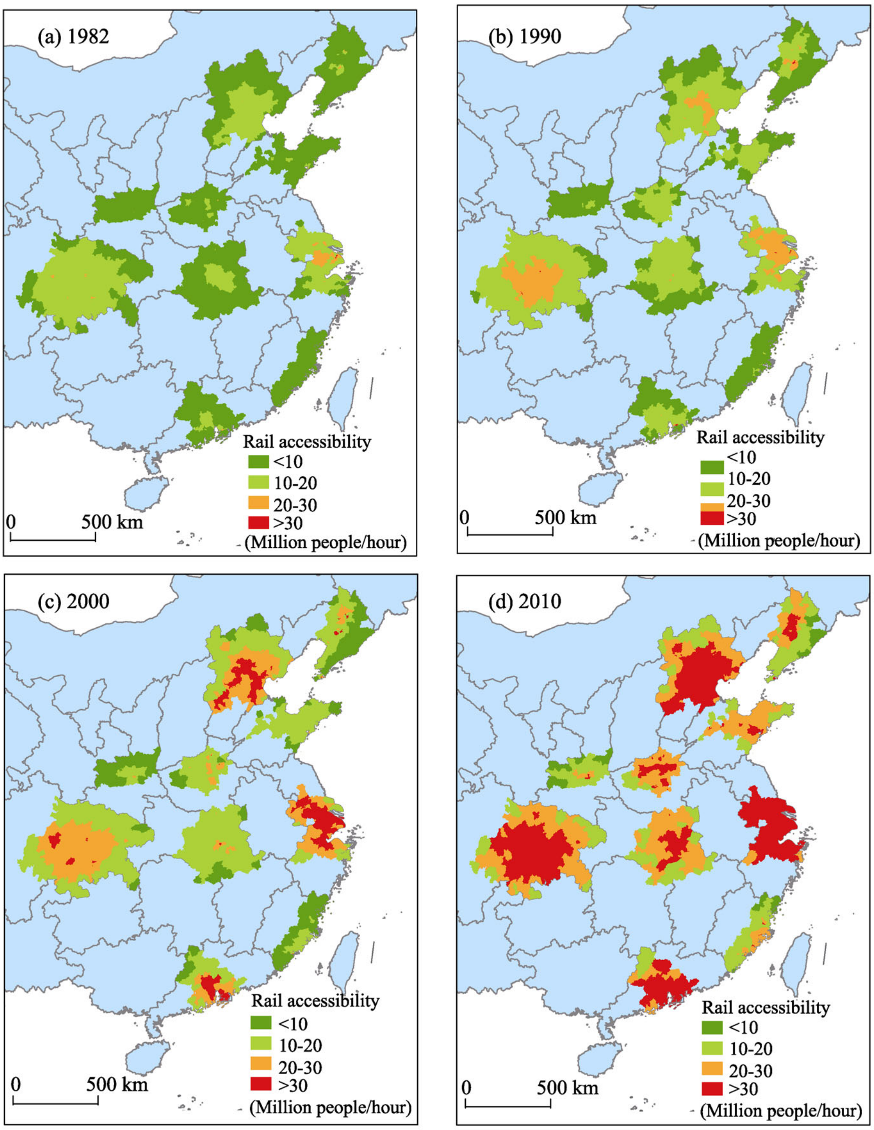


Figure 13 Rail accessibility 1982–2010

less significant in 1990, when most areas' accessibility by road and by rail were about equal. However, Capital Economic Zone was the exception in 1990, with majority areas of it still having higher accessibility level by road. In 2000, it was reversed back to the pattern as in 1982, and accessibility by road was higher than accessibility by rail for large areas of the ten megaregions. In 2010, Capital Economic Zone was the only megaregion having larges areas of higher accessibility by road, while for the other megaregions, large areas had similar accessibility level by road and by rail. However, some areas, mostly central areas, had higher accessibility level by road, while peripheral areas had higher accessibility level by rail.

