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Distribution Characteristics of the Transportation Network in China at the County Level

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ABSTRACT Evaluation of the rationality of transportation network distribution and its impact on social and economic development have great significance for building an efficient and comprehensive transportation system, which is also an important research topic in economic geography and regional economics. Because evaluation indicators to express the characteristics of transportation network distribution at the macro scale are lacking, this paper selects three indicators—highway network density, transportation network proximity, and location dominance related to the central city—to form the basis of an integrated transportation network distribution index for characterizing China's transportation network distribution using geographical information system technology in 2015. The research shows that transportation network distribution is low in most Chinese counties, and that there are obvious differences in distribution between counties in the east and west in addition to identifying multiple dense areas of transport layout distribution. Transportation network distribution is intrinsically coupled with social economic development: the more complete are transportation network facilities, the greater the population density, and the higher the level of economic development. The results highlight the need to focus on strengthening population concentration and economic development in areas with good transportation network distribution. The study can guide the optimization of transportation network structures and provide a macro decision-making reference for planning and evaluation of major transportation projects in China.

INDEX TERMS Geographical information system, highway network density, location dominance, proximity, transportation network distribution.

I. INTRODUCTION

Transportation infrastructure is a basic element of regional socio-economic development. With the recent rapid development of urbanization in China, the line length of the transportation network has reached a considerable scale. By the end of 2016, the lengths of China's railway, high speed rail and highway were 1.24×10^5 km, 2.4×10^4 km and 1.31×10^5 km, respectively [1]. The length of China's high-speed rail network is nearly sixty-six times that of the United States (362 km) and its highway network is nearly twice the length of that of the United States (7.7×10^4 km). At the same time, China's GDP (USD 11.20 trillion) is only three-fifths that of the United States (USD 18.62 trillion) [1] which implies a potential mismatch between transportation investment and economic development and highlights the significance of an efficient and comprehensive transportation system. Evaluating the rationality of transportation network distribution and its impact on social and economic development is an important topic of research in economic geography and regional economics [2], [3]. In the field of economic geography, scholars have mainly considered the characteristics of transportation network distribution based on transportation accessibility.

Accessibility is used for measuring the connection capability between nodes in the transportation network [2]. Nonetheless, different scholars apply different definitions to the concept of accessibility. Hansen was the first to define accessibility in 1959, and in his definition, accessibility is the size of the interaction between nodes in transportation network [4]. The potential energy model for measuring accessibility is proposed in the development model of population and residential land in metropolitan areas, and the model is suitable for calculating the accessibility of commercial

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facilities such as regional shopping centers without competition [4]. In 1979, Morris *et al.* believed that accessibility was the means to reach a given activity site from a certain place by means of a specific transportation system. The degree of convenience, travel time, distance, cost and other variables have been used to study the advantages and disadvantages of accessibility [5]. Shen developed an employment opportunity accessibility model of a competitive relationship based on the reachability potential model proposed by Shen [6].

Since then, scholars have conducted numerous studies on the accessibility of transportation, mainly adopting various related methods based on characteristics of geometric and topological transportation networks. The methods for assessing transportation accessibility based on geometric networks include the distance method [7], [8], the cumulative opportunity method [9], [10] and the gravity model method [11]. The most commonly used indicators for measuring transportation accessibility in China have mainly involved the weighted average method for transportation costs [3], [12], opportunity accessibility and daily accessibility [13], [14], and the potential model [15], [16]. The methods for transportation accessibility based on topological networks have mainly included the matrix method [17]–[19] and the space syntax method [20]–[22]. The advantages and disadvantages of these methods for geometric networks are as follows: The distance method takes the cost of the individual flowing into account in the transportation network, but does not consider the distance attenuation and the magnitude of the force at each point; The cumulative opportunity method essentially measures the accessibility level by evaluating the convenience of a certain point of travel, without considering the interaction between the measurement point and the attraction point and the attenuation of its spatial effect with distance; The gravity model method combines the spatial effect of each attraction point in space with the distance and the gravitational scale of each attraction point to measure the accessibility. The larger the force between the attraction point and the measurement point, the smaller the distance, the higher the accessibility level. The matrix method and the space syntax method based on topological networks are commonly used for measuring accessibility at medium and micro scales, such as aviation network at the regional scale, public transport network at the city scale, urban interior blocks or parks, and interior spaces of buildings.

In summary, scholars have developed research methods and applications for transportation accessibility based on geometric networks, thereby laying a methodological foundation for the study of transportation network distribution. The above methods analyzed the spatial effects of traffic accessibility or transportation conditions from different perspectives. However, although many scholars have done their research for a macroscopic analysis of transportation distribution, it is still needed to propose a method to systematically and deeply explore the overall connotation and comprehensive evaluation system of transportation network distribution. Hence, the system mechanism of transportation network for shaping regional spatial structure needs to be further refined. At present, the most representative method for identifying and evaluating transportation accessibility for China at the national level is that outlined by Jin et al. (2010) [3]. In their research, quality, quantity, and advantage that measured by density, proximity, and accessibility indices are used to describe the spatial structure of transport dominance of China.

The transportation advantage of a region is reflected in three aspects of ''quality'', ''quantity'' and ''superiority'' [2]. Each aspect has relatively independent and specific connotation, and has different effects on regional social-economic development. ''Quantity'' refers to the scale of transportation facilities, ''Quality'' refers to the technical and capable characteristics of transportation facilities, and ''Superiority'' refers to a certain state of dominant position that an individual possesses overall [3]. To truly reflect the advantages and disadvantages of the regional traffic environment, we need integrate, characterize, and evaluate all three aspects comprehensively.

