



Intercity accessibility and equity: Empirical study of high speed rail and air travel network in China

Shixiong Jiang^{a,b,*}, Canhuang Cai^{a,b}, Lide Xiao^{a,b}

^a College of Computer and Data Science, Fuzhou University, Fuzhou 350116, China

^b Key Laboratory of Intelligent Metro of Universities in Fujian, Fuzhou University, Fuzhou 350116, China

ARTICLE INFO

Keywords:

Intercity accessibility
High speed rail (HSR)
Air travel
Potential accessibility
Equity

ABSTRACT

With the rapid increase of high speed rail (HSR) network and air travel network in China, the intercity accessibility is reshaped. This study aims to measure the intercity accessibility by considering the two modes. Based on the current networks, timetable and socioeconomic data, this study utilizes connectivity, cumulative opportunity accessibility and potential accessibility to calculate intercity accessibility in the network consisting of 36 major cities in China. Furthermore, the relative and weighted average intercity accessibility of the two modes are obtained to provide a comparison and overall evaluation. The results indicated that the selected indicators are effective to evaluate the accessibility from different perspectives. The intercity accessibility shows different spatial distributions in HSR and air travel. Besides, the air travel network has higher equity than the HSR network in all accessibility measures. Furthermore, it is found that the correlation between the potential accessibility and economic development is stronger than that of others. This study can provide some advices for the further development of the HSR and air travel.

1. Introduction

In the most recent decade, high speed rail (HSR) and air travel have attained rapid development in China. The HSR operates with the speed between 250 and 350 km/h, which brings large impacts on intercity travels. The reduction in travel time has increased people's intercity mobility significantly. From the perspectives of travel time, comfort, and price, HSR can compete with air travel for the short and medium intercity travels (Chen, 2017, Zhang et al., 2019b).

The benefits obtained from the HSR and air travel infrastructure can be illustrated with the perspective of accessibility (Hansen, 1959, Kim and Sultana, 2015). The intercity accessibility has strong relation to regional economic development (Zhu et al., 2018), which is widely used as an influence factor of many economic activities (Geurs and Wee, 2004), such as trade, investment and tourism. Thus, it is important to measure intercity accessibility from the modes of HSR and air travel.

In addition, the spatial development of the HSR network is not even across the country as construction costs and passenger travel demands are different for different routes. And there are similar issues in the air travel network. Besides, as each mode owns its specific advantages, it is necessary to compare the relative accessibility between the two modes

and integrate different modes to attain overall accessibility.

This study aims to measure and analyze intercity accessibility in the HSR network and air travel network. This study employs three methods to evaluate the intercity accessibility from different perspectives. Furthermore, the overall and relative intercity accessibility are formulated for further analysis. Besides, the equities of intercity accessibility of the two modes are calculated and compared. These measurements can give guidance for decision-making on further planning of intercity corridors.

The remainder of this paper is organized as follows. Section 2 gives a review about the existing studies. Section 3 describes the research data. Section 4 introduces the adopted methods of intercity accessibility, overall accessibility, relative accessibility and equity. Section 5 presents the results of intercity accessibility and equity. Finally, Section 6 concludes the findings and limitations.

2. Literature review

2.1. Intercity accessibility of HSR network

In the recent ten years, the large-scale implementation of HSR system

* Corresponding author at: No. 2 Xueyuan Road, Minhou, Fuzhou 350116, China.

E-mail address: sxjiang@fzu.edu.cn (S. Jiang).

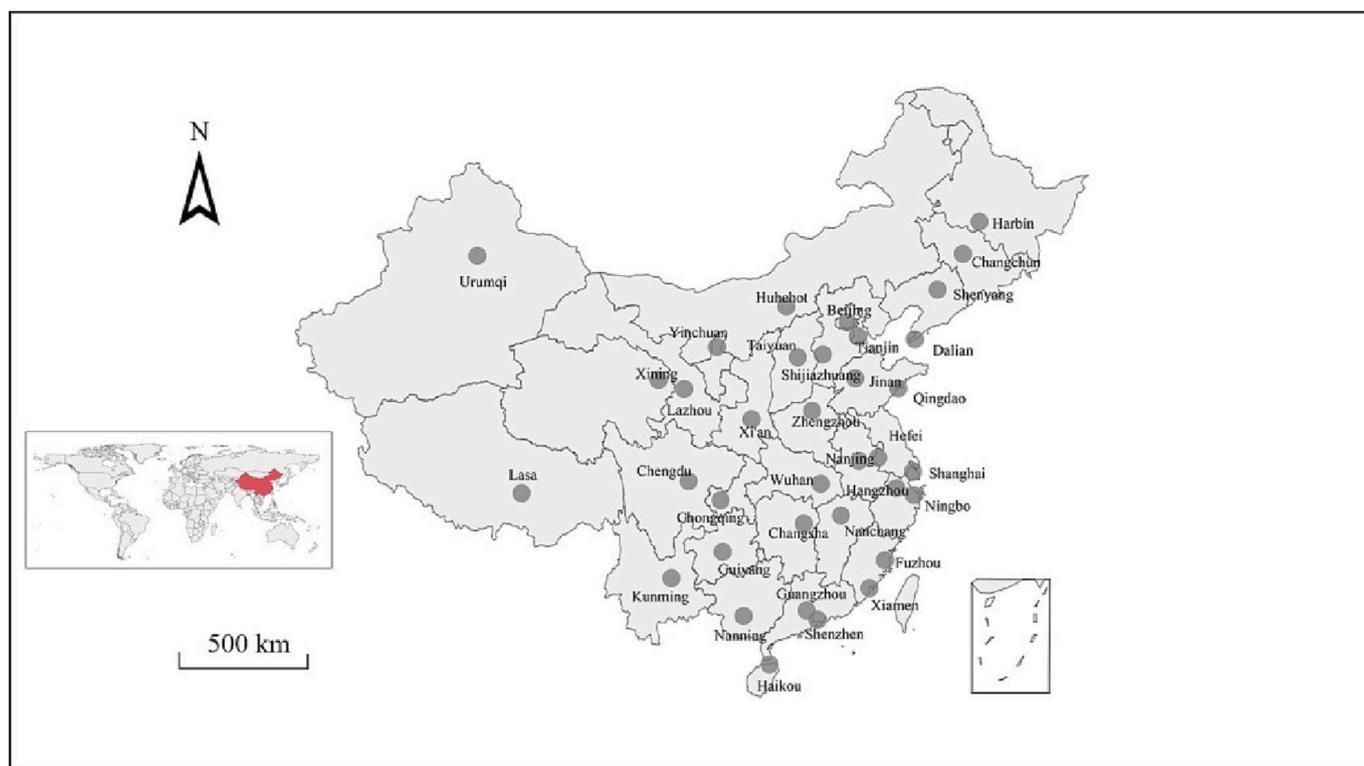


Fig. 1. The selected 36 major cities in China.

in China brings a large impact on the intercity accessibility, which might influence the development and competitiveness of cities. [Chen et al. \(2018\)](#) applied network analysis to identify HSR network accessibility changes over time from the perspectives of node degree, strength, closeness and betweenness. [Liu and Zhang \(2018\)](#) analyzed HSR's impacts and found the improvements of travel times, accessibility, and productivity gain. [Ortega et al. \(2012\)](#) proposed a GIS-based method to analyze changes in the territorial distribution of accessibility resulting from HSR investments in Spanish Galician HSR corridor. In addition, [Shaw et al. \(2014\)](#) utilized the timetable to evaluate accessibility. Similar studies were also conducted in South Korea ([Kim and Sultana, 2015](#)). [Moyano et al. \(2018a\)](#) analyzed the comparative accessibility of the Spanish HSR network with two indicators: location-based accessibility and schedule-based accessibility. Furthermore, the service frequency is incorporated into the speed-dominated accessibility measure, which found that the HSR services network implementation helps to enhance regional accessibility ([Wang, 2018](#)). Besides, [Wang et al. \(2020b\)](#) analyzed HSR development's impacts on knowledge-intensive economy of major cities, which found that the varying effects from HSR network development and service frequency at multiple spatial scales.

