J. Geogr. Sci. 2015, 25(4): 451-484
DOI: 10.1007/s11442-015-1180-0

Evolution, accessibility and dynamics of road networks in China from 1600 BC to 1900 AD

WANG Chengjin[1], DUCRUET César[2], WANG Wei[1,3]

1. Institute of Geographic Sciences and Natural Resources Research, CAS, Beijing 100101, China;
2. French National Centre for Scientific Research (CNRS), UMR 8504 Géographie-cités, F-75006 Paris, France;
3. University of Chinese Academy of Sciences, Beijing 100049, China

Abstract: Before the emergence of modern modes of transport, the traditional road infrastructure was the major historical means of carrying out nationwide socio-economic exchange. However, the history of transport infrastructure has received little attention from researchers. Given this background, the work reported here examined the long-term development of transport networks in China. The national road network was selected for study and the 3500 years from 1600 BC to 1900 AD was chosen as the study period. Indicators were designed for the maturity level of road networks and an accessibility model was developed for the paths of the shortest distance. The evolution of the road network in China since the Shang Dynasty (1600 BC) was described and its major features were summarized to reveal long-term regularities. The maturity level of the road network and its accessibility was assessed and regions with good and poor networks were identified. The relationship between China's natural, social, and economic systems and the road network were discussed. Our analysis shows that the road network in China has a number of long-term regularities. The continuously expanding road network follows a path of inland expansion especially towards the border areas. However, its coverage and accessibility are characterized by a core–peripheral configuration, which has close relationships with, not only the natural conditions, but also national defense and warfare. The centralization of national power, national land governance, postal transport, the transport of specialized cargos, and international trade are also related to the development of the road network. This research draws attention to the evolving regularities of transport networks.

Keywords: China; road networks; historical evolution; accessibility; dynamic mechanisms

1 Introduction

Transport infrastructure and its spatial networks play crucial roles in regional development and have been a significant force in shaping the spatial structure of land development (Jin *et*

Received: 2014-02-10 **Accepted:** 2014-06-30
Foundation: Key Research Program of the Chinese Academy of Sciences, No.KZZD-EW-06-02; Exploratory Forefront Project for the Strategic Science Plan in IGSNRR, CAS, No.2012QY004; National Natural Science Foundation of China, No.41171108
Author: Wang Chengjin (1975–), Associate Professor, specialized in economic geography and transport geography.
E-mail: cjwang@igsnrr.ac.cn

al., 2010). Before the emergence of automobile highways and railways, traditional road transport and water shipment were the main modes of transport and profoundly influenced economic development and social progress in China for over 35 centuries. China constructed the Chi Road in the Qin Dynasty (221 BC to 207 BC) and expanded the road network to the western regions in the Han Dynasty (202 BC to 220 AD). Postal stations have been distributed across the country since the Tang Dynasty (618 AD to 907 AD). It has long been recognized that China is a land-oriented country and has a long history of civilization. China's road system has gradually improved over its long period of development and a nationwide network has been shaped. From a historical point of view, the road network has brought major improvements in accessibility, modified the relative distances between locations, and generated an unprecedented convergence of time and space (Gutiérrez, 2001). Therefore the road network has important implications for land development and is generally believed to have contributed to national growth and driven the agglomeration of the population. Furthermore, it has strategic significance for land territory and the centralization of national power. The long-term role of the road infrastructure in promoting socio-economic systems is important, yet has received little attention from researchers (Spence and Linneker, 1994).

The spatial and temporal effects of the transport infrastructure, a central issue in transport geography, have been studied extensively. Although the nature of the relationship between transport infrastructure and regional development has been the subject of debate for many years (Linneker and Spence, 1996), it is widely believed that transport infrastructure has a positive impact on regional development. The regional economy generally abstracts it as a transport cost. In addition to the monetary cost, indicators such as distance and time are often applied to topological models to evaluate the effect of the transport network and location (Taaffe *et al*., 1996). Accessibility is a commonly used indicator (Hansen, 1959) and uses a number of variables, such as distance (Keeble *et al*., 1988), travel time (Gutiérrez and Urbano, 1996), and transport costs (Spence and Linneker, 1994) to express different purposes, including locational accessibility (Handy and Niemeier, 1997), individual accessibility (Kwan, 1998) and economic potential (Koenig, 1980). Research on accessibility has included the highways, railways, and aviation routes covering the area of interest, which may be a transnational region, a country, a metropolitan region, or the countryside (Ingram, 1971). Transport networks and improvements in these networks generate time–space convergence and affect the development of nodes (George, 1999). Numerous efforts have been made to analyze a single transport network (Dupuy and Stransky, 1996; Li and Shum, 2001); many project-oriented studies, in particular, have been undertaken to investigate accessibility (Gutiérrez and Urbano, 1996; Gutiérrez, 2001).

Despite the long history of research, published papers are mainly concerned with modern transport infrastructures on a short timescale; little attention has been paid to the long-term evolution of transport networks and their accessibility. However, some long-term research studies on port systems have been published, such as those by Rimmer (1967a, 1967b) on New Zealand (1853–1960) and Australia (1861–1961). Many works have analyzed the evolution of railway networks, including Koopmans *et al*. (2012), who studied railway development in the Netherlands from 1840 to 1930, and Murayama (1994), who studied railway development in Japan from 1868. Another branch of research has investigated the accessibility of integrated transport networks, such as the work of Taaffe *et al*. (1963) on Ghana, Erath *et al*.

(2009) on Switzerland from 1950 to 2000, Axhausen *et al*. (2011) on Switzerland from 1850 to 2020, and Kreutzmann (2004) on high Asian transport networks during the 19th and 20th centuries. An amount of effort has been dedicated to the evolution and accessibility of road networks, such as the work of Weber (2012) on the USA since the 1940s, Muntele and Cimpoesu (2011) on Moldavia over three centuries, and Strano *et al*. (2012) on Milan over 200 years. One classic work was carried out by Bel (2011) to analyze the development of road networks in Spain since 1720 and this showed a long-term pattern, although the discussion integrated railways and motorways. However, all this previously published work has covered periods of only 200–300 years, or even a much shorter time, and the long-term development of traditional road networks has received little attention. This is a topic which has generated interest for a long time, but one for which a conclusive answer has not yet been found (Vickerman, 1995). A complete picture of the birth, growth, and maturity of road networks gives a basis on which to understand the land development and socio-economic systems of a country that examining the current transport network alone cannot achieve (Levinson, 2009). In this context, a better understanding of the regularity of traditional road networks over a historical time period is required.

Although China has a long history of road transport, there has been very little research on the traditional road network. Over the past few decades, a significant amount of research has focused on modern highways. With the rapid development of expressways, accessibility and its relationship with regional development have attracted much attention (Cao *et al*., 2005; Wu *et al*., 2010; Wang, 2006). A wide range of literatures concerned the accessibility of the integrated transport network (Zhang *et al*., 2006; Wu *et al*., 2006, 2007; Cao and Yan, 2003; Jin *et al*., 2010). Some works paid their attention to the relationship between policies and the transport network (Comtois, 1990; Loo and Leung, 1997; George, 1999).

Although these studies have shed light on the highway network, most have focused on the 25–35 years since the 1980s; only a small number of papers have presented long-term research studies. Wang and Ducruet (2012) investigated the evolving regularities of the port system over the past 2000 years and Jin and Wang (2004) looked at the expansion of the railway network and accessibility over a 100-year period. For the road network, classic works have been published by Li and Shum (2001) and Cao *et al*. (2005) assessing the accessibility of the highway network and its impact over the past 20 years and projecting into the next 20 years; however, their analyses focused on the highway system, especially the expressways. The latest work by Hou and Li (2011) analyzed the transport network and changing accessibility in the Pearl River Delta over the period 1990–2020.

It is widely recognized that long-term studies are an important methodology in geographical research. However, there have been few studies in China which have assessed the long-term regularities and accessibility of the transport network with a time range covering all the historical periods in China; most research has focused on the modern transport network over a short time period. Historically, the main road transport and shipping networks have supported socio-economic development in China. Wang (2006) has published work on the port system, but there is still lack of work on the road network and accessibility. China's unique character offers a rare chance to study this issue. From a historical perspective, several questions are of concern to geographers: (1) how have China's road networks evolved over the long term; (2) what are their special regularities; (3) how should the changes in their structure and accessibility be evaluated; and (4) what are the relationships between China's natural and socio-economic systems and the road network?

This paper is divided into four parts. The first section designs the models to assess the infrastructure network and the shortest distance path, and describes the sources of data. The second section analyzes the evolution of road networks and their developing regularities in China over the past 3500 years. The details of connectivity and accessibility are analyzed in the third section, with a particular focus on a discussion of the changes over time. The fourth section examines the relationship between China's natural and socio-economic systems and the road network, taking into consideration the natural conditions, national defense and governance, trade transport, and the postal network. In the conclusion section, the main results are presented.

2 Methodology

2.1 Data

The selection of the road network, nodes, and timescale is critical in determining accessibility. When an accessibility study is undertaken, the transport system must first be defined. We choose the "national road" for this study; central government is directly responsible for the planning, construction, and operation of this road. Meanwhile, it is very difficult to obtain systematic statistical data. To overcome this problem, we used maps as the major source of data. These were taken from the official cartographic document *China's Ancient Road Transport History*, edited by the Ministry of Transport and published by China Communications Press in 1994, supplemented by the *Historical Atlas of China* (Tan, 1982). These data allowed us to make a faithful reconstruction of the historical road networks.

The nodes were chosen to provide regular coverage across China. Historically, China has implemented a three-level division of administration. The system of prefecture and county took shape in the Qin Dynasty (221 BC–207 BC), when the county became the fundamental administrative unit with a stable administrative center, which became a historically stable transport node. In this context, it seems logical to select the county as the basic unit of analysis and to select the prefectural and provincial cities as the auxiliary units. We therefore selected 2322 counties, 334 prefectural cities, and 31 provincial cities as candidates for the nodes by defining a centroid for each area at the main town to summarize all the information. These data and nodes then allowed us to construct an undirected, but fully interconnected, topological graph of the road network for each time period.

The selection of the timescale and time periods is also important in interpreting the evolution of the road network and to assess accessibility (Linneker and Spence, 1996). Importantly, analyses based on time-series observations allow various time periods to be compared. We used all the dynasties, covering about 3500 years (1600 BC to 1900 AD), to obtain detailed information about the road network at the national scale. The time periods selected to describe the distinct changes in the evolution of the road network overlapped major geopolitical changes.

A data set containing the road network data over a long period of time was then established in a geographical information system. When defining a study area, it should be remembered that different land territories in each time period will affect the coverage of the road network and the selection of nodes. In this paper, we used the current territory of the People's Republic of China to define the study area in the various historical periods.

2.2 Indicators of the structure of the road network

In the topological sense, a complex transport network can be abstracted as a graph consisting of vertices and edges (Dupuy and Stransky, 1996). Based on the road network, we transformed all the routes into edges (e) and all the cities into vertices (v) to construct a topological graph. The following indicators, corresponding to different conceptualizations, are commonly used to evaluate the overall structure of a road network and to offer complementary information. The connectivity is used to evaluate the number of links between the nodes. Two parameters are used to measure this concept, the beta index (β) and the cyclomatic index (μ):

$$\beta = e/v \tag{1}$$

$$\mu = e - v + p \tag{2}$$

where β is the average number of routes (e) per city (v). If $\beta < 1$, the road network shows a tree-like structure and if $\beta > 1$, it is a circuit network and tends to be fully connected. The parameter μ measures the number of circuits and is equal to the difference between e and v while accounting for the number of subnets p (p = 1 for a fully connected network). The greater the value of these parameters, the more developed the network. η is the shortest path from a node to the furthest node; generally the node with the smallest value of η is the center of the road network. The α index and γ index are used as analytical tools to examine the developing potential of the road network:

$$\alpha = \frac{(e - v + p)}{(2v - 5p)} \quad 0 \leqslant \alpha \leqslant 1 \tag{3}$$

$$\gamma = \frac{e}{3 \times (v - 2)} \quad 0 \leqslant \gamma \leqslant 1 \tag{4}$$

where α is the ratio of the actual to the maximum number of circuits in a fully connected network and reflects the actual ringing level. γ is the equivalent of the actual to the maximum number of edges. Generally, the value of this index varies from 0, if there are no links, to 1, when the network contains every possible direct link.

2.3 Accessibility model of the shortest distance path

Accessibility is generally defined as the convenience of travelling from one particular node to all other nodes taking advantage of a specific transport system (Hansen, 1959) and is commonly used as an indicator to evaluate the transport network and location conditions. In this paper, the cost of the shortest travel distance between the nodes through a road network was used (Keeble *et al*., 1988). Operationally, the topological method transforms the complex network computation into a simple matrix operation. Within this context, the fully connected and shortest travel distance matrix M was constructed for the road network to show the total number of topological connections among all locations in China (Taaffe *et al*., 1996):

$$M = [d_{ij}]_{n \times n} \tag{5}$$

where d_{ij}, an element in matrix M, is the minimum distance through the shortest path between a given pair of nodes i and j, and n is the number of nodes. If d_{ij} meets the following conditions:

$$d_{ij} = 0 \text{ when } i = j$$

and

$$d_{ij} = d_{ij}^{0}$$

when node i is adjacent to node j, then d_{ij}^{0} is the direct distance between the two nodes, where the superscript 0 indicates the number of intermediate steps between nodes i and j through the edges.

