

Research Article

An Evaluation Method of Urban Public Transport Facilities Resource Supply Based on Accessibility

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The two indices of the supply level of urban public transport facilities resource and the public transport-private cars traveling time ratio are used to evaluate the public transport accessibility in urban networks. An evaluation method for urban public transport facilities resource supply is proposed based on accessibility by taking Shenzhen as the research area and by using the London PTAL evaluation system. The method takes into account the walking time outside the public transit station and the spatial layout of public transit stations, reflects regional development opportunity, and can reflect regional differences regarding public transport facilities resources in various spatial scales. This paper evaluates the relative service competitiveness of public transports and private cars in the entire travel of individuals based on the public transport-private cars travelling time ratio, which lays a foundation to judge the service level of public transport and to make a purpose-specific transportation policy and public transport development scheme.

1. Introduction

Accessibility has been applied in the fields such as urban and land use planning, transportation management, and public facility location analysis. The earliest research on accessibility is the classical location theory. Reilly defined accessibility as the index to calculate transport cost in 1931 [1–3], and Hansen indicated that accessibility presented the possibility of interaction among various nodes of the transportation network in 1959 [4, 5]. As people have deeper and deeper understanding of the concept of accessibility, both foreign and domestic scholars give explanation on accessibility from several aspects such as time, space, sociology, and psychology, and many classical accessibility calculation models have been created, but they are not internationally recognized [6]; from the point of urban area and land use, accessibility can be used to calculate space among different areas and to analyze the convenience to reach other places from current area; from the point of transportation system, accessibility can be used to evaluate the difficulty level of traveling by vehicles; from the point of individuals, accessibility reflects the possibility and

effectiveness of people's trip [7] and it can be used to measure the degree of freedom of individuals of traveling by vehicles in traffic environment and ecological environment. Currently, foreign and domestic research methods for urban public transport accessibility can be divided into two categories, i.e., the method based on classical space obstacle model [8, 9], taking time distance as the measurement index and calculating the cost of passengers by taking public transport facilities, the method reflecting the level of accessibility based on indexes such as line coverage and density from the point of infrastructure availability [9, 10]. There are two problems in current methods; i.e., the “non-door-to-door” feature of public transport facility makes time outside the station become the key factor impacting the accessibility of public transport facilities, while most public transport accessibility evaluation method does not consider the walking time outside the station because it is difficult to create a pedestrian network, or straight-line distance is used to replace actual walking distance [11, 12], resulting in a certain discrepancy between the evaluation results and the actual situation. According to the General Investigation on Basic Data of

Shenzhen Passenger Transport Planning, the walking time needed to reach a conventional public transport accounts for 33% of the total travelling time [13], so slow-moving traffic such as walking is the most important connection method to achieve door-to-door service of public transport. Some studies about public transport accessibility considered actual walking time outside the station, which is usually represented by the shortest walking time of the public transit stop at the starting point or the end point [14–20], which include walking from the point of origin to the appropriate public transport station (“access time”) and walking from the last public transit station to the final destination (“egress time”). The second problem is that such methods fail to evaluate the accessibility from the point of individuals by considering the selection or opportunities of individuals.

In the new cosmopolis plan, the transport for London promotes public transport accessibility to urban strategic level and the Public Transport Accessibility Levels (PTAL for short) proposed by it take into account the difference in the distribution of public facilities resource and the level of public service enjoyed by individuals in various areas [21]; New York transportation planning emphasizes the fairness of transportation system and measures the public transport accessibility based on the population and number of posts covered by public transport taken by individuals under certain time constraints [22]. The London PTAL accessibility evaluation method analyzes the level of service enjoyed by individuals under certain time-space constraints and reflects the real accessibility of urban public transport facilities resource from the point of passengers’ demand. Currently, the PTAL evaluation method on urban public transport facilities resource supply and public transport service level has not been applied yet in China. Nowadays, urban center has the highest public transport supply level but also heavy congestion, mainly because people making transportation policy only pay attention to the balance of facility supply but fail to realize fairness from the point of users.

