The Impact of High-Speed Railway on the Accessibility Pattern of Triangle of Central China

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Abstract—For exploring the impact of high-speed rail construction on urban accessibility pattern and spatial equity, this paper takes Triangle of Central China as an example, and takes counties and cities as objects to compare and analyze the two travel modes of driving and high-speed railway. Firstly, a model is established for the travel time of driving and high-speed rail by using Baidu map data and high-speed train information. Then the weighted average travel time and economic potential are adopted to evaluate the accessibility level and analyze the accessibility pattern. Furthermore, the coefficient of variation is used to evaluate the spatial equity of accessibility. Key conclusions include: The high-speed rail construction has significantly improved the accessibility of Triangle of Central China; In driving mode, the accessibility level in the middle areas is higher, and Wuhan, Changsha and Nanchang are the three regional centers of high accessibility, while in the high-speed rail mode, the high accessibility area forms a triangular hollow ring structure with Wuhan, Changsha and Nanchang as the vertices and the high-speed rail line as the side; High-speed rail strengthens the spatial imbalance, with the unbalanced growth of Hubei is the biggest, and prefecture-level cities benefit more from high-speed railway.

Keywords-high-speed railway; accessibility; spatial equity; Triangle of Central China; spatial pattern

1. INTRODUCTION

Transportation network is the link of socio-economic activities in geographical space and plays a key role in spatial economic linkage. As an important means of transportation, high-speed railway can greatly shorten the time and space distance between cities, improve the accessibility of cities, and play an important role in shaping the spatial economic structure and the integrated development of urban agglomerations. With the rapid development of China's high-speed railway, frequent intercity communication has developed from limited to large cities to the county level, which greatly improves the accessibility of intercity transportation.

Scholars have conducted extensive research on the spatial effects of high-speed rail construction. In terms of research content, it explores the impact of high-speed rail construction on travel time and accessibility between cities[1-2], urban spatial structure[3-4] and socio-economic benefits[5]. In the study of accessibility, scholars adopt weighted average travel time (WATT), economic potential (EP) and daily accessibility (DA) as indicators to measure accessibility[6], and find that high-speed rail can significantly reduce the cost of time and space travel, reduce the WATT of cities, enhance the EP of cities, form a 'core-periphery' pattern, and show a significant corridor effect along the high-speed rail[7].

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However, with the increasing popularity and development of the high-speed rail network, the travel mode of high-speed rail has penetrated from large cities to the county level, and has a great advantage in people's short-distance intercity travel together with driving cars. Therefore, the accessibility level measured by a single travel mode in the past has been difficult to accurately reflect the actual accessibility changes, and it is also difficult to accurately grasp the evolution of the spatial pattern of accessibility when the research object stays at the city level. Therefore, this paper uses two travel modes of high-speed rail and driving for comparative analysis, and takes the county and city as the unit to more clearly understand the impact of high-speed rail on regional accessibility.

In addition, most of the existing research is based on a high-speed rail line or a province or region to evaluate the impact of high-speed rail on spatial accessibility[1,4,7], and the research on urban agglomerations is also more concentrated in the more mature regions such as Beijing-Tianjin-Hebei and the Yangtze River Delta, while the high-speed railway in Triangle of Central China is developing rapidly, which is more meaningful for the exploration of developing regions. Therefore, this paper takes Triangle of Central China as the research area, takes counties and cities as the research object, divides 153 research units, and compares the two travel modes of high-speed rail and driving to explore the impact of high-speed rail construction on the accessibility pattern and spatial equity of Triangle of Central China.

2. Materials and Methods

2.1 Research areas and data sources

Triangle of Central China is a super-large urban agglomeration formed by Wuhan metropolitan area, Changsha-Zhuzhou-Xiangtan urban agglomeration and Poyang Lake urban agglomeration. It covers a total of 31 prefecture-level cities and provincial municipalities in Hubei Province, Hunan Province and Jiangxi Province. In this paper, the municipal districts of Triangle of Central China are merged into 153 evaluation units, including 28 prefecture-level cities, 3 county-level cities directly under provincial jurisdiction, 40 county-level cities and 82 counties.

