

Transport Accessibility and Spatial Connections of Cities in the Guangdong-Hong Kong-Macao Greater Bay Area

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Abstract: Based on geographic information system (GIS) spatial analysis technology, the spatial pattern of raster grid transport accessibility for the Guangdong-Hong Kong-Macao Greater Bay area was studied and the states of spatial connectedness were simulated using highway passenger transport, railway passenger transport, port passenger transport and aviation passenger transport data. The result shows that transport accessibility within the Guangdong-Hong Kong-Macao Greater Bay area costs ‘one hour’ and the spatial distribution of accessibility in the area presents clear ‘core-periphery’ spatial characteristics, with Guangzhou, Foshan, Shenzhen constituting the core. The transport accessibility of Guangdong-Hong Kong-Macao is high. Average accessibility of urban nodes as measured by travel time is 0.99 h, and the areas accessible within 1.42 h occupy 79.14% of the total area. Most of the areas with the lowest accessibility are found in the peripheral area, with the worst accessibility being 4.73 h. Compared with the west-side cities, the economically developed east-side cities of the Guangdong-Hong Kong-Macao Greater Bay area have higher connectivity with roads, railways, ports, and aviation transport. Guangzhou, Foshan, Zhuhai, Shenzhen, Hong Kong and Macao are closely linked. The higher the accessibility, the closer the intercity connectedness.

Keywords: transport accessibility; urban spatial connection; Guangdong-Hong Kong-Macao Greater Bay Area; China

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1 Introduction

In the report of the 19th Chinese National Congress on the issues of Hong Kong and Macao, it was proposed that the Guangdong-Hong Kong-Macao Greater Bay Area should be given priority for development. The Guangdong-Hong Kong-Macao Greater Bay Area Initiative (also known as Greater Pearl River Delta Initiative) is an advanced version of the Pearl River Delta Initiative, which concentrated primarily on the mainland Chinese part of the region. In contrast to its predecessor, the Bay Area Initiative intends to highlight the region’s

role and aspiration in the global economic supply chain to rival other bay area regions such as San Francisco or Tokyo, and emphasizes the inclusion of the Special Administrative Regions of Hong Kong and Macao. In addition to these two cities, the city cluster includes nine Chinese cities in the Pearl River Delta (Shenzhen, Guangzhou, Zhuhai, Zhaoqing, Dongguan, Huizhou, Foshan, Zhongshan, Jiangmen) (Table 1). Hong Kong and Guangzhou were rated as first-tier cities in the world by GaWC, the world’s most authoritative urban research institution, and Shenzhen was rated as a second-tier city (GaWC, 2016). A bay area is a densely

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Table 1 Urban area, economy and population of the Guangdong-Hong Kong-Macao Greater Bay Area

Urban	Guangzhou	Shenzhen	Zhuhai	Foshan	Huizhou	Dongguan	Zhongshan	Jiangmen	Zhaoqing	Hong Kong	Macao
Area (km ²)	7434	1997	1711	3875	11599	2465	1783	9554	15006	1106	32.8
GDP (10 ⁸ yuan (RMB))	19547	19493	2226	8630	3412	6828	3203	2419	2084	21596	3017
Population (10 ⁶ persons)	14.04	11.91	1.68	7.46	4.78	8.26	3.23	4.54	4.08	7.34	0.65

Notes: China Statistical Abstract and Guangdong Statistical Yearbook, 2017

populated urban area with many gulfs and consisting of spatial elements such as powerful megalopolises and port clusters, as well as interconnected and efficient transport systems (Zhang, 2017). A bay area has an excellent natural ecological environment and a superior economic geographical location, with a dense population, a developed economy, a high degree of openness and many innovation resources (Deng, 2017). The best and most competitive urban agglomerations in the world are concentrated in coastal areas; the Tokyo Bay Area, the New York Bay Area and the San Francisco Bay Area are recognized as the three major bay areas in the world. The objective is to build the Guangdong-Hong Kong-Macao Greater Bay Area into the fourth largest bay area in the world and build a world-class urban agglomeration (Li, 2017; Peng, 2017).

Transport accessibility is an important driver of urban growth and key to the sustainable development of cities (Ford et al., 2015). Hansen (1959) first proposed the concept of accessibility and defined it as the opportunity to interact between different nodes in a transportation network. Researchers have offered different understandings of the notion of accessibility (Kim and Kwan, 2003; Kwan et al., 2003a; Geurs and van Wee, 2004; Chang and Lee, 2008; Cascetta, 2009; Vandenbulcke et al., 2009; Curtis and Scheurer, 2010; Páez et al., 2012; Van Wee, 2016). In general, there are three issues: how easy it is to travel (Weibull, 1976; Koenig, 1980; Geertman and Ritsema Van Eck, 1995; Yang and Song, 2004; Wixey et al., 2005); how much it costs to travel (Vickerman, 1974); and the intensity of space interactions (Shen, 1998; Kwan et al., 2003b). Geurs and Van Wee (2004) identified four types: accessibility of transport infrastructure, accessibility based on socioeconomic activities, accessibility based on individual needs, and utility function-based accessibility. Li et al. (2017) described two important concepts of accessibility, that is, attraction accessibility and the radiation accessibility. Van Wee (2016) focused on indicators of accessibility and evaluation. Accessibility is a pivotal element

because it may induce increases in land value and to recover the capital costs of a transport investment (Medda, 2012).

Scholars have offered different methods for the measurement of transport accessibility. Accessibility measures are reviewed using a broad range of relevant criteria, including theoretical basis, interpretability and communicability, and data requirements of those measures (Geurs and Van Wee, 2004). Since the 1990s, when GIS analysis technology began to be applied in the study of accessibility, the shortest space-time distance and topological operation has been able to be calculated more conveniently, and the enormous data on the micro-unit scale of operation has been possible (Mavoa et al., 2012; El-Geneidy et al., 2016). Both network and grid methods are used to calculate the shortest time distance, and the topological calculation can be carried out using the space syntax method (Johnson et al., 2017). Using GIS technology (Ford et al., 2015), network analysis (Cheng and Chen, 2015), grid analysis (Ahlström et al., 2011), topological analysis technology (Wang et al., 2017), shortest time distance and topological network values are used to measure various accessibility indicators (Gómez et al., 2018). Some scholars have analyzed accessibility using other methods. Hawas et al. (2016) presents an approach for accessibility categorization in areas where there are no extensive data available to run the conventional analyses. Duran-Fernandez and Santos (2014) introduced an empirical accessibility model for Mexico based on land transport infrastructure. The model assesses an attraction-accessibility measure derived from a gravity framework.