[Yu and Fan \(2018\)](#) evaluated the door-to-door accessibility resulted from the future high speed rail corridor in the US, which chose the weighted average travel time (WATT), potential accessibility and daily accessibility as indicators. Furthermore, [Wang and Duan \(2018\)](#) integrated intercity and intracity travel times to simulate the changes in regional territorial and population accessibility. Considering the temporal variations of taxi and public transport travel time, [Moyano et al. \(2018b\)](#) conducted a spatiotemporal accessibility analysis in Madrid and Barcelona. The results indicated that access time and egress time vary significantly in a day, which is up to the traffic congestion and the frequency of public transport services.

2.2. Intercity accessibility of air travel network

For long distance intercity travels, air travel has advantage on the speed and obtains a large market share. Using the schedule data of air travel service, [Matisziw and Grubestic \(2010\)](#) incorporated access to airport and accessibility within air transportation networks to explore spatial differentials in accessibility. Similarly, [Yang et al. \(2016\)](#) measured the accessibility of landside and airside by considering the surface transportation and flight networks. [Zhang et al. \(2017\)](#) found that Chinese airports have gained a great increase in connectivity during 2005–2016, and several hub airports were much better than other airports from the perspective of connectivity. [Bansal and Sen \(2021\)](#) assessed the airport's network from its type, connectivity and accessibility in India. In addition, [Grubestic and Zook \(2007\)](#) explored how the three key consumer measures of air transport accessibility, including connection, cost and time, shape the spatial and economic landscapes. [Vega and Reynolds-Feighan \(2016\)](#) quantified that changes in air transport accessibility in Ireland from both road network accessibility and air transport accessibility during 2005–2010. Furthermore, [Rothfeld et al. \(2019\)](#) analyzed access/egress time to/from European airports to establish linear regression models for identifying the potential in door-to-door travel time decrease.

2.3. The impacts of HSR and air travel

Furthermore, some scholars try to analyze the impacts of HSR and air travel. [Xu and Huang \(2019\)](#) applied a geographically weighted regression model to explore the relationship between the economic development and the spatiotemporal development of HSR in China. [Jiao et al. \(2020\)](#) examined the effects of connectivity and accessibility in the HSR network on the economic development. [Guo et al. \(2020\)](#) applied Quadratic Assignment Procedure to test the relationship between HSR and city economic networks, which found that there is a strong relationship between HSR and economic growth. Moreover, [Jin et al. \(2020\)](#) examined HSR's impacts on economic disparity during 2002–2016 with

Table 1

The GDP (unit: billion yuan) and population (unit: million) of the selected 36 cities in 2017. ()

City	GDP	Population	City	GDP	Population
Beijing	2800.04	21.71	Lanzhou	252.35	3.26
Shanghai	3013.39	24.18	Nanning	411.88	7.57
Tianjin	1859.54	15.57	Nanjing	1171.51	8.34
Chongqing	1950.03	30.75	Nanchang	500.30	5.46
Changsha	1053.55	7.92	Shenyang	586.50	8.29
Changchun	653.00	7.49	Shijiazhuang	646.09	10.88
Chengdu	1388.94	16.05	Taiyuan	338.22	4.38
Fuzhou	710.40	7.66	Urumqi	274.38	2.23
Guangzhou	2150.30	14.50	Wuhan	1341.03	10.89
Guiyang	353.80	4.80	Sining	128.49	2.36
Huhehot	31.15	3.12	Xi'an	747.19	9.62
Harbin	635.50	9.55	Yinchuan	180.32	2.23
Hefei	721.35	7.97	Zhengzhou	913.02	9.88
Hangzhou	1255.60	9.47	Shenzhen	2243.84	12.53
Haikou	139.05	2.27	Dalian	736.39	5.95
Jinan	720.20	7.32	Tsingtao	1103.73	9.29
Kunming	485.76	6.78	Ningbo	984.69	5.97
Lasa	47.93	0.54	Xiamen	425.12	4.01

Source: <http://www.stats.gov.cn/tjsj/ndsj/2018/indexch.htm>

a spatial econometric model, which confirmed that the HSR promotes local economic growth significantly. Besides, Liang et al. (2020) found that opening of HSR lead to regional economic growth along the route, but not a “corridor effect”, with a greater increase in less developed regions. However, Wang et al. (2020a) indicated that HSR construction exerted a greater influence on the economic development level of big cities.

Zhang et al. (2019a) found that HSR can cause a traffic redistribution result for airport traffic, similarly, the introduction of HSR also changed spatial disparity of economic activities. Chen (2017) revealed that the domestic air transportation is substituted significantly by HSR, but the influenced level varies in different routes, distances and cities. In addition, HSR competition can promote the air travel to decrease fares and frequencies, and adopt the socially optimal network structure and market coverage (Zhang et al., 2019b). In details, Ma et al. (2019) found that the frequency of train and the number of seats on the HSR line were significantly and negatively associated with air travel demand. Bergantino and Madio (2020) conducted a discrete choice experiment to determine the optimal modal choice on the Bari-Rome and Brindisi-Rome route to find that the probability of shifting to HSR increases with age, income and education.

3. Research data

3.1. Background and the selection of cities

The HSR and air travel are experiencing fast expansion in China, actuated by the large population, rapid economic growth and policy reform (Xu et al., 2018, Zhang et al., 2017, Zhu et al., 2018). In 2018, the length of new railways put into operation was 4,600 km in total, of which HSR took up 3,900 km. By the end of 2018, the length of HSR reached 29,000 km, with 2,775 pairs of HSR trains in operation

everyday. The railway system delivered 3.37 billion passengers and 2.01 billion passengers were delivered by the HSR system. In 2018, nine new airports were put into use and the number of China’s civil aviation airport reached 235. The air transportation system deals with 610 million passengers (including 537 million passengers in the domestic flights), with 10.9% increase than 2017 (Zhang et al., 2017).

This study selects 36 major cities in mainland China to construct a network to measure intercity accessibility (see Fig. 1), including 31 provincial capitals and 5 vice-provincial cities. Each city’s gross domestic product (GDP) and population in 2017 are presented in Table 1.

3.2. Transport data

The data of HSR schedule were obtained from the Railway Customer Service Center of China (<https://www.12306.cn/index/>), which is the official train service booking website (Zhu et al., 2018). The train information contains the train number, departure station, departure time, arrival station, arrival time, travel time and fare. The data of flight were collected from the website of Feizhu (<https://www.fliggy.com/>), which is a popular online platform providing air travel booking service. The flight information contains the flight number, departure airport, departure time, arrival airport, and arrival time. The schedule data between each study city pair on March 20, 2019 were collected from the two websites. Besides, for the case with code-shared flights, this study only takes the operating airline into consideration.

4. Methodology

4.1. Travel time and opportunity measurement

In the accessibility evaluation, travel time is a widely used performance indicator. Actually, passengers are more sensitive to travel time than travel distance. The intercity travel time can be divided into travel time of each stage from the origin to the destination (Benenson et al., 2011, Lei and Church, 2010). In general, the intercity travel time is made up of access time, dwell time, in train/flight time, and egress time (Cools et al., 2010). Fig. 2 shows the intercity travel process from an origin of the departure city to a destination of the arrival city.

In this study, the intercity travel time is divided into access time, dwell time, in train/flight time, and egress time. As a result, the total intercity travel time is calculated as Eq. (1).

$$t_{ij}^{total} = t_i^{access} + t_i^{dwell} + t_{ij}^{in} + t_j^{egress} \quad (1)$$

where t_{ij}^{total} is the total intercity travel time from city i to city j , t_i^{access} is the access time in city i , meaning the intracity travel time from the origin to the departure station/airport in city i , t_i^{dwell} is the dwell time in the station/airport of city i , which means the time to deal with some necessary procedures in terminals, such as security check and collecting tickets, t_{ij}^{in} is the in-vehicle travel time from departure station/airport in city i to arrival station/airport in city j , and t_j^{egress} is the egress time in city j , indicating the intracity travel time from the station/airport to the destination in city j .

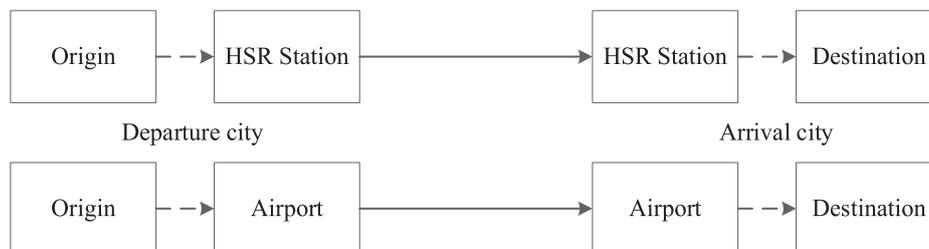


Fig. 2. The intercity travel process from an origin of the departure city to a destination of the arrival city.