In all other instances, d_{ij} is computed by following the shortest path through multiple connections in the road network:

$$d_{ij} = \min(d_{ik} + d_{kj}) \quad (k \in n) \tag{6}$$

where d_{ij} is the minimum distance from node i to node j. We applied the network analyst in ArcGIS to calculate this distance and to obtain the topological information required to construct matrix M. In general terms, the total travel distance of node i is defined as follows:

$$D_i = \sum_{j=1}^{n-1} d_{ij} \tag{7}$$

where D_i is the summation of the minimum travel distances from node i to all other nodes, i.e. the accessibility. The smaller the value of D_i, the better the accessibility and the more superior the location of node i. To measure the accessibility of the entire road network and to make the results comparable in each period, the total travel distance of the whole road network is defined as:

$$D = \sum_{i=1}^{n} D_i \tag{8}$$

To compare the locational advantage among the cities in each time period, the locational coefficient, a type of relative accessibility proposed by Ingram (1971), was designed and is equal to the ratio of the shortest travel distance of each node to the average travel distance of the whole road network across all nodes. The formula most used is normalized in the following equation:

$$AC_i = \frac{D_i}{\sum_{i=1}^{n} D_i / n} \tag{9}$$

where AC_i is the locational coefficient of node i and reflects the locational position of each node in the whole road network. The smaller its value, the higher its accessibility and the more superior its location. More specifically, if $AC_i > 1$, the travel cost of node i is higher than the average level of the whole network and therefore its accessibility is less than the average level and it has an inferior location. If $AC_i < 1$, it has a lower travel cost than the average level of the whole network and has a significant locational advantage. The node with the minimum AC_i value is the locational center of the road network.

3 Expansion and evolution of the road network in China

Over the past 35 centuries, China's road network has expanded stage by stage. In this work, expansion of the road network is divided into four eras to illustrate the whole process and to provide a comparative analysis. The following sections discuss the spatial pattern of the road network and its changes in each of these four eras.

3.1 Earlier development and regional network

It is widely acknowledged that China has a long history of road transport. Historically, the Chinese constructed roads as early as the 21st century BC. Before the Qin Dynasty (221 BC), China was acquiring land territory. The middle and lower reaches of the Yellow River Valley, the most fertile plain in China with plentiful resources of both water and heat, became the production base for agriculture and land expansion moved outwards from here. In this period, in spite of the flat terrain features, the road network was in an early and slow phase of expansion, typically characterized by the development of a regional network limited to the Central Plains with short distances, a small land coverage, and a simple structure, but shaped by an obvious inland-oriented or plain-oriented origin (Jin *et al*., 2010).

In the Xia Dynasty (2070 BC to 1600 BC), human activity mainly emerged in the plain region along the Yellow River in Henan and Shanxi and this narrow territory brought about a small-scale road system. The Shang Dynasty (1600 BC to 1046 BC) established its capital in Shangqiu and its territory expanded from Henan to Shandong and Hebei along the Yellow River; its activities were also concentrated on this plain. The road network reached 6500 km, covering 12 provinces, and stretched from the capital of Shangqiu eastward to the Shandong Peninsula, southward to north Hubei, northward to Beijing, and westward through the narrow valley between the Funiu Mountains and the Zhongtiao Mountains, the Loess Plateau and the Qinling Mountains, to the edge of the Loess Plateau in east Gansu (Figure 1). The middle and lower reaches of the Yellow River Valley, especially central Henan, had the most dense road network. The wars against the northern minority groups promoted the construction of a military road to connect with Wuyuan in the Mongolian Plateau along the east edge of the Taihang Mountains and across the Jundu Mountains.

The following Western Zhou Dynasty (1046 BC to 770 BC) extended the land territory to the Guanzhong Plains and the world’s earliest road plan and administration were formulated. Importantly, a trunk road network was formed from the capital and hub of Xi’an to the kingdoms, but the network shrunk slightly to a length of 4797 km, covering seven provinces. A simple road network of central–local mode I developed a close contact between the capital and local cities within a narrow land territory; Figure 2 shows a conceptual model of this type of network. It was characterized by routes from the center eastward to Shandong Peninsula, northward to Anyang, southward to Bengbu, and westward to the edge of the Loess Plateau, but was still concentrated in the middle and lower reaches of the Yellow River Valley, the Guanzhong Plains, and the Huaihe River valley; in other words, at the third ladder in China. The Loess Plateau became an obstacle to the northward and westward expansion of the road network.

The following Spring–Autumn and Warring States Periods (770 BC to 221 BC), also known as the Eastern Zhou Dynasty, was a turbulent period with numerous wars when there were over 170 kingdoms across the country. Importantly, the coexistence of these regimes promoted a new central–local mode II: multiple kingdoms (Figure 2) shape in the road network. Each kingdom constructed roads in its own domain to develop the regional network,

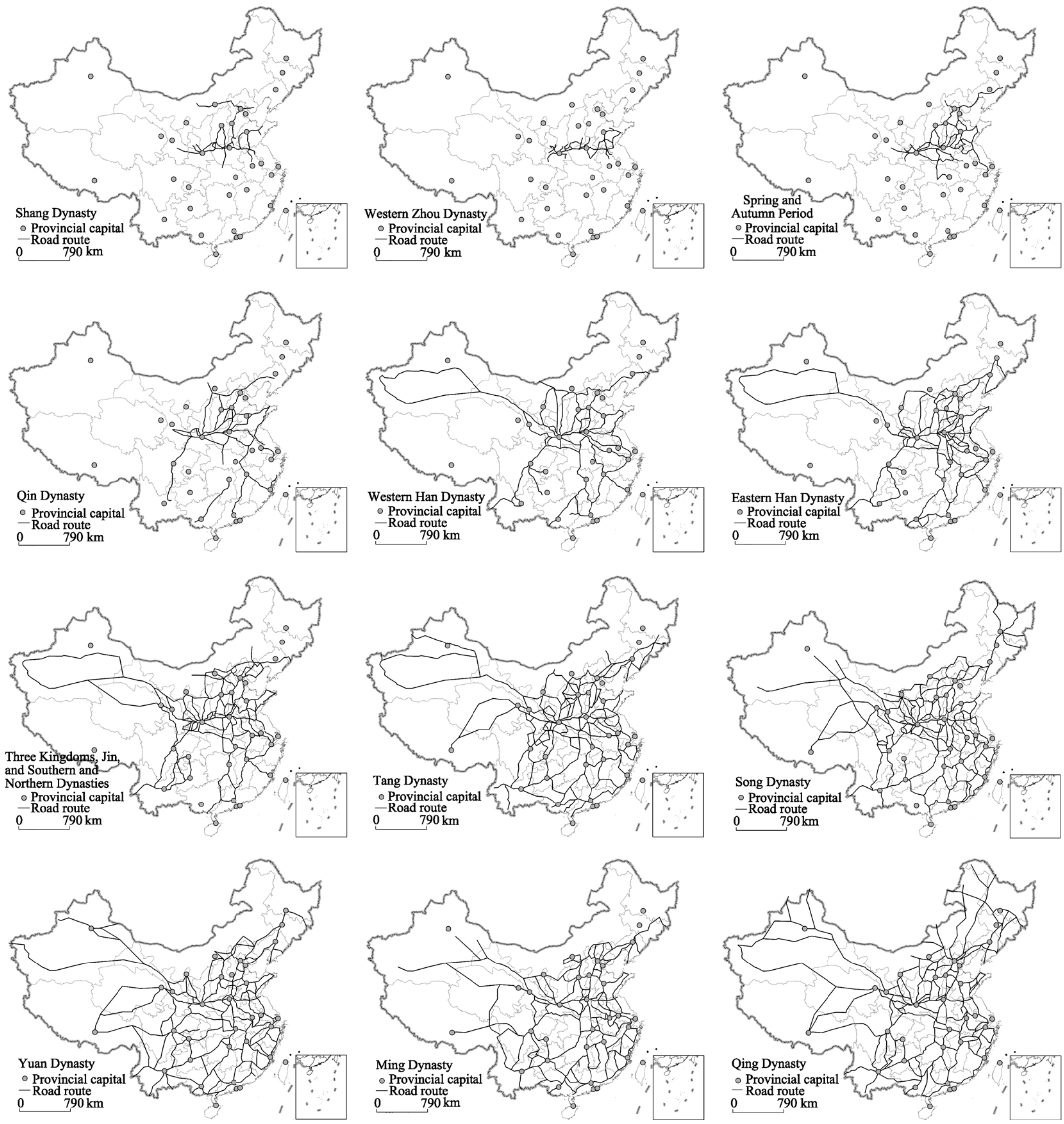

Figure 1 Spatial evolution of the road network in China since the Shang Dynasty

but still maintained a relationship with the central area through trunk routes. The total distance covered grew rapidly to over 10,000 km (Figure 3). In terms of the spatial dimension, the road network extended from the middle and lower reaches of the Yellow River Valley to the northern Yangtze River Valley, the Huaihe River Valley, and northeast China, covering 14 provinces. Four trunk routes developed from the hub of Luoyang eastward to the Shandong Peninsula, southward to the Yangtze River Delta and Wuhan, westward to Lanzhou, and northward to Jilin. However, this network was mainly concentrated in the inland region, including the third and second ladders, and the Yangtze River became another obstacle to the expansion of the road network southward. Contacts among the states increased due to the construction of roads for troop movements as well as commercial activities. The coexistence of multiple kingdoms, most of which were located in the peripheral regions, enlarged the land territory and, as a result, the road network during the turbulent war periods generally had a wider coverage than in the period with a unified empire. This analysis shows that this pattern coincided with that of the national territory, indicating the close relationship between transport infrastructure and the growth of a country.

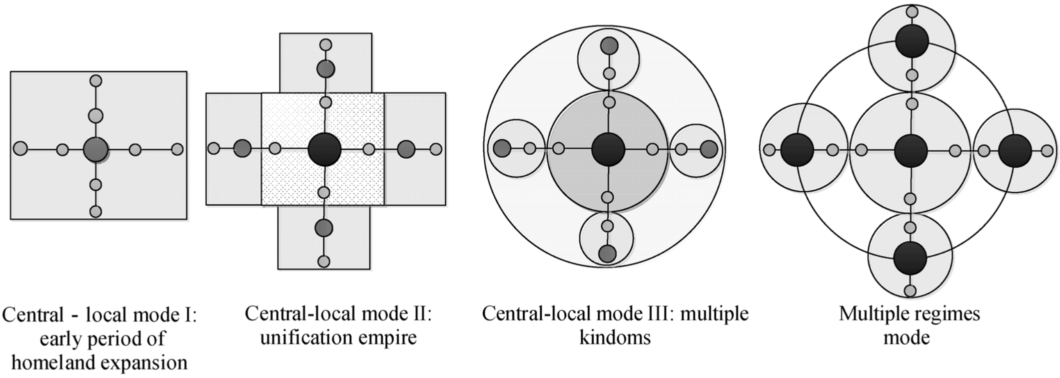

Figure 2 Spatial patterns in the road network and relationship with the administration

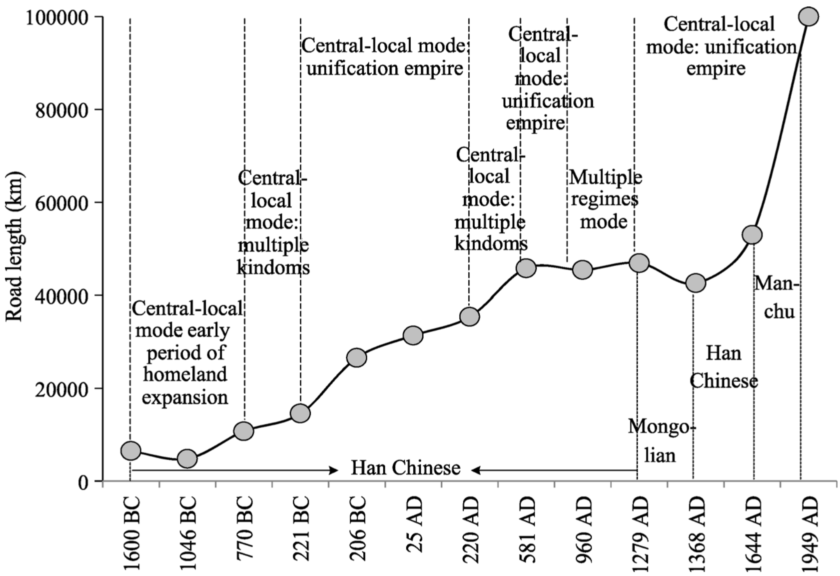

Figure 3 Road length in each dynastic period in China

3.2 Expansion of the road network from regions to the whole country

Generally, the growth of road networks is governed by two processes: (i) densification, corresponding to an increase in the local density of roads around existing centers; and (ii) exploration, whereby new roads trigger the evolution of the land frontier (Strano *et al.*, 2012). These processes were both experienced in China in the following periods. After the Qin Dynasty, China developed into a unified empire. Correspondingly, the road system was also reformed and developed a normative planning, construction, and management system; its network enlarged with the expansion of territory, overcoming many natural obstacles such as mountains, plateaus, rivers, and lakes. The spatial pattern of the road network changed from the multi-kingdom mode to the central–local mode under the centralized power (Figure 2). Importantly, the basic mode and spatial patterns of the ancient road network were laid down for that in the following dynasties.