Therefore, based on the transportation accessibility method of highway network density representing ''quantity'', transportation network proximity representing ''quality'' and location dominance related to the central city representing ''superiority'', this study constructs an analysis model of transportation network distribution to explore the characteristics of China's transportation network in 2015, which could guide the optimization of the transportation network structure and provide a macro-level decision-making reference for evaluating major transportation projects.

II. METHODOLOGY

A. DATA SOURCES

In China, the administrative divisions are divided into the provincial administrative district, the prefecture-level administrative district, the county-level administrative district, and the town-level administrative district. The county-level administrative district includes city-governed district, county-level city, county, autonomous county, flag, autonomous flag, special zone, and forest area [23]. In this study, the county-level administrative district of China is the basic statistical unit, and city-governed districts are merged into a whole. The specific data sources are shown in Table 1, and cover: (1) land area, household registered population and GDP at county-level administrative district of China for 2015 obtained from the ''*China County Statistical Yearbook*'' and the ''*China City Statistical Yearbook*'' [24], [25]; and (2) 2015 vector data of national railways, national highways, provincial highways and county roads, as well as railway stations and airports acquired from the Data Centre for Resources and Environmental Sciences, Chinese Academy of Sciences [26].

B. METHODS

Based on the above data, the aim of this study is to examine the distribution characteristics of the transportation network

TABLE 1. Data sources for transportation network distribution of China in 2015.

Name	Source
Land area, household registered population, GDP	China County Statistical Yearbook, China City Statistical Yearbook
Railways, highways, county roads, Railway stations, airports	Data Centre for Resources and Environmental Sciences, Chinese Academy of Sciences

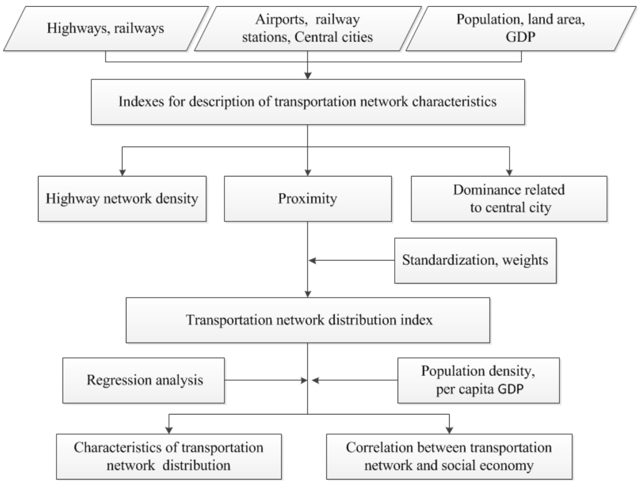

FIGURE 1. Technical flow for describing distribution characteristics of transportation network.

at the county level, as well as its impact on social and economic development. Three indicators of highway network density, transportation network proximity, and location dominance related to the central city are selected. Then, the integrated transportation network distribution index is used for description of the overall features of the transportation network. The specific technical process is shown in Figure 1. The main research steps are as follows: (1) Based on highway vector data, highway network density is used to evaluate the supporting capacity of highway network facilities, that is, the intra-county connectivity; (2) based on the location of the county centre, airports and railway stations, the transportation network proximity is used to reflect the convenience of the county with respect to other counties, that is, the inter-county reachability; (3) based on the county centre and the related centre city, the regional conditions, advantages and disadvantages are portrayed by the distance between the county centre and the related central city, which is evaluated by location dominance; (4) integrating highway network density, transportation network proximity, and location dominance related to the central city to establish the transportation network distribution index, which is used to describe the macro characteristics of transportation network distribution; and (5) revealing the relationship between the transportation network and social economy using the transportation network distribution index, population density and per capita GDP.

TABLE 2. Proximity of important transportation infrastructure.

Type	Standard	P_m
Airport	Owns airport	1
	L≤30 km	0.5
	Others	0
Railway	Owns railway station	2
	L≤30 km	1.5
	30 km<L≤60 km	1
	L>60 km	0
Road (Highway)	Owns highway	1.5
	L≤30 km	1
	30 km<L≤60 km	0.5
	L>60 km	0
Road (National highway)	Owns national highway	0.5
	Others	0

L is the distance from the nearest airport, railway station or highway to the county centre. The weighted value refers to "Provincial-level functional area division (trial)" [27].

The specific methods for determining the distribution characteristics of the transportation network in China at the county-level are as follows:

1) HIGHWAY NETWORK DENSITY, C_{1i}

Transportation within a county is mainly dependent on highways, so the degree of connectivity within a county can be reflected by the highway network density. Highway network density is a positive indicator: the larger its value, the denser the highway network, and the better the regional transportation conditions. Let the highway network density of county$i$ be C_{1i}, the length of the highway network of county i be L_i, and the area of county i be A_i, then the county highway network density can be calculated as follows:

$$C_{1i} = \frac{L_i}{A_i} \quad i \in (1, 2, 3, \ldots\ldots n) \tag{1}$$

2) TRANSPORTATION NETWORK PROXIMITY, C_{2i}

This reflects the convenience of the county to other counties through the proximity of its transportation network. In general, proximity is mainly used to describe the reachability of two features in a geographical space. In this study, proximity is used to characterize the impact of railways, highways and airports on regional transportation advantages. Based on the distance from the nearest airport, railway station or highway to the county centre, qualitative indicators are quantified using expert scoring, and then proximity value is assigned and classified. As shown in Table 2, P_{im} presents the proximity of the transportation network infrastructure of type m in county

TABLE 3. Distance between county center and central cities.