The socio-economic data (resident population, GDP and urbanization rate, etc.) used in the study are derived from the 'China County Statistical Yearbook', 'Hubei Statistical Yearbook', 'Hunan Statistical Yearbook' and 'Jiangxi Statistical Yearbook'. The traffic road data (high-speed railway network, etc.) is obtained through OpenStreetMap. The high-speed rail travel time data comes from the website of China Railway Customer Service Center. The python program is used to obtain the train information in batches, and the shortest scheme between the two high-speed rail stations is obtained through data processing. The driving data is derived from Baidu map navigation information. With the help of python program, the time and distance data of the optimal driving route between any two locations are obtained in batches during non-peak period, and then the shortest travel time of self-driving cars is obtained.

2.2 Travel time calculation model

Intercity travel time by high-speed rail consists of departure point - high-speed rail station, high-speed rail station - high-speed rail station, high-speed rail station - destination, waiting time and transit time, and can be calculated as follows:

$$T_{ij}^{HSR} = T_{os} + T_{ss} + T_{sd} + T_{\theta} \tag{1}$$

where T_{ij}^{HSR} is the total travel time from city i to city j by high-speed rail, T_{os} and T_{sd} is the driving time from the origin to the starting point of the high-speed rail station and from the end point of the high-speed rail station to the destination, T_{ss} represents the travel time of the high-speed rail train between the two high-speed rail stations, T_{θ} represents the deviation, including the waiting time and transit time, referring to the existing research[7-8], the waiting time is set to 30 minutes, for the case that there is no direct train between the two high-speed railway stations, the travel mode with one transfer and the least time is selected, and the transit time is set to 50 minutes.

Since a city may correspond to multiple high-speed rail stations, and some cities do not have high-speed rail stations, the one with the smallest total travel time among all possible schemes is taken as the final scheme, and the minimum time is taken as the travel time by high-speed rail. Since people start from different places, the government of each city is taken as the starting point, and the shortest driving time from the starting point to the high-speed railway station and from the high-speed railway station to the destination is calculated by using Baidu map navigation data[9].

The driving travel time is calculated by using Baidu map navigation service, taking the government seat of each city as the starting point and ending point, and using python program to obtain the shortest time-consuming driving route between the two cities in batches, and the shortest time is taken as the driving travel time.

2.3 Accessibility indicators

The measurement indicators of accessibility are roughly divided into two types, that is, the calculation of travel costs such as travel time and cost, and the calculation of the attraction of location by introducing urban population and economy[10]. This paper uses WATT and EP as indicators of accessibility.

The WATT is used to reflect the average level of travel time required to travel from one city to all other cities and is weighted by city influence to reflect differences between cities. The calculation method is as follows:

$$A_i = \frac{\sum_{j=1}^{n} \left(T_{ij} \times M_j \right)}{\sum_{j=1}^{n} M_j} \tag{2}$$

where, A_i is the WATT of city i, the smaller its value is, the higher the accessibility is. T_{ij} is the shortest travel time from city i to city j, which is divided into high-speed rail travel time and driving travel time. M_j is the influence of city j, which can be calculated as follows:

$$M_j = \sqrt{GDP_j \times POP_j} \tag{3}$$

where GDP_j is the economic scale of city j, and the data adopts the GDP of 2020; POP_j is the population size of city i, and the data adopts the urban resident population in 2020.

The EP can reflect the radiation-driven capacity of a certain city to the surrounding areas, and complement the WATT model. The calculation method is as follows

$$P_i = \sum_{j=1}^{n} \frac{M_j}{T_{ij}^{\alpha}} \tag{4}$$

where: P_i is the EP of city i, and the greater its value, the greater the development potential of city i. α is the distance friction coefficient, which is set to 1 here[11].

2.4 Indicators of fairness

The opening of high-speed rail will change the level of accessibility, but there are also fairness problems between cities due to differences in factors such as the development of high-speed rail networks. In order to verify whether the construction of high-speed rail will enhance or narrow the accessibility gap between cities, the coefficient of variation is selected for calculation[12]. The calculation method is:

$$CV = \frac{\sigma^t}{\sum_{i=1}^{n} A_i \times P_i / \sum_{i=1}^{n} P_i} \tag{5}$$

$$P_i = \left(W_i \times C_i\right) / \left(W_1 \times C_1 + W_2 \times C_2 + \ldots + W_n \times C_n\right) \tag{6}$$

where: σ^t is the standard deviation of accessibility value; P_i is the weight of population size in city i; W_i is the permanent resident population in city i; C_i is the urbanization rate of permanent resident population in city i. The greater the value of CV, the lower the fairness.