The integration of land territory was accomplished by a nationwide expansion of the road network (Murayama, 1994). After succeeding in unifying China, the Qin Dynasty (221 BC to 206 BC) implemented the policy of the Same Track Gauge and integrated the various disconnected roads constructed in the previous war period. Moreover, a substantial number of roads were constructed, in particular the Chi Road, fanning out in all directions from the capital Xi'an, the Zhi Road, and the Plank Road across the Qinling Mountains. The road network increased considerably to 14,534 km, covering 20 provinces northeastward to Liaoning, northwestward to Gansu, southeastward to the coast, and southwestward to the Sichuan Basin and Yunnan, as shown in Table 1. In the Qin Dynasty, 6000 km of roads were built, overcoming the obstacles of the Qinling Mountains and the Loess Plateau. Although several routes crossed the Yangtze River, this river was a major natural obstacle to road expansion and divided the whole network into two parts. A network was developed to connect the capital Xi'an to the prefectures and counties, shaping the central–local mode II of the unified empire. However, this was concentrated in the inland region, covering the eastern inland, central, and near western regions, namely the second and third ladders. It was noteworthy that the road network shaped a differentiation of the two-level structure. The middle and lower reaches of the Yellow River valley around Xi'an had a well-connected and high-density road network and represented the core of the first level, but the peripheral regions, such as northeast, south, and southwest China and the southeast coastal region, were connected mainly by trunk routes with a tree-like structure and became the second level; this is attributed to the obstacles of the Qinling Mountains and the Yangtze River. Several cities, such as Dingtao, Handan, Linfen, Beijing, Yiyang, Zibo, Kaifeng, and Shangqiu, became major hubs. Moreover, a functional differentiation emerged within the road network. The nine Chi roads became the earliest national roads to connect major cities in north, central, and east China, as well as trunk routes connecting the central and local regions, but the Zhi Road, connecting Xi'an to Baotou, functioned as a military road against the Huns. In this period, the major obstacle to road expansion changed from the Loess Plateau to the Yangtze River, the Daba Mountains, the Tibetan Plateau, and the Yunnan–Guizhou Plateau.

After the short Qin Dynasty, China entered the Western Han Dynasty (206 BC to 9 AD), with a stronger capacity to conquer natural obstacles. The governor improved the road infrastructure inherited from the Qin Dynasty and increased the road network dramatically to 2.65×10^4 km, covering 26 provinces. In particular, the road network spread westward to Kashgar through the Hexi Corridor and along the northern Tibetan Plateau and Tianshan Mountains, northward to Jilin through the narrow plain between the coast and mountains, and southward into Vietnam across the dense tropical rainforest, with the explicit objective of promoting the accessibility of peripheral regions. However, the network was still concentrated in the inland region and covered most of the regions in the second and third ladders. Similarly, the road network differentiated between trunk and branch routes. The road density increased in the middle and lower reaches of the Yellow River valley and the Huaihe River valley; a fully interconnected road network developed. Simultaneously, because of the Yangtze River, regional networks took shape in southwest, south, and northwest China and

Table 1 Road lengths in each province in each historical period in China

Province	Shang	Western Zhou	Spring and Autumn	Qin	Western Han	Eastern Han	Wei-Jin	Sui and Tang	Song	Yuan	Ming	Qing
Beijing	144.7		136.1	233.4	247.4	339.6	287.4	255.6	252.8	174.1	332.3	361.4
Tianjin	30.8		210.1		38.0	182.2	103.4	54.7	54.7	236.8	226.1	252.4
Shanxi	1013.9	526.0	1029.4	1540.5	1364.8	1761.4	2029.9	2639.6	1985.9	1296.9	1801.3	2101.0
Hebei	801.3		1276.3	1214.7	1155.9	1623.5	2490.5	1929.4	1896.6	2282.8	2147.2	2371.4
Inner Mongola	495.2			367.4	1283.3	781.8	1574.2	1293.7	1969.5	1723.7	1491.8	4230.6
Liaoning			571.1	343.9	579.8	1241.2	876.2	1725.4	1036.7	1140.5	1631.5	1637.2
Jilin			50.2		50.2	454.7	121.3	820.6	617.7	537.2	490.2	1169.4
Heilongjiang								86.3	1564.2	403.8	133.1	1748.1
Shanghai										100.3	37.8	37.8
Jiangsu	164.8	205.6	733.3	619.7	715.3	616.2	859.2	1063.4	1115.2	969.4	1111.4	832.9
Zhejiang			152.7	216.0	444.7	630.8	517.9	1097.9	1164.6	1294.2	1202.5	1495.2
Fujian				482.9	292.9	264.2	308.2	876.4	1532.8	1547.3	1356.0	1004.9
Anhui	327.3	312.2	393.0	652.5	781.2	1423.3	1206.7	1395.2	1702.3	1677.0	2002.3	1667.1
Jiangxi				711.5	955.3	1138.4	971.1	1147.9	1389.6	1595.0	1747.0	1349.0
Shandong	912.1	1229.9	1879.0	1403.6	1204.5	2083.1	2063.7	1573.9	1505.6	2015.2	1613.6	1877.0
Henan	1388.8	1183.2	2144.4	1559.4	2344.7	3086.0	2510.3	2612.1	2860.1	2364.3	2536.0	1992.8
Hubei	36.2		474.8	541.5	788.5	1285.1	1302.6	1640.2	1977.2	1884.2	1449.5	1485.1
Hunan				507.8	834.7	953.0	728.2	1144.2	1235.4	1246.2	1323.9	1377.6
Guangdong				311.5	615.7	615.4	599.2	1416.4	1412.3	1449.9	1529.5	1417.6
Guangxi				576.1	1022.2	1339.0	599.2	1932.7	980.1	1839.8	1983.5	2113.0
Sichuan				559.3	1396.8	1415.2	1694.8	2642.6	2519.4	3056.7	2521.0	2147.6
Chongqing					119.6	89.0	223.2	498.9	115.2	622.1	222.4	223.2
Guizhou					163.8	336.8	711.0	1039.9	1023.5	1000.7	1578.2	1425.4
Yunnan				412.2	982.6	1000.5	1329.0	1757.2	1371.6	2673.4	1748.8	2342.9
Tibet								662.3	676.1	1650.8	1217.9	1578.9
Ningxia					553.6	523.6	601.0	896.3	1030.4	784.2	482.4	653.0
Qinghai							1521.9	2173.4	3023.4	2103.0	1755.2	2649.0
Shaanxi	873.3	1246.7	1466.2	1867.8	2874.6	2586.1	3396.2	3631.9	3918.4	2321.6	2064.9	2728.3
Gansu	270.2	86.3	218.3	734.7	2160.7	2090.8	3147.9	3049.3	3646.3	2929.5	2763.3	2941.3
Xinjiang					3347.6	3381.8	3580.4	4501.4	1783.9	3912.7	1981.6	5511.3

the southeast coastal region, but were still chiefly trunk routes. This fits the pattern of the central–local mode II. Importantly, international corridors emerged, which crossed the mountains, plateaus, and desert regions; the Silk Road (to western regions), the Shu Cloth Road (to Southeast Asia), and the Maritime Silk Road (to West Asia and North Africa) began to develop. However, road transport was concentrated in the northern part of the eastern region and the Loess Plateau, which included 14 hubs, such as Luoyang, Xi’an, Handan, Beijing, and Zibo. Xi’an, in particular, became a nationwide hub. Only six hubs (Shouxian, Hefei, Jiangling, Suzhou, Guangzhou, and Chengdu) developed in the southern region.

In the following Eastern Han Dynasty (25 to 220 AD), the centralized organization persisted, in which the essential principle of structuring the network was the capital as the main node of convergence. As a result, the road network expanded to 3.13×10^4 km and seven trunk routes were developed. In addition, the capital of Luoyang became the largest road hub. In this period, although the Yangtze River had an important influence on the expansion of the road network, the Tibetan Plateau, the Greater Khingan Mountains, and the Wuling Mountains became the major obstacles.

The fall of the Han Dynasty was followed by an age of fragmentation and several centuries of disunity amid warfare by rival kingdoms. China entered the Wei–Jin and Southern and Northern Dynasties (220 to 581 AD) and the road network returned to the multi-kingdom mode. A set of state road networks coexisted, but they were well interconnected. In this context, construction by each kingdom prompted expansion of the road network to 3.54×10^4 km. Meanwhile, the road network in the middle and lower reaches of the Yellow River valley recovered and gradually improved in connectivity; the roads developed into a regional network in southwest China because of the obstacles of the Qinling Mountains and Daba Mountains. Central China, south China, and the southeast coastal region were connected to the Central Plains by a tree-trunk network across the Yangtze River. The Tibetan Plateau, the Greater Khingan Mountains, the Daba Mountains, and the Wuling Mountains were still the major obstacles to the road network. The coexistence of multiple kingdoms also fostered multiple hubs, such as Xi’an, Xuchang, Chengdu, Hangzhou, Kunming, and Luoyang.

3.3 Development and maturity of the skeleton network

From the Sui Dynasty (581 to 618 AD), China began to take steps toward nationwide road coverage, not only constructing a nationwide skeleton network, but also building many new routes, which increased the distances covered to 4.58×10^4 km; however, the roads were still concentrated in the inland region in the second and third ladders. The Sui Dynasty unified China into an entirely new empire and promoted the road network into a standardized central–local mode. The governors rebuilt the Chi Road and developed a trunk route along the canal from Xi’an to Hangzhou by constructing branches and collection–distribution roads. They also reopened the Dayu Road (Ganzhou–Guangzhou) across the Wuling Mountains to connect south China with the middle reaches of the Yangtze River Valley.

The political and economic prosperity in the following Tang Dynasty (618 to 907 AD) promoted the rapid expansion of roads into a nationwide network, more closely fitting the central–local mode II. The middle and lower reaches of the Yellow River valley, with the majority of the population and superior conditions for agricultural production, such as water and a warm climate, still had the densest road network. The peripheral regions, such as south and southwest China and the southeast coastal region, also further overcame natural obstacles (mountains, deserts, including the Gobi Desert, rivers, and lakes) to achieve better connectivity, which provided greater competitiveness for these areas, which had previously been disadvantaged by their distance from the core area. Interestingly, the road network differentiated into both latitudinal and longitudinal routes, and trunk and branch routes, including 11 horizontal trunk routes, six vertical trunk routes, and seven trunk routes to the border regions, which played a prominent role in uniting the whole country after long periods of war. This trunk network was accompanied by various secondary roads connecting the main towns of each province. In particular, the route connecting Tibet across the Tibetan Plateau was constructed to join this region into the road network for the first time. The Silk Road was also strengthened along the Tianshan Mountains and its growing success became one of most famous achievements of the Tang Dynasty. Xi'an and Luoyang were still the major hubs, but Kaifeng, Beijing, Taiyuan, Chengdu, Jingzhou, Guangzhou, and Yangzhou became secondary hubs. Importantly, the system of two capitals resulted in the development of the Xi'an–Luoyang corridor. China's road network shaped a special mode, called the inland expansion model (Jin *et al*., 2010). The influence of several natural obstacles such as the Tibetan Plateau, the Qinling Mountains, the Yangtze River, the Wuling Mountains, and the Yunnan–Guizhou Plateau weakened greatly, but the Hengduan Mountains and the Kunlun–Altun–Qilian Mountains along the northern edge of the Tibetan Plateau, and the Greater Khingan and Lesser Khingan Mountains, still had an obvious impact.

At the end of the 10th century, clearly a turning period for the road network, China entered a period of coexistence of multiple regimes, with much more warfare. In addition to the Song Dynasty, several local regimes founded by minority groups in the peripheral areas (mainly the plateau, mountain, desert, and steppe regions) also existed, including the Liao, Western Xia, Jin, Dali, and Tubo regimes. These separatist regimes promoted the development of the regional road network and trunk routes and increased the total distance covered to peak at 4.54×10^4 km.

The Northern Song Dynasty (960 to 1279 AD) constructed many new routes, such as the Northern Road across the Xiao Mountains, the Taihang Road across the Taihang Mountains, the Dali Market–Horse Road across the Hengduan Mountains, and the Zhejiang–Fujian Road across the Wuyi Mountains. Four trunk routes were also developed from the capital Kaifeng. The southward shift of the Southern Song Dynasty promoted Hangzhou as a major hub and the increase in overseas trade also allowed routes connecting the sea ports of Guangzhou, Hangzhou, Ningbo, and Quanzhou to become trunk routes. For the first time, the road network displayed a maritime-oriented character, similar to the port penetration model proposed by Taaffe *et al.* (1963), but it still remained mainly in the inland-oriented mode.