Type	Standard	D
Distance to central city	0≤L≤100 km	2
	100 km<L≤300 km	1.5
	300 km<L≤600 km	1
	600 km<L≤1000 km	0.5
	L>1000 km	0

L is the distance from the county center to the nearest central city. The weighted value refers to "Provincial-level functional area division (trial)" [27].

i, and the distance from the nearest airport, railway station or highway to the centre of county i is used to determine the weight; m presents the type of transportation network infrastructure, such as airport, railway station, and highway; i presents the county of China. The expression of the proximity is as follows:

$$C_{2i} = \sum P_{im} i \in (1, 2, 3, \ldots\ldots n), \quad m \in (1, 2, 3, \ldots\ldots M) \tag{2}$$

L is the distance from the nearest airport, railway station or highway to the county centre. The weighted value refers to "Provincial-level functional area division (trial)" [27].

3) LOCATION DOMINANCE RELATED TO CENTRAL CITY, C_{3i}

The location condition—that is, the advantages and disadvantages due to the distance between the county center and the central city—are evaluated by location dominance. D_i is the distance between the county center and the nearest central city. Table 3 shows the weighted distance between county center and central cities. Based on the existing administrative management system, county-level economies are mainly concentrated around prefecture-level cities in China. Hence, in principle, central cities are chosen to be the provincial capital city or prefecture-level cities that have significant influence on the surrounding area. The number of selected central cities in this study is 61, as shown in Table 4 and Figure 2, which include 22 provincial capital cities, 4 municipalities directly under the central government, 5 capitals of autonomous regions, 5 planned cities, 9 coastal open cities, 13 open cities adjacent to the border and 3 open cities along the Yangtze River. The expression of location dominance related to the central city is as follows:

$$C_{3i} = \sum D_i \quad i \in (1, 2, 3, \ldots\ldots n) \tag{3}$$

L is the distance from the county center to the nearest central city. The weighted value refers to "Provincial-level functional area division (trial)" [27].

TABLE 4. Selected central cities.

Type	Quantity	Name
Capital cities	22	Harbin, Changchun, Shenyang, Shijiazhuang, Lanzhou, Xining, Xi'an, Zhengzhou, Jinan, Taiyuan, Hefei, Wuhan, Changsha, Nanjing, Chengdu, Guiyang, Kunming, Hangzhou, Nanchang, Guangzhou, Fuzhou, Haikou
Municipalities	4	Beijing, Shanghai, Tianjin, Chongqing
Capital of autonomous regions	5	Urumqi, Hohhot, Yinchuan, Nanning, Lasa
Planned cities	5	Dalian, Qingdao, Ningbo, Xiamen, Shenzhen
Coastal open cities	9	Qinhuangdao, Yantai, Lianyungang, Nantong, Wenzhou, Zhanjiang, Beihai, Yingkou, Weihai
Open cities along the border	13	Heihe, Suifenhe, Hunchun, Manzhouli, Erenhot, Yining, Bole, Tacheng, Ruili (Wanding), Hekou, Pingxiang, Dongxing, Dandong
Open cities along the Yangtze River	3	Yueyang, Jiujiang, Wuhu

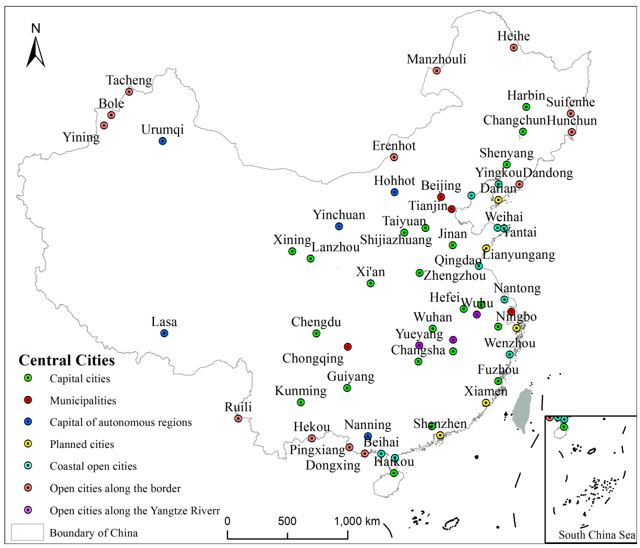

FIGURE 2. Distribution of central cities.

4) TRANSPORTATION NETWORK DISTRIBUTION INDEX, C_i

The three indicators—highway network density, C_{1i}, transportation network proximity, C_{2i}, and location dominance related to the central city, C_{3i}—were selected following expert consultation and based on existing research results [3]. They were then integrated at a ratio of 1:1:1 to constitute the transportation network distribution index. As an intermediate step, the three indicators were standardized; as shown in Equation 4, C_{ji} is the normalized value of the index j in county i, E_{ji} is the original value of the index j in county i , $Max(E_{ji})$

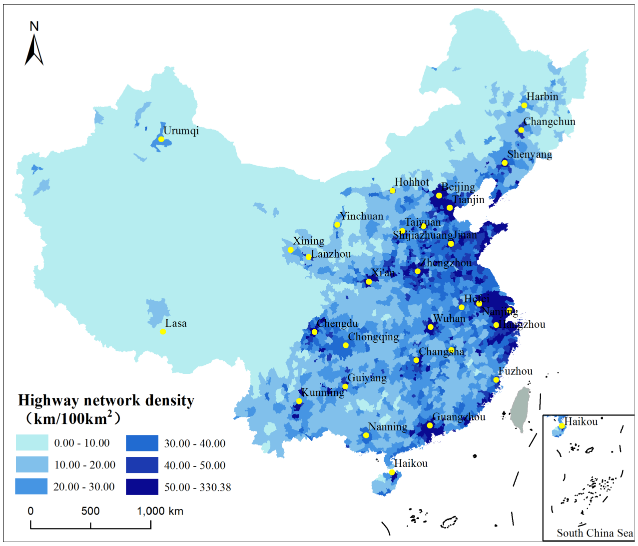

FIGURE 3. Spatial pattern of China's highway network density in 2015.