In terms of urban accessibility and spatial connection, some scholars have conducted empirical research from different perspectives. The emergence of new forms of transportation will also bring about significant changes in regional accessibility and spatial connectivity (Lau and Chiu, 2004; Velaga et al., 2012). The construction of high-speed railways has become an important driving

force for improving urban accessibility and promoting regional spatial development (Grengs et al., 2010), and it has important influence on the reconstruction of urban and regional spatial organization (Kim, 2000; Tong et al., 2015; Cheng et al., 2016). European scholars have calculated the changes in the spatial accessibility of the highways along the Spain-France border and studied their impact on the European region (Gutiérrez and Urbano, 1996; Gutiérrez et al., 1996). Scholars have quantitatively evaluated the impact of the evolution of the rapid transport infrastructure network planned for construction on regional accessibility and proved that rapid traffic network construction is conducive to improving the accessibility of the border areas (Zhang et al., 2016; Wu et al., 2017a; Guzman et al., 2017). At the same time, some scholars drew the conclusion that transport accessibility can improve the total economic linkages of urban agglomerations (Jiao et al., 2016; Wang et al., 2017). Based on structuration theory, the accessibility of an individual is regarded as the product of their travel coping behavior and social systems across time and space (Lau, 2006; Yang et al., 2017).

Researchers have studied transport accessibility in the Pearl River Delta. The opening of the Hong Kong-Zhuhai-Macao Bridge to enhance the transport accessibility of the Guangdong-Hong Kong-Macao Greater Bay Area, and the closer intercity spatial connection will accelerate the promotion of economic and regional integration (Hou and Li, 2011). Cao et al. (2017) explored the impact of the intercity rail transit system planning on the regional development based on an accessibility approach in the Pearl River Delta Region. Wu et al. (2017b) proposed a spatial impact model for the trans-strait fixed links in the Pearl River Delta and the results showed that the Hong Kong-Zhuhai-Macao Bridge and Shenzhen-Zhongshan Bridge greatly improve regional accessibility with a maximum decrease weighted average travel time of 1.3802 h and 0.4020 h, respectively. Song et al. (2016) focused on the characteristics of nightlife in urban villages, and attempted to identify the factors that influence the use of public spaces at night in the Pearl River Delta Region.

Many scholars have carried out more theoretical and empirical studies on the Pearl River Delta and the above transport accessibility and spatial connections provide useful inputs for constraint identification. However, it is evident there are very few studies directly related to the

spatial interaction and coordinated development of the urban agglomeration in the Guangdong-Hong Kong-Macao Greater Bay Area from the perspective of spatial structure and spatial connection of urban agglomerations. This paper attempts to explore the transport accessibility and spatial distribution relationship in the Guangdong-Hong Kong-Macao Greater Bay Area based on GIS spatial analysis technology. This study is an application of various GIS-based spatial analysis methodologies to understand the complex layers of the transportation infrastructure of one of the world's largest multicentric bay area conglomerates. The analysis of this study tries to give some suggestions to the government for the development of transportation infrastructure and economy in the future.

2 Methodology and Data

2.1 Study area

The research area for this study is the Guangdong-Hong Kong-Macao Greater Bay Area (114°47'–114°53'E, 21°50'–23°53'N) (Fig. 1). It includes 9 cities, Guangzhou, Shenzhen, Zhuhai, Foshan and Huizhou, Dongguan, Zhongshan, Jiangmen, and Zhaoqing, and 2 special administrative regions of Hong Kong and Macao. The land area is 56 000 km² and the area is densely paved (Fig. 2).

2.2 Data sources

The data used for this study comprises two parts: one part is sample data on regional transportation network, and the other part is data on highway passenger transport, railway, port and aviation passenger transport. Vector data of spatial administrative boundaries come from the 1 : 1 M-scale Topographic Database of the National Fundamental Geographic Information System of China (National Geomatics Center of China, 2017). The vector data of railways, highways, national roads, provincial roads, county roads and rural roads are extracted from the 2017 edition of the 1 : 1 M-scale Topographic Database of the National Fundamental Geographic Information System of China. The highway passenger transport data are from the Guangdong Provincial Highway Passenger Transportation Convenient Service Network (<http://ticket.gdcd.gov.cn/BaseSchedule.aspx>) and Ctrip Bus Tickets Reservation (<http://bus.ctrip.com/>). The railway passenger transport data are