In general, travel time, travel expenses, travel comfort, and safety are important factors affecting the competitiveness of private cars and public transport. Service quality is perceived as an important determinant of users’ travel demand [23]. Yet the measurement of service quality remains a challenging and important research area with practical implications for service providers [24]. Service quality is difficult to measure by quantitative comprehensive evaluation method [25]. Existing research usually selects one or more quantifiable evaluation indicators for comparison the competitiveness of public transport and private cars. For example, a methodological analysis framework was constructed to quantify operational performance measures that enable the comparison of the different travel modes. This analysis framework was then applied to two cities—Auckland, New Zealand, and Paris, France—to assess the overall performance metrics of PC, PT, and CB, such as travel costs, travel time, and fuel consumption. This comparison sheds light on the differences between the travel modes, their viability, and their competitiveness [26, 27]. Some studies use accessibility to compare the relative competitiveness between public and

private cars; spatial accessibility comparison [28–32] and traffic isochronism [33, 34] are two important methods. Few researches aim to compare the travel time between public transport and private cars. Travel time is one of the key indicators to reflect accessibility, and it is also the most intuitive indicator of service level. The travel time ratio is used to define the relative competitiveness between public transport and the private car [14, 35, 36]. The purpose is to provide a service that can compete with the private car by improving the resources of the public transport facility.

Therefore, this paper proposes an evaluation method for urban public transport facilities resource supply based on accessibility by taking Shenzhen as the research area and by using the London PTAL evaluation system. The method takes into account the time a passenger needs to reach a public transit stop and the spatial layout of public transit stops, reflects regional development opportunity, and can reflect regional differences regarding public transport facilities resources in various spatial scales. This paper evaluates the relative service competitiveness of public transports and private cars in the entire travel of individuals based on the public transport-private cars travelling time ratio by using the evaluation system of Singapore land transport planning [35], which lays a foundation to judge the service level of public transport and to make a purpose-specific transportation policy and public transport development scheme.

2. Evaluation Method of Urban Public Transport Resource Supply

2.1. Technical Route. The public transportation methods of this paper include bus, subway, and railway. This paper proposes an accessibility-based evaluation method for urban public transport facilities resource supply by using London PTAL public transport evaluation method and proposes the relative service competitiveness of public transport and private cars in the entire travel of individuals based on the public transport-private cars travelling time ratio by using the evaluation system of Singapore land transport planning. The main technical route is as follows: obtaining basic data, using big data acquisition technology during research, and knowing the actual time passengers need to reach a bus stop and public transit network data based on network map. The isochron from the demand point is drawn by using ArcGIS space analysis technology based on the walking time and concept of isochron. Walking range and covered stops are determined based on the maximum acceptable walking time of passengers. Then the accessibility of demand point can be achieved by calculating total accessibility of stations in the walking range of all demand points by taking into account station type, number of routes, weight, and walking walk-to-public transit-stop time. Finally public transport-private cars travelling time ratio is calculated based on the network map and public transport-private cars travelling time to reflect the relative service competitiveness of public transport and private cars and to make it possible to evaluate the public transport accessibility of main areas. For the technical route, please see Figure 1.

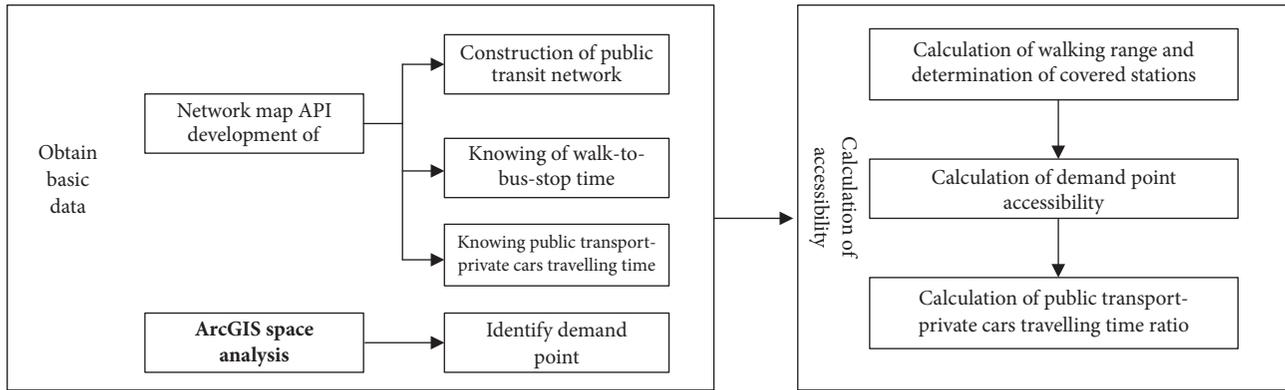


FIGURE 1: Technology roadmap.