In this period, the northern local regimes were in an expansion phase during the frequent wars; multiple, but unstable, capitals developed. Liao state had five capitals and developed a road network to connect these capitals with the Song Dynasty and Korea across the Changbai Mountains. The changes in the capital of Jin state promoted a shift of the road hub to Daxing and Beijing. The Western Xia Dynasty also developed a regional network around Lingzhou and Haiyuan. Therefore, as a response to the coexistence of local regimes, the road network became a classic multiple-regimes mode with significant expansion of the road coverage, although Song Dynasty China relied less on overland trade from the Silk Road. This analysis fully reflects a large difference between the multiple-states mode and the unified-empire mode.

3.4 Maturity and consolidation of the nationwide road network

From the Yuan Dynasty (1206 to 1368 AD), China entered a new period of unified empire.

The further integration of land territory was accomplished by a nationwide expansion of the road network, which entered a mature and stable phase with the prevalence of the central–local mode model. The network was still concentrated inland and inherited the inland-oriented mode, but many routes, even trunk roads, were connected with the large sea ports, showing some features of the port penetration model. Mountains, plateaus, deserts, and rivers were no longer obstacles to road expansion. Another interesting characteristic emerged between road network and the ethnicity of the governors. The northern minority groups had a strong expansionary nature, but the Han Chinese were more conservative and the shape of the road network reflected a significant difference between the empire of the minority groups of the Yuan and Qing dynasties and that of the Han Chinese in the Ming Dynasty.

In the period of the Yuan Dynasty, governed by the Mongolians, the road network was developed under a specific historical condition. Since the Temujin was given the name of the "Great Mongol Emperor.", successive wars lasting for a half-century were launched, involving the Eurasian region from East China to the valley of the Danube River. The frequent wars greatly stimulated road construction to increase the length to 4.69×10^4 km.

After the inheritance of China from the Song Dynasty, the Yuan governors constructed roads in each province to link the capital to local areas, covering the land northeastward to the Heilongjiang River estuary, southwestward to the Pamir Plateau, and northward to the upper reaches of the Yenisei River, shaping a multi-layer system. First, a developed inter-urban network was constructed around the capital Beijing. These improvements in transport further promoted the concentration of economic activity and population in this favored region, which became the core of the whole country. Second, a differentiation emerged between the nationwide trunk road network from Beijing to each province and the provincial network from the provincial capitals to the smaller cities. Third, the multiple nations founded by the Mongolian empire promoted international roads connecting Central and Southeast Asia and Siberia. The peripheral regions, such as the southeast coastal region, south, and southwest China, also developed better connected road networks, but these regions, especially the vast Inner Mongolia grassland, were still poorly developed (Spiekermann and Wegener, 1996). In addition, most of the important sea ports were well connected by the trunk roads. It was noteworthy that the separation of road network between south China and the Yangtze River Valley by the Wuling Mountains disappeared and the old commercial corridor of the Silk Road quickly declined. The influence of the Hengduan Mountains on road expansion also decreased. The expansionary nature of the minority groups therefore had a considerable impact on road construction.

The Ming Dynasty (1368 to 1644 AD) was the last dynasty to be ruled by the Han Chinese and its conservative nature resulted in a shrinking of the land territory. However, the country's unification and economic development improved the road network. Specifically, the governors reinforced road construction in southwest, northeast, and northwest China, in particular renovating the postal roads in the southwest region. Importantly, the postal and trade routes intersected; trunk and branch routes were also interlinked across the country. A nationwide road network operated around the two capitals, Beijing and Nanjing, including eight trunk routes from the former to connect Liaoyang, Kaiyuan, Songfan, Baoshan, Guangzhou, Fuzhou, Ningcheng, Xi'an, and Jiuquan, and 13 trunk routes from the latter, which confirms our earlier observation of an inland-oriented mode. To a great extent, as a result of the governance of the Han Chinese, the shrinkage of land territory to the east, in central China around the middle and lower reaches of the Yellow River valley, and the near-west of China, caused a decline in the roads in the border area, especially in northwest and northeast China and Tibet; the total length of roads decreased to 4.26×10^4 km. It was noteworthy that the road density obviously increased in the southeast coastal region across the Wuyi and Wuling Mountains.

The Qing Dynasty (1616 to 1911 AD) was governed by the Manchu, originating from the grasslands of northeast China, and traditional road transport flourished. The expansionary nature of the Manchu minority greatly expanded the road network. It was evident that the origins of the Manchu governor promoted the construction of roads in northeast China into a better connected regional network, overcoming the obstacles of the Greater Khingan and Changbai Mountains, although the wetlands of the Sanjiang Plains still lacked road routes. The roads in northwest China recovered and were even expanded after the Yuan Dynasty; connectivity in southwest China was enhanced. These developments increased both the density and coverage of the road network and the distance covered increased to 5.3×10^4 km, higher than the levels of the Song Dynasty, shaping a road network around the capital of Beijing and radiating outwards in every direction to connect the provincial capitals, frontier fortresses, prefectures, and counties.

Interestingly, a complex functional structure developed within the road network and differentiated the roads into official roads, royal roads, postal roads, causeways, immigration roads, and border roads, with different functions to support the various activities and to integrate the land over space (Spence and Linneker, 1994). The official roads from Beijing were developed into three corridors, joined by many trunk and branch routes, connecting south China (Guilin and Guangzhou) across the Yangtze River and Wuling Mountains, northwest China (Yili and Lhasa) across the Tibetan Plateau, the Hengduan Mountains and the Yunnan–Guizhou Plateau, and northeast China (Qiqihaer and Uliastai) across the Greater Khingan Mountains and the Changbai Mountains. This circumferential system became the main means of achieving the highly efficient operation of administration from the center to the local levels. In addition, the Qing governors developed a road system for the defense of their frontier along the Heilong River. This illustrates the relationship between the road network and the minority governors. Overall, China's road network better fits a special mode of the inland-expansion model (Jin *et al.*, 2010).

4 Accessibility and evolution of the road network in China

It is widely acknowledged that infrastructure networks play a crucial role in land development. Theoretically, road improvement leads to direct effects in the form of changing travel times, distances, and costs. Accessibility is the main product of a transport network as it relates to all the nodes in the spatial system under analysis and is therefore a major factor in the socio-economic development of a region.

4.1 Connectivity of the road network

Roads are significant transport linkages and are important components in shaping regional structures and promoting economic development, even after the unification of a country. The analysis of road accessibility generally first examines the connectivity of the county used as the vertices on the graph of the road network, fully reflecting the regularities of its changes over time. Table 2 summarizes the changes in connectivity, including the number and proportion of connected cities and the proportion of land serviced by various levels of cities. With the continuous expansion of the road network, the number of counties connected showed a dramatic increase. An increasing area of land benefited from a transport service, reflecting the improving capacity of the road network to support land development.

Table 2 Cities connected by road network in China in the various dynasties and their level of development.

Dynasty		Shang	Western Zhou	Spring and Autumn	Qin	Western Han	Eastern Han	Wei-Jin	Tang	Song	Yuan	Ming	Qing
County	Edges/*e*	180	140	291	333	548	674	722	831	927	808	754	901
	Vertices/*v*	175	133	276	321	526	629	666	758	843	738	678	815
	Proportion	7.54	5.73	11.89	13.82	22.65	27.09	28.68	32.64	36.3	31.78	29.2	35.1
	Beta/β	1.029	1.053	1.054	1.037	1.042	1.072	1.084	1.096	1.1	1.095	1.112	1.106
	Loop index/*μ*	6	8	16	13	23	46	57	74	85	71	77	87
	Alpha/*α*	0.0174	0.0307	0.0293	0.0204	0.022	0.0367	0.043	0.049	0.0506	0.0483	0.057	0.0535
	1-*α*	0.9826	0.9693	0.9707	0.9796	0.978	0.9633	0.957	0.951	0.9494	0.9517	0.943	0.9465
	Gamma/*γ*	0.347	0.356	0.354	0.348	0.349	0.358	0.362	0.366	0.367	0.366	0.372	0.369
	Proportion	2.31	1.68	3.74	5.37	18.47	19.79	23.31	29	29.49	27.16	23.41	34.47
Prefectural city	Node number	39	28	66	79	127	162	141	185	194	190	160	140
	Proportion	11.68	8.38	19.76	23.65	38.02	48.5	42.22	55.39	58.08	56.89	47.9	41.92
	Edges/*e*	75	39	106	100	171	266	256	314	403	300	279	301
	Beta/β	1.923	1.393	1.606	1.266	1.346	1.642	1.816	1.697	2.077	1.579	1.744	2.150
	Loop index/*μ*	37	12	41	22	45	105	116	130	210	111	120	162
	Alpha/*α*	0.5068	0.2353	0.3228	0.1438	0.1807	0.3292	0.4188	0.3562	0.5483	0.296	0.381	0.5891
	Gamma/*γ*	0.6757	0.5	0.5521	0.4329	0.456	0.5542	0.6139	0.5719	0.6997	0.5319	0.5886	0.7271
Provincial city	Edges/*e*	9	2	21	39	57	131	115	200	256	187	253	263
	Vertices/*v*	7	3	8	12	18	22	20	24	26	28	27	26
	Beta/β	1.286	0.667	2.625	3.250	3.167	5.955	5.750	8.333	9.846	6.679	9.370	10.115
	Loop index/*μ*	3	0	14	28	40	110	96	177	231	160	227	238
	Alpha/*α*	0.3333	0.0000	1.2727	1.4737	1.2903	2.8205	2.7429	4.1163	4.9149	3.1373	4.6327	5.0638
	Gamma/*γ*	0.6000	0.6667	1.1667	1.3000	1.1875	2.1833	2.1296	3.0303	3.5556	2.3974	3.3733	3.6528

Note: α = actual to maximum possible circuits; β = average links per vertex; γ = proportion of possible route.

In the early period, the limited land territory, which was confined by the middle and lower reaches of the Yellow River Valley, joined a small number of counties, chiefly concentrated in the Central Plains, to the road network. In the Shang Dynasty, the road network connected 175 counties, 7.5% of the total number of counties in China, but this coverage decreased to 133 counties in the Western Zhou Dynasty. However, this indicator increased two-fold in the Spring and Autumn Period, involving 276 counties, but still serving only a small area of land.

The unification of China progressively increased this number to 321, with a rate of 13.8% in the Qin Dynasty, but only 5.4% of the land benefited from the service of a road system. In the following Western Han Dynasty and Eastern Han Dynasty, the number of counties connected by the road network greatly increased to 526 (22.7%) and 629 (27.1%), respectively, meaning that nearly one-fifth of the land benefited from road transport. The Qin Dynasty and Han Dynasty therefore became a period of rapid increase in road transport capacity.

A nationwide period of expansion of the road network in the Tang Dynasty increased the number of connected counties to 758 (32.6%) and the amount of land serviced was estimated to be 29%. The connectivity peaked at 843 counties, a growth of 3.7%, in the following Song Dynasty, and this growth contributed to the coexistence of several local regimes with the central Song Dynasty. These cities benefited from the expansion of road network (Willigers *et al*., 2007). However, this process was not constant over time; a marked change in indicators emerged and the number of counties connected decreased slightly to 738 (31.8%) in the Yuan Dynasty. The shrinkage of land territory in the Ming Dynasty further decreased this number to 678 counties. In contrast, the Qing Dynasty recorded a growth to 815 (35.1%) counties and the amount of land serviced increased to 34.5% at a substantially growing pace. Overall, only a small number of counties were connected by the road network over the study period; about one-third of the counties in China were connected by a developed road network. These different growth rates are the signature of distinct phases of expansion of the road network and are strongly related to national territory and the political situation.

The prefectural city is a higher level unit than the county and generally governs a number of counties. For this type of city, an improved road network will bring many benefits. Table 2 shows that the number of connected prefectural cities followed a similar pattern to the counties during the expansion of the road network. Before the Qin Dynasty, the number was very small and reached just 39 (11.7%) in the Shang Dynasty and 66 (19.8%) in the Spring and Autumn Periody. The number then increased, reaching 127 (38%) and 162 (48.5%) in the Western Han Dynasty and the Eastern Han Dynasty, respectively. In the Tang Dynasty, over half of the prefectural cities were connected by the road network, mirroring the closer administrative linkage between central and local governments. The highest level of connectivity was reached in the Song Dynasty: 194 (58.1%) cities. Similar to the counties, the number of connected prefectural cities decreased in the later dynasties, reducing to 190 in the Yuan Dynasty, 160 in the Ming Dynasty, and 140 in the Qing Dynasty. In addition, the number of provincial cities connected by the road network increased, especially after the Tang Dynasty, when the number was stable and reached 80%–90%.

4.2 Evaluation of the structure of the road network

The development level of a road network generally refers to the connectivity and the level of convenience of linking among the nodes. In a time-series analysis, graph theory is particularly useful in analyzing the evolving features of a transport network as simplified abstractions/nodes connected by links (Weber, 2012). This conversion can be accomplished using simple topology, assuming a qualitative uniformity of the nodes and links. Several measurements can be used to examine the road network as a whole and to provide insights into its changing character over the period covered by Table 2.