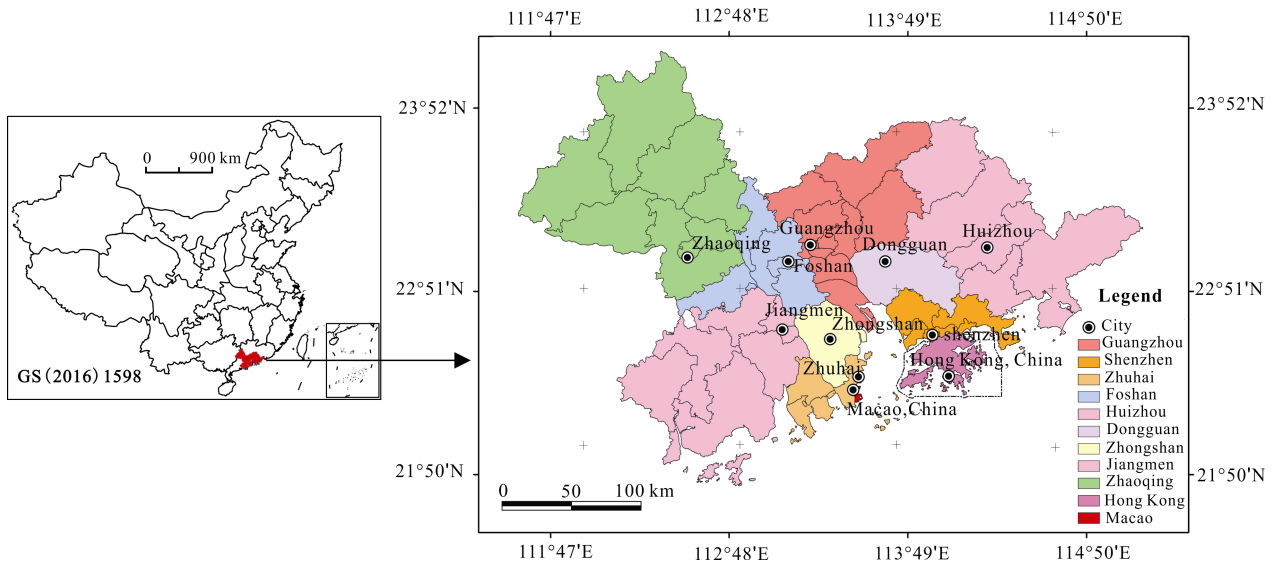


Fig. 1 Location of the Guangdong-Hong Kong-Macao Greater Bay Area

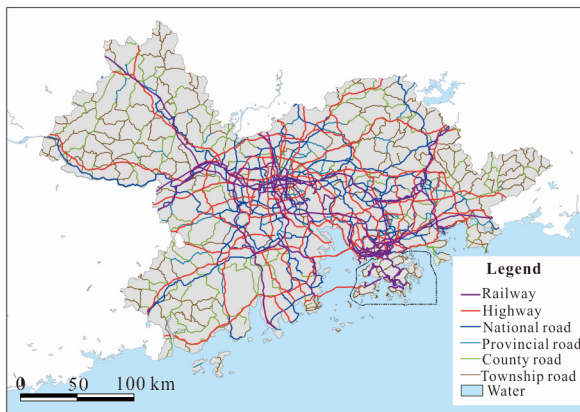


Fig. 2 The configuration of the road network in the Guangdong-Hong Kong-Macao Greater Bay Area

from the 12306 Ministry of Railways online booking website (<http://www.12306.cn>). The port passenger transport data are from Ctrip Ship Tickets Reservation (<http://bus.ctrip.com/ship/>). The aviation passenger transport data is from Ctrip Flights Tickets Reservation (<http://flights.ctrip.com/>). Roads, railways, ports, and air passenger data statistics can only involve passenger flights reserved on the Internet, and because of difficult access to information, the passenger flights that were not reserved on the Internet are therefore not included in the statistics.

2.3 Research methods

2.3.1 Cost weighted distance

County accessibility is defined as the average value of trip distance, starting from the county government to its

adjacent areas within a certain period of time (Wang et al., 2011). The cost weighted distance algorithm based on the spatial full coverage grid data can reflect the spatial accessibility of the region more precisely and accurately. The shortest path method is used to calculate the shortest weighted distance from each grid to a destination grid (or grid set) for the raster data. It is also called the cost weighted distance method. Its innovation lies in abstracting raster data into figure structure for calculation.

The principles are as follows. First, the certain accuracy orthogonal grid is used to divide the research area into raster graphs. Each attribute value of the grid represents its cost. This research defines the cost as the degree of time consumption level required through it. There are only eight other grids around each nonedge grid, with each grid center as a node, that can be abstracted into eight sides. The length value of the opposite side is defined as the following: if the side is connected with two directly horizontal or vertical adjacent grids, the length is the average of two grid values; if the side is connected diagonally adjacent to each other, it is $\sqrt{2}$ time as long as the average of two grids. The length of the side from the middle node to its left and right nodes is $(2+4)/2=3$ and $\sqrt{2}(4+1)/2=3.535$. Thus, each source is set as a single node, the cost value of the grid to which it belongs is set as 0. Then, the raster grids around each source and the source form n edges, namely, the calculation method of the shortest path is

built a complete graph structures, to get the total cost of each source node to the cumulative value.

2.3.2 Grid accessibility

We firstly conducted projection transformation of graphic data, which was based on the ArcGIS Desktop 10.2 software platform. Then, the data were hierarchically vectorized by referring unified space to the Mercator system. Data information was stored in a geodatabase.

By rasterizing and analyzing the research area and road data, the time accessibility results were obtained (Ahlström et al., 2011; Jiang et al., 2018). The specific processing steps were as follows. We classified the land surface types as land, road and water area, and set up time cost values for each of them. The assumptions included that all roads are not congested, that there is only one car and one route, and that there is no difference in the way each visitor travels. To improve computational accuracy as much as possible, this research selected the raster with an area of $100\text{ m} \times 100\text{ m}$, and set up the reference of time cost value as the minutes required to travel approximately 100 m on average. The equation was:

$$\text{cost}(\text{time cost}) = \frac{1}{v} \times 60 \quad (1)$$

where v represents setting speed of various types of spatial objects.

The objects were divided into railways, highways, national highways, provincial highways, county roads, township roads, water area, and land (land referred to continuous land areas except for roads). According to the ‘China Road Traffic Safety Law’ and the ‘Regulations on the implementation of China Road Traffic Safety Law’, the various restrictions on speed were used to determine the cost of various types of road transit time (Sun et al., 2017). Therefore, the speed was set to be 1 km/h on average. The cost values can be seen in Table 2.

According to cost value, the spatial objects mentioned above were abstracted from the basic geodatabase to establish vector features classes, including eight

layers referring to roads, water and land. A cost field was added to the attribute list and was assigned a corresponding cost value, after which vector data were converted to raster data. The values of the raster data were the cost value. The time cost raster of the spatial ground object, set as the cost layer, was then obtained by using the raster calculator to spatially superimpose raster data of time cost at each layer. Based on the map of 1 : 1 M-scale Topographic Database, detailed location points of 49 counties (county-level city, district) in the Guangdong-Hong Kong-Macao Greater Bay Area were selected to establish a point object layer. By executing the cost weighted command in Arc-Map, the cost weighted distance of each point was calculated based on the cost layer.

2.3.3 Moran's I Index

In statistics, Moran's I is a measure of spatial autocorrelation developed by Patrick Alfred Pierce Moran (Moran, 1950; Li et al., 2007). Spatial autocorrelation is characterized by a correlation in a signal among nearby locations in space. Moran's I was used to examine the relationships between similarity, dissimilarity (positive spatial correlation and negative spatial correlation) and mutual independence for adjacent areas. The expression of Moran's I index is as follows.

$$I = \frac{N}{W} \frac{\sum_{i=1}^i \sum_{j=1}^j w_{ij} (x_i - \bar{x})(x_j - \bar{x})}{\sum_{i=1}^i (x_i - \bar{x})^2} \quad (2)$$

where N is the number of spatial units indexed by i and j ; x is the variable of interest; \bar{x} is the mean of x ; w_{ij} is a matrix of spatial weights with zeroes on the diagonal from i to j ; and W is the sum of all w_{ij} . The significance levels of the results from the Global Moran's I test are analyzed by the z test.

$$Z(I) = \frac{I - E(I)}{\sqrt{\text{Var}(I)}} \quad (3)$$

Table 2 Main spatial factor time cost

Spatial objects	Railway	Highway	National highway	Provincial highway	County roads	Township roads	Water area	Land
Speed (km/h)	120	100	80	60	40	30	20	3
Time cost (min)	0.05	0.06	0.075	0.1	0.15	0.2	0.3	2

where $E(I)$ is the mathematical expectation and $Var(I)$ is the variance.