2.2. Data Acquisition

2.2.1. Demand Point. Traditional accessibility research generally takes small traffic area or fixed grid as analysis unit, and the evaluation result focuses more on macrospace and cannot reflect microtraffic characteristics. According to relevant regulations, spaces between public transport stations are different in different areas, which is 300-500m in urban center and larger in suburban areas. To reflect the accessibility of any point in a city as well as spatial layout of public transport stations, the research uses GIS space analysis tool to insert sample points in the research area every 200m, which covers essentially all public transport stations, where one sample point represents a demand point, and there are 50,549 demand points in total. The demand points distribution can be seen in Figure 2. Demand points will be taken as center points, and public transport stations covered in a walking range will be the basic unit to measure the public transport accessibility. The selection of demand point can be adjusted based on spatial scale, the shorter the distance between demand points is, the higher the calculation accuracy will be.

2.2.2. Public Transit Network. Urban public transit network is always changing and being adjusted, so it is difficult to get real-time and latest basic data on the network. Online maps such as Baidu, Google, and Amap provide rich geographic information, and their data updating is fast and coverage is extensive. The research takes Baidu map as the example to develop a urban public transit network capture system by using Baidu development interface and doing secondary development of ArcGIS Engine, which has successfully captured Shenzhen public transport and transit network data, which mainly include public transport station data (station name as well as longitude and latitude) and route data. This system can be applied to all domestic cities which are covered by network maps to obtain true and comprehensive public transit network data.

The captured Shenzhen public transit network contains 47,858 stations and 904 routes, and the number of routes publicized by Shenzhen transport and communications committee in January 2016 was 908, so the two numbers are almost the same. All data are integrated on the GIS platform for the convenience of later visualization and analytical

calculation. For data of Shenzhen public transit network, please see Figure 3.

2.2.3. Walking Time. Traditional walking time calculation is usually straight-line distance divided by walking speed, which is less than actual time. Baidu map contains actual walking route network which can be used to obtain real walking time and distance, so walking time of passengers to the public transport station is calculated with Baidu map Direction API which is a bus, drive, and walking query and retrieval interface in the form of http and then returning retrieved data in format xml or json. The process can be seen in Figure 4. Baidu map interface can be used to obtain walking time to the station to the accuracy of second.

2.3. Model Building. Model calculation mainly considers two factors: ① the type of public transit stations in a certain walking range of the demand point. For example, large junction station, transfer station, or common stop station. ② The number and characteristics of public transit stations which can be reached from the demand point in certain walking time.

2.3.1. Calculation of Walking Range. In the ideal and accessible plane space, the walking range is determined by taking the initial point as the center and walking distance in certain time as the radius. In the actual road network, however, constraints caused by the road network and impedimental buildings are also main factors determining the walking range. The real walking time between demand point and various stations can be obtained based on network map, and the walking time to the points in other locations in the area can be calculated according to the walking time to the adjacent stations. Here we use Inverse Distance Weighted (IDW) method to realize spatial interpolation and rendering of walking space.

IDW calculates the value of sample point by taking the distance between insertion point and sample point as the weight; the smaller the distance between the sample point and insertion point is, the larger the impact on interpolating point will be; otherwise the impact will be smaller. When it is assumed that there are several metro stations ($D(x_i, y_i)(i = 1, 2, \dots, m)$) available in an area, the accessibility of such

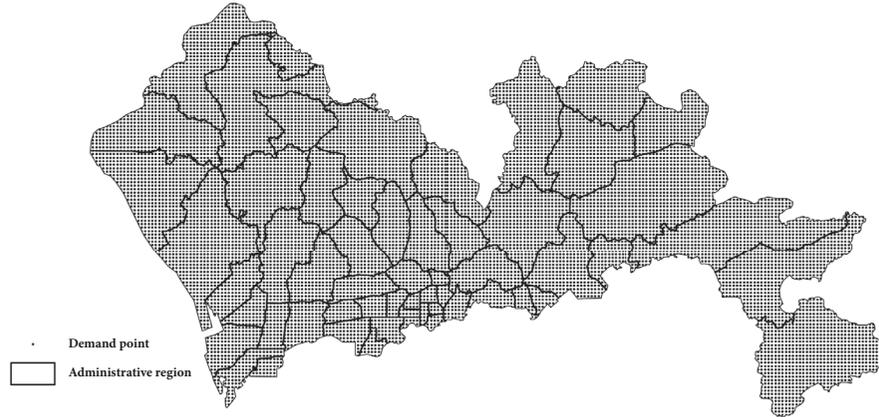


FIGURE 2: Demand points distribution.

