Analysis of Railway Network Accessibility in the Yangtze River Delta Urban Agglomeration Based on Space Syntax

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Abstract. The study abstracts the 26 main cities of urban agglomeration in Yangtze River Delta as convex space, and constructs a convex drawing based on the passenger railway network of 2008, 2018, and 2030 in Yangtze River Delta with Depthmap. After calculating the network integration and intelligibility, the relationship between the development of the railway network and the spatial structure change of urban agglomeration in the Yangtze River Delta are analysed and it finds that: (1) The development of the ordinary railway network is relatively slow and uncoordinated, while the high-speed railway network is developing rapidly and co-ordinately. (2) The spatial layout of railway network accessibility develops from the circle structure to the point-axis structure, and then to the multi-core structure. As a whole, the overall network development becomes increasingly mature and balanced, but the small-scale networks of local area become more differentiated. (3) As the development of multiple cores, the network accessibility has changed from low-level equilibrium period to an unbalanced period and then to a high-level equilibrium period.

1. Introduction
With the proposal of “13th plan of five-year national development” and the promotion of new-type urbanization, China's urban development has begun to enter a transitional stage, focusing on improving the quality of urbanization. Among them, the development of urban agglomerations plays an important role in the development of Chinese cities. On May 11, 2016, the executive meeting of State Council adopted the “Yangtze River Delta Urban Agglomeration Development Plan”. Compared with the 2010, not only the eight cities of Anhui have been included in the urban agglomeration of Yangtze River Delta officially, but also a series of adjustments have been made in terms of spatial pattern, infrastructure construction and industrial development.

At the same time, with the development of China's high-speed railway (HSR), the railway network, as the main artery, advances the inter-regional flow in talents and information, driving related industries transferred from developed regions to underdeveloped regions. Therefore, the railway network plays an increasingly significant role in the development of urban agglomerations.

2. Literature review
Large-scale high-speed railway (HSR) networks have a huge impact on urban accessibility and the city network, and a few studies have focused on this.

Since 1959, Hansen first proposed the concept of “accessibility” and used the gravity method to study the relationship between accessibility and land use relations [1]. There are many researches on accessibility in China and abroad, including urban and regional network analysis, transportation and
land use. At present, the methods of the railway network accessibility evaluation are various: distance-based measurement, such as various travel time/distance models [2]-[4], time matrix [5]; cumulative opportunity method, through the accumulation of time and distance to indicate accessibility, such as hour economic circle of central cities [6]; gravity method, combined with socio-economic and other factors, such as gravity model [7], economic potential [8]; topological metrics, analysis of spatial accessibility from topological connectivity characteristics, such as P space [9], [10], space syntax [11], [12]. Of course, many accessibility models combine a variety of methods, such as models combined GIS with gravity method and travel time to build indicators [13], multi-model analysis [14], [15], there are also some comprehensive analysis based on train schedules [16], [17]. Among all these models, the topological metric models are relatively advantageous in analysing the regional network relationship than other methods because this method focuses on studying the connection relationship between points.

In 2017, Liang Yu et al. applied the spatial syntax model at the macro scale with the 2007, 2016 and 2030 data of the Chinese railway and highway network [18]. In 2015, Liu Chengliang et al. quantitatively analysed the spatial accessibility evolution of urban and rural road network development with the road data of Wuhan Metropolitan area from 1989 to 2010 [14]. In 2018, Gu Hengyu et al. based on the method of space syntax and spatial autocorrelation, analysed the highway transportation network of the urban agglomeration in mid-stream of Yangtze River in terms of the overall and local road network, space collaborative evaluation, etc [19].

However, most of the spatial-syntax-based accessibility studies are on the foundation of the axis model for network analysis, lacking analysis about network nodes. Secondly, the accessibility analysis process usually only considers the spatial topological relationship alone.

Therefore, this paper applies the convex model, focusing on the node cities in the regional railway network. According to the passenger railway network of the Yangtze River Delta in 2008, 2018 and 2030, the spatial structure changes of the Yangtze River Delta Urban Agglomeration are quantitatively analysed. Integration and intelligibility are calculated to study the temporal and spatial changes on the accessibility of lines and nodes. Finally, combined with the development of the region, the driving mechanism of accessibility changes is speculated.