The value of Global Moran's I index is range from -1 to 1 . If the value of Global Moran's I index is close to 1 , it will show many regions with similar attribute values together, whereas if the value is closer to -1 , it will show many regions with dissimilar attribute values together. If the value of Global Moran's I index is close to 0 , the result will show all regions with the attribute values distributed randomly.

2.3.4 Getis-Ord index

The Getis-Ord index is calculated with respect to a specified threshold distance (defined by the user) rather than to an inverse distance, as with the Moran's I (Getis and Ord, 1996; Fischer and Wang, 2011). The Global G statistic computes a single statistic for the entire study area, while the G statistic is an indicator for local spatial autocorrelation for each data point. The expression of Getis-Ord index is as follows.

$$G = \frac{\sum_i \sum_{j \neq i} w_{ij} x_i x_j}{\sum_i \sum_{j \neq i} x_i x_j} \quad (4)$$

where x_i is the value of variable x at location i ; x_j is the value of variable x at location j ; w_{ij} is the elements of the weight matrix. The significance levels of the results from the Getis-Ord index test are analyzed by the z test.

$$Z(G) = \frac{I - E(G)}{\sqrt{Var(G)}} \quad (5)$$

where $E(G)$ is the mathematical expectation and $Var(G)$ is the variance.

The positive $Z(G)$ indicates that there is a high concentration, and the negative $Z(G)$ indicates that there is a low concentration.

2.3.5 O-D network

This research adopts the method of GIS spatial analysis based on an O-D network. An O-D contact network links two central cities together by using certain transportation to form a space contact O-D path in a certain space within the region. The two central cities are the starting points of the contact path (Origin) and end (Destination) (Yang et al., 2017). Central cities within the region are intertwined by different transportation modes between many spaces and communicate with each other forming a network of O-D Contact network

(O-D network for short) (Wang et al., 2016).

The specific operation method is as follows. First, GIS network analysis of the Network Analyst tool O-D cost matrix analysis capabilities is applied to establish the Guangdong-Hong Kong-Macao Greater Bay Area above the level of the central city above the shortest path of contact between the two centers, that is, the interactive space between the two cities Contact connection and the establishment of O-D network for the space contact path is $11 \times 10 = 110$. Then, the original data of road, rail, port and aviation is used to link it.

3 Results and Analyses

3.1 Transport accessibility in the Guangdong-Hong Kong-Macao Greater Bay Area

3.1.1 Transport accessibility distributed in a 'core-periphery' spatial pattern

Given the spatial distribution of accessibility, there are clear spatial differences in the Guangdong-Hong Kong-Macao Greater Bay Area, which presents a 'core-periphery' distribution (Fig. 3). The main traffic roads along the strip in Guangzhou, Foshan, and Shenzhen are the core of the optimal regional accessibility, while the accessibility of the peripheral region is at a lower level. With the accelerating construction of cross-border infrastructures such as the Hong Kong-Zhuhai-Macao Bridge and the Shenzhen-Zhongshan Bridge, the accessibility of Zhuhai and Zhongshan on the west coast of the Pearl River Estuary is at a high level. There is poorer accessibility in the eastern and western wings of the region, and the accessibility of Huizhou in the east is better than that of Zhaoqing and Jiangmen in the west. As seen from Fig. 3, the accessibility of the core area of Guangzhou-Foshan is at a relatively high level. The accessibility of the core area of Shenzhen-Dongguan-Huizhou and the Zhuhai-Zhongshan, in contract, is still relatively low. In addition, low accessibility exists in the peripheral areas, including Taishan of Jiangmen, Duanzhou of Zhaoqing, Huidong and Boluo of Huizhou, and Zengcheng and Conghua of Guangzhou.

3.1.2 Transport accessibility overall is at a high level

We used the trip distance of the county (county-level city, district) within 6 time segments of 0.47 h, 0.95 h, 1.42 h, 1.89 h, 2.36 h and 4.73 h, and statistics of each grade city area to determine the proportion of the whole area to represent the overall transportation accessibility value (Fig. 4). From the distribution of time accessibility

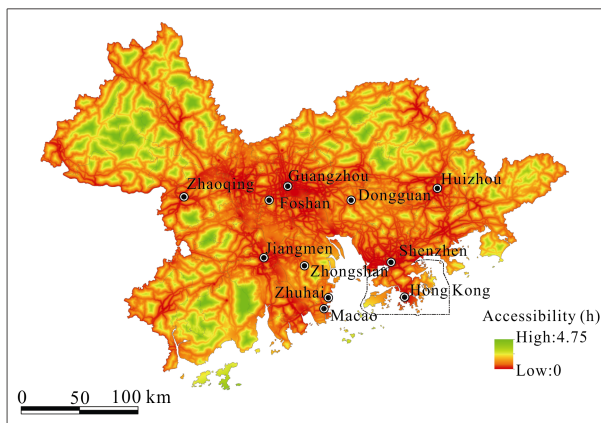


Fig. 3 Transport accessibility in the Guangdong-Hong Kong-Macao Greater Bay Area

period, the maximum accessibility reaches 4.73 h, the average accessibility is 0.99 h, and the coefficient of variation is 0.63. Observing the cumulative distribution of accessibility values, it can be found that the area within the accessibility value of 1.42 h accounts for 79.14% of the total area. Among them, accessibility accounts for 18.90% in the period of 0–0.47 h and accounts for 37.79% in the period of 0.47–0.95 h. Correspondingly, the areas with relatively poor urban accessibility are the least distributed, while the areas above 2.36 h occupied only 0.04% of the total area. This shows that the accessibility of the Guangdong-Hong Kong-Macao Greater Bay Area is generally at a relatively high level.