3. Results and discussions

3.1 The construction of high-speed railways has improved the accessibility of Triangle of Central China

The spatial distribution pattern and change trend of accessibility measured by WATT are shown in Figure 1, Figure 2 and Figure 3.

On average, the construction of high-speed rail has reduced the average travel time of cities in the middle reaches of the Yangtze River and significantly improved the accessibility level of cities. The total average travel time in self-driving mode is 262.53 min, while that in high-speed rail mode is 233.40 min. The opening of high-speed rail reduces the average travel time by 11.09%.

In general, the construction of high-speed rail has shortened the travel time of 75.16% of the cities, but there are also some cities with underdeveloped high-speed rail and reduced accessibility of roads than railways, such as Yichang, Jingmen, Jingzhou, etc. Due to the developed high-speed rail network, the accessibility level of some big cities has been significantly improved, such as Wuhan, Changsha, Nanchang and so on. Some small and medium-sized cities that high-speed rail lines pass through also benefit from the corridor effect, such as Chibi City, Yushan County, Gao 'an, etc., and the improvement of cities at the intersection of high-speed rail lines is more significant, such as Shangrao City and Hengyang City. In addition, small and medium-sized cities around big cities have also been greatly improved, such as Macheng and Hanchuan.

In the accessibility pattern, under the driving mode, the high accessibility areas are concentrated in the central area of Triangle of Central China, with Yueyang City and Xianning City as the center to spread outward, and the marginal cities such as Xiangyang City, Yichang city, Hengyang city and Shangrao city having the lowest accessibility. In the high-speed rail mode, the high accessibility area is centered on the three provincial capitals of Wuhan, Changsha and Nanchang, and forms corridors along both sides of the high-speed rail line, forming an obvious triangular ring pattern. The closer it is to the urban agglomeration center and the high-speed rail line, the higher the accessibility is.