In most Chinese cities, airports are more far away from city centers than HSR stations. Besides, the travel time between the different parts of city and airports/HSR stations is various, and it varies in a day according to the traffic congestion and the frequency of public transit (Moyano et al., 2018b, Rothfeld et al., 2019). Thus, in order to simplify the calculation, the access/egress time of airport is assumed to be 60 min in this study, while the access/egress time for HSR stations is set as 30 min. After passengers arriving airports/stations, they are required to pass some procedures, such as check-in and security check. For air passengers, they may need to check baggage in the departure airport and pick up baggage in the arrival airport. As a result, air passengers need more time to finish these procedures than HSR passengers. Thus, air passengers and HSR passengers are assumed to require at least 60 min and 30 min respectively to finish responding procedures.

To measure accessibility, the opportunity of study cities should be attained. Rather than using only GDP or population, this study refers to Jiao et al. (2014), Wang et al. (2016) and Yu and Fan (2018), and combines GDP (denoting the size of the economy) and population (denoting the number of people served) to attain the opportunity of each city for intercity accessibility measurement (see Eq. (2)).

$$O_i = \sqrt{GDP_i \times Population_i} \quad (2)$$

where O_i is the opportunity of city i , GDP_i is the gross domestic product of city i , and $Population_i$ is the population of city i . This indicator can not only consider the number of population served in the destination city, but also contain the size of economy in the destination city, which provides a more comprehensive attractiveness measure of the city (Luo and Zhao, 2021).

4.2. Accessibility measures

4.2.1. Connectivity and link

Connectivity and link can denote the basic structure of the network, which can represent the connection and its width among cities in the network. Connectivity has been applied to explore HSR network (Xu, et al., 2018; Jiao et al., 2020) and air travel network (Bansal and Sen, 2021). Connectivity is calculated as Eq. (3).

$$C_i = k \quad (3)$$

where C_i is the connectivity of city i , and k means the number of directly connected cities for city i .

However, the connection can only reflect the physical connection between cities. But we also care about the number of links between cities, which refers to the number of trains/flights between cities in daily life. Thus, the number of connected links is calculated as Eq. (4).

$$L_i = \sum_{j=1, i \neq j}^N link_{ij} \quad (4)$$

where L_i is the number of connected links of city i , and $link_{ij}$ means the number of direct trains/flights between city i and city j , and N is the number of cities.

4.2.2. Cumulative opportunity accessibility measure

Cumulative opportunity accessibility counts the number of opportunities which can be attained from the specific location within the given distance, travel time, or cost (Cao et al., 2013). Actually, a time threshold of 4 h is the cut-off point for a comfortable intercity trip, which can provide enough time to deal with some business (Cao et al., 2013). In addition, a time threshold of 2 h is more suitable for passengers to make a daily return journey (Jiao et al., 2014). Cumulative opportunity accessibility (COA), which can be also called as daily accessibility, is calculated by Eqs. (5) and (6).

$$COA_i = \sum_{j=1, i \neq j}^J O_j f(t_{ij}^{total}) \quad (5)$$

$$f(t_{ij}^{total}) = \begin{cases} 1, & \text{if } t_{ij}^{total} \leq T \\ 0, & \text{if } t_{ij}^{total} > T \end{cases} \quad (6)$$

where COA_i denotes the cumulative opportunity accessibility for city i opportunity in all cities j , O_j is the number of opportunity in city j , $f(t_{ij}^{total})$ denotes the weighting function with t_{ij}^{total} being the total intercity travel time from city i to city j , and T means the travel cost threshold. If the cost is larger than the given threshold, the corresponding opportunities are not counted. According to previous studies (Cao et al., 2013, Jiao et al., 2014), this study utilizes 2 h and 4 h as the travel time thresholds to measure the responding intercity accessibilities.

4.2.3. Potential accessibility measure

The potential accessibility (PA), also called gravity-based accessibility is widely applied to calculate accessibility by travel cost decay effect, which assumes that closer places might own a larger influences on each other. In this study, the total travel time is adopted as travel cost to show the attraction ability among different cities. The potential accessibility is calculated according to Eq. (7).

$$PA_i = \sum_{j=1, i \neq j}^J \frac{O_j}{(t_{ij}^{total})^\beta} \quad (7)$$

where PA_i is the accessibility of city i , i and j denote city i and city j , O_j is the opportunity of city j , t_{ij}^{total} denotes the total intercity travel time from city i to city j , β means the efficiency of the travel mode, which is calibrated from (Yu and Fan, 2018) In typical, β is assumed to be 1 in national-scale analyses (Yu and Fan, 2018).

4.2.4. Overall intercity accessibility measure

Both HSR and air travel are important intercity travel modes, which take a large share of the market. In 2018, there are 2.01 billion passengers delivered by the HSR system and 537 million passengers delivered by the domestic airline system. As HSR and air travel are the most populous modes for intercity travels, this study combines the accessibilities of the two modes to attain the overall intercity accessibility according to Eq. (8).

$$A_{all,i} = \alpha \frac{A_{hsr,i}}{\max(A_{hsr,j}, j \in (1, 2, \dots, 36))} + (1 - \alpha) \frac{A_{air,i}}{\max(A_{air,j}, j \in (1, 2, \dots, 36))} \quad (8)$$

where $A_{all,i}$ is the overall intercity accessibility of city i , $A_{hsr,i}$ is the intercity accessibility of city i by HSR, $A_{air,i}$ is the intercity accessibility of city i by air travel, and α denotes the ratio of HSR ridership (see Eq. (9)).

The value of α is calculated as Eq. (9).

$$\alpha = \frac{r_{hsr}}{r_{hsr} + r_{air}} \quad (9)$$

where r_{hsr} and r_{air} are the annual domestic ridership in China of HSR and air travel respectively.

4.2.5. Relative intercity accessibility measure

To evaluate the difference between HSR and air travel in intercity accessibility, the relative intercity accessibility is formulated as Eq. (10).

$$A_{rel,i} = \frac{(A_{air,i} - A_{hsr,i})}{\max(A_{air,i}, A_{hsr,i})} \quad (10)$$

where $A_{rel,i}$ is the relative intercity accessibility in city i between air

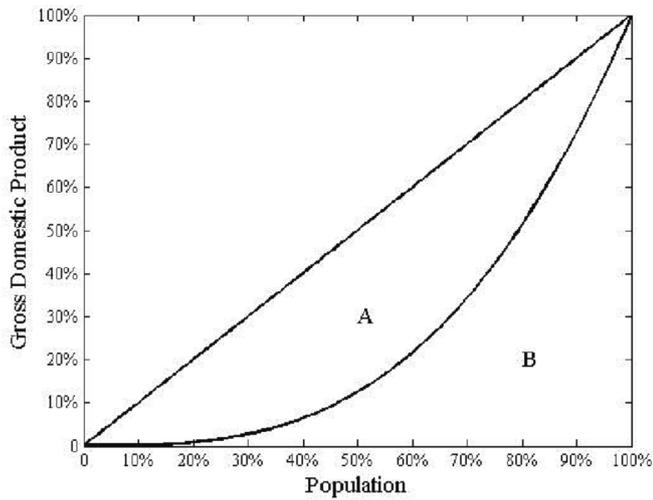


Fig. 3. Lorenz curve: the Gini index (Farris et al., 2010).