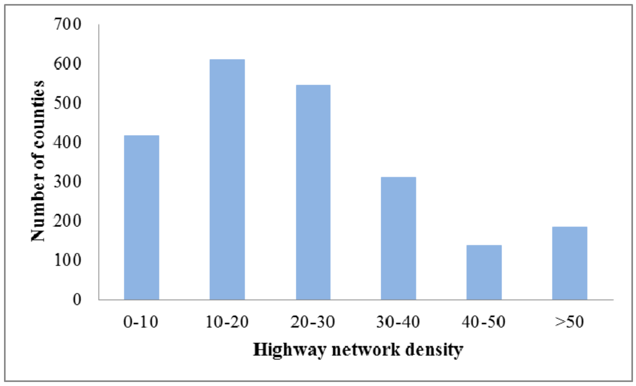

FIGURE 4. Statistical result of highway network density and number of counties.

is the maximum of the index j in county i, $Min(E_{ji})$ is the minimum value of the index j in county i, $j = 1, 2, 3$, $i \in (1, 2, 3, \ldots\ldots n)$.

$$C_{ji} = \frac{E_{ji} - Min(E_{ji})}{Max(E_{ji}) - Min(E_{ji})} \tag{4}$$

The transportation network distribution index, C_i, of each county i can then be expressed as:

$$C_i = \sum_{j=1}^{3} a_j \times C_{ji} (j = 1, 2, 3) \tag{5}$$

where a_j is the weight of each indicator. Assuming that each indicator has the same role in the transportation network, $a_1 = a_2 = a_3 = 1$.

III. RESULTS

A. SPATIAL CHARACTERISTICS OF HIGHWAY NETWORK DENSITY

China's highways can be divided into national roads, provincial roads, county roads and rural roads. The first three categories are the main components of the highway network and currently provide important support for the development of various regions. Figure 3 and Figure 4 show the distribution pattern of highway network density based on the county-level administrative regions of China and reflects the degree of connectivity in the counties.

From the distribution pattern of highway network density, the following features are noteworthy. (1) The total length of highways in China is 4.57 million km, the total highway network density is 0.4886 km/ km^2, and the planned total highway network density in 2030 is 0.6 km/ km^2[28]. (2) The highway network density is low in most counties and less than 20 km/100 km^2. The lengths of some highways in some counties are relatively small, so their densities are also low. For example, highway network densities are between 0 and 10 km/100 km^2 in 417 counties, which account for 18.95% of all counties and have less capacity for development. Highway network densities are between 10 and 20 km/100 km^2 in 610 counties, which account for 27.71% of total counties; 543 counties' (24.67%) highway network densities are between 20 and 30 km/100 km^2; and, 310 counties' (14.08%) highway network densities are between 30 and 40 km/100 km^2. Only 8.36% of counties' highway network densities are much higher than the national average, and these counties receive high support and protection. (3) Highway network density is high in the central and eastern part of China, while it is relatively low in the western part of China. In eastern China, in particular, the highway network density of the south is lower than that of the north. (4) Some regions of the highway network are particularly dense, including the Beijing-Tianjin region, the Yangtze River Delta region, the Pearl River Delta region and the Wuhan Economic Zone. These areas have high spatial coupling with economic agglomeration and high level of urbanization [29]–[31], showing that highway networks have a significant ability to support the socio-economic development of China's dense urban areas. (5) Huang-Huai-Hai Plain, Shandong Peninsula, the south-east of Fujian province and central Liaoning province have higher highway network density but have not fully homogenized. This indicates that the highway network has an important guarantee capability for the development of these regions. (6) Highway network density in some areas is relatively high, including Chengyu City Group, Changsha-Zhuzhou-Xiangtan City Group, Guanzhong City Group. (7) In western and north-eastern regions of China, high highway network density areas are formed around the capital cities, such as Harbin, Lanzhou, Changchun and Kunming.

B. SPATIAL CHARACTERISTICS OF TRANSPORTATION NETWORK PROXIMITY

Transportation network proximity not only represents the technical level of the transportation facilities, but also the composition of different transportation modes. Comprehensive transportation network proximity formed by various transportation facilities can better reflect the accessibility of transportation in all counties.

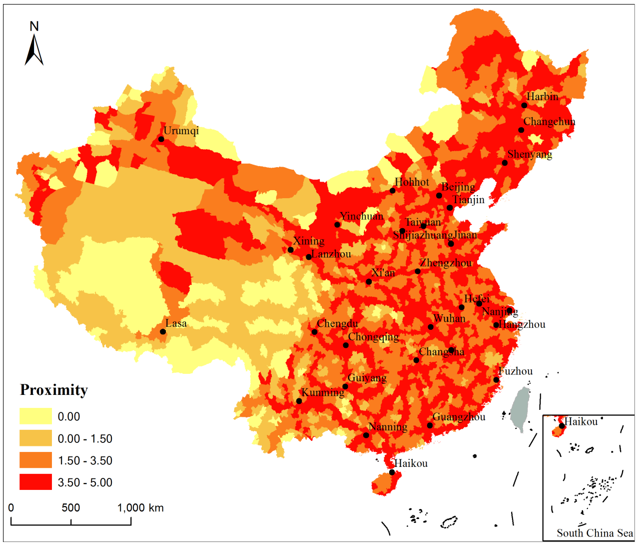

FIGURE 5. Spatial pattern of China's transportation network proximity in 2015.