3.1.3 Accessibility of the counties (county-level, district) appears to be high in the middle and low at both ends

To grasp the overall accessibility of different cities in the Guangdong-Hong Kong-Macao Greater Bay Area,

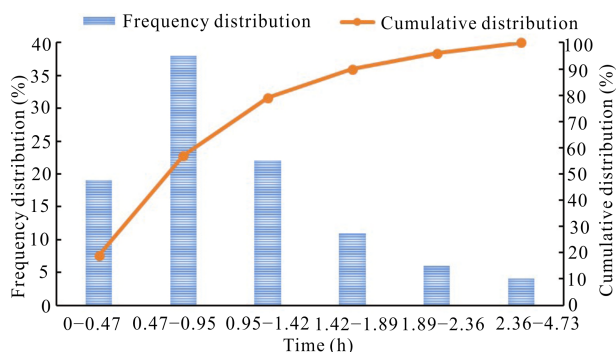


Fig. 4 Frequency distribution and cumulative frequency of transport accessibility in the Guangdong-Hong Kong-Macao Greater Bay Area

the overall accessibility of administrative units was analyzed. The accessibility level of the entire administrative unit was represented by means of the average grid accessibility in county (county-level, district) administrative units. After that, we classified the county (county-level, district) accessibility value into 5 classes with the method of Natural Breaks (Fig. 5).

Generally, the accessibility of the counties (county-level, district) reveals that both ends are low, and the middle is high. Specifically, the highly accessible areas are located in the middle part of the Guangdong-Hong Kong-Macao Greater Bay Area, including the districts of Yuexiu, Tianhe, Liwan, Haizhu, Panyu in Guangzhou; the districts of Nanshan, Futian, Luohu and Yantian in Shenzhen; the district of Jianghai in Jiangmen; and the Macao Special Administrative Region. The second most accessible region is located outside the most accessible region and includes Guangzhou (Baiyun, Huangpu and Nansha), Foshan City, Shenzhen (Bao'an and Longgang), Doumen in Zhuhai, and Jiangmen (Pengjiang and Jianghai). The areas with overall accessibility of 0.69–0.99 h are located at the periphery of the most accessible area and the second most accessible area, and include the Hong Kong Special Administrative Region, Huadu in Guangzhou, Dinghu in Zhaoqing, Dongguan and Huizhou (Huicheng and Huiyang), Zhongshan, and Zhuhai (Xiangzhou and Jinwan). It can be seen that the one-hour living circle in the bay area is concentrated in the middle part, while the least accessible areas are mainly located on the two sides of the Guangdong-Hong Kong-Macao Greater Bay Area, including Guangzhou (Conghua and Zengcheng), Huizhou (Boluo and Huidong),

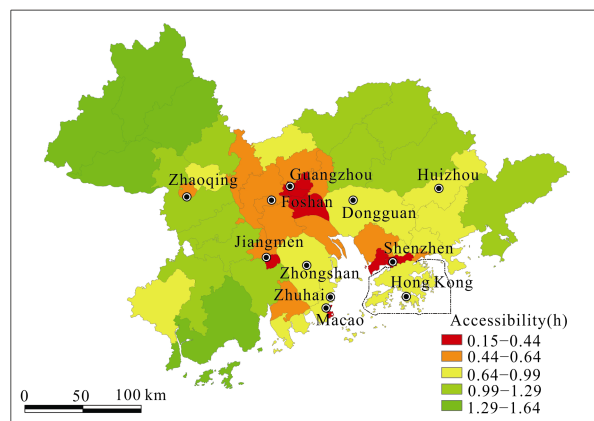


Fig. 5 Accessibility grade of cities at the county level in the Guangdong-Hong Kong-Macao Greater Bay Area

Zhaoqing (Gaoyao, Duanzhou and Sihui) and Jiangmen (Heshan and Kaiping). The least accessible area, with an overall accessibility greater than 1.32 h is the city of Taishan in Jiangmen.

3.1.4 A strong spatial agglomeration effect in the spatial pattern of transport accessibility

To determine reveal the spatial correlation of traffic accessibility in the Guangdong-Hong Kong-Macao Greater Bay Area, the Global Moran's I index and the local Getis-Ord index of the ESDA were used to characterize the accessibility agglomeration characteristics. Global autocorrelation statistics showed a Moran's I of 0.77, Z score of 24.66 which is greater than 2.58. Considering the calculation results, the Moran's I index is positive, the Z score is high, and the P value is low, indicating that there is a strong spatial agglomeration effect on the spatial pattern of traffic accessibility in the Guangdong-Hong Kong-Macao Greater Bay Area. Further analysis of the local Getis-Ord coefficient showed that the Z -scores are negative, and the test results are significant, showing that most parts of the Guangdong-Hong Kong-Macao Greater Bay Area are characterized by aggregate accessibility and low correlation agglomeration.

As seen from Fig. 6, the areas with cold accessibility spots are mostly in downtown Guangzhou, Foshan, Zhongshan, Jiangmen and Zhuhai. The accessibility level suggests that these areas have a higher level of accessibility. The hot spots are located in the city of Enping, Taishan and Huidong, which indicates that the accessibility of the two wings of the Guangdong-Hong Kong-Macao Greater Bay Area is low.

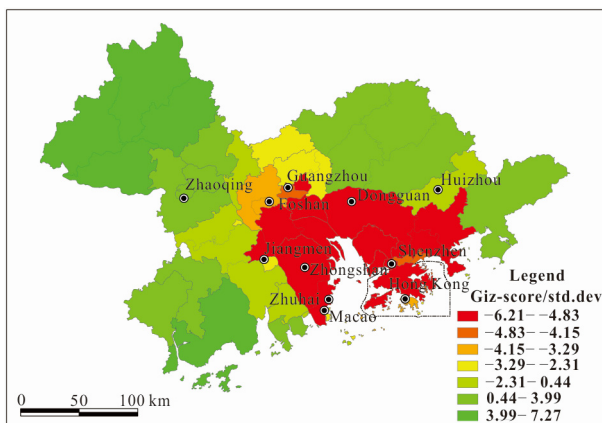


Fig. 6 Hot spots of accessibility at the county (county-level city, district) level

3.2 Urban spatial connections in the Guangdong-Hong Kong-Macao Greater Bay Area

3.2.1 Highway passenger transport

In terms of the total number of round trips (Fig. 7), Foshan ranked first with 9591 bus trips per day, followed by Zhuhai and Zhaoqing with 7672 and 7571 bus trips per day, respectively, while Shenzhen, Zhongshan, Guangzhou, Huizhou, Dongguan and Hong Kong followed behind. In terms of the dispatch of passenger transports from all cities in the Guangdong-Hong Kong-Macao Greater Bay Area, Shenzhen, Zhuhai, Foshan and Zhaoqing issued the most trips, while Guangzhou, Zhongshan, Huizhou and Dongguan took second place, and Jiangmen and Hong Kong issued the fewest trips. From the comparison of the departure and arrival number of the buses in single city, it was typical for Guangzhou and Dongguan for the number of arrival buses to be much larger than the departure buses, while Foshan, Zhaoqing, Huizhou exhibited the opposite pattern. In addition, the number of arrival buses was similar to the number of departure buses in Shenzhen, Zhongshan, Jiangmen, and Hong Kong.