From a historical point of view, the expansion and maturity of a road network is a long-term process and various indicators show evolving regularities (Table 2). With the expansion of the road network, the number of edges (*e*) among the nodes grew continuously and the overall efficiency of the network increased. It increased from 180 in the Shang Dynasty to 333 in the Qin Dynasty, followed by a further rapid two-fold increase to 674 in the Han Dynasty, and climbed to the highest level of 927 in the Song Dynasty. After a continuous decrease in the Yuan Dynasty and Ming Dynasty, it increased again to 901 in the Qing Dynasty. The construction of more routes brought about an increase in the growth and complexity of the road network and changes in accessibility, with an obvious expansion of the road coverage.

The increase in the complexity of the network structure can be seen in the increase in the other indicators. The connectivity β and loop index μ are commonly used to assess the relationship between the nodes and edges. β refers to the average amount of connecting route for each node. Since the Shang Dynasty, β has been >1, with a small growth over time, and the road system has been in the form of a circuit network. The value of β maintained a rapid increase from 1.029 in the Shang Dynasty to 1.1 in the Song Dynasty and increased further to 1.106 in the Qing Dynasty. This shows that the road network before the Sui Dynasty shaped a differentiation between the core region and the peripheral regions. The core region showed a high connectivity network with many circuits when $\beta > 1$, but the peripheral regions have an obvious tree-like network, or even a linear pattern, with $\beta < 1$. However, after the Tang Dynasty this pattern gradually faded and the roads developed into a unified nationwide loop network. The increasing value of β mirrors this more complex network. Another measure used to describe a network topologically is μ, which represents the loop number. This showed a continuously increasing trend from 6 in the Shang Dynasty to 85 in the Song Dynasty, and then entered a slightly decreasing phase in the Yuan Dynasty and Ming Dynasty before gradually increasing again to 87. Overall, China had had a well-developed road network since the Tang Dynasty.

Several other measures (α and γ) have been used to characterize not only the developing level of the road network, but also the potential for development. In spite of the high level of connectivity since the Shang Dynasty, there has been a high potential for further expansion of the road network. The value of α for China initially had an extremely low value <0.06, with an enormous potential to improve the road network, but continuous growth meant that the total number of possible circuits in the network increased for each city. Table 2 also shows that the index γ has increased over time and represents the increasing connectivity. However, it has been maintained between 0.34 and 0.37 and has a lower connectivity, which also shows the large potential for expansion. This was due to the natural barriers (mountains, plateaus, rivers, and lakes) to road construction. In summary, both the connectivity and complexity of the road network in China have increased over time.

These values were also calculated for the prefectural and provincial cities and a comparative analysis among the three units presented some interesting results. With an increase in spatial scale, the road network became more simplified and the edge numbers (*e*) for the prefectural and provincial cities were much smaller than for counties, although they also show an increasing trend since the Shang Dynasty. Interestingly, the edge number for the prefecture cities always accounts for 35%–40% of the county, although the share for provincial cities increased from 5% in the Shang Dynasty to 29.2% in the Qing Dynasty. In contrast, the values of β for the prefectural and provincial cities were higher than those of the county. In particular, the values for provincial cities since the Tang Dynasty were remarkably high and even reached 10.1 in the Qing Dynasty. These analyses show that the building of administrative linkages between the central and provincial capitals and among the provincial capitals is very important. The index μ also shows the higher connectivity and increasing number of loops among the prefecture and provincial capitals. Strikingly, α showed more disparities among the three units; specifically, the value for the prefectures was about 10 times that for the counties and the value for the provincial cities was 100 times of that of the county value; the prefectural and provincial cities had much higher ringing levels. The value of γ showed that the prefectural and provincial capitals had a much lower potential for expansion of the road network. Overall, these analyses show that the higher the administrative level for one node, the more mature is its road network and the higher its connectivity.

4.3 Accessibility of the road network

Accessibility is often seen as an important determinant of the location of socio-economic activities (Willigers *et al*., 2007). Figure 4 and Table 3 present summary statistics and descriptions for the accessibility of each period.

Table 3 Major accessibility indicators of the road network in China in each period

Indicator		Shang	Western Zhou	Spring and Autumn	Qin	Western Han	Eastern Han	Wei-Jin	Sui	Song	Yuan	Ming	Qing
Total travel distance/10000 km		2227	979	6320	13439	42618	57833	63590	91601	105788	86579	67555	111474
Average travel distance per node/10000 km		727	553	830	1304	1540	1462	1434	1594	1489	1590	1470	1678
Maximum travel distance/10000 km		28.3	11.6	43.8	77.0	202.3	254.8	253.5	298.7	299.9	308.5	239.7	315.7
Minimum travel distance/10000 km		7.8	5.0	16.5	26.1	50.0	56.9	61.5	78.6	83.8	78.1	66.9	90.8
Peripheral	Node name	Wuyuan	Gaomi	Tonghua	Fuyang	Shufu	Artux	Artux	Artux	Hotan	Kashi	Hotan	Yuepuhu
	Location coefficient	2.223	1.574	1.914	1.839	2.497	2.772	2.655	2.472	2.39	2.63	2.406	2.308
Core	Node name	Yanshi	Luo-yang	Jinan	Luo-yang	Luo-yang	Luo-yang	Luo-yang	Luo-yang	Kai-feng	Zheng-zhou	Zheng-zhou	Zheng-zhou
	Location coefficient	0.615	0.685	0.719	0.623	0.617	0.619	0.645	0.65	0.668	0.666	0.671	0.664
Locational coefficient > 1	Node number	68	56	97	127	193	229	256	260	350	272	297	289
	Rate in total county	2.93	2.41	4.18	5.47	8.31	9.86	11.02	11.2	15.07	11.71	12.79	12.45
Locational coefficient < 1	Node number	107	77	179	194	333	400	410	498	493	466	381	526
	Rate in total county	4.61	3.32	7.71	8.35	14.34	17.23	17.66	21.45	21.23	20.07	16.41	22.65

(1) Travel distance

A simple means to measure changes in a road network is to examine the total travel distance *D*, which reflects the coverage and density of a road network. Continuous road construction enlarges the travel distance of the entire network and expands its coverage. The value of *D* reached 2.2×10^7 km in the Shang Dynasty and has increased continuously since then. In particular, it has grown dramatically since the Qin Dynasty, when it exceeded 1×10^8 km, and then increased by two to three times in the Han Dynasty, reaching a peak of

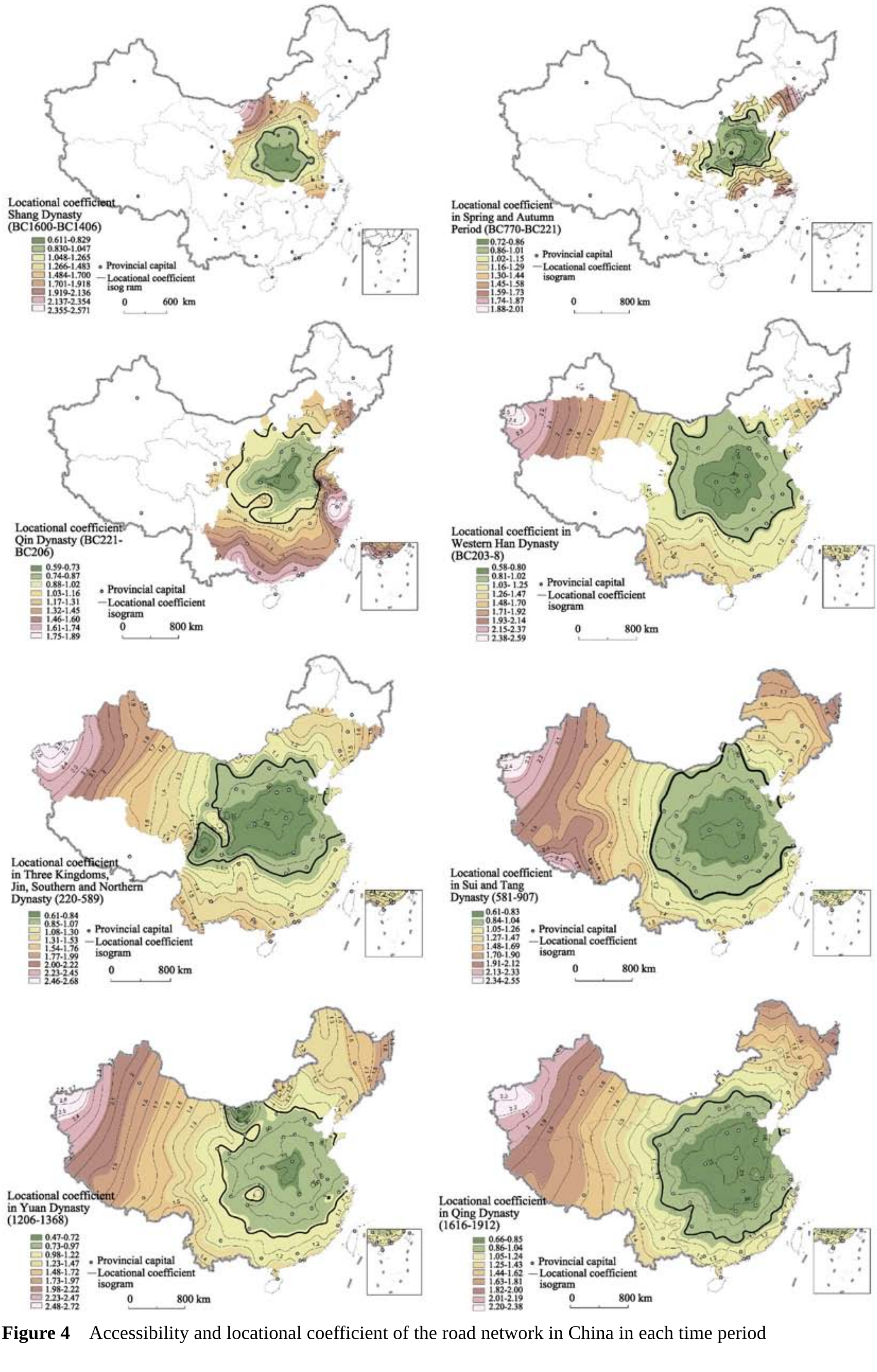

Figure 4 Accessibility and locational coefficient of the road network in China in each time period

over 1×10^9 km in the Song Dynasty. Thereafter, it decreased slowly in the Yuan Dynasty and Ming Dynasty, but increased to 1.1×10^9 km in the Qing Dynasty. The continuous growth of the travel distance shows that the road network has been improving its connectivity and covering more land. In fact, the growth in travel distance resulted in a continuous expansion of land territory.

The mean travel distance for each node showed a similar pattern. It reached 7.27×10^6 km in the Shang Dynasty, but decreased to 5.53×10^6 km in the Zhou Dynasty. However, from the Zhou Dynasty to the Western Han Dynasty it has shown rapid growth and increased to 1.54×10^7 km, entering a fluctuating phase when it varied from 1.43×10^7 to 1.68×10^7 km. To some extent, the increase in the mean travel distance illustrates the expansion of the road network coverage, although its decrease when the total travel distance increases may be largely attributed to a reorganization of the shortest path among the nodes due to the emergence of new routes. This change coincided with the expansion of the road network. As a consequence, the road network compressed time and space, commonly referred to as temporal–spatial convergence. In essence, the road network became more efficient, as evidenced by the increase in the total travel distance.

(2) The spatial pattern of accessibility

In theory, the road network differentiates the locational advantage among the nodes by giving them different levels of accessibility and this further determines their potential for development. As shown in Figure 4, the accessibility was unevenly distributed over space in every time period, but has displayed the general pattern of a core–peripheral concentric circle configuration from the more central regions to the more peripheral regions. All the historical periods typically followed this concentric pattern, in which the center had the best accessibility, but the most peripheral nodes were the least accessible (Gutiérrez, 2001). The middle and lower reaches of the Yellow River Valley and its surrounding counties represent the core and the accessibility decreases gradually from this center outwards in the form of successive accessibility rings, so the most peripheral regions, especially the remote regions, mountain regions, and border areas had a lower than average accessibility. Accessibility therefore shows a significant differentiation between the central and peripheral locations. Interestingly, the pattern of accessibility displayed a distinctly expanding process, with a continuous distortion of these concentric circles and movement of the central space outwards before the Eastern Han Dynasty, but after this time it moved into a relatively stable phase with similar patterns. A gap emerged between the eastern and western regions in terms of accessibility, with most eastern places having an accessibility above average and the western region below average. In the Shang Dynasty the regions, including Henan, south Shanxi, south Hebei, west Shandong, north Anhui, and north Hubei, had superior locations, but the most accessible regions were mainly delimited at Henan. This pattern coincided with the overall pattern of territory origination and the development of civilization in China. The coexistence of multiple kingdoms in the Spring and Autumn Period extended the superior region to Shaanxi, North Hebei, and Shandong; the most accessible region expanded to Shandong, but obviously shrank to the north. The superior regions stretched discontinuously north–south and westward in the Qin Dynasty and Shaanxi, Gansu, and northwest Hubei had a locational advantage; the most accessible region was again Henan, shaping a central region around Xi’an, Luoyang, and Zhengzhou along the Yellow River.