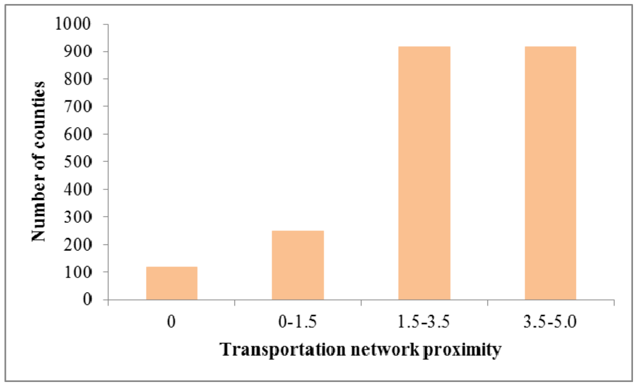

FIGURE 6. Statistical result of transportation network proximity and number of counties.

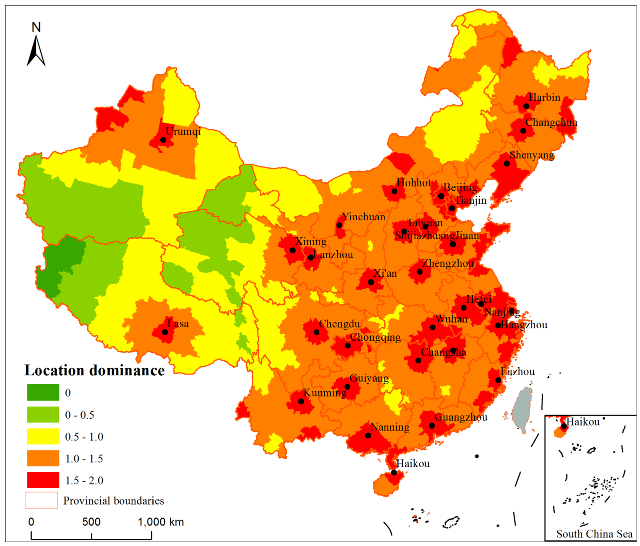

FIGURE 7. Spatial pattern of location dominance related to the central city in China.

The spatial pattern of transportation network proximity at the county-level is shown in Figure 5 and Figure 6, and has the following main characteristics. (1) Nearly half of the counties in China have high transportation network proximity, which indicates that the transportation network has an important rule for development in these counties. The transportation network proximity is zero in 117 counties, which account for 5.32% of all counties, indicating a lack of accessibility. The number of counties with transportation network proximity of 0–1.5 is 248, accounting for 11.27% of the total number, meaning that the transportation network has lower supporting capacity for development in these counties. The transportation network proximity of 918 counties is in the range 1.5–3.5, accounting for 41.71% of the total counties, and suggesting that the transportation network has had a positive effect on the development of these counties. (2) Transportation network proximity is high in central and eastern parts of China, while it is relatively low in western China, which indicates that transportation network proximity has stronger supporting capacity for eastern counties then for western counties. (3) In eastern China, there is a clear spatial difference in transportation network proximity between the north and the south. For example, the northeastern region, Inner Mongolia, the capitals of Ningxia and Qinghai provinces, Beijing-Tianjin-Hebei, the Yangtze River Delta, Wuhan and Chongqing have high transportation network proximity, while the southern region has low transportation network proximity and presents a strip distribution.

C. SPATIAL CHARACTERISTICS OF LOCATION DOMINANCE RELATED TO THE CENTRAL CITY

Central cities are of great significance to the development of all regions and have the ability to command the spatial structure. The distance between the county center and the nearest central city directly affects its location dominance and ability to accept social and economic radiation and determines the development potential of each county.

The spatial pattern of location dominance related to the central city is shown in Figure 7 and Figure 8. It illustrates the following characteristics. (1) Nearly 30% of Chinese counties (636) have the highest location dominance, indicating that central cities have the strongest radiation effect in these counties; 1359 counties (61.74%) have high location dominance, that is, the central cities have strong radiation capacity in these counties; 203 counties (9.22%) have lower location dominance, indicating central cities have lower radiation capacity in these counties; and, only three counties (0.14%) have no location dominance, meaning that the central cities have no influence in these counties. (2) Location dominance decreases from the central city to the surrounding counties in line with the distance between the county centre and the central city, and the counties with higher location dominance have a mosaic distribution in China. In addition, the eastern part of China has higher location dominance relative to the lower location dominance of western China.

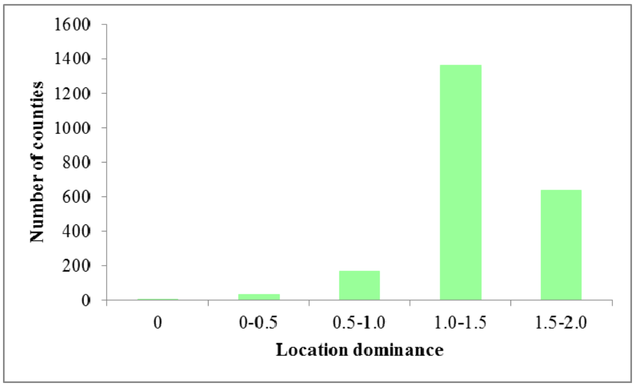

FIGURE 8. Statistical result of location dominance and number of counties.