In terms of the total number of arrivals, Guangzhou, Shenzhen and Dongguan took the lead and were followed by Zhongshan and Foshan. Zhuhai, Huizhou, Hong Kong, Jiangmen and Zhaoqing had fewer arrivals, while Macao had the least. Because the main links between Hong Kong and Macao with other cities were tourism and the procedure of customs was complicated, were fewer arrival buses. Guangzhou, Shenzhen and Dongguan had the highest number of passenger arrivals

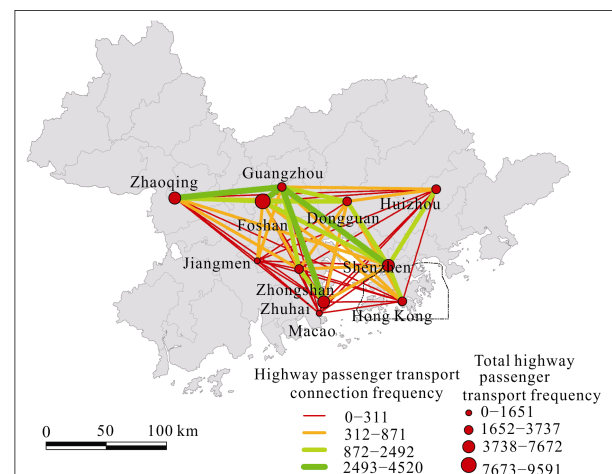


Fig. 7 Spatial distribution of the Guangdong-Hong Kong-Macao Greater Bay Area's highway passenger transport connections

because of their relatively high level of economic development, high population density and close links with other cities in the Guangdong-Hong Kong-Macao Greater Bay Area.

As seen from the arrivals in individual cities in O-D (Fig. 7), the cities that are most closely linked to Guangzhou were Zhaoqing, Zhuhai, Foshan and Shenzhen, followed by Zhongshan, Dongguan and Huizhou. Hong Kong, Macao, and Jiangmen, are more weakly linked. Similarly, cities that are closely linked to Shenzhen are Foshan, Hong Kong and Huizhou. In terms of the number of arrivals in Zhuhai, cities are relatively average, and there is less movement of passengers, which is related to the low level of economic development and population density in Zhuhai. Zhongshan was more closely linked with Zhuhai and Foshan, mainly due to economic development and geographical proximity. The number of daily buses from Hong Kong to Foshan is the most compared to other cities. For Huizhou, most buses arrived from Shenzhen due to geographical proximity. For destinations, the arrival of buses is least in Zhaoqing, Jiangmen, and Hong Kong.

As seen from Fig. 7, the highway transport facilities between cities in the Guangdong-Hong Kong-Macao Greater Bay Area are highly connected and closely linked. From the intercity O-D contact data, the highway passenger transport links between cities show a clear economic and population orientation, as well as distance attenuation. Therefore, the traffic links between cities are first proportional to the level of population and economic development and then inversely proportional to the distance between them. However, due to the different political systems between Hong Kong and Macao and Mainland China, economic ties have some obstacles. Passenger transport links are mainly dominated by tourist transport. Therefore, the passenger transport links with other cities in Guangdong-Hong Kong-Macao Greater Bay Area are relatively weaker. Hong Kong and Macao has fewer passenger transport links with other cities in Guangdong-Hong Kong-Macao Greater Bay Area due to the economic obstacles caused by the different political systems between Hong Kong, Macao and mainland China. Hence, the passenger transport is dominated by tourist transport.

3.2.2 Railway passenger transport

In terms of train journey frequency (Fig. 8), the provincial capital of Guangdong, Guangzhou was far ahead of

other cities, with 584 trips per day. Next, came the cities of Shenzhen and Dongguan with 471 trips a day and 314 trips a day, respectively. It can be seen from Fig. 8 that in Guangzhou, Shenzhen and Dongguan, the railway traffic links and the contact are closer and more frequent than between other cities. Due to the proximity of Guangzhou, Foshan appears to have a ‘shielding effect’; many train trips directly to Guangzhou and by other means of transport arrived in Foshan.

Viewed from a city’s O-D, Guangzhou is the most closely linked by railway transport, with the top three cities being Shenzhen, Dongguan and Zhongshan, followed by Zhaoqing, Huizhou, Jiangmen and Foshan. Similarly, due to geographical constraints, there are a few rail links or no connections on northwestern and southern sides of many cities in the Guangdong-Hong Kong-Macao Greater Bay Area. For example, there are no rail links between Shenzhen and Jiangmen, Dongguan and Jiangmen and Zhongshan, and Huizhou and Jiangmen. Due to the low level of economic development among the cities on the western side of the Guangdong-Hong Kong-Macao Greater Bay Area, their close geographic distance influences that there are also fewer rail links between them. For each city’s departures and arrivals, the number of arrivals was less than the number of trips issued in Shenzhen City, and the number of arrivals was more than the number of departures in Huizhou and Zhongshan cities. The other cities have little difference between the arrivals and departure

As seen from Fig. 8, as a whole, there are obvious differences in the railway transport connectivity among cities in the Guangdong-Hong Kong-Macao Greater Bay

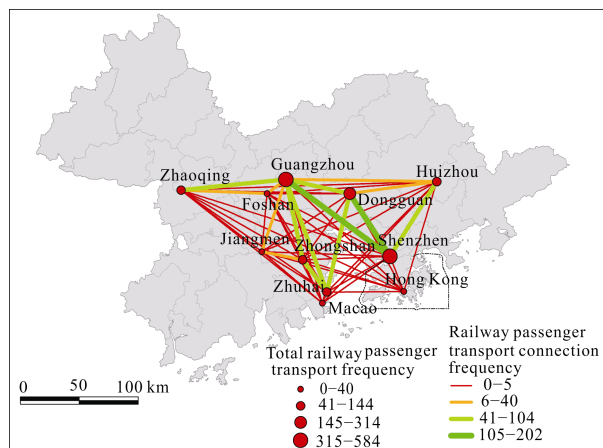


Fig. 8 Spatial distribution of the Guangdong-Hong Kong-Macao Greater Bay Area’s railway passenger transport connections

Area. Geographical factors and the level of economic development are the major factors affecting railway transport connectivity. Guangzhou, Shenzhen and Dongguan have relatively developed economies and are on the eastern side of the Guangdong-Hong Kong-Macao Greater Bay Area, which means their railway connections tend to be relatively close. The cities on the west side of the Guangdong-Hong Kong-Macao Greater Bay Area have lower levels of economic development than those on the eastern side and have poorer connectivity. The eastern and western cities have a low degree of rail transport connectivity because of the sea.