![Figure 1. Topology diagram of the Yangtze River Delta railway network in 2008, 2018 and 2030.](image)

3. Data source

The railway network data of the Yangtze River Delta is collected from the map of the People’s Republic of China (railway transportation version) with the scale of 1:3500000 produced by the State Bureau of Surveying and Mapping in 2008, the map of China's railway transportation in 2014, and “the plan of the medium-term and long-term railway network (2016-2030)” of 1:8000000. It is modified and supplemented according to the relevant information on the 12306 website (https://www.12306.cn/) which is the main ticketing website in China, as well as the news post on the internet about the existing, under construction or planned railways.
According to the current situation map and plan of the railway network in 2008, 2018 and 2030, the topology map of the railway network in Yangtze River Delta in 2008, 2018 and 2030 (Fig. 1) can be constructed. In addition, the railway network is simplified to two different systems: with train operating speeds higher than 160km/h are listed in the high-speed rail network, and railways with operating speeds below 160km/h are included in the ordinary railway network.

4. Methodology
Space syntax was first proposed in the 1970s by Bill Hillier of the University of London's Bartlett School of Architecture. It abstracted the connection between one space and a neighbouring space into a “step”, in order to construct a topological network for analysis. At present, the following indicators of spatial syntax are mainly used in domestic transportation accessibility research.

| Indicator | Formula | Implement |
|-----------|---------|-----------|
| choice | The number of times the centre space appears on the shortest topology path from one point to another. | The global topological depth value calculated from a single point reflects the accessibility of the network. |
| Mean depth | \( MD_i = \frac{d_i}{n-1} \) | \( MD_i \) indicates the average depth value of the centre space \( i \) when the step size of the direct contact is 1, \( n \) indicates the number of spaces (including itself) connected to the centre space \( i \), \( d_i \) indicates the step sum of a certain centre space to each space. |
| Integration | \( RA_i = \frac{2(MD_i - 1)}{n-1} \) \( I_i = \frac{1}{RA_i} \) \( D_n = \frac{2n\left[\log_2\left(\frac{n+2}{3}\right) - 1\right] + 2}{(n-1)(n-2)} \) | An indicator to describe the extent to which a certain space of a system is concentrated or discrete with other spaces, including local integration and global integration. The global integration expresses the relationship between a centre space and all other spaces, and the local integration expresses the relationship between a centre space and other spaces within \( n \) steps. |
| Intelligibility | \( U = f\left(\frac{I_n}{I_N}\right) \) | In areas with higher intelligibility, the local network can be integrated into the global network, resulting in the multiplier effect of economic and social activities, leading to the diversity and complexity of spatial system functions. |
5. Network accessibility evolution

In each type of spectrogram (Fig. 2) and the interannual comparison table (Table 2, Table 3), the degree of choice and integration can reflect the accessibility of the net, where the global integration reflects the accessibility of the entire area, as the local integration degree represents the partial accessibility within the range of 3 or 5 steps. The intelligibility R=3, R=5 respectively represent the compatible relationship between the small-scale network and overall network, the medium-scale regional network and the overall network. The result shows that:

The development of the ordinary railway network from 2008 to 2030 is relatively slow and uncoordinated. The accessibility of the road network in small-scale network is enhanced, but accessibility and coordination degree of the overall network are reduced.

From the perspective of the large-scale network, the Wuhu-Xuancheng-Huzhou-Wuxi section maintains a high level of accessibility. From the perspective of the small-scale network, Hefei is an important regional hub for small-scale ordinary railway network. With the construction of ordinary railways, the importance of Huzhou and Xuancheng in the ordinary railway network is decreasing, while Anqing's is increasing.

![Figure 2. Spectral map of various types of railway networks.](image)

From 2008 to 2030, the high-speed railway (HSR) network has developed rapidly. The number of small-scale core network has increased. From a broad perspective, the core of the railway network migrated from the northwest to the southeast. Huzhou, Nanjing, and Hefei are regional hubs. In 2018, the high-speed railway with high accessibility is Nanjing-Hangzhou section which shares the record in 2030 with Chizhou-Hangzhou section of the Wuhang high-speed railway.

| Table 2. Comparison of spatial characteristic values of various types of railway networks. |
|---------------------------------------------------------------|
| **Type**          | **Ordinary Railway** | **HSR** |
|                  | 2008  | 2030  | 2018  | 2030  |
| Choice           | 105.7 | 132.3 | 93.8  | 134.95|
| Global Integration | 0.96853 | 0.96773 | 0.83752 | 1.61772|
| Local Integration (R=3) | 1.41393 | 1.61358 | 1.24456 | 2.11611|
| Intelligibility (R=3) | 0.57348 | 0.14681 | 0.65145 | 0.67737|
| Intelligibility (R=5) | 0.94415 | 0.83159 | 0.7791 | 0.99409|