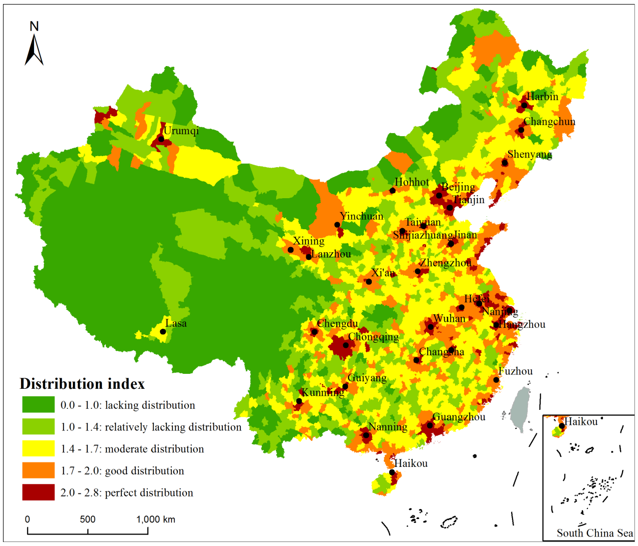

FIGURE 9. Spatial pattern of the whole transportation network in China.

(3) Beijing-Tianjin-Hebei, the Yangtze River Delta (Shanghai, Nanjing, Hefei and Hangzhou), the Pearl River Delta, Wuhan, Nanchang, Changsha, Shijiazhuang, Taiyuan, Xining, Lanzhou, Liaodong Peninsula, Harbin, Changchun and the North Gulf have high location dominance, and also have strong radiation capability to surrounding areas; Chengyu, Guiyang and Kunming also have high location dominance, although their radiation capability to surrounding areas is relatively weak.

D. SPATIAL CHARACTERISTICS OF TRANSPORTATION NETWORK DISTRIBUTION

Highway network density, transportation network proximity and location dominance related to the central city together reflect the support and guarantee capability of the transportation network for each county's development, and demonstrate counties' future development potential. By integrating these three indicators, the spatial pattern of the aggregating transportation network in China is formed, as shown in Figure 9.

The transportation network distribution index is divided into five levels, namely: [0-1.0], lacking transportation network distribution; [1.0-1.4], relatively lacking transport network distribution; [1.4-1.7], moderate transportation network distribution; [1.7-2.0], good transportation network distribution; [2.0-2.8], perfect transportation network distribution. The following are the main observations of transportation network distribution in China. (1) There are 594 counties (27%) with good and perfect transportation network distribution, and which provide strong support for future development. A total of 860 counties (39%) have a moderate transport network distribution, indicating normal support for future development, and 747 counties (34%) lack a transportation network distribution, suggesting future development potential is relatively low. (2) The transportation network distribution index shows a pattern of decline from coastal counties toward the interior, reflecting the highest transportation network distribution indices in coastal counties, and the lowest indices in western counties and parts of central counties. (3) The transportation network distribution index of central and eastern counties is significantly higher than the western counties of China; Beijing-Tianjin-Hebei, the Yangtze River Delta, the Pearl River Delta, Chengdu-Chongqing, the Wuhan metropolitan area, the North Gulf Area, Shandong Peninsula and Hachang District have better transportation network distribution than other areas of China, and also have strong support for their development.

IV. DISCUSSION

A. TRANSPORTATION NETWORK, POPULATION AND GDP

In general, transportation network distribution has a positive impact on population density and per capita GDP. That is, the more complete the transportation network, the greater the population density and the higher the level of economic development, reflecting the supporting role and positive impact of the transportation network distribution on social-economic development of the region [13], [32]. This is consistent with other related studies. For example, Dong *et al.* proposed an indicator named population-weighted efficiency (PWE) to quantitatively measure the efficiency of the transportation networks, and showed that PWE is better than excess commuting index on evaluating the average commuting time [33]. Li *et al.* explored a simple model based on spatial attraction and matching growth mechanisms to reveal the spatial scaling rules of population, roads, and socioeconomic interactions in a consistent framework [34].

Analyzing the relationship between different levels of transportation network distribution index and population density and per capita GDP (see Figure 10a, b), we find that the population density and per capita GDP are generally low in regions either lacking or with moderate transportation network distribution, reflecting the general lack of economic development in these regions, while regions with perfect transportation network distribution have the highest population density and per capita GDP. There is an increasing trend of population density and per capita GDP as the