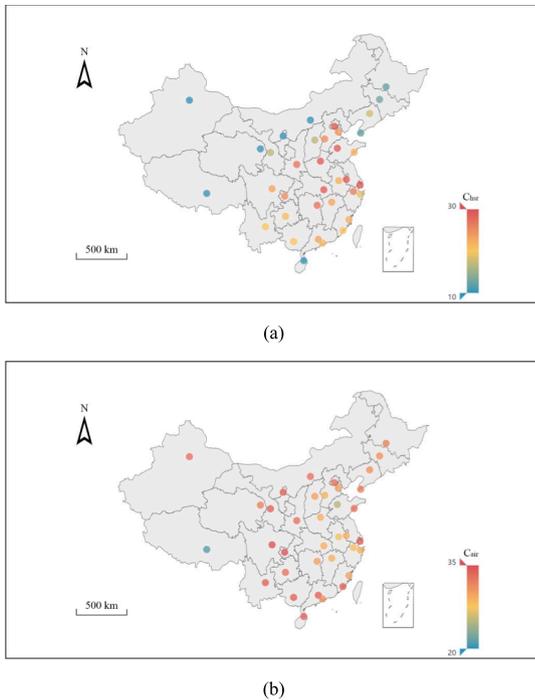


Fig. 4. The spatial distribution of connectivity in the intercity (a) HSR network and (b) air travel network.

travel and HSR, which is in the range of [-1, 1]. If the $A_{rel,i}$ is positive, it means that air travel service is superior to HSR service in city i , and the negative value means the HSR service is superior to the air travel service. Its absolute value reflects the superiority or inferiority level (Cao et al., 2013).

4.3. Equity evaluation methods

This study further investigates the equity of intercity accessibility for different cities. To achieve the goal, the coefficient of variation (CV) and Gini index are introduced to evaluate the spatial equity. The CV can evaluate the spatial variation degree of intercity accessibility. The CV can be expressed as Eq. (11).

$$CV = \frac{\sigma \sum O_i}{\sum (A_i O_i)} \quad (11)$$

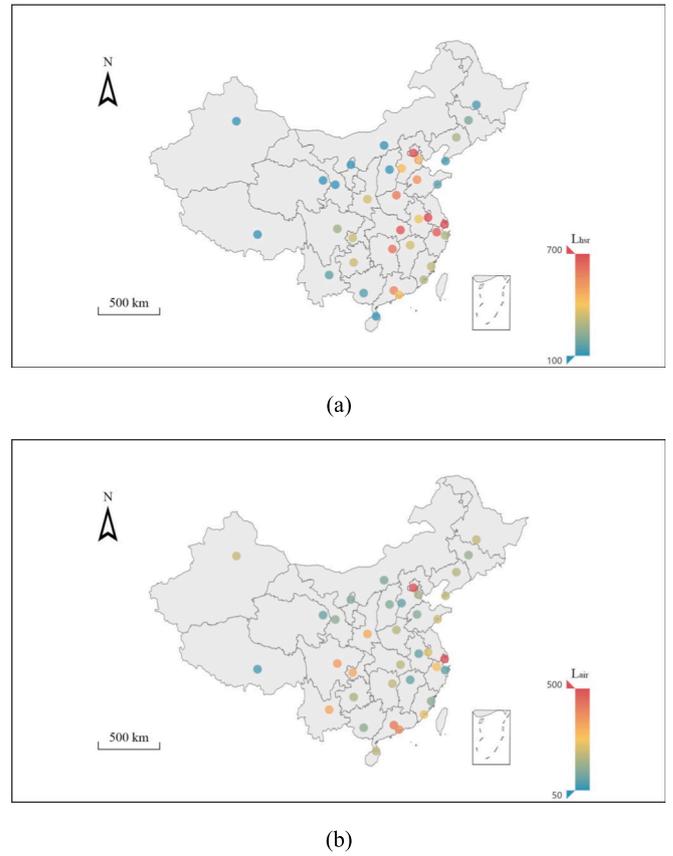


Fig. 5. The spatial distribution of links in the intercity (a) HSR network and (b) air travel network.

where CV is the coefficient of variation, σ is the standard deviation of intercity accessibility, A_i means the accessibility in city i , and O_i is the opportunity in city i . The perfect equality situation is denoted by a CV value of 0 and a higher CV value indicates larger inequality.

Besides, the Gini index is widely used to measure the equity. The Gini index is a quantity calculated from a particular Lorenz curve (Farris et al., 2010) (see Fig. 3). The Gini index summarizes how much the Lorenz curve of the given situation deviates from perfect equity.

The calculation of Gini index is presented in Eq. (12).

$$G = \frac{A}{A + B} \quad (12)$$

where G means the Gini index, A and B represent the areas of their corresponding graphs.

5. Results

5.1. Connectivity and link

The connectivity of each city is calculated and presented in Fig. 4. In the HSR network, the cities with the highest connectivity locate in the central and eastern parts of China, which includes Beijing, Shanghai, Jinan, Nanjing, Wuhan and Zhengzhou (see Fig. 4(a)). These cities are connected by several HSR lines. On the contrary, cities in the periphery of the country have much lower connectivity.

According to Fig. 4(b), all connectivity values are more than 20 in the air travel network. Chongqing and Chengdu have the highest connectivity of 35, which means that they have direct flights to all other cities. Besides, many cities have high level of connectivity, which is close to the highest value. In addition, some cities with low values in HSR connectivity have high values in air travel connectivity, such as Haikou,

Table 2
Ten cities with highest COA in HSR and air travel networks.

Rank	HSR (2 h)	HSR (4 h)	Air travel (2 h)	Air travel (4 h)
1	Shijiazhuang	Jinan	Zhengzhou	Xi'an
2	Hangzhou	Zhengzhou	Nanchang	Taiyuan
3	Nanjing	Hefei	Wuhan	Tsingtao
4	Jinan	Nanjing	Tsingtao	Shanghai
5	Tianjin	Taiyuan	Changsha	Guiyang
6	Beijing	Shijiazhuang	Xi'an	Huhehot
7	Chengdu	Nanchang	Xiamen	Xiamen
8	Hefei	Changsha	Taiyuan	Beijing
9	Shenzhen	Hangzhou	Dalian	Yinchuan
10	Guangzhou	Ningbo	Nanjing	Chengdu

Yinchuan, Urumqi, Huhehot and Sining. And all of them are located in the periphery of the country.

Connectivity can only represent the physical relation among cities. Moreover, the number of HSR trains and air flights plays an important role in the actual communication. Each train and flight can provide the certain capacity and the specific departure time. According to Fig. 5(a), cities with high links are concentrated on the central and eastern part of the country in the HSR network. Nanjing owns the highest links of 863, followed by Shanghai, Beijing, Wuhan and Hangzhou.

In the air travel network, the cities with high links own major hub airports. Shanghai has the highest value of link, followed by Beijing, Guangzhou, Shenzhen and Chengdu (see Fig. 5(b)). The cities with high links are spread widely and almost each region has a city with high links. Rather than the remote cities, cities close to mega cities have relatively

low links, as more flights are assigned to nearby mega cities. This is consistent with the hub-and-spoke system of air travel network.

5.2. Cumulative opportunity accessibility

This section utilizes cumulative opportunity measure to count the reachable opportunities within 2 h and 4 h. The top 10 cities with high COA are presented in Table 2. For the HSR network with a 2-h threshold, the high COA cities are along the Beijing-Shanghai HSR, located in the eastern part of China (see Fig. 6(a)). When the threshold is extended to be 4 h, more cities within the central and eastern parts show higher COA (see Fig. 6(c)). This area has high population density, rapid economic development and more developed HSR system.

For the air travel network with a 2-h threshold, the high COA cities are located in the most central part of China, such as Zhengzhou and Wuhan (see Fig. 6(b)). Most cities in the air travel network show pretty well performance in COA when the travel time threshold is set as 4 h (see Fig. 6(d)). This is resulted from the fact that the total travel time of 4 h enables these cities to reach most cities in the air travel network.

In terms of COA, the air travel network has a better performance than the HSR network. As the air flight owns higher operation speed than the HSR train and the HSR is limited to the implemented railway. In the both modes, the northeast area, Ulumuqi and Lasa have relative low COA, because they are far away from most study cities.