3.2.3 Port passenger transport

Among all of the cities in the Guangdong-Hong Kong-Macao Greater Bay Area, Hong Kong had the highest frequency of port passenger transport departures and arrivals, with 413, followed by Macao (335) and Shenzhen (190). Hong Kong (222) ranked first in departure routes. In arrival routes, Macao (195) ranked first and Hong Kong (191) second. In terms of regional port transport, Hong Kong is equipped with the best connectivity of infrastructure, followed by Macao, Shenzhen and Zhuhai.

Specifically, according to the spatial distribution of the Guangdong-Hong Kong-Macao Greater Bay Area's port passenger transport connections (Fig. 9), it can be seen that in terms of port connections, Hong Kong is the closest to Guangzhou. The cities with the top three contacts with Shenzhen are Macao, Hong Kong and Zhuhai, followed by Zhongshan with only Four trips per day to Shenzhen. Shenzhen and Hong Kong have the closest contact with Zhuhai. Shenzhen and Zhuhai have the highest level of connectedness. The only city that contacts with Foshan is Hong Kong. Huizhou does not have connections with other cities in this Area.

Huizhou Port consists of the East Malaysia, Tsuen Wan and Aotou. The goal is to build a regional logistics and distribution center, as well as the largest oil and gas chemical storage facilities in the Guangdong-Hong Kong-Macao Greater Bay Area. Because of its freight transport position, Huizhou does not connect with other cities. The only city that connects with Dongguan is Hong Kong. Hong Kong and Guangzhou are the only cities that are connected to Zhongshan. The city with the closest contact with Jiangmen is Hong Kong, Zhaoqing is not connected to other cities in the Area. Since 2012, Zhaoqing port passenger transport has been canceled.

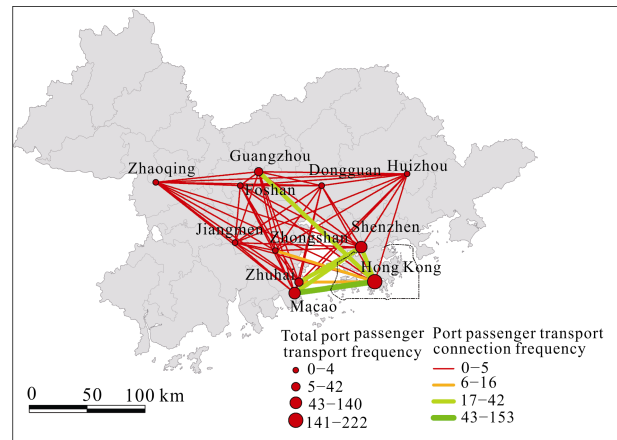


Fig. 9 Spatial distribution of the Guangdong-Hong Kong-Macao Greater Bay Area's port passenger transport connections

The most connected cities to Hong Kong are Macao, Shenzhen and Guangzhou, followed by Zhuhai and Zhongshan, and Dongguan and Jiangmen are the least connected. The cities that are most closely associated with Macao are Hong Kong and Shenzhen.

Huizhou and Zhaoqing for the same reason have no passenger transport connections with other cities for the same reason. In other cities, Guangzhou has nearly twice as many scheduled departures as scheduled arrivals, and Guangzhou only has contact with Hong Kong. Zhuhai, Shenzhen, Zhongshan and Hong Kong are more frequent arrivals than departures. Departures from Foshan and Macao are more frequent than arrivals. Departures from Dongguan and Jiangmen are the same as arrivals.

As seen in Fig. 9, there are obvious differences in port connectivity between cities in the Guangdong-Hong Kong-Macao Greater Bay Area. The total departures and arrivals of Hong Kong and Macao far exceed those of other cities, and Shenzhen and Zhuhai are also high. Hong Kong is geographically adjacent to Shenzhen and Macao is geographically adjacent to Zhuhai. In total, there are more trips in Macao, Hong Kong, Shenzhen and Zhuhai.

3.2.4 Aviation passenger transport

Seven cities in the Guangdong-Hong Kong-Macao Greater Bay Area have airports (Guangzhou Baiyun International Airport, Zhuhai Jinwan Airport, Shenzhen Bao'an International Airport, Foshan Shadi Airport, Huizhou Pingtan Airport, Hong Kong International Airport and Macao International Airport). Among the cities with regional routes, the total number of flights to

Guangzhou is 221, ranking first, followed by Hong Kong and Macao. Guangzhou ranks first in departure flights, with Hong Kong ranking first in arrival flights with Zhuhai second. In terms of regional flights, the best-connected city is Guangzhou, followed by Hong Kong, Macao and Zhuhai. Foshan Airport is a joint military and civilian airport, with China United Airlines and China Eastern Airlines navigation companies, but we were unable to obtain passenger transport contact data. There were 135 domestic flights departing from Shenzhen Airport and 132 domestic arrivals, but within the Guangdong-Hong Kong-Macao Greater Bay Area, there were only 8 daily departures from Guangzhou to Shenzhen, so the connectivity of flight facilities is comparatively low.

Specifically, in terms of passenger transport connections (Fig. 10), it can be seen that the closest relationship to Guangzhou is Macao, followed by Hong Kong. Shenzhen connects the most closely with Guangzhou. Hong Kong connects the most closely with Zhuhai, followed by Macao. The closest contact with Huizhou is Guangzhou. Guangzhou is the closest city to Hong Kong and Macao, followed by Zhuhai. Guangzhou has the same number of departures as arrivals and is primary aviation hub in the Guangdong-Hong Kong-Macao Greater Bay Area. In Shenzhen and Huizhou, there are no departure flights, only arrival flights. Zhuhai and Hong Kong have more arrivals than departures, while Macao has more departures than arrivals.

As seen from Fig. 10, there are obvious differences in the degree of aviation connectivity between cities in the Guangdong-Hong Kong-Macao Greater Bay Area. The

accessibility of Hong Kong and Macao mainly affects the degree of air connectivity among cities. Guangzhou and Hong Kong have far more total flights than other cities. Airports and ports are similar in terms of passenger connectivity.