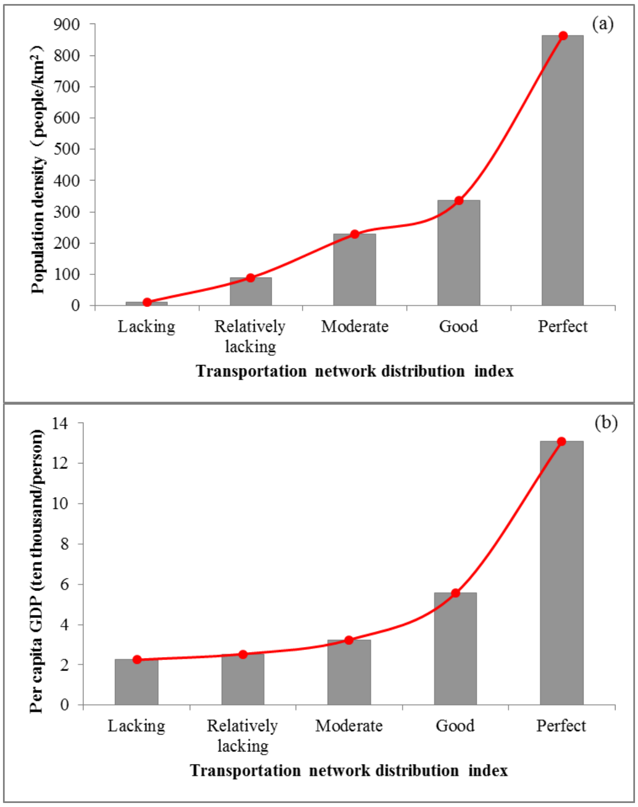

FIGURE 10. Relationship between different levels of transportation network distribution index and population density (a) and per capita GDP (b).

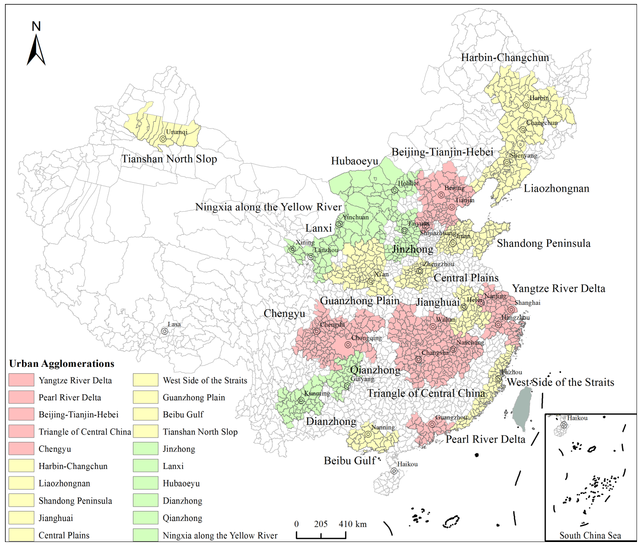

FIGURE 11. Distribution structure of urban agglomeration following the "5 + 9 + 6" plan in China.

transportation network becomes more and more complete. More importantly, regions with good transportation networks seem to be a turning point in the trend. That is, population density and per capita GDP increase relatively slow when transportation network distribution turns from lacking to relatively lacking, moderate, and good. But the increasing trend becomes steep dramatically when transportation network distribution turns from good to perfect condition. These suggest that there is great potential in regions with good transportation network distribution but relatively low population density and per capita GDP for further development.

Therefore, in order to satisfy continued rapid urbanization demands and promote improvement of urbanization efficiency in China, it is necessary to focus on strengthening population concentration and economic development in regions with good transportation network distribution, such as Yangtze River Delta, the central and southern regions of Liaoning Province, the Pearl River Delta, the Central Plains, the west side of the Straits, and Shandong Peninsula (see Figure 9).

B. TRANSPORTATION NETWORK DISTRIBUTION IN CHINA'S URBAN AGGLOMERATION

There are many distribution structures of urban agglomerations according to different criteria and principles. In China, the main structures of urban agglomerations are Shimou Yao's "6 + 7" plan [28], Chaolin Gu's "3 + 3 + 7 + 17" plan [29] and Chuanglin Fang's "5 + 9 + 6" plan [30]. In this paper, we select Chuanglin Fang's "5 + 9 + 6" plan to discuss the transportation network distribution in regard to urban agglomeration because this plan takes into account China's major function-oriented zoning [35] and national urban system planning 2006–2020 [36], and can describe urban agglomeration comprehensively. The distribution structure of urban agglomeration according to the "5 + 9 + 6" plan is shown in Figure 11, in which, pink areas represent five national-level urban agglomerations, yellow areas represent nine regional-level urban agglomerations, and green areas represent six local-level urban agglomerations.

Based on this distribution structure of urban agglomeration, we can calculate the transportation network distribution index in each urban agglomeration (see Figure 12). The transportation network distribution indices for all urban agglomerations range from 1.46 to 1.86, which indicate moderate and good distribution according to the spatial characteristics of transportation network distribution discussed in Section III. Of the five national-level urban agglomerations, only Yangtze River Delta and Pearl River Delta have good distribution of the transportation network. This indicates that transportation network distribution should continue to be a focus for supporting the fastest urbanization in national-level urban agglomerations [37], [38]. Of the nine regional-level urban agglomerations, Beibu Gulf, Harbin-Changchun, Guanzhong Plain and Tianshan North Slop have moderate distribution of the transportation network. Construction of transportation network facilities should be increased as an important driving force for urbanization in these areas [39]. Of the six local-level urban agglomerations, only Ningxia along the Yellow River has a good distribution of transportation network. These local-level urban agglomerations are mainly located in western China, with relatively low urbanization levels and lacking transportation infrastructure. In order to improve the level of

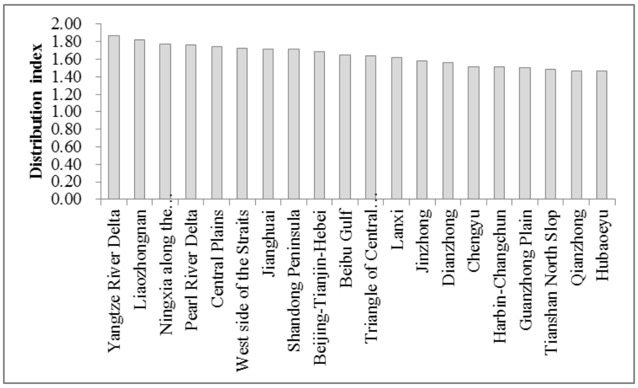

FIGURE 12. **Transportation network distribution index in each urban agglomeration.**

urbanization and promote rapid economic development, it is necessary to strengthen transportation infrastructure in these areas to match economic development with transportation input [40].