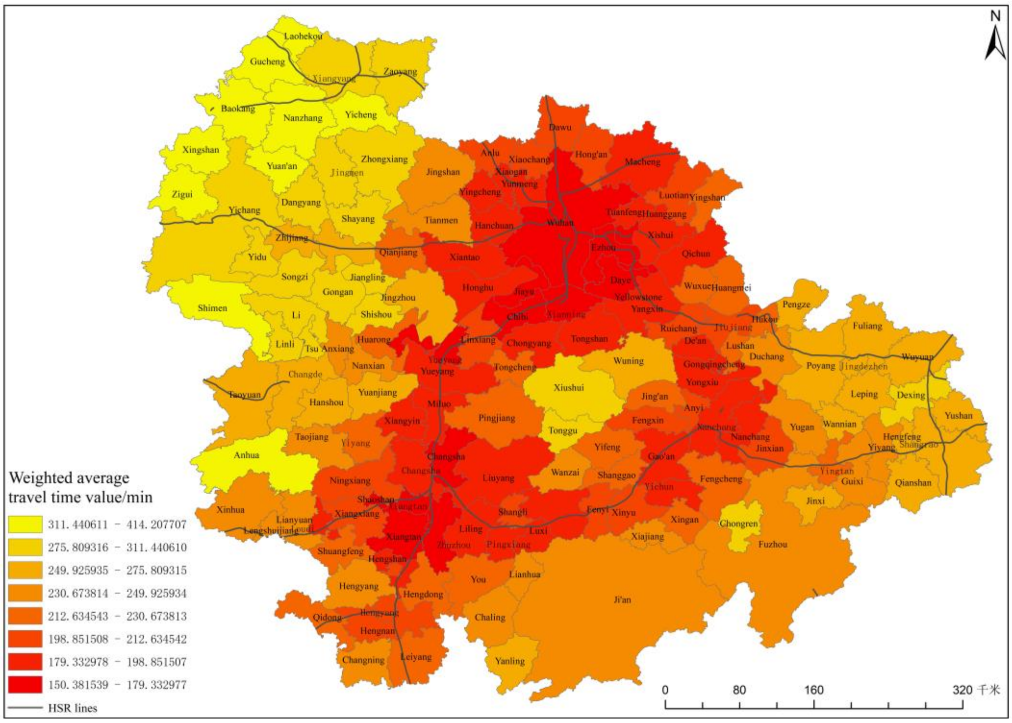

Figure 1. WATT distribution in high-speed rail mode

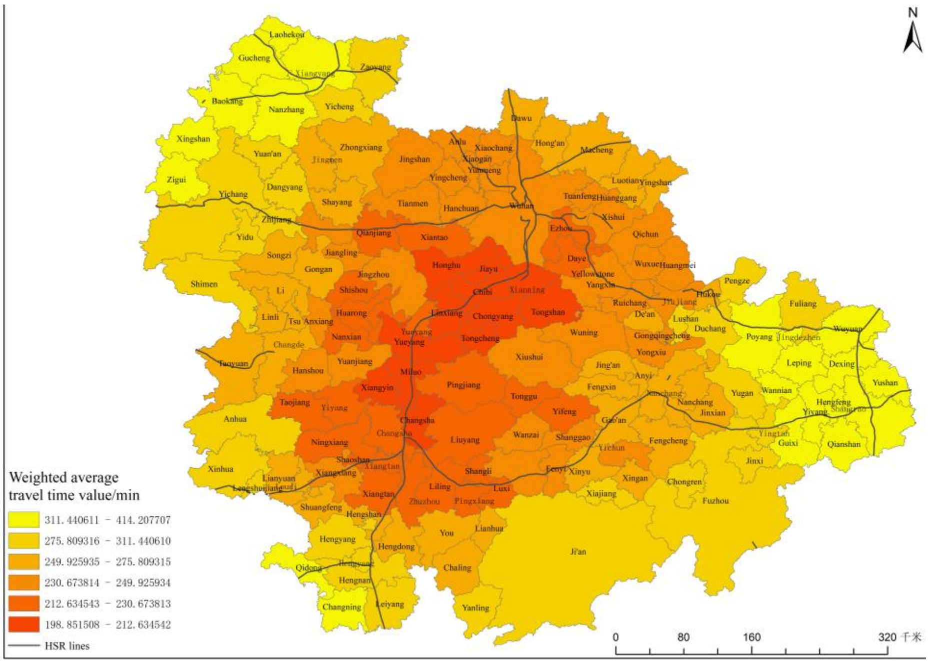

Figure 2. WATT distribution in driving mode

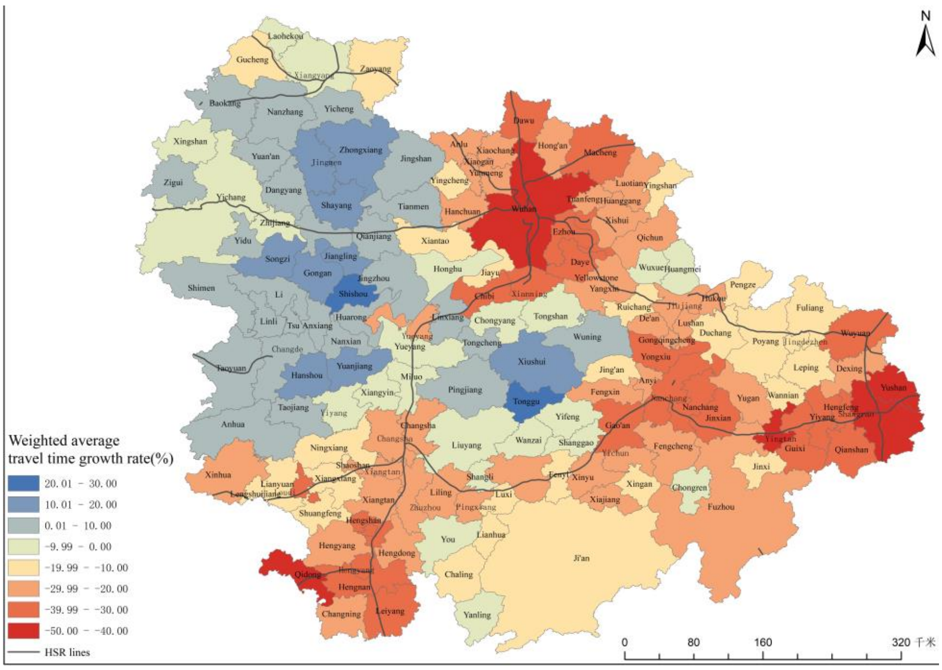

Figure 3. Growth rate of WATT

3.2 The construction of high-speed railways has boosted the economic potential of Triangle of Central China

The spatial distribution pattern and change trend of urban EP in urban agglomeration are shown in Figure 4, Figure 5 and Figure 6.

The construction of high-speed rail has improved the EP of the city. The total average EP of the city is 238.86 when driving and 262.26 when taking high-speed rail, which is a relative increase of 9.80%.