| Table 3. Comparison of eigenvalues of network space in the Yangtze River Delta |
|---------------------------------------------------------------|
| **Year** | 2008 | 2018 | 2030 |
| Choice | 100.811 | 196.844 | 177.506 |
| Global integration | 1.0576 | 1.18982 | 1.68638 |
| Local Integration (R=3) | 1.54419 | 1.727 | 2.33343 |
| Local Integration (R=5) | 1.18707 | 1.33304 | 1.73766 |
| Intelligibility (R=3) | 0.658129 | 0.654386 | 0.439458 |
| Intelligibility (R=5) | 0.825202 | 0.878779 | 0.988707 |
The growth of railway network of the Yangtze River Delta in 2008-2030 mainly depends on the development of HSR network (Fig. 2, Table 3). As the development of multiple cores, the network accessibility has changed from low-level equilibrium period to an unbalanced period and then to a high-level equilibrium period. High-level core of the region accessibility shifts from the east area to the south. The number of the cores in the small-scale region increases. The intelligibility between the small-scale(R=3) network and the overall network is continuously decreasing, while the figure of the medium-scale(R=5) network is relatively high, which means the medium-scale network has a high degree of coordination with the regional road network.

6. Spatial pattern of accessibility

![Figure 3. Evolution of the cities’ accessibility of the Yangtze River Delta in 2008-2030.](image)

Considering only the topological relationship (Fig. 3), the high accessibility area in 2008 concentrate on the northwestern part of the Yangtze River Delta, implying a diminishing tendency of accessibility from north to south with a clear circle structure.

The spatial layout in 2018 presents a new spatial pattern. The middle area of the Yangtze River Delta is the new core. The Hefei-Nanjing Railway and the Nanjing-Hangzhou Railway are the axis. The core and the axis radiate the surrounding areas.

The high accessibility area in 2030 return to the northwestern part of the Yangtze River Delta, but the difference is that the impact of the core is weakening as well as the tendency of the multi-cores is strengthening.

In summary, the spatial network accessibility layout of the Yangtze River Delta in 2008-2030 has evolved from a circle structure to a point axis structure, and then to multiple-core structure. Meanwhile, the regional accessibility has an increasingly balanced trend.

7. Driving mechanism

7.1. Geographic conditions

From the evolution of the accessibility spatial structure of the Yangtze River Delta over the years (Fig. 3), it can be found that the accessibility of coastal areas such as Yancheng, Nantong, Shanghai, Jiaxing, Ningbo and Zhoushan is relatively low, while the inland accessibility is high. This may be related to the unique geographical location of the coastal area. Since it faces the sea, it compresses the space for the development of land transportation. For example, Zhoushan, an island group, where there is no railway passing between 2008 and 2018. The situation is not improved until the opening of the Jinyuzhou Railway in 2030. Another example is Shanghai. Although its economic development is at first class, the position in the railway network is still only at the third and fourth echelons. However, waterway transportation in coastal areas has always occupied a large proportion in the entire transportation system, so it can make up for the disadvantage of land railway accessibility to a certain extent.
Secondly, according to the topographical distribution pattern of the Yangtze River Delta, the northwestern part of the Yangtze River Delta, represented by Hefei, has maintained relatively high accessibility, which is closely related to its relatively flat terrain and less hills. The accessibility level in Zhejiang has been at a low level and it is probably caused by the resource pattern of “much mountains and water, few field”. In areas with relatively flat terrain, the technical difficulty of railway construction is low, so it is easy to form a transportation hub.

7.2. Economic and technological development
According to railway development in recent years, we can find that the development of railway network mainly depends on the high-speed railway network, supplemented by the growth of ordinary railway network. High-speed railway has become the main force of railway transportation in the new era. Since 2008, when the first high-speed railway started operating, the development of high-speed railway technology has not been mature enough in the early stage, and still required a lot of practical exploration and progress. Therefore, the construction was relatively slow. After the technology has matured and improved, it will definitely bring the railway network quick increase.

Secondly, the transformation of national urbanization also has an important impact on the development of accessibility. The rapid urbanization characterized by rapid economic development in the early stage provides the necessary funds and technology for the development of high-speed rail network. The new urbanization characterized by comprehensive and stable development now requires a large amount of infrastructure construction and strengthens the relationship between the regions, which is bound to bring regional accessibility rapid growth.