C. METHOD FOR TRANSPORTATION NETWORK DISTRIBUTION

In this study, three indicators—highway network density, transportation network proximity, and location dominance related to the central city—were selected for describing the distribution characteristics of the transportation network in China. The three indicators can comprehensively reflect intra-county connectivity and inter-county reachability [3], [31], [41]. Highway network density is an important traditional method of transportation network evaluation, and mainly applicable to linear transportation facilities. Highway networks exist in nearly every county in China and have a positive significance for characterization of intra-county connectivity [42], [43]. Transportation network proximity can explain the convenience of one county relative to other counties: the higher the proximity, the better the traffic conditions, the higher the support for regional development and the greater the potential for external contacts [44], [45]. Location dominance related to the central city reflects the important influence of a central city on a county: the closer the distance, the greater the location dominance and the stronger the ability to accept socio-economic radiation from the central city [46], [47]. This indicator could also identify the rationality of central cities.

This study mainly refers to the method proposed by Jin *et al.* [3], with correction for local conditions. In his study, the concept of transportation superiority from three aspects—''quality'', ''quantity'' and ''field''—is presented to reflect the scale, technical level and relative advantage of transport infrastructure in China. Then, transport network density, degree of influence of the transport trunk line and transport superiority degree of location are selected as the basic indicators to express transport superiority by utilizing Geographical Information System (GIS) technology. Based on the concept of transportation superiority, we adapted these three indicators to yield highway network density, transportation network proximity, and location dominance related to the central city, which are better able to describe transportation network distribution. Since Jin's research [3], China's transportation infrastructure construction has developed rapidly, and transportation network distribution is superior in 2015 to that of 2006.

In this study, the distances from the nearest airport, railway station or highway to the county center, and from the county center to the nearest central city, based on ''*Provincial-level functional area division (trial)*'', are used to decide the weights of transportation network proximity and location dominance related to the central city, respectively, using expert scoring. Setting different distance intervals, modifying the selection of central cities, and the choice of valuation method of expert scoring that determines the transportation network distribution are areas for potential future improvement. In addition, the present research into transportation network distribution has the limitation of being used at a macro scale. For small- and medium-scale regions, the applicability of the theory and evaluation method needs further testing.

V. CONCLUSIONS

Based on indicators of highway network density, transportation network proximity and location dominance related to the central city, this study integrates the transportation network distribution index to investigate the characteristics of transportation network distribution of China in 2015, which could guide the optimization of the transportation network structure and provide a basis for macro decision making for planning and evaluation of major transportation infrastructure construction.

The findings are as follows. (1) In 2015, highway network density was relatively low in most counties of China. Highway network density was high in central and eastern parts of China, relatively low in western China, and forms multiple dense areas of highway networks. Transportation network proximity was high in nearly half of the counties of China, evident in two major zones and in a distribution of strips. Most counties were affected by strong radiation of the central cities (0–300 km), location dominance related to the central city showed a decreasing trend depending on the distance from the central city to the surrounding areas, and there were multiple dense areas of location dominance.

(2) The transportation network distribution index of most counties of China was moderately low in 2015, grouped into two major zones, and with multiple dense areas of the index. The transportation network distribution index is intrinsically coupled with social economic development. The more complete the transport network distribution, the greater the population density and the higher the level of economic development. The index has an important role in strengthening population concentration and economic development in areas with levels of good transport network distribution, thereby supporting China's urbanization demands and efficiency.

This study reveals the distribution characteristics of the transportation network in China based on indicators of highway network density, transportation network proximity and location dominance related to the central city and has important guiding significance for the optimization of transportation network structure and the development direction of urbanization in China. Based on the transportation network distribution indicator, the national transportation network is divided into five levels, namely, lacking transportation network distribution, relatively lacking transport network distribution, moderate transportation network distribution, good transportation network distribution, and perfect transportation network distribution. Utilizing the advantages of transportation and avoiding transportation inferiority should be an important factor to consider when conducting economic activities and industry selection. The five major urban agglomeration areas, such as Beijing-Tianjin-Hebei, the Yangtze River Delta, the Pearl River Delta, Chengdu-Chongqing, and the Wuhan metropolitan area, have a relatively complete transportation infrastructure, and the local governors should utilize their obvious transportation advantages, and actively participate in international economic competition to enhance China's urbanization level. Other regions that have transportation advantages are small areas with large cities as the core, such as the North Gulf Area, Shandong Peninsula, and Hachang District. Therefore, it is an effective way to take advantage of transportation by focusing on these regions in economic development.

However, the selection of indicators has certain limitation, so, based on the results of this study, a more rational evaluation model is needed for transportation network distribution. The focus can then move to systematic coordination of transportation network distribution and population economic development, and formation of a reasonable evaluation system for transportation networks, in order to direct the optimization of the transportation network structure into the future.

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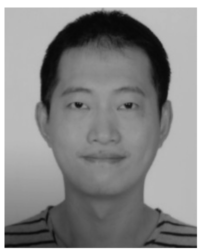

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