There is a certain imbalance in the improvement of the EP of different cities by high-speed rail construction. 71.24% of the cities' EP has been improved, and Shangrao City has the largest improvement, reaching 51.78%, while 28.76% of the cities have slightly decreased due to the underdeveloped high-speed rail network. Among them, Tonggu County, for example, is located in the circular high accessibility region composed of three provincial capitals and the high-speed railway line, which is affected by the siphon effect and has the largest reduction.

Under the driving mode, the high-potential regions spread out from the capital cities of Wuhan, Changsha and Nanchang. On the whole, the EP of the central region of the urban agglomeration is higher, while that of the marginal region is lower. In the case of high-speed railway, the high-potential areas spread out from Wuhan, Changsha, Nanchang and along the high-speed railway, forming a ring region. The areas with a large increase in EP are all corridor areas formed by high-speed railway lines, and the areas far from high-speed railway lines generally have a low improvement degree or even negative growth.

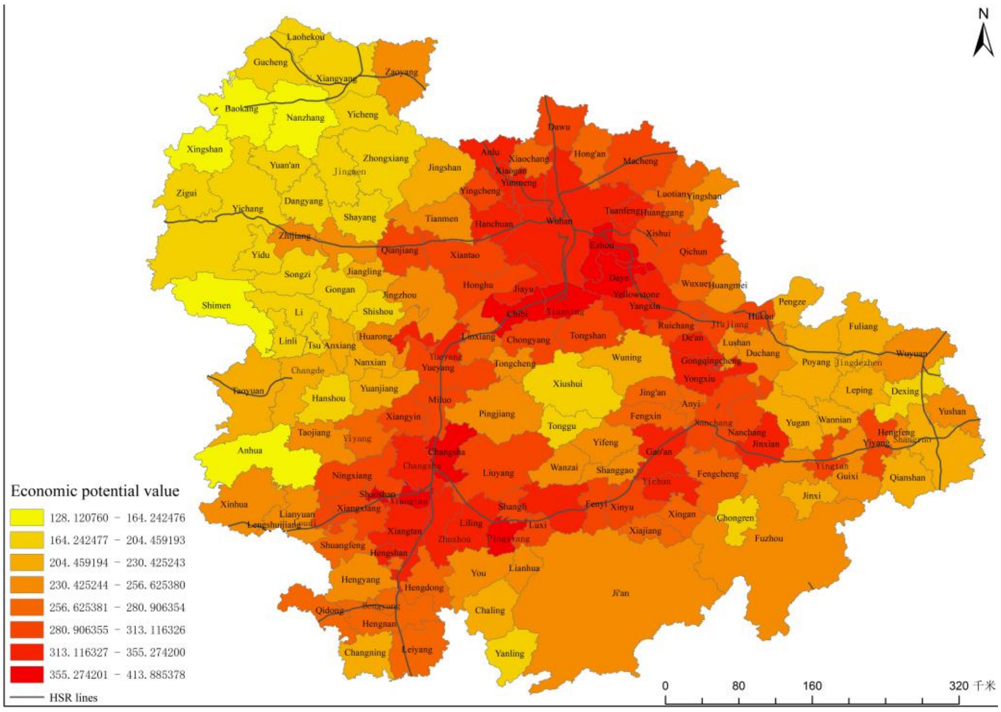

Figure 4. EP distribution in high-speed rail mode

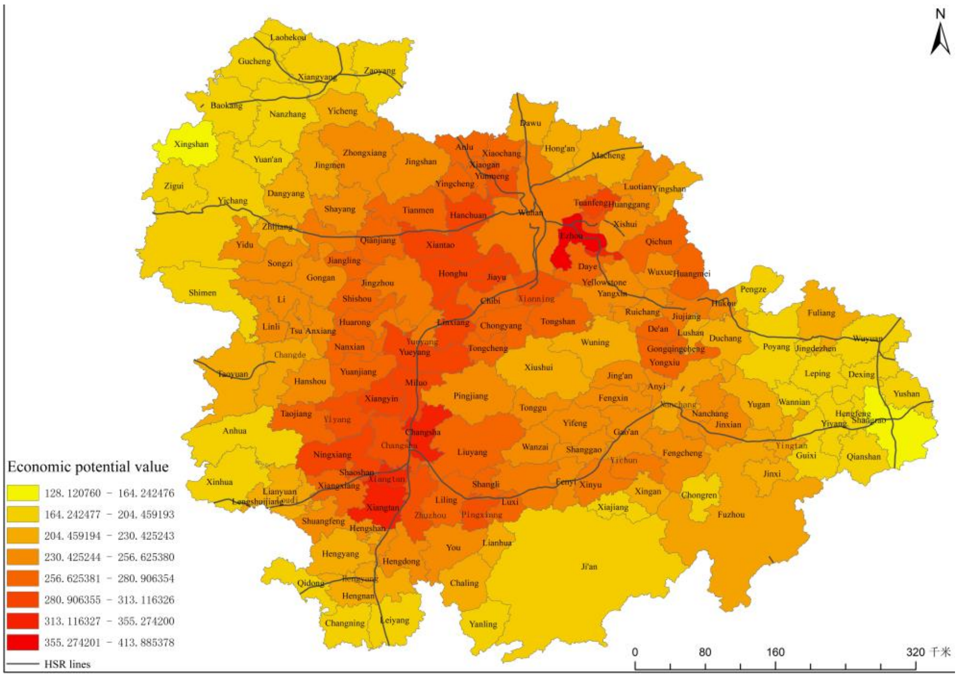

Figure 5. EP distribution in driving mode