Subsequent building of many new routes brought about noticeable changes in accessibility. The major feature in the Western Han Dynasty was that the improvement in accessibility spread to more areas and the superior region enlarged to include the whole of north China and even parts of northwest and central China. In the Eastern Han Dynasty, however, the most accessible region transformed significantly from outward expansion around Xi'an and Luoyang in the Western Han Dynasty into northward extension. In the Tang Dynasty the superior region continued to expand southward, even near the Wuling Mountains, whereas the development of local northern regimes in the Song Dynasty promoted extension northward, but shrinkage southward. However, in the Yuan Dynasty the direction of extension returned southward to the Wuling Mountains and westward to the near-western region, and new routes brought the peripheral regions closer to each other and the center (Gutiérrez and Urbano, 1996). The most accessible region shrank significantly inward in the Ming Dynasty, but significantly extended outward, especially northwestward and northward, in the Qing Dynasty.

Over the whole study period, the lowest accessibility was recorded in the less developed northwestern and northeastern margins, which are mountain regions, deserts, the Gobi region, and steppes traditionally controlled by minority groups. This shows that the peripheral regions were still marginalized despite the improved road network (Vickerman, 1995). To some extent, this pattern is determined jointly by the geographical shape of China and the geometric properties and connectivity of the road network, which displays both topological and geometrical variations. The time–space effects of the road network have undoubtedly significantly altered the economic geography of China. Overall, the pattern of accessibility coincides with the spatial pattern of the population and agricultural production in China; in particular, the areas with high accessibility correspond with the areas with a developed economy and with densely populated regions.

(3) The superior location

The value of AC_i reflects the convenience of the locational condition and its accessibility is relative to other locations. In general, the lower the coefficient of a node, the more superior the location. The maps in Figure 4 show that this indicator followed a statistically uneven distribution. A value of $AC_i < 1$ for a given node shows a greater than average presence of locational advantage and a higher socio-economic potential. A remarkably large set of counties (over one-half to nearly two-thirds) in each period had nodes with a lower than average value and a superior location, but the proportion of such counties in China has been increasing. In the Shang Dynasty 107 counties had a lower than average AC_i value and superior location, but these accounted for only 4.6% of the total number of counties. Another observation that can be made is that only 1.04% of the land fell within the region benefiting from a road service. In the Zhou Dynasty and the Spring and Autumn Period, the number of superior locations expanded to 77 and 179 counties. Subsequently, this group increased to 194 in the Qin Dynasty and a further noticeable increase to 333 was seen in the Western Han Dynasty and 410 in the Eastern Han Dynasty, with its proportion and area covered also increasing to 17.2% and 7.33%, respectively. These analyses show that road network gave a locational advantage to more counties and its capacity for transport increased rapidly.

The number and proportion of superior counties increased slightly in the Wei-Jin Period. This group further increased to 498 (a 21.5% share) and about 9.4% of the land had a better service than the national average in the Tang Dynasty. In spite of the relatively stable amount and proportion of land, the area covered by the road network decreased to 8.64% in the Song Dynasty. After this time, the number of superior counties decreased and reduced to 466 in the Yuan Dynasty and 381 in the Ming Dynasty; the area covered reduced to 6.4%. However, in the Qing Dynasty the downward trend was reversed and 526 counties with a share of 22.7% and one-tenth of the land area have an obvious locational advantage. Overall, it is evident that the superior counties continued to maintain their position as the core region in the middle and lower reaches of the Yellow River Valley throughout history. In contrast, many counties, especially the border, mountain, and peripheral regions, had poor accessibility that impeded local socio-economic development.

(4) The central nodes and peripheral nodes

It is widely accepted that the node with the highest or lowest locational coefficient has particular geographical significance in describing a road network across a country. The value of η represents the route number of the shortest path from a node to the furthest node; the node with the minimum travel distance and locational coefficient is the center of the road network. Interestingly, Table 3 shows that the central node of the road network continued to change its micro-location, but maintained a stable macro-location over time. In most periods this node was located at Henan and its locational coefficient ranged from 0.6 to 0.7. In the Shang Dynasty, Yanshi in Henan had the highest locational advantage and its coefficient was 0.615, whereas in the Western Zhou Dynasty Luoyang was the central node, but this center shifted further eastward to Jinan in the Spring and Autumn Period. In the period from the Qin Dynasty to the Tang Dynasty, Luoyang had the most strikingly locational performance and became a central node with the longest and most stable duration of 1100 years. The central node subsequently shifted eastward to Kaifang in the Song Dynasty, then westward to Zhengzhou in the Yuan, Ming, and Qing dynasties. Zhengzhou, the geometric center of China, was by then functioning as a dominant pole in terms of accessibility and became the most accessible city and the second central node with a stable duration lasting for 700 years. This conclusion is in accordance with the observations of railway accessibility by Jin and Wang (2004) and expressway network by Li and Shum (2001).

In general, the city with the lowest accessibility is the most peripheral node and has the worst location in the road network. Table 3 shows that, before the Western Han Dynasty, this node was an unstable location corresponding to the expansion of land territory, but thereafter it was in a stable location at Xinjiang. In the first phase, the eastward extension of the road network caused this node to shift from Wuyuan in Inner Mongolia in the Shang Dynasty to Gaomi in Shandong in the Western Zhou Dynasty, but the increase in connectivity in northeast China caused this node to be recorded in Tonghua in Jilin in the Spring and Autumn Period and then to shift southward to Fuyang in Zhejiang in the Qin Dynasty. In the Western Han Dynasty the most peripheral node shifted northwestward to Shufu. Artux was the most peripheral node with the worst location from the Eastern Han Dynasty to the Tang Dynasty. In the Song Dynasty this node shifted to Hotan and then to Kashi in the Yuan Dynasty. It migrated to Hotan again in the following Ming Dynasty, but shifted to adjacent Yuepuhu in the Qing Dynasty.

5 Relationship between the road network and natural and socio-economic systems

Over a long time period, the creation and development of a road network, including its quality and mode of use, are rooted in the natural environment and the changing economic, political, and military geography. These conditions are fundamental to understanding the spatial regularity of the road network. Historically, the evolution of a road network and the spatial pattern of accessibility are driven, not only by the requirements of commercial and economic activities, but also by the desire to centralize the transport system around the capital city (Marton and McGee, 1996). Beyond the direct impacts of accessibility and connectivity, the road network inevitably has longer term indirect impacts on the geography of the land territory, economic activity, and even national governance.

5.1 Physical conditions and natural obstacles

As a result of the low level of technology, natural conditions such as the terrain, the local geology, the water system, and the climate have an important influence on historical road construction and may even become barriers to expansion. In China, these conditions include mountains, rivers and lakes, deserts and the Gobi region, steppes and plateaus, and wetlands, as shown in Table 4. To some extent, these factors have defined the fundamental pattern or

Table 4 Geographical regions and major natural obstacles to road expansion in China

Type	Name of obstacle	Location or covering scope
Geographical region	Central Plains	Most parts of Henan, south Hebei, southeast Shanxi, east Shaanxi and west Shandong
	Guanzhong Plains	Alluvial plains of Weihe River in Shaanxi
	Sanjiang Plains	Alluvial plains of Heilongjiang River, Ussuri River and Songhua River in east Heilongjiang
Natural obstacle	Yangtze River	Largest river in China; its valley includes Shanghai, Jiangsu, Anhui, Jiangxi, Hubei, Hunan, Chongqing and Sichuan
	Huaihe River	One large river in East China; its valley includes Henan, Hubei, Anhui and Jiangsu
	Qinling Mountains	E–W trend mountains at the border between Shaanxi and Sichuan
	Wuling Mountains	E–W trend mountains at the border between Hunan, Jiangxi and Guangdong, Guangxi
	Taihang Mountains	N–S trend mountains at the border of Shanxi and Hebei
	Hengduan Mountains	N–S trend mountains at the southeastern part of the Tibetan Plateau
	Greater Khingan Mountains	NE–SW trend mountains in west Heilongjiang and northeastern Inner Mongolian Plateau
	Funiu Mountain	E–W trend mountains in west Henan
	Lesser Khingan Mountains	NE–SW trend mountains in central and north Heilongjiang
	Wuyi Mountains	NE–SW trend mountains in west Fujian
	Kunlun-Altun-Qilian Mountains	Mountains along the north edge of the Tibetan Plateau at the border between Xinjiang and Tibet, and between Qinghai and Gansu
	Changbai Mountains	NE–SW trend mountains in west Jilin
	Daba Mountains	E–W trend mountains in northeast Sichuan and northwest Hubei
	Jundu Mountains	Mountains in Beijing
	Dalou Mountains	NE–SW trend mountains in Yunnan–Guizhou Plateau
	Loess Plateau	One plateau in northwest China involving Shanxi, north Shaanxi, Gansu, Qinghai and Ningxia
	Tibetan Plateau	Largest plateau in China involving Tibet, west Sichuan, north Yunnan, Qinghai, and south Xinjiang
	Yunnan-Guizhou Plateau	One plateau in southwest China involving east Yunnan, Guizhou and west Guangxi

structure of the traditional road network because the choice of any route will aim to reduce costs and avoid natural obstacles during construction.

The road network in China varies among the regions because of the highly complex topography. The territory of mainland China lies between latitudes 18°N and 54°N and longitudes 73°E and 135°E and the terrain varies significantly across the country. The whole of China shapes the differentiation into three ladders with different altitudes, terrains and locations. In the east, along the shores of the Yellow Sea and the East China Sea, there are extensive alluvial plains where it is easy to construct roads, while broad grasslands predominate on the edge of the Inner Mongolian Plateau in the north. Southern China is dominated by hills and low mountain ranges; the high altitude mountains in particular are major obstacles to the southward expansion of the road network. The major mountains are located to the west, most notably the Hengduan Mountains and the Qilian Mountains. A high plateau region dominates the more arid landscapes of northwest and southwest China, such as the Loess Plateau, the Yunnan–Guizhou Plateau and the Inner Mongolia Plateau. In addition, there are vast areas of desert, including the Gobi Desert, in northwest China, which impede the expansion of the road network. In the long term, the natural conditions of mainland China determine that most of the routes of the road network are concentrated in the second and third ladders.

In the early periods of the Shang Dynasty and the Western Zhou Dynasty, most roads were concentrated at the Central Plains along the middle and lower reaches of the Yellow River Valley and the northern part of the third ladder because of the fertile soil, rainfall, and heat resources especially the flat plains; in contrast, the Loess Plateau, the Funiu Mountains, the Qinling Mountains, and the complex water system of the Huaihe River impeded the expansion of the road network. In the Spring and Autumn Period, the road network coverage extended to the mountain regions of the east Loess Plateau in the second ladder, with an obvious reduction of influence by the Taihang Mountains.

The unification of China in the Qin Dynasty gave the government more capacity to overcome natural obstacles and many new long distance trunk routes crossed the Qinling Mountains, the Yangtze River and the Wuling Mountains to connect the remote southwest and south of China and the southeast coast. The major obstacles to road expansion changed from the Loess Plateau to the Yangtze River, the Daba Mountains, the Tibetan Plateau, and the Yunnan–Guizhou Plateau. In the following Han Dynasty, the road network expanded to the first ladder, and the Tibetan Plateau, the Greater Khingan Mountains, the Wuling Mountains, and the Gobi Desert in northwest China became major obstacles. In the Sui Dynasty and Tang Dynasty, the influence of these natural obstacles weakened greatly, but the Hengduan Mountains, the Kunlun–Altun–Qilian Mountains, and the Greater Khingan and Lesser Khingan Mountains still had an obvious impact. In the following Yuan, Ming, and Qing dynasties, mountains, plateaus, deserts, and rivers were no longer obstacles to road expansion. In the Yuan Dynasty and Ming Dynasty, the influence of the Wuling and Wuyi Mountains disappeared and the influence of the Hengduan Mountains also decreased. In the following Qing Dynasty the wetland in the Sanjiang Plains, the core part of the Tibetan Plateau, and the Gobi Desert still had an influence on the expansion of the road network.

5.2 National defense and governance and ethnicity

The road network is a primary part of the infrastructure system of any country. Several factors relating to the national governance have affected the evolution of the road network in China over the centuries; the function of the road network in national integration has been emphasized by other works (Leung, 1980; Loo and Leung, 1997).

In the previous centuries, especially in the multi-state periods when regimes coexisted, the primary function of the road network was to support national defense and warfare (Leung, 1980); warfare has therefore been a major factor in the expansion of the road network. There were hundreds of tribes in the Shang Dynasty and the governor opened a route from the capital to Wuyuan to fight against the northern minority groups; wars with the southern minority groups also brought about the construction of mountain roads in Hubei and Hunan. Frequent warfare was common in the Spring and Autumn Period and each state constructed roads in its own domain to service the war. In this period, about 483 chariot wars took place and this greatly promoted the development of regional road networks. Similarly, the road also supported the wars in the Three States. The continuous wars deriving from the coexistence of multiple local regimes in the Song Dynasty resulted in a peak in the development of road networks. After the establishment of the Mongol Empire, Mongolia engaged in half a century of wars in the Eurasian region from East China to the Danube River, which also greatly increased road construction. Even in the periods with a unified empire, wars against minority groups contributed to road expansion in the border areas (Loo and Leung, 1997). An example is the construction of the Zhi Road from Xi’an to Baotou by the Qin governor to fight against the Huns; the Qing governors also opened new roads to transfer military supplies to fight the Junggar Rebellion and the Jaxa Battle.