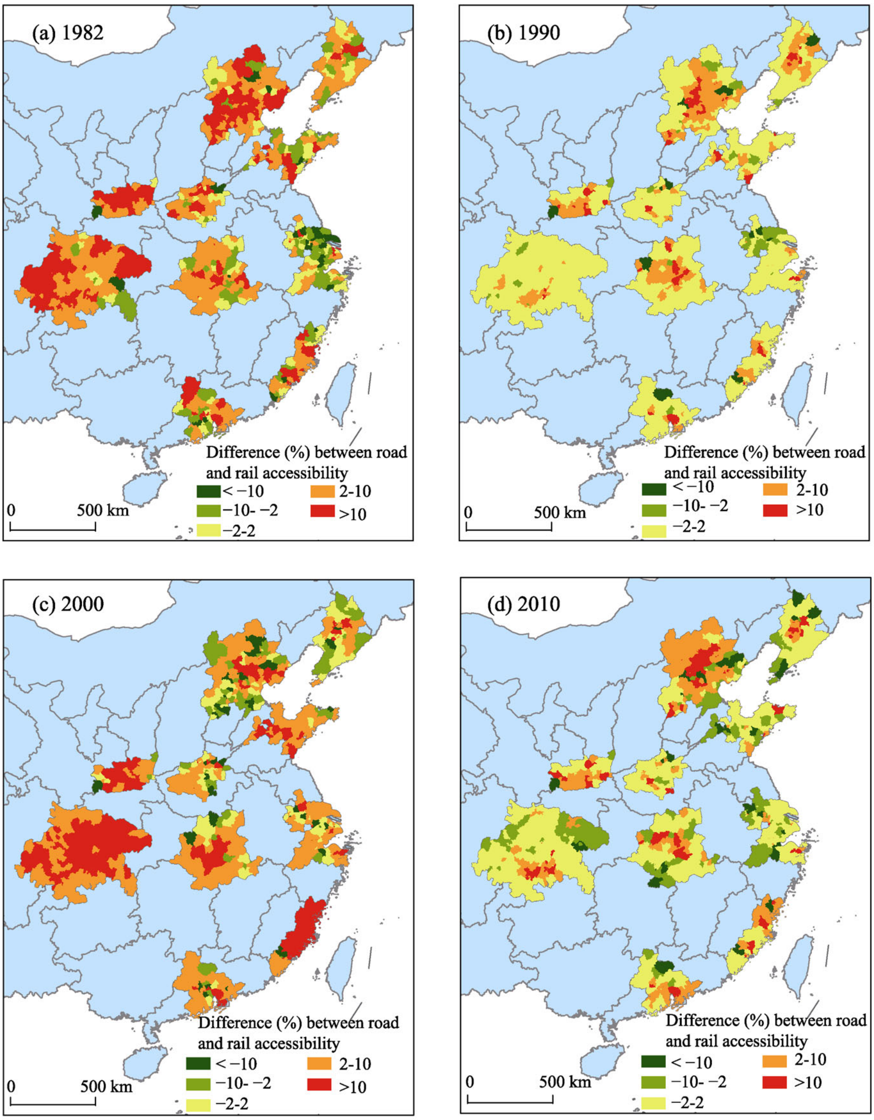


Figure 14 Difference (%) between road and rail accessibility 1982–2010

6 Conclusions

Understanding the accessibility impacts of recent transport infrastructure development in China's ten megaregions is the main objective of this research. This paper examined the spatiotemporal variation and evolution of transport networks of China's ten megaregions at two scale levels: the megaregion level and the county level. Major findings of this research are summarized below:

(1) The most striking aspect of transport network is that the growth rates of network densities accelerated during the 2000–2010 period. This trend was more significant for railway network, due to the large-scale construction of high-speed rail network. Railway network

density growths were even more significant in the coastal megaregions, and this was due to the fact that large share of the new high-speed railways were constructed in the coastal areas. Road network densities in inland megaregions were generally lower than the coastal megaregions.

(2) In terms of transport infrastructure endowment per capita, initially coastal areas had higher road endowment per capita, while inland areas had higher rail length per capita. The trends were shifted during the 2000–2010 period. In 2010, the average road endowment per capita in inland megaregions became higher than coastal megaregions, and the average rail endowment per capita in coastal megaregions became higher than in inland megaregions. However the difference between coastal and inland areas decreased.

(3) The size and directions of the standard ellipses changed continuously during the period from 1982 to 2010. The ellipse sizes of road and rail networks for many megaregions decreased. This reflected the tendency toward strengthening the existing core corridors and concentrating transport investment in the core areas, and this trend was more significant for railway network.

(4) The county level analyses of transport network look at the changes of accessibility for counties measures by Weighted Average Travel Time and potential megaregional accessibility. For both measures, the most significant changes occurred between 2000 and 2010. Coastal and inland megaregions have all benefited significantly from the transport improvement in terms of WATT and potential accessibility in the past few decades. Among the ten megaregions, the three giant megaregions experienced the most significant changes, and had the highest accessibility levels.

The research results confirm the strong positive accessibility effects of transport developments for China's ten megaregions. However, the megaregions that benefited most were the coastal megaregions, especially the central areas. In some peripheral areas, accessibility levels by road and rail are particularly lower. In China, high speed railways, highway, airports and other traditional transportation modes have been used to establish greater links between cities within megaregion and between megaregions, and the trend of fast transportation infrastructure construction continues. Improved transportation infrastructure could bring development opportunities in some of the places currently lagging behind and help them grow into major centers. Improved megaregional transportation infrastructure could contribute to a more balanced spatial development pattern of population and economic activities. Therefore, future transport infrastructure development should target the bottlenecks and missing links in the peripheral areas.

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