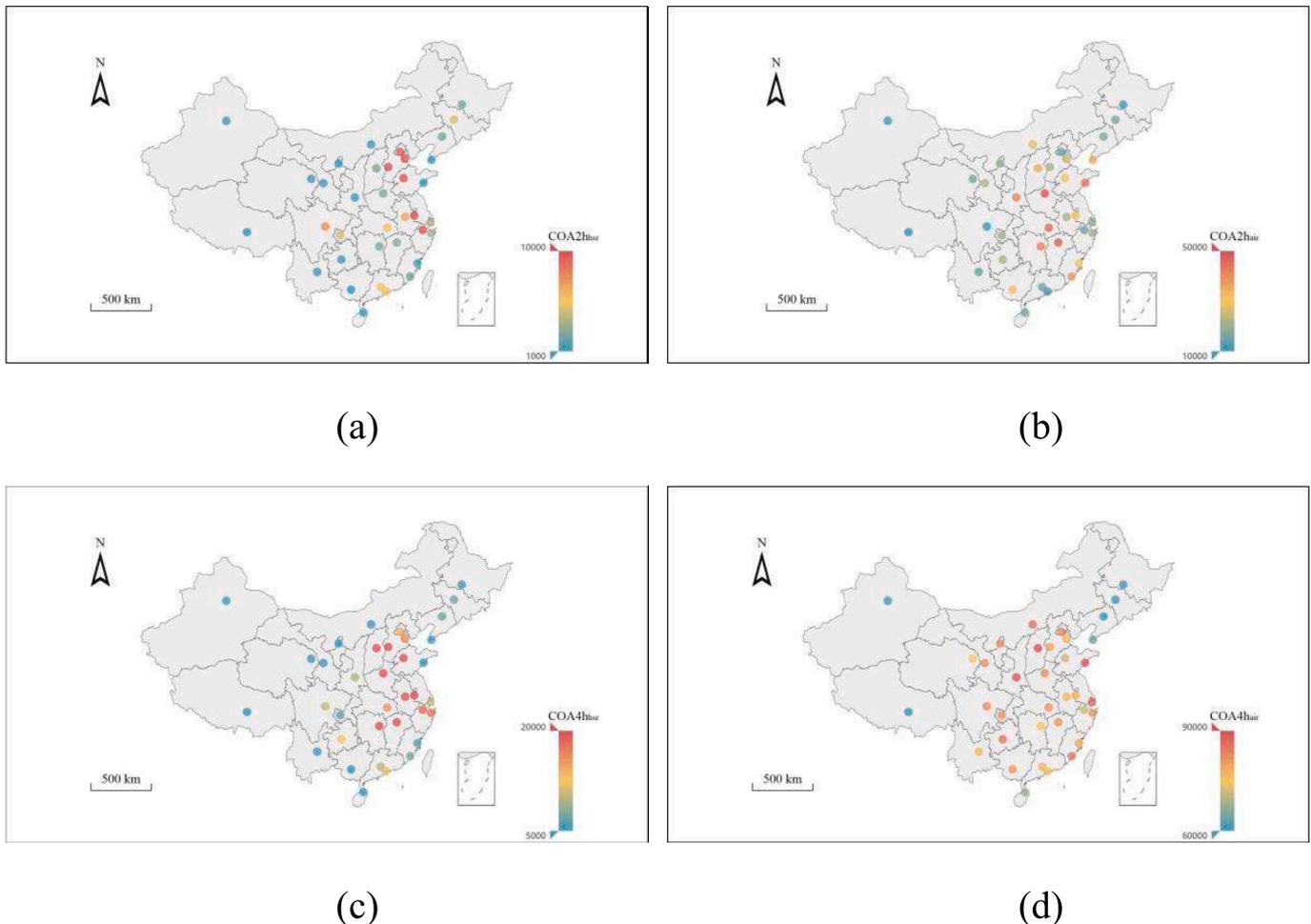
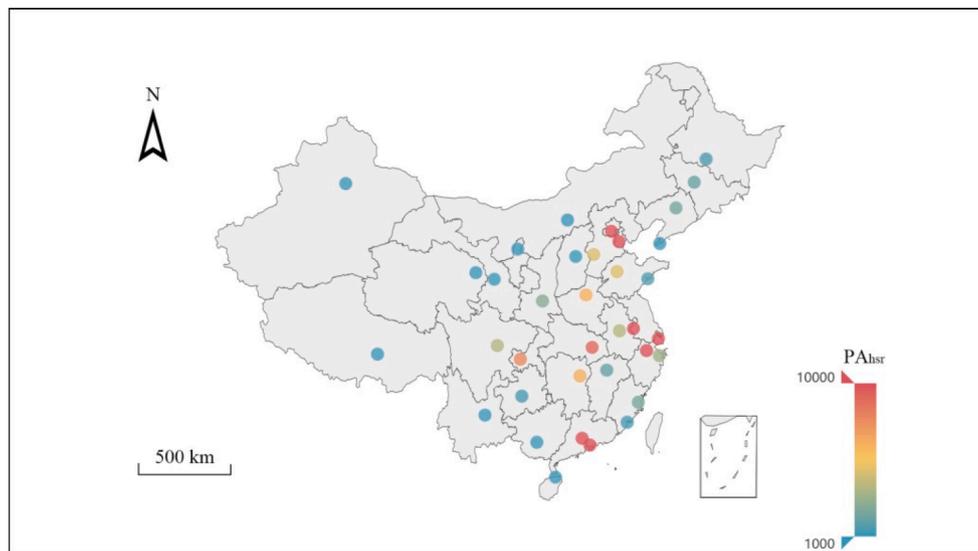
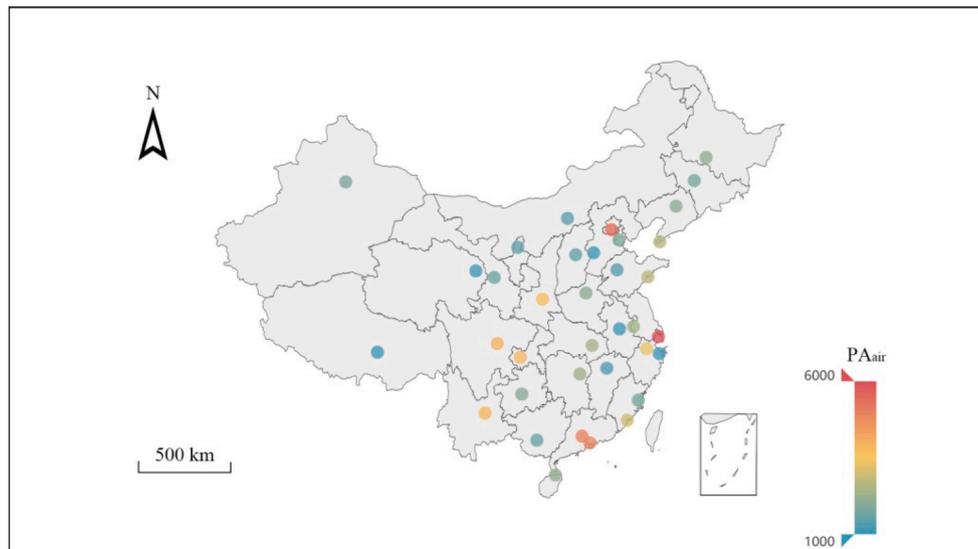


Fig. 6. The spatial distribution of COA with a time threshold of: (a) 2 h in HSR network, (b) 2 h in air travel network, (c) 4 h in HSR network, and (d) 4 h in air travel network.



(a)



(b)

Fig. 7. The spatial distribution of PA in the (a) HSR network, and (b) air travel network.

Table 3

Ten cities with highest intercity potential accessibility of HSR and air travel networks.

Rank	HSR	Air travel
1	Shanghai	Shanghai
2	Beijing	Beijing
3	Guangzhou	Guangzhou
4	Tianjin	Shenzhen
5	Nanjing	Chengdu
6	Shenzhen	Kunming
7	Hangzhou	Chongqing
8	Wuhan	Xi'an
9	Chongqing	Hangzhou
10	Changsha	Xiamen

5.3. Potential accessibility

The intercity potential accessibilities of HSR and air travel networks are presented in Fig. 7. According to the spatial distribution of intercity PA in the HSR system, some regions record higher PA than the general level. It can be found that these cities have higher level of GDP and population. Besides, the cities have the ability to reach other high attraction cities. As a result, the city within a city agglomeration tends to attain higher PA.

For the air travel network, high PA cities are spread more widely. Many high intercity PA cities are located in the peripheral of the country, such as Kunming, Chengdu, Xi'an, Xiamen, which is different from the HSR network (see Table 3).