Road development and accessibility are correlated with national development. The governance of national land, especially the management of new land, relies heavily on the road network and promotes the sinicization in the peripheral areas. After unification, the Qin governor constructed the Wuling Mountains Road, the Plan Road across the Qinling Mountains, and the Wuchi Road (Sichuan–Yunnan) across the Yunnan–Guizhou Plateau to govern the border areas. In order to rule northwest and southwest China and the Wuling Mountains region, the Han governors also opened the Yelang Road across the Dalou Mountains, the Lingguan Road along the southern edge of the Hengduan Mountains, the Guoxie Road across the Daba Mountains, the Huizhong Road across the Liupan Mountains, the Ziwu Road across the Qinling Mountains, the Feihu Road, the Cochin Road across the tropical forests, and the Qiao Road across the Wuling Mountains. The Tang Dynasty constructed the Tang–Tibet Road across the Tibetan Plateau and roads to the Bohai Sea and Nanzhao across the Yunnan–Guizhou Plateau and Uighur, and also developed seven trunk routes to remote regions. The Song Dynasty also extended the southwest roads, especially the Dali Market–Horse Road across the Hengduan Mountains.

Historically, an overall increase of exchange following the improvement in accessibility was generally envisaged as a tool to solve the problem of underdevelopment (Kreutzmann, 2004) and most of the dynasties implemented the Duntian system in the border areas to exploit the cultivated lands and residential areas. After a series of wars, the Han Dynasty established many new frontier command posts in the Hexi Corridor and moved the Han Chinese population to settle in this area after 111 BC. The Yuan Dynasty often moved the Han Chinese population and army captives to the border regions from 1272 to 1293 AD, which promoted new road construction. The Ming government constructed the border roads in northwest China, especially the Horse Road along the Great Wall. To connect all the suitable border points, after the signing of the Sino-Russian Treaty of Nipchu in 1689, the Qing Dynasty constructed roads to patrol the border in northeast China. In addition, the opening of forbidden areas in northeast China after the 17th century attracted a large number of Han immigrants into this region and developed hundreds of new roads. Hence the roads in the peripheral regions were active in shaping the nationwide road network of which they were a part and the road network also shaped a significant spatial expansion from inland to the borders of China.

The relationship between the transport network and the centralization of national power is an interesting topic (Bel, 2011). Most periods have prioritized the development of the transport network because this favors the integration of national power. Administrative linkage between central and local governments or among the states greatly promoted the expansion of the road network and, in particular, the capital city became the core of the road network. In general, the roads shaped a network from the capital to the adjacent counties in the period of a small territory (mode I) and the Shang Dynasty constructed a regional network around its capital of Shangqiu. The Western Zhou Dynasty implemented a feudal system with the power divided among the vassals and developed a road network from Xi'an to each state. In the Spring and Autumn Period, over 170 states emerged successively and built roads in their own domain, but a network still developed around Luoyang to maintain a loose relationship between central and local control (mode III). The Han Dynasty laid equal stress on both the feudal system and the centralization of national power and developed a road network from the country capital to the state and provincial capitals.

In a unified empire, the administrative linkage between central and local government became a key impetus. By positioning the national capital and center of national power in a more vital role, a new pattern of road network (mode II) was generated, bringing a more complex structure and more differential functions. The nationwide radial trunk network developed from the country capital to the provincial capitals to facilitate the dispatch of orders; regional networks emerged between the provincial capital and the counties in its domain. This centralized organization persisted in the Qin, Tang, Yuan, Ming, and Qing dynasties, with the same principle of structuring the network to maintain the capital as the main node of convergence. This mode maintained a hierarchical system to centralize national power at the capital, which was also observed in other countries, e.g. Spain (Bel, 2011). The relationship between road networks and the centralization of power is now widely accepted. Interestingly, the coexistence of the central dynasty and local regimes in the Song Dynasty, and especially the changes in the capitals, developed a multi-core network (mode IV). Therefore it can be seen that, before the rise of a unified empire, a regional network was constructed around the different state capitals, but it was the unified empire that developed a nationwide network around the national capital. The road network in China shaped a special mode called the inland expansion model, which is mirrored by the railway network, but is in contrast with the port penetration model (Taaffe *et al*., 1963; Jin *et al*., 2010).

Traditionally, the road network seems to have no relationship with ethnicity in any one country. Surprisingly, however, the experience in China verifies a close relationship between ethnicity and the road network in two different contexts (i.e. the Han Chinese and minority groups), as shown in Table 5. Historically, the Han Chinese lived in the Yellow River and

Yangtze River valleys with advantageous natural conditions, such as high-fertility soils and rainfall, and therefore they developed an advanced agriculture. This meant that they did not have a desire to expand their land territory. In contrast, the minority groups can be divided between the northern and southern parts of China. In a similar manner to the Han Chinese, as a result of complex natural conditions (mountain and forest) and their production mode of hunting or agriculture, the southern minority groups also seem to have lacked a desire to expand their territory. In contrast, the northern and western minority groups developed a nomadic culture in the vast steppes and wilderness. The formidable natural conditions and their brave character on horseback illustrate their desire to expand their territory; they often formed a more powerful empire. Consequently, disparity among ethnic groups influenced the land territory and the coverage of the road network.

Table 5 Capital cities in each dynasty in China

Dynasty	Capital (State)	Ethnicity of governor
Shang	Luoyang, Zhengzhou, Anyang	–
Western Zhou	Xi'an, Luoyang	–
Spring and Autumn	Zibo (Qi), Jingzhou (Chu), Beijing (Yan), Xinzheng (Han), Handan (Zhao), Kaifeng (Wei), Xi'an (Qin)	–
Qin	Xi'an	–
Western Han	Xi'an, Luoyang	Han Chinese
Eastern Han	Luoyang, Xi'an	Han Chinese
Three Kingdoms	Luoyang (Wei), Xi'an (Wei), Chengdu (Shu), Nanjing (Wu)	Han Chinese
Western Jin	Luoyang, Xi'an	Han Chinese
Eastern Jin	Nanjing	Han Chinese
Southern and Northern	Nanjing, Luoyang, Taiyuan, Xi'an, Handan, Datong	Han Chinese; Sienpi;
Sui-Tang	Xi'an, Luoyang	Han Chinese
Five Dynasties and Ten States	Kaifeng (late Liang, late Jin, late Han, late Zhou), Luoyang (late Tang)	Han Chinese; Khitans; Tebitan; Hui
Song	Kaifeng (Northern Song), Hangzhou (Southern Song), Ningcheng and Datong (Liao and Jin), Liaoyang (Liao and Jin) and Beijing, Balin (Liao), Yinchuan and Wuwei (Western Xia), Huining (Jin), Dali and Kunming (Nanzhao)	Han Chinese; Jurchen; Khitans; Tangusts; Mongolian; Tebitan
Yuan	Beijing, Zhenglan, Zhangbei, Datong	Mongolian
Ming	Nanjing, Beijing	Han Chinese
Qing	Liaoyang, Shenyang, Beijing	Manchu

After the fall of the Han Dynasty, areas of northern China were overrun by various non-Han nomadic people, who established kingdoms of their own, such as Northern Wei by the Sienpi. The next few centuries saw the foundation of local regimes by minority groups in peripheral areas, such as in Liao by the Khitans and in Tubo by the Tibetans. In the following Song Dynasty, the minority groups were stronger and several regimes were founded, such as the Jin by the Jurchens, the Liao by the Khitans, the Western Xia by the Tangusts, and Mongolia. In particular, in 1279, the Mongolians conquered all of China and the Yuan Dynasty became the first non-Han dynasty to rule all of present-day China and its surrounding areas, with a territory of 1100×10^4 km^2. Kublai Khan also claimed the title of Great Khan, controlling an area covering 3100×10^4 km^2, supreme over the successor khanates of

Chagatai, Golden Horde, and Ilkhanate. The vast homeland therefore required a huge road network. After 250 years, the Manchus, from northeastern China, founded the last empire of the Qing Dynasty, but expanded beyond China's previous and later boundaries with a territory of 1400×10^4 km^2, expanding the road network once more. Many similar examples are found across the world, such as the Assyrian Empire and the Ottoman Turks.

5.3 Transportation of specialized cargos and trade

The transport infrastructure provides defined channels of movement for the interaction of goods between places. Improvements in the transport infrastructure are therefore a key factor in the transport of specialized cargos. Historically, the transport of specialized cargos (such as salt, metal minerals, and grain) is controlled directly by the government and has greatly motivated the construction of roads.

Over the centuries, the policy of a monopoly on the transport and sale of salt by the government made salt a bulk cargo. Its specialized transport can be dated back to the Western Han Dynasty and the governors controlled the salt production bases and transit centers. Likewise, in the Tang Dynasty, salt was transported in bulk across the country and its annual traffic reached 3.4×10^4 tons and increased further to 4×10^4 tons in the Ming Dynasty.

The transport of metal minerals (e.g. iron, copper, lead, and tin) used for minting coinage has remained the monopoly of the government. In the Western Han Dynasty, metal minerals became a special cargo. In the Qing Dynasty, Yunnan and Sichuan produced 6840 tons of copper. Zinc was mined mainly in Guizhou, with an output of 3000 tons per year, and Yunnan had the highest aluminum output of 380 tons annually; tin production occurred mainly in Yunnan, with an annual output of 720 tons. These minerals were mainly transported to Wuhan, Suzhou, Tianjin, and especially Beijing to mint coins.

The governors in each dynasty constructed a substantial number of palaces, temples, mausoleums, and gardens and the nobility and officials also built luxury mansions. Building materials therefore had to be collected and transported nationwide on a large scale. In particular, the demand for building materials increased greatly during the periods of unified empire.

The integrated transport of long distance shipping and short distance road collection and distribution became a major mode of grain transport in China. Since the Sui and Tang dynasties, grain has been transferred from the Yangtze River Delta to the northern capital; its traffic reached 24×10^4 tons in 742 AD. The road network mainly transferred grain from the port of Luoyang to the capital of Xi'an. In the early Yuan Dynasty the road network provided land transport for the grain outside canal navigation; even after the completion of the Great Canal it still functioned as a means for the collection and distribution of grain.

Historically, most periods have given priority to the development of transport as this favors the prosperity of trade markets. Conversely, the development of domestic and international trade have stimulated the expansion of the road network. In the Shang Dynasty, business activity was only on a small scale and was concentrated in the middle and lower reaches of the Yellow River Valley, but the amount of goods increased and diversified in the Warring States Period and, specifically, agricultural outputs were exchanged in bulk. The improvement in the road network promoted regional division and favored the appearance of specialized products, such as bamboo in Sichuan, silk and ramie textiles in Shandong, metal-working in Henan, and ceramics in the Yangtze River Delta. A group of commercial cities located at the road hub emerged in the Yellow River and Yangtze River valleys to collect and distribute the various cargos nationwide. In the Qin Dynasty, the important commercial cities were mainly located along the trunk routes and in the Western Han Dynasty the developed road network in the northern region led to 14 of the 20 commercially important cities being located in this region, but only six in the southern region.

The *Junshu* and *Pingzhun* laws issued by the Han Dynasty in 110 BC to manage long distance and short distance transport, respectively, stimulated trade and road construction. The Northern Song Dynasty promulgated a new *Junshu* law in 1069 AD to coordinate the transfer of cargo, promoting the flourishing road transport network, especially the roads connecting Guangzhou, Hangzhou, Ningbo, and Quanzhou ports, which became trunk roads. The following encouraging policies on trade issued by the Kublai Khan prompted road transport to extend to Tibet, Xinjiang, and the upper reaches of the Yenisei River. Improvements in transport allowed a massive amount of indigenous trade to concentrate along the Grand Canal and the Yellow River; Beijing and Hangzhou became distribution centers for the northern and southern cargos. The economy became prosperous in the middle Qing Dynasty; a large amount of commerce trade relied on road transport and many commercial cities boomed.

The development of international trade promoted road construction at the border areas and, in particular, opened many trade corridors. Three commercial corridors developed in the Han Dynasty. Of these, the Silk Road started from Xi'an and continued westward to the Western Regions and the Roman Empire, becoming one of the transcontinental Euro-Asian routes. The Cloth Road became the second road to export cloth and silk from the Sichuan Plains to South Asia and the Maritime Silk Road mainly shipped silk and porcelain from sea ports such as Guangzhou to South Asia and North Africa. These corridors reached the peak of prosperity in the Tang Dynasty. It is noteworthy that the Dayu Road across the Wuling Mountains connected the Yangtze River Valley from Ganzhou directly to Guangzhou and expanded the hinterland of the Maritime Silk Road.

The tea–horse market, a major border trade with the northwestern, northeastern, and southwestern minority groups, was developed from the Tang Dynasty, and led to the development of many trade routes. Simultaneously, the Tang–Tibet Road was developed from Xi'an to Lhasa to complete the envoy trip over 200 times and the Nanzhao Road was opened to connect with South Asia. The Song Dynasty continued to actively develop the bulk tea–horse trade with local regimes for over 200 years. The following Yuan Dynasty further reinforced international road construction, especially routes to Western Regions. Other successor khanates under the control of the Great Khan opened trade roads from Beijing to Novosibirsk, West Asia, and Northeast Asia. The tea–horse market was still an important trade between the Ming Dynasty and the northwestern minority groups and developed the Zhangjiakou–Ulan Bator trade corridor. Domestic trade developed around the core region with the high accessibility of the road network, but international trade mainly tended to develop in the peripheral and remote regions with the lowest accessibility (Vickerman *et al.*, 1999). To some extent, the road network displayed a mode of inland expansion to the border area.