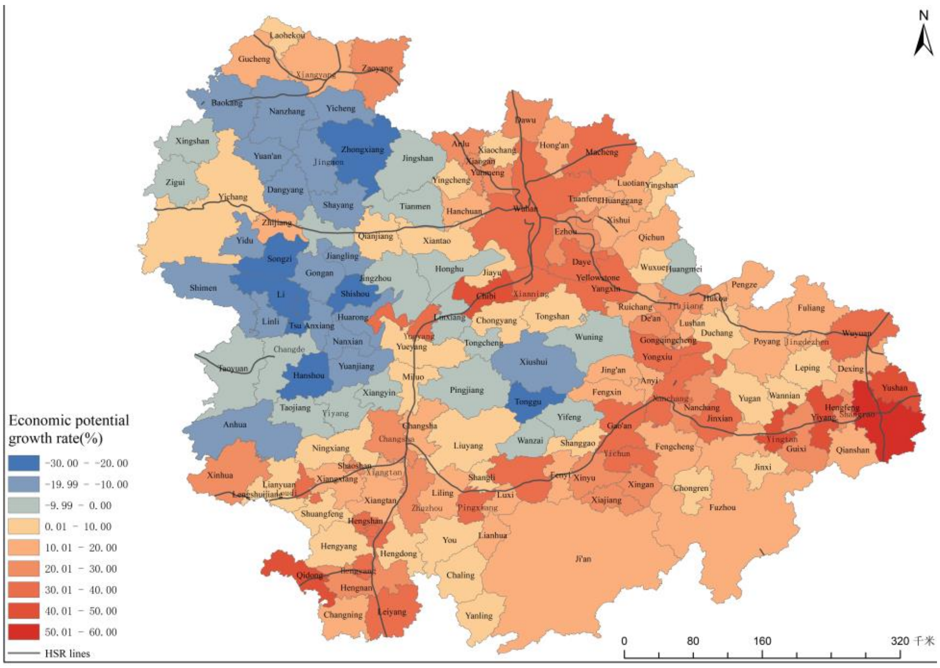

Figure 6. Growth rate of EP

3.3 The construction of high-speed rail has reshaped the accessibility pattern of Triangle of Central China

Based on the calculation results of WATT and EP, it can be seen that the accessibility level without high-speed rail is generally higher in the central region than in the surrounding areas, and higher in big cities than in small cities. with Wuhan, Changsha and Nanchang as the peak centers of accessibility, the accessibility level decreases to the surrounding areas.

In the high-speed rail mode, the high accessibility area is centered around Wuhan, Changsha and Nanchang, and the accessibility level decreases as it spreads around. Meanwhile, the high accessibility area is centered around the corridor formed by the high-speed rail line, and the accessibility level decreases with the diffusion to both sides. The accessibility at the intersection of the high-speed rail line is higher, and the accessibility is lower when there is no high-speed rail. On the whole, the high accessibility area forms a triangular hollow ring structure with the three points of Wuhan, Changsha and Nanchang as the vertices and the high-speed rail line as the sides, and shapes the pattern with accessibility decreasing from the inner and outer sides with the hollow ring as the center.