5.4. Overall intercity accessibility

According to Eq. (8), the intercity accessibilities of HSR and air travel

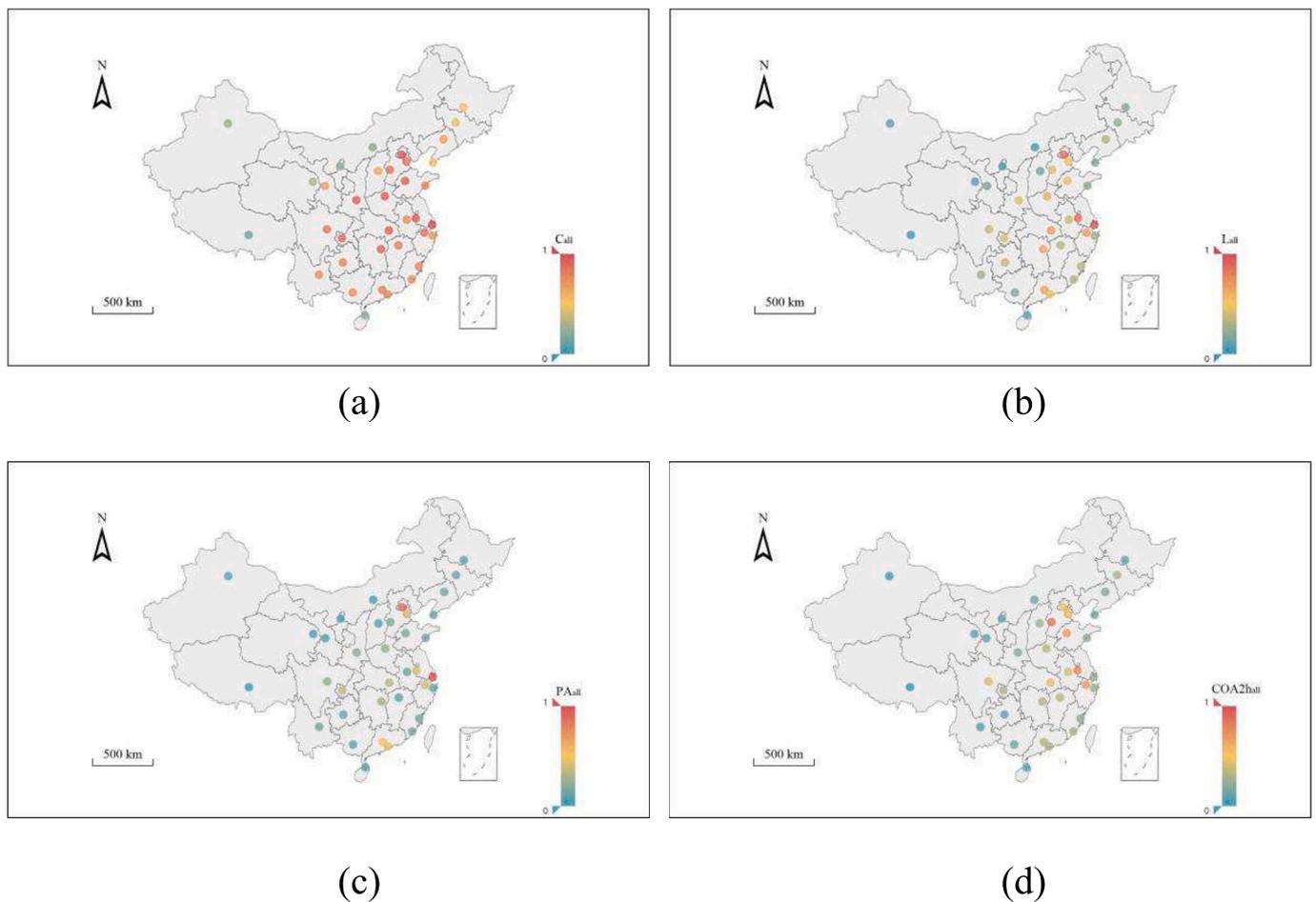


Fig. 8. The overall intercity accessibility combining air travel network and HSR network: (a) connectivity, (b) link, (c) PA, and (d) COA (2 h).

networks are integrated to generate the overall intercity accessibility (see Fig. 8). As shown in Fig. 8(a), the overall connectivity has higher values in the central, eastern and southern part of China. The similar pattern can be found in the spatial distribution of the overall link, however, megacities own higher values than that of overall connectivity, such as Beijing and Shanghai (see Fig. 8(b)). For the spatial distribution of overall potential accessibility in Fig. 8 (c), Shanghai and Beijing are extremely higher than other cities, followed by Shenzhen, Guangzhou, and Tianjin. However, the overall COA (2 h) is higher in the central area, especially Shijiazhuang, Jinan, Nanjing and Hangzhou.

5.5. Comparison of intercity accessibility

With the rapid development of HSR and air travel systems, there is intensive competition between HSR system and air travel system. The relative intercity accessibility between air travel and HSR is calculated and presented in Fig. 9. The positive value means that the air travel has the superiority and the negative values means that the HSR has the superiority. Fig. 9(a) shows that the air travel network has the superiority in all cities except for Jinan in connectivity. For the relative difference of link in Fig. 9(b), the HSR has the superiority in some cities, including the cities in the central and eastern parts of China. In similar, the distribution of relative PA (see Fig. 9(c)) is similar with that of link. For the COA (2 h) shown in Fig. 9(d), the air travel is superior than HSR in most cities, except Hangzhou and Harbin where the intercity COA of two modes are competitive.

5.6. Equity of accessibility

To show the equity of intercity accessibility for the two modes, the CV and Gini indexes of accessibility measures are calculated and presented in Table 4. According to CV and Gini indexes of the intercity accessibilities, the air travel network has higher equity level than the HSR network in all kinds of intercity accessibility indicators. The overall intercity accessibility has the moderate equity in the three ones. In general, the equity is the highest for connection and the lowest for PA in both modes. For the COA, when the travel time threshold increases, the equity will increase.

5.7. Correlation between intercity accessibility and GDP

As we know, intercity accessibility can affect the levels of economic development (Jiao et al., 2020; Jin et al., 2020; Liang et al., 2020). GDP is the most widely used indicator to represent the economic status of a city, and the intercity accessibility of a city is likely to be correlated with its local economic status (Liu et al., 2021). Thus, the correlations between the intercity accessibility index and GDP are calculated and presented in Table 5. It shows that the correlation from the potential accessibility is stronger than that of others. Moreover, the overall potential accessibility is more proper to explore the impact of intercity accessibility on economic development.

6. Conclusion and discussion

One of the main goals of this study was to measure the intercity accessibility of 36 major cities in China by considering high speed rail