4 Discussion and Conclusions

4.1 Discussion

Transport infrastructure development has direct impacts on regional accessibility, as indicated by reduction in travel time or strengthen spatial connections to increase in economic and population potentials. Guangzhou and Shenzhen has remained its regional dominance as two hub in the regional transport network, in particular the highway and railway road network. With the continuous improvement of transportation infrastructure, accessibility is getting better and better. As exemplified by the finding that average accessibility of urban nodes as measured by travel time is 0.99 h, and the areas that are accessible within 1.42 h occupy 79.14% of the total area. Accessibility accounted for 18.90% in the period of 0–0.47 h. Most of the areas with the lowest accessibility are found in the peripheral area, with the worst accessibility reaching 4.73 h.

The spatial pattern of connections in the Guangdong-Hong Kong-Macao Greater Bay Area has been conditioned by variations in accessibility. Compared with the west-side cities, the economically developed east-side cities of the Guangdong-Hong Kong-Macao Greater Bay Area have higher connectivity with roads, railways, ports, aviation transport and Guangzhou, Foshan, Zhuhai, Shenzhen, Hong Kong and Macao are the most closely linked. The level of economic development and administrative functions of the city in the Guangdong-Hong Kong-Macao Greater Bay Area determines the level of connectivity with other intercity transport facilities. Economic development level and geographical barriers jointly determine the connectivity of intercity railway transport facilities. The west side of the Guangdong-Hong Kong-Macao Greater Bay Area is, in terms of economic development, relatively weak compared to the east side. Meanwhile, due to geographical factors, the transport connectivity of intercity railway is relatively low. Because of its geographical position, the Eastern Wing has the most convenient transport connection with Hong Kong and Macao. Transport convenience facilitated the four municipalities there, Shenzhen,

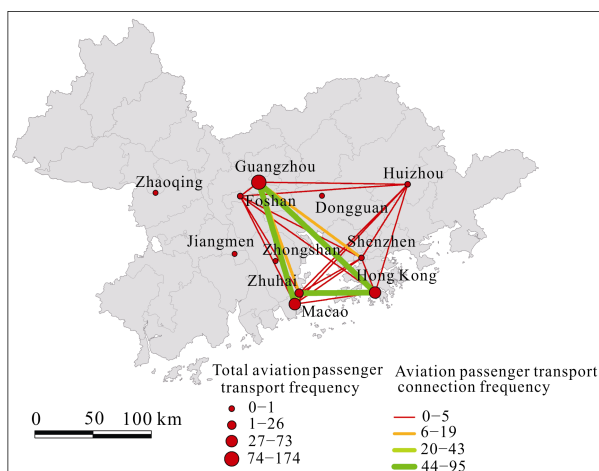


Fig. 10 Spatial distribution of the Guangdong-Hong Kong-Macao Greater Bay Area's aviation passenger transport connections

Dongguan, Huizhou and Zhuhai, in their efforts to attract export processing ventures from Hong Kong and Macao. The connectivity of the highway transport facilities between cities is relatively high, and the passenger transport links between each city are relatively close. Meanwhile, accessibility to Hong Kong and Macao is a major factor affecting the port connectivity between cities. The total frequency of port traffic in Hong Kong and Macao far exceeds that of other cities, and the total frequency of port traffic in Shenzhen and Zhuhai is also high. In aviation, the best connectivity of infrastructure is in Guangzhou, followed by Hong Kong, Macao and Zhuhai. Improved accessibility can facilitate regional integration and co-operation as spatial friction which deters the flow of people and goods is reduced.

4.2 Conclusions

This paper uses road network data and O-D network data, and applies a GIS raster distance matrix algorithm and an O-D cost analysis algorithm to estimate the transportation accessibility and intercity spatial connectivity of the Guangdong-Hong Kong-Macao Greater Bay Area. The study has important practical significance, and it is realistic for the Guangdong-Hong Kong-Macao Greater Bay Area. This paper is an application of various GIS-based spatial analysis methodologies to provide a complete outline of the transportation and spatial connections of the world's largest multicity bay area conglomerates. It provides a clear structural picture to the government for the development of transport and economy in the future. The following conclusions can be drawn.

Transport accessibility within the Guangdong-Hong Kong-Macao Greater Bay area costs 'one hour' and the spatial distribution of urban accessibility in the Guangdong-Hong Kong-Macao Greater Bay Area presents obvious 'core-periphery' spatial characteristics, with Guangzhou, Foshan, Shenzhen constituting the core. Specifically, the traffic accessibility of the Guangdong-Hong Kong-Macao is high.

There is a strong spatial agglomeration effect in the spatial pattern of traffic accessibility. Generally, the accessibility of the counties (county level, district) reveals that both ends are low, and the middle is high. The counties with cold accessibility spots are mostly in downtown Guangzhou, Foshan, Zhongshan, Jiangmen and Zhuhai. These areas are highly accessible. The hot spots are located in the city of Enping, Taishan and

Huidong, which are areas that are much less accessible.

We see that the higher the accessibility of transportation is, the closer the intercity spatial connection will be. The core status of Guangzhou and Shenzhen is highlighted. Foshan, Zhuhai, and Dongguan are closely connected with Guangzhou and Shenzhen. Hong Kong and Macao are closely linked with Guangzhou, Shenzhen and Zhuhai. The spatial connection of Zhaoqing, Huizhou and Jiangmen areas with lower accessibility is relatively weaker than that of other cities.

This study lays a scientific foundation for implementing the strategy of the Guangdong-Hong Kong-Macao Greater Bay Area as the fourth largest bay area in the world. There is still some relatively low accessibility in the core areas, which indicates that the transport network in the Guangdong-Hong Kong-Macao Greater Bay Area needs to be further improved. In this paper, only the O-D network is used to simulate the urban spatial relationship between the Guangdong-Hong Kong-Macao Greater Bay area, and the future can be analyzed based on different travelers. From the perspective of regional integration, the focus of future construction of the integrated transport network in the Guangdong-Hong Kong-Macao Greater Bay Area should be to improve the accessibility of nodes in the periphery. At present, the layout of the airport and port system in the Guangdong-Hong Kong-Macao Greater Bay Area is basically established. However, it is necessary to strengthen the construction of the highway and railway transportation corridors to enhance the spatial connectivity between cities. Moreover, despite different political systems, Hong Kong and Macao need to strengthen their contact and cooperation with other cities in the Guangdong-Hong Kong-Macao Greater Bay Area.

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