3.4 The construction of high-speed rail has changed the spatial equity of accessibility of Triangle of Central China

The calculation results of coefficient of variation are shown in Table 1 and Table 2.

In general, the CV values calculated by WATT and EP increased by 33.067% and 20.194%, respectively, indicating that the construction of high-speed rail has aggravated the inequality of urban agglomeration in the middle reaches of the Yangtze River, and the former is more obvious.

From the perspective of provinces, the two CV values of the three provinces all increased by different ranges, and Hubei Province was the largest, Hunan Province was the second, and Jiangxi Province was the least, indicating that the differences within the three provinces were also widened, and the inequality of Hubei and Hunan province increased more sharply, and exceeded the overall level.

In addition, from the perspective of urban administrative level, the cities with both WATT and EP improved were selected. In terms of the proportion of improvement, 25 out of 31 prefecture-level cities were upgraded, accounting for 80.65%; 28 out of 40 county-level cities were upgraded, accounting for 70%; and 55 out of 82 counties were upgraded, accounting for 67.07%. This indicates that on the whole, prefecture-level cities benefit the most from the construction of high-speed railway, and the development of different levels of cities is uneven with the construction of high-speed railway.

Table 1. CV value of WATT

Area	**Driving mode**	**High-speed railway mode**	**Relative range of change (%)**
All	0.153	0.204	33.067
Hubei	0.133	0.258	93.699
Hunan	0.102	0.152	48.994
Jiangxi	0.147	0.173	17.951

Table 2. CV value of EP

Area	Driving mode	High-speed railway mode	Relative range of change (%)
All	0.163	0.196	20.194
Hubei	0.153	0.229	49.255
Hunan	0.122	0.164	34.340
Jiangxi	0.152	0.166	8.588

4. Conclusion

This paper takes 153 counties and cities in Triangle of Central China as the research object, and compares the two modes of self-driving and high-speed rail travel to explore the impact of high-speed rail construction on urban accessibility pattern and spatial equity. The main conclusions are as follows:

The construction of high-speed railway has significantly improved the accessibility level of Triangle of Central China. On the whole, compared with driving, the WATT of cities in high-speed rail mode is significantly shortened, and the EP is greatly improved. Based on the two indicators, the areas with a greater degree of accessibility improvement are mainly distributed in large cities (Wuhan, Changsha, Nanchang, etc.), small and medium-sized cities (Chibi City, Yushan County, etc.) where the high-speed rail line passes, the cities where the high-speed rail line intersections are located (Shangrao City, Hengyang City, etc.) and small and medium-sized cities around large cities (Macheng City, Hanchuan City, etc.). The accessibility level of a few cities with underdeveloped high-speed rail network (Yichang, Jingmen, etc.) is slightly lower.

The construction of high-speed rail has reshaped the accessibility pattern of urban agglomerations in the middle reaches of the Yangtze River. Under the driving mode, the accessibility level of Triangle of Central China is generally higher than that in the surrounding areas, and the accessibility level of large cities is higher than that of small and medium-sized cities. Wuhan, Changsha and Nanchang are the high accessibility regional centers, and the accessibility decreases with the concentric circle diffusion. And in the high-speed rail mode, the high accessibility areas are concentrated in the corridors formed along the high-speed rail and near the capital cities of Wuhan, Changsha and Nanchang, and the accessibility level decreases from the center of the corridor to both sides, and decreases from the center of the three provincial capital cities to the periphery. The accessibility of the high-speed rail line intersection is higher, and the accessibility is lower when there is no high-speed rail. The high accessibility area presents a triangular hollow ring structure with Wuhan, Changsha and Nanchang as the vertices and the high-speed rail line as the side.

The construction of high-speed railway has strengthened the spatial inequity of accessibility in urban agglomerations in the middle reaches of the Yangtze River. The coefficients of variation calculated from the WATT and EP indicate that the spatial equity of the accessibility pattern of urban agglomerations in the middle reaches of the Yangtze River is significantly reduced after the construction of high-speed railway. From the perspective of provinces, due to the influence of high-speed railway construction, Hubei Province has the largest increase in urban inequality, and the spatial inequality of Hubei Province is far more than that of the other two provinces. In addition, from the perspective of urban administrative level, the prefecture-level cities in the middle reaches of the Yangtze River urban agglomeration benefit the most from the construction of high-speed rail, which is higher than the county-level cities and counties.

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