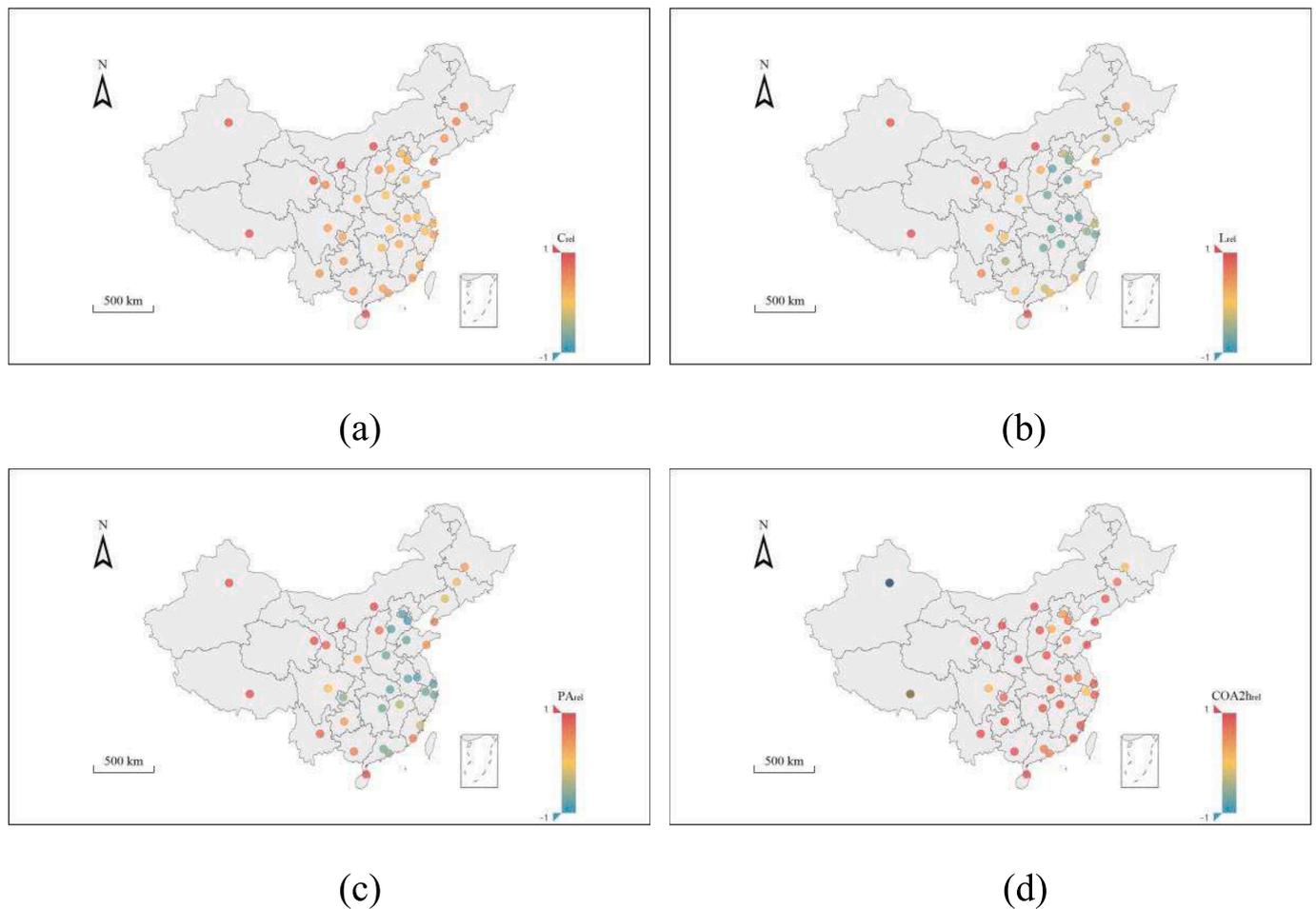


Fig. 9. The spatial distribution of the relative intercity accessibility between air travel network and HSR network: (a) connectivity, (b) link, (c) PA, and (d) COA (2 h).

Table 4
The equity of intercity accessibility.

Item	HSR	Air travel	Overall
CV of connectivity	0.4958	0.0966	0.3614
Gini of connectivity	0.2624	0.0505	0.1907
CV of link	0.7688	0.5589	0.6766
Gini of link	0.4287	0.2891	0.3748
CV of potential accessibility	1.3294	0.5716	1.0163
Gini of potential accessibility	0.6180	0.2983	0.4724
CV of cumulative opportunity accessibility within 2 h	1.1924	0.5485	0.7824
Gini of cumulative opportunity accessibility within 2 h	0.6063	0.3043	0.4133
CV of cumulative opportunity accessibility within 4 h	0.8872	0.1954	0.5522
Gini of cumulative opportunity accessibility within 4 h	0.4862	0.0942	0.3066

Table 5
Correlations between intercity accessibility index and GDP for 36 major cities in China.

Index	Correlation (Pearson)		
	HSR	Air travel	Overall
Connectivity	0.619	0.160	0.632
Link	0.727	0.808	0.794
Potential accessibility	0.918	0.813	0.937
Cumulative opportunity accessibility within 2 h	0.420	-0.050	0.401
Cumulative opportunity accessibility within 4 h	0.237	0.271	0.264

and air travel. Three methods are utilized to measure the location-based accessibility of HSR network and air travel network, including connectivity and link, cumulative opportunity accessibility and potential accessibility. According to the results of this study, it can be found that the spatial distributions of intercity accessibility are significantly different for HSR network and air travel network. In detail, cities with high connectivity are clustered and located in the central-eastern part in the HSR network. Xu et al. (2018) also noticed that connectivity of HSR network was higher in eastern and central area of China. While in the air travel network, cities with high connectivity are more dispersed. The connectivity is not high in the central part of China, which is contrary to the spatial distribution of the connectivity in the HSR network. Bansal and Sen (2021) also found that high connectivity airports and dispersed, which is consistent with our findings. This is due to the fact that the central part has pretty developed HSR system which is more competitive than the air travel. As a result, some airlines with short distances are canceled. Strauss et al. (2021) have confirmed that the increase of HSR routes in China contributed to significant and negative influences on air travel. Furthermore, Wang et al. (2018) validated that HSR's impact on airline traffic is empirically stronger on short-haul routes where the HSR and airline services are more substitutable. In general, the air travel has a higher connectivity than HSR. Furthermore, considering the number of trains/flights, the value of link has a similar pattern with connectivity, but the value of link is even larger in specific megacities than others, such as Beijing and Shanghai.

In the HSR network, cities with high COA (2 h) are located in the eastern part. When the travel time threshold is extended to 4 h, the high COA (4 h) cities move west a bit. For the air travel network, the cities with high COA are located in the central part and are more dispersed. In

the HSR network, high PA cities are located along the Yangtze River, Beijing-Guangzhou HSR and Beijing-Shanghai HSR. While for the air travel network, the high PA cities are dispersed, such as Beijing in the northern part, Shanghai in the eastern part, Shenzhen and Guangzhou in the southern part, and Kunming, Chengdu and Chongqing in the western part. As the HSR trains are traveling along the railway, cities along a railway tend to share similar accessibility. In a previous study about intercity accessibility in the HSR network, [Jiao et al. \(2014\)](#) also confirmed that cities with high daily accessibility and potential accessibility are located in the eastern part of China, which is consistent with our findings. [Luo and Zhao \(2021\)](#) found that potential accessibility in HSR network is higher in the central part of Liaoning Province, China. However, most of previous studies are concentrated on intercity accessibility of HSR only. This study considers the two modes, both high speed rail and air travel at the same time.

Overall, the air travel system has higher equity than the HSR system in intercity accessibility. Among the intercity accessibility indicators, the equity is highest for connectivity, and lowest for potential accessibility in both modes. [Jiao et al. \(2014\)](#) have compared the equity of intercity accessibility of HSR in different stages, which indicated that the implement of HSR increased inequalities in the first stage, and the inequalities decreased as the expansion of HSR in the second stage. Similar results have been found by [Kim and Sultana \(2015\)](#), they also found that the equity of intercity accessibility is higher in PA than WATT.

Comparing the intercity accessibility of air travel and HSR network, overall, the intercity accessibility is higher in the air travel network in most indicators. However, link and PA of HSR are higher than the air travel in the central-eastern part of China. Similar comparisons between intercity accessibility of HSR and airline are also conducted in a previous study ([Cao et al., 2013](#)), which found that airline performs better than HSR in WATT for all cities. While in PA, airline also performs better in most cities, except for several megacities, such as Beijing, Shanghai, and Guangzhou. Compared with the situation of the previous study, the HSR network in our study has expanded significantly, and HSR performed better than air travel in PA with larger areas.

Besides, comparing the correlations between the intercity accessibility index and GDP, it is found that the correlation from the potential accessibility is stronger than that of others. Overall, the intercity accessibility of HSR is more related to GDP than that of air travel. It is also noticed that overall intercity accessibility is the most suitable one to investigate the impact of intercity accessibility on economic development.

This study is innovative to measure the intercity accessibility by HSR and air travel with three methods at the national scale. Furthermore, the overall and relative intercity accessibility are also calculated to analyze the spatial distribution and modal differences. We also compare the equity of intercity accessibility by the two modes, and the correlation between intercity accessibility and economic development. This study provides some advices to consider HSR and air travel at the same time as the two modes compete and complement with each other.

However, there are some limitations in this study. The intercity transfer travels are not taken into consideration. Besides, the travels within the catchment area of the stations/airports are simplified which cannot reflect the actual travel behaviors. It should be acknowledged that location-based accessibility measures focused on land-use and transportation components to conduct the valuation at a macroscopic level ([Cao et al., 2013](#)). The accessibility measures are conducted based on listed timetables and the actual accessibility experienced by passengers might differ from them. In the further study, more influenced factors should be taken into consideration, such as human component and different modes of intracity travels.

CRedit authorship contribution statement

Shixiong Jiang: Conceptualization, Methodology, Software, Data curation, Writing – original draft, Investigation, Project administration,

Funding acquisition. **Canhuang Cai:** Investigation. **Lide Xiao:** Visualization, Investigation, Validation.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

This work was supported by National Natural Science Foundation of China [grant number 61976055].