5.4 Postal transport network

It is widely accepted that the postal transport network is the oldest specialized form of transport and has played an important role in shaping the nationwide road network. Historically, the emperors established a rapid service of public couriers to obtain information about military affairs, politics, and economy in all parts of the country as quickly as possible. In ancient China, the postal system, also called *Youyi*, was controlled by the government to provide a transport service for official intercourses, administrative and military decrees, communication, the transfer of governmental and military materials, and for tours of diplomatic envoys. This profoundly influenced road construction and transport organization over the centuries.

The official postal network can be traced to the Shang Dynasty, but the regular official postal system was developed by the Zhou Dynasty. The following Qin Dynasty merged the postal system of each state and implemented the Same Track Gauge to formulate the standardization of the postal road. They also constructed the Yi Road between central and local areas to develop a postal network, which is similar to the Royal Road in the Roman Empire. This network was considerably enlarged under the Han Dynasty, which began to develop postal relay stations. Of these, *Chuan* was transported by horse and carriage, and *Yi* by horse, and *You* on foot. Generally, a post station was set every 15 km along the trunk road, a pavilion every 5 km, and a stop every 2.5 km along the branch. Naturally, this system facilitated the conveyance of decrees and linkage among the cities to consolidate the centralization of power. In the Eastern Han and Jin dynasties, in particular, the government promulgated the Postal Law to construct the postal road. Furthermore, the postal network was improved by the Tang Dynasty and the number of postal stations was 1643 during the period 713 to 741 AD, including 1297 inland stations, 260 shipping stations, and 86 land shipping stations.

Much of the population and many towns developed along the postal road; in particular, the postal artery of Xi'an–Luoyang–Kaifeng with 35 stations became an axis for urban growth and economic development. The Song Dynasty set a postal station every 10 km and a postal house every 30 km. A new specialized postal house, commonly known as *DiPu*, was set every 10 km to transfer government documents and mail, which was divided into foot post, horse post, urgent post, and gold-emblem urgent post, with a consequent increase in speed of delivery in this sequence.

During the Yuan Dynasty, the world's largest postal system was established and extended northward to the upper reaches of the Yenisei River and southwestward to Tibet. A series of laws was developed to support the postal network. Operationally, the whole postal network was divided into the horse postal network, dominated by the postal station, and the foot postal network, dominated by houses for urgent transfer. After the rebuilding of the postal road in southwest, northwest, and northeast China in the Ming Dynasty, a nationwide postal network was developed around the capital Nanjing and the postal nodes also differentiated into *Huitong* offices, and a total of 1936 shipping and horse postal stations, together with 15,000 express houses across the country. It is striking that the Ming Dynasty established a specialized freight organization–delivery station separate from the postal system that was dedicated to the transport of official and military material. The Qing governors strengthened the postal network in northeast China, Xinjiang, and Tibet. In 1890 there were over 2000 postal stations and 14,799 delivery stations across the country. However, in the early 20th century the development of modern railways, ships, telecommunications, and postal services led to the decline of the traditional postal system. The traditional postal system developed over 2000 years in China and its road infrastructure was not only the backbone of the road network, but also laid the framework for the modern network of highways.

6 Conclusions

The historical relationships between road networks and land development have previously received little attention. China has long been widely regarded as a land-oriented country and the road network has played a crucial role in socio-economic development. Several valuable points can be concluded from our analyses.

(1) The expansion of the road network in China over the past 3500 years, overcoming the various natural obstacles, can be divided into four phases with distinct spatial patterns and features. These phases are: the early and regional network (the Shang and Zhou dynasties); the expansion to whole country (the Qin, Han, and Weijin dynasties); the skeleton network (the Tang and Song dynasties); and the national network (the Yuan, Ming, and Qing dynasties). These correspond with growth and changes in land territory. Overall, the road network has shaped a conceptual model of inland expansion from China's homeland to the border areas.

(2) The special historical conditions have determined the shape of the road network and the different spatial patterns. These include an earlier land expansion of the central–local mode in the Shang and Zhou dynasties and the central–local multiple kingdoms mode of the Spring and Autumn Period; also the unification empire mode in the Qin, Han, Sui, Yuan, Ming, and Qing dynasties and the multiple regimes mode in the Weijin and Song dynasties.

(3) The road network has connected growing cities to enlarge the coverage from the middle and lower reaches of the Yellow River Valley to the whole country and its accessibility has long shown the pattern of a core–peripheral concentric circle. The superior region has been enlarging, but the middle and lower reaches of the Yellow River Valley have always been the core.

(4) Historical evidence shows that a number of motives initiated the construction of the road network. Natural barriers such as mountains, rivers, plateaus, and deserts have been the main obstacles to the expansion of the road network, but their influence has weakened continuously over time. In each time period national defense and land governance have been important factors in propelling road construction, especially the disparities in the governors between the conservative Han Chinese and the expansive minority groups, who greatly influenced the road network. The central–local linkage and centralization of national power has been another crucial force. In particular, the traditional postal system, the specialized cargo transport system controlled by the government, and the growth of domestic trade have influenced not only the mode of road construction mode and organization of transport, but also the differentiation of the structure of the road function. International land trade has enlarged the road network in the border areas, especially in northwest, southwest, and northeast China and has developed the commercial routes.

The analysis reported here help a fuller understanding of the long-term regularities of the expansion of the road network in China and fill a gap in the current literature on this topic.

References

Axhausen K W, Froelich P, Tschopp M, 2011. Changes in Swiss accessibility since 1850. *Research in Transportation Economics*, 31(1): 72–80.

Bel G, 2011. Infrastructure and nation building: The regulation and financing of network transportation infrastructures in Spain (1720–2010). *Business History*, 53(5): 688–705.

Cao X S, Xue D S, Yan X P, 2005. A study on the urban accessibility of national trunk highway system in China. *Acta Geographica Sinica*, 60(6): 903–910. (in Chinese)

Cao X S, Yan X P, 2003. The impact of the evolution of land network on spatial structure of accessibility in the developed areas: The case of Dongguan city in Guangdong province. *Geographical Research*, 22(3): 305–312. (in Chinese)

Comtois C, 1990. Transport and territorial development in China 1949–1985. *Modern Asian Studies*, 24 (4): 777–818.

Dupuy G, Stransky V, 1996. Cities and highway network in Europe. *Journal of Transport Geography*, 4(2): 107–121.

Erath A, Löchl M, Axhausen K W, 2009. Graph theoretical analysis of the Swiss road network over time. *Network Spatial Economics*, 9(3): 379–400.

George C S L, 1999. Transportation and metropolitan development in China's Pearl River Delta: The experience of Panyu. *Habitat International*, 23(2): 249–270.

Gutiérrez J, 2001. Location, economic potential and daily accessibility: An analysis of the accessibility impact of the high-speed line Madrid–Barcelona–French border. *Journal of Transport Geography*, 9 (4): 229–242.

Gutiérrez J, Urbano P, 1996. Accessibility in the European Union: the impact of the trans-European road network. *Journal of Transport Geography*, 4(1): 15–25.

Handy S L, Niemeier D A, 1997. Measuring accessibility: an exploration of issues and alternatives. *Environment and Planning A*, 29(7): 1175–1194.

Hansen W G, 1959. How accessibility shapes land-use. *Journal of the American Institute of Planners*, 25(2): 73–76.

Hou Q, Li S M, 2011. Transport infrastructure development and changing spatial accessibility in the Greater Pearl River Delta, China, 1990–2020. *Journal of Transport Geography*, 19(6): 1350–1360.

Hugill P J, 1982. Good roads and the automobile in the United States 1880–1929. *Geographical Review*, 72(3): 327–349.

Ingram D R, 1971. The concept of accessibility: A search for an operational form. *Regional Studies*, 5(2): 101–107.

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. (in Chinese)

Jin F J, Wang J E, 2004. Railway network expansion and spatial accessibility analysis in China: 1906–2000. *Acta Geographica Sinica*, 59(2): 293–302. (in Chinese)

Keeble D, Offord J, Walker S, 1988. Peripheral Regions in a Community of Twelve. Brussels: Office for Official Publications of the European Communities.

Koenig J G, 1980. Indicators of urban accessibility: theory and applications. *Transportation*, 9(2): 145–172.

Koopmans C, Rietveld P, Huijg A, 2012. An accessibility approach to railways and municipal population growth, 1840–1930. *Journal of Transport Geography*, 26(1): 98–104.

Kreutzmann H, 2004. Accessibility for High Asia: Comparative perspectives on Northern Pakistan's traffic infrastructure and linkages with its neighbours in the Hindukush–Karakoram–Himalaya. *Journal of Mountain Science*, 1(3): 193–210.

Kwan M P, 1998. Space–time and integral measures of individual accessibility: A comparative analysis using a point-based framework. *Geographical Analysis*, 30 (3): 191–216.

Leung C K, 1980. China: railway patterns and national goals. *Department of Geography Research Paper No. 195*. Chicago: Chicago University Press.

Levinson D, 2009. Introduction to the special issue on the evolution of transportation network infrastructure.

Networks and Spatial Economics, 9(3): 289–290.

Li S M, Shum Y M, 2001. Impacts of the national truck highway system on accessibility in China. *Journal of Transport Geography*, 9(1): 39–48.

Linneker B, Spence N, 1996. Road transport infrastructure and regional economic development: The regional development effects of the M25 London orbital motorway. *Journal of Transport Geography*, 4(2): 77–92.

Loo B P Y, Leung C K, 1997. Characteristics of transport infrastructural development in the Pearl River Delta under the open policy. *Acta Geographica Sinica*, 52(Suppl.): 28–38. (in Chinese)

Marton A, McGee T, 1996. New patterns of mega-urban development in China: The experience of Kunshan. *Asian Geographer*, 15(1–2): 49–70.

Muntele I, Cimpoesu G, 2011. The evolution of the road transport network in Moladvia: From geographical coherence to peripheral dependence. *Revista Română de Geografie Politică*, XIII(2): 210–228.

Murayama Y, 1994. The impact of railways on accessibility in the Japanese urban system. *Journal of Transport Geography*, 2(2): 87–100.

Rimmer P J, 1967a. The changing status of New Zealand seaports, 1853–1960. *Annals of the Association of American Geographers*, 57(1): 88–100.

Rimmer P J, 1967b. The search for spatial regularities in the development of Australian seaports 1861–1961. *Geografiska Annaler B*, 49(1): 42–54.

Spence N, Linneker B, 1994. Evolution of the motorway network and changing levels of accessibility in Great Britain. *Journal of Transport Geography*, 2(4): 247–264.

Spiekermann K, Wegener M, 1996. Trans-European networks and unequal accessibility in Europe. *European Journal of Regional Development*, 96(4): 35–42.

Strano E, Nicosia V, Latora V, Porta S *et al.*, 2012. Elementary processes governing the evolution of road networks, *Scientific Reports*, 296(2): 1–8.

Taaffe E J, Gauthier H L, O'Kelly M E, 1996. Geography of Transportation. New Jersey: Prentice-Hall.

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

Tan Qixiang, 1982. Historical Atlas of China. Beijing: China Cartographic Publishing House.

Vickerman R W, 1995. The regional impacts of Trans-European networks. *The Annals of Regional Science*, 29(2): 237–254.

Vickerman R W, Spiekermann K, Wegener M, 1999. Accessibility and economic development in Europe. *Regional Studies*, 33(1): 1–15.

Wang C J, 2006. Regional impaction and evolution of express way networks in China. *Progress in Geography*, 25(6): 126–137. (in Chinese)

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 J, Ducruet C, 2012. New port development and global city making: emergence of the Shanghai–Yangshan multilayered gateway hub. *Journal of Transport Geography*, 25(4): 58–69.

Weber J, 2012. The evolving interstate highway system and the changing geography of the United States. *Journal of Transport Geography*, 25(1): 70–86.

Willigers J, Floor H, Van Wee B, 2007. Accessibility indicators for location choices of offices: An application to the intraregional distributive effects of high-speed rail in the Netherlands. *Environment and Planning A*, 39(9): 2086–2098.

Wu W, Cao Y H, Cao W D *et al.*, 2006. Spatial structure and evolution of highway accessibility in Yangtze River Delta. *Acta Geographica Sinica*, 61(10): 1065–1074. (in Chinese)

Wu W, Cao Y H, Cao W D *et al.*, 2007. On the patterns of integrated transportation accessibility in the Yangtze River Delta under opening conditions. *Geographical Research*, 26(2): 391–402. (in Chinese)

Wu W, Cao Y H, Liang S B, 2010. Temporal and spatial evolution of integrated transport accessibility in the Yangtze River Delta: 1986–2005. *Progress in Geography*, 29(5): 619–626. (in Chinese)

Zhang L, Lu Y Q, 2006. Assessment of regional accessibility based on land transportation networks: A case study of the Yangtze River Delta. *Acta Geographica Sinica*, 61(12): 1235–1246. (in Chinese)