7.3. Regional Planning
In 2010’s spatial planning of Yangtze River Delta Urban Agglomeration, Nanjing, Suzhou, Wuxi, Hangzhou and Ningbo will be the centre cities apart from Shanghai. In 2016’s planning, there are five metropolitan areas going to be developed. They are Nanjing metropolitan area (Nanjing, Zhenjiang, Yangzhou), Hangzhou metropolitan area (Hangzhou, Jiaxing, Huzhou, Shaoxing), Hefei metropolitan area (Hefei, Maanshan, Wuhu), Suzi Chang metropolitan area (Suzhou, Wuxi, Changzhou) and Ningbo metropolitan area (Ningbo, Zhoushan, Taizhou). This demonstrates the tendency of urbanization is from one city growth to region development, which is also showed in the changes in railway network.

According to the R=3 local integration in 2018, Hefei, Nanjing, Wuxi, Hangzhou, and Ningbo are at the centre of the highly accessibility or in the high-accessibility road section. However, R=3 local integration in 2030 depicts that the number of road sections with high integration is increasing, indicating the urbanization pattern from the central city to the metropolitan area, from “point” to “polygon”.

In 2018-2030, the accessibility of railway small-scale networks is improving, but the coordination with the overall network is declining. The medium-scale network and the overall network have a high degree of coordination, indicating that the links within the metropolitan area are constantly strengthening. The connections in the region depend on the metropolitan area on a medium scale.

The 2010 edition of the Yangtze River Delta plan strengthened the links between Jiangsu and Zhejiang regions, and fostered the Jiangsu-Zhejiang metropolitan area with Hangzhou, Ningbo, Nanjing and other cities as the core, thus making the R=5 local integration of railway transportation between Jiangsu and Zhejiang in the 2008-2018 Yangtze River Delta increasing. In 2016’s planning, Hefei metropolitan area is added in the Yangtze River Delta Urban Agglomeration, which, at the same time, is asked to pay more attention to coordinate with Jiangsu and Zhejiang. This change is also reflected the evolution in the accessibility spatial structure, especially in the R=5 local integration of the network in the Yangtze River Delta. In 2030, the accessibility of Hefei has increased significantly, and an obvious circle structure has been formed, reflecting the incubation process of the Hefei metropolitan area. Besides, we can also find that the Jiangsu-Zhejiang region has strengthened its connection with the Hefei metropolitan area through the Wuhan-Hangzhou high-speed railway and the Nanjing-Hefei high-speed railway.
8. Conclusion and discussion
This paper takes the Yangtze River Delta railway network as the research object, analysing the characteristics of the Yangtze River Delta railway network in three stages of 2008, 2018 and 2030 by using spatial syntax. And then the evolution characteristics of the Yangtze River Delta railway network are explored with the driving mechanism. Finally, the results show that:

- Lines in the middle of the network possess high accessibility, but as time goes by, the core of the high-level accessibility network moves southward. Besides, the development of the ordinary railway network is relatively slow and uncoordinated, while the HSR network develops rapidly and coordinately. As a whole, the overall network development becomes increasingly mature and balanced, but the small-scale networks of local area are distinctly differentiated.

- The spatial distribution of railway network accessibility develops from the circle structure to the point-axis structure, and then to the multi-core structure, and the accessibility of the region has changed from low-level equilibrium period to an unbalanced period and then to a high-level equilibrium period.

- Terrain is the base of accessibility distribution, and the economic and technological conditions are important factors in accessibility growth, while the regional spatial planning and construction of infrastructure are the significant means to change the spatial distribution of accessibility.

Combined the characteristics and driving mechanism of railway network evolution from 2008 to 2030; it is believed that the following points should be noted in the future regional development planning process:

- Enhancing the attractiveness of the cities which has high accessibility in network. It shows that the accessibility of Xuancheng and Huzhou has been maintained at a relatively high level, but these city economic development is not very outstanding, so how to make good use of transportation advantages to achieve rapid economic growth is a problem that needs to be consider in policy making.

- Coordinating the relationship between the ordinary railway network and the HSR network to achieve efficient operation of the overall railway network. Due to the development of the HSR network, the development of the ordinary railway network is slow and uncoordinated, but in the long run, the ordinary railway will still not be eliminated. Therefore, how to make full use of the existing ordinary railway to corporate with the HSR in the network is an important factor to achieve efficient operation of the overall network.

- Strengthening the links between the eastern and western area of the urban agglomeration. In 2030, the accessibility of eastern area in the urban agglomeration is relatively balanced, but in the western area, it presents a circle structure with a high level core——Hefei. Moreover, there is an evident gap between the western and eastern area, so how to strengthen the railway connection between the eastern and western part of the urban agglomeration should be paid attention to during the railway transportation planning.

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