References

- Bansal, S., Sen, J., 2021. Network assessment of Tier-II Indian cities' airports in terms of type, accessibility, and connectivity. *Transp. Policy* 124, 221–232.
- Benenson, I., Martens, K., Rof, Y., Kwartler, A., 2011. Public transport versus private car GIS-based estimation of accessibility applied to the Tel Aviv metropolitan area. *Ann. Reg. Sci.* 47, 499–515.
- Bergantino, A.S., Madio, L., 2020. Intermodal competition and substitution. HSR versus air transport: understanding the socio-economic determinants of modal choice. *Res. Transp. Econ.* 79, 100823.
- Cao, J., Liu, X.C., Wang, Y., Li, Q., 2013. Accessibility impacts of China's high-speed rail network. *J. Transp. Geogr.* 28, 12–21.
- Chen, Z., 2017. Impacts of high-speed rail on domestic air transportation in China. *J. Transp. Geogr.* 62, 184–196.
- Chen, C., D'Alfonso, T., Guo, H., Jiang, C., 2018. Graph theoretical analysis of the Chinese high-speed rail network over time. *Res. Transp. Econ.* 72, 3–14.
- Cools, M., Moons, E., Creemers, L., Wets, G., 2010. Changes in travel behavior in response to weather conditions: do type of weather and trip purpose matter. *Transp. Res. Rec. J. Transp. Res. Board* 2157, 22–28.
- Geurs, K.T., Wee, B.V., 2004. Accessibility evaluation of land-use and transport strategies: review and research directions. *J. Transp. Geogr.* 12, 127–140.
- Grubestic, T., Zook, M., 2007. A ticket to ride: evolving landscapes of air travel accessibility in the United States. *J. Transp. Geogr.* 15, 417–430.
- Guo, Y., Li, B., Han, Y., 2020. Dynamic network coupling between highspeed rail development and urban growth in emerging economies: evidence from China. *Cities* 105, 102845.
- Hansen, W.G., 1959. How accessibility shapes land use. *J. Am. Plann. Assoc.* 25, 73–76.
- Jiao, J., Wang, J., Jin, F., Dunford, M., 2014. Impacts on accessibility of China's present and future HSR network. *J. Transp. Geogr.* 40, 123–132.
- Jiao, J., Wang, J., Zhang, F., Jin, F., Liu, W., 2020. Roles of accessibility, connectivity and spatial interdependence in realizing the economic impact of high-speed rail: evidence from China. *Transp. Policy* 91, 1–15.
- Jin, M., Lin, K.C., Shi, W., Lee, P.T.W., Li, K.X., 2020. Impacts of high-speed railways on economic growth and disparity in China. *Transp. Res. A Policy Pract.* 138, 158–171.
- Kim, H., Sultana, S., 2015. The impacts of high-speed rail extensions on accessibility and spatial equity changes in South Korea from 2004 to 2018. *J. Transp. Geogr.* 45, 48–61.
- Lei, T.L., Church, R.L., 2010. Mapping transit-based access: integrating GIS, routes and schedules. *Int. J. Geogr. Inf. Sci.* 24, 283–304.
- Liang, Y., Zhou, K., Li, X., Zhou, Z., Zeng, J., 2020. Effectiveness of high-speed railway on regional economic growth for less developed areas. *J. Transp. Geogr.* 82, 102621.
- Liu, L., Zhang, M., 2018. High-speed rail impacts on travel times, accessibility, and economic productivity: a benchmarking analysis in city-cluster regions of China. *J. Transp. Geogr.* 73, 25–40.
- Luo, H., Zhao, S., 2021. Impacts of high-speed rail on the inequality of intercity accessibility: a case study of Liaoning Province, China. *J. Transp. Geogr.* 90, 102920.
- Ma, W., Wang, Q., Yang, H., Zhang, A., Zhang, Y., 2019. Effects of Beijing-Shanghai high-speed rail on air travel: passenger types, airline groups and tacit collusion. *Res. Transp. Econ.* 74, 64–76.
- Matisziw, T.C., Grubestic, T.H., 2010. Evaluating locational accessibility to the US air transportation system. *Transp. Res. A Policy Pract.* 44, 710–722.
- Moyano, A., Mart Nez, H.S., Coronado, J.M., 2018a. From network to services: a comparative accessibility analysis of the Spanish high-speed rail system. *Transp. Policy* 63, 51–60.
- Moyano, A., Moya-G Mez, B., Guti Rrez, J., 2018b. Access and egress times to high-speed rail stations: a spatiotemporal accessibility analysis. *J. Transp. Geogr.* 73, 84–93.
- Ortega, E., López, E., Monzón, A., 2012. Territorial cohesion impacts of high-speed rail at different planning levels. *J. Transp. Geogr.* 24, 130–141.
- Rothfeld, R., Straubinger, A., Paul, A., Antoniou, C., 2019. Analysis of European airports' access and egress travel times using Google Maps. *Transp. Policy* 81, 148–162.
- Shaw, S.L., Fang, Z., Lu, S., Tao, R., 2014. Impacts of high speed rail on railroad network accessibility in China. *J. Transp. Geogr.* 40, 112–122.
- Strauss, J., Li, H., Cui, J., 2021. High-speed Rail's impact on airline demand and air carbon emissions in China. *Transp. Policy* 109, 85–97.
- Vega, A., Reynolds-Feighan, A., 2016. The impact of the great recession on Irish air travel: an intermodal accessibility analysis. *J. Air Transp. Manag.* 51, 1–18.

- Wang, L., 2018. High-speed rail services development and regional accessibility restructuring in megaregions: a case of the Yangtze River Delta, China. *Transp. Policy* 72, 34–44.
- Wang, L., Duan, X., 2018. High-speed rail network development and winner and loser cities in megaregions: the case study of Yangtze River Delta, China. *Cities* 83, 71–82.
- Wang, L., Liu, Y., Sun, C., Liu, Y., 2016. Accessibility impact of the present and future high-speed rail network: a case study of Jiangsu Province, China. *J. Transp. Geogr.* 54, 161–172.
- Wang, L., Acheampong, R.A., He, S., 2020b. High-speed rail network development effects on the growth and spatial dynamics of knowledge-intensive economy in major cities of China. *Cities* 105, 102772.
- Wang, C., Meng, W., Hou, X., 2020a. The impact of high-speed rails on urban economy: an investigation using night lighting data of Chinese cities. *Res. Transp. Econ.* 80, 100819.
- Wang, K., Xia, W., Zhang, A., Zhang, Q., 2018. Effects of train speed on airline demand and price: theory and empirical evidence from a natural experiment. *Transp. Res. B Methodol.* 114, 99–130.
- Xu, W.A., Huang, Y., 2019. The correlation between HSR construction and economic development – Empirical study of Chinese cities. *Transp. Res. A Policy Pract.* 126, 24–36.
- Xu, W.A., Zhou, J., Yang, L., Li, L., 2018. The implications of high-speed rail for Chinese cities: connectivity and accessibility. *Transp. Res. A Policy Pract.* 116, 308–326.
- Yang, Z., Yu, S., Notteboom, T., 2016. Airport location in multiple airport regions (MARs): the role of land and airside accessibility. *J. Transp. Geogr.* 52, 98–110.
- Yu, M., Fan, W., 2018. Accessibility impact of future high speed rail corridor on the piedmont Atlantic megaregion. *J. Transp. Geogr.* 73, 1–12.
- Zhang, R., Johnson, D., Zhao, W., Nash, C., 2019b. Competition of airline and high-speed rail in terms of price and frequency: Empirical study from China. *Transp. Policy* 78, 8–18.
- Zhang, A., Wan, Y., Yang, H., 2019a. Impacts of high-speed rail on airlines, airports and regional economies: a survey of recent research. *Transp. Policy* 81, A1–A19.
- Zhang, Y., Zhang, A., Zhu, Z., Wang, K., 2017. Connectivity at Chinese airports: the evolution and drivers. *Transp. Res. A Policy Pract.* 103, 490–508.
- Zhu, Z., Zhang, A., Zhang, Y., 2018. Connectivity of intercity passenger transportation in China: a multi-modal and network approach. *J. Transp. Geogr.* 71, 263–276.