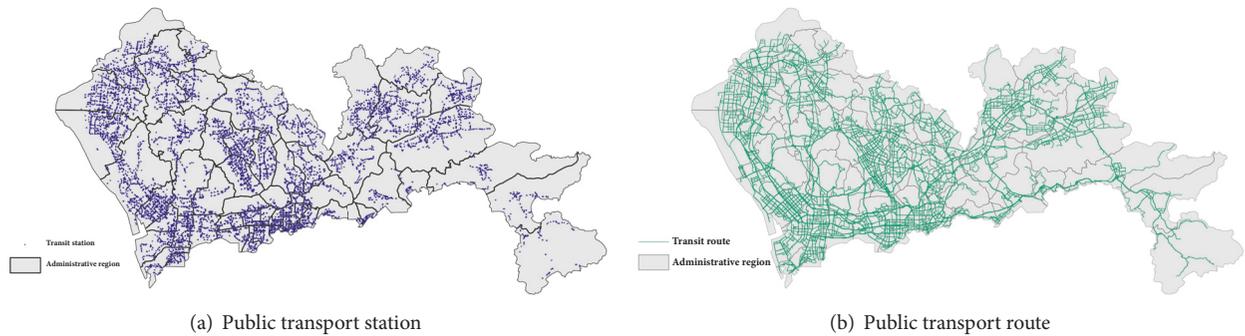


FIGURE 3: Shenzhen public transportation network diagram.

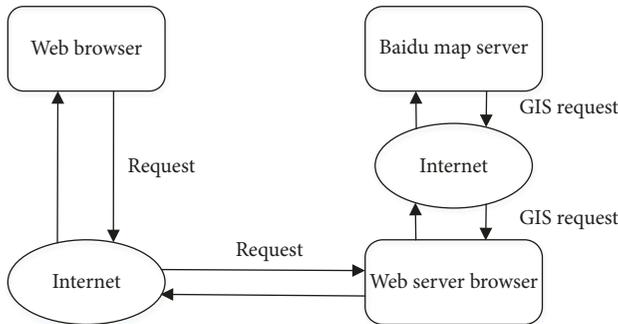


FIGURE 4: Process of direction API to obtain data.

stations will be A_i . If stations with equal A_i value are connected with each other, a smooth curve cannot be obtained since the number of sample points is insufficient. Smooth curve can be obtained with IDW method, and the equation is as follows.

$$A(Z) = \frac{\left(\sum_{i=1}^m \left(Z_i / [d_i(x, y)]^n\right)\right)}{\left(\sum_{i=1}^m \left(1 / [d_i(x, y)]^n\right)\right)} \quad (1)$$

where $d_i(x, y) = \sqrt{(x - x_i)^2 + (y - y_i)^2}$, $d_i(x, y)$ is the distance between insertion point $A(x, y)$ and station $D(x_i, y_i)$; m is the number of stations in the area; $A(Z)$ is the accessibility

of insertion point; Z_i is the accessibility of station i ; in the weight coefficient $w_i(x, y) = 1/[d_i(x, y)]^n$, n controls the degree of reduction of weight coefficient when the distance between insertion point and surrounding sample points is increased. Generally speaking, people will feel easy if they can arrive at the destination point or traffic interest point in a walking time of 10 minutes, and most people will be tired if the walking time exceeds 10 minutes [12]. Therefore, this paper decides 10 minutes is the maximum acceptable walking time. Stations covered by the demand point in different time limits can be obtained by using the spatial interpolation, as shown in Figure 5.

2.3.2. Calculation of Accessibility. Different types of stations are of different grades, can provide different service levels, and have different levels of attraction to passengers; the research indicates that station weight, walking time, and the number of lines are key factors affecting station accessibility, and the equation to calculate station accessibility is as follows:

$$W_i = \partial_m \times \frac{L_i}{T_w} \quad (2)$$

where W_i is the attraction of station i , ∂_m is the weight of class m station (common station, transfer station, subway station, and railway station), L_i is the total number of lines passing station i , and t_w is the walking time of individuals to public transport station. Station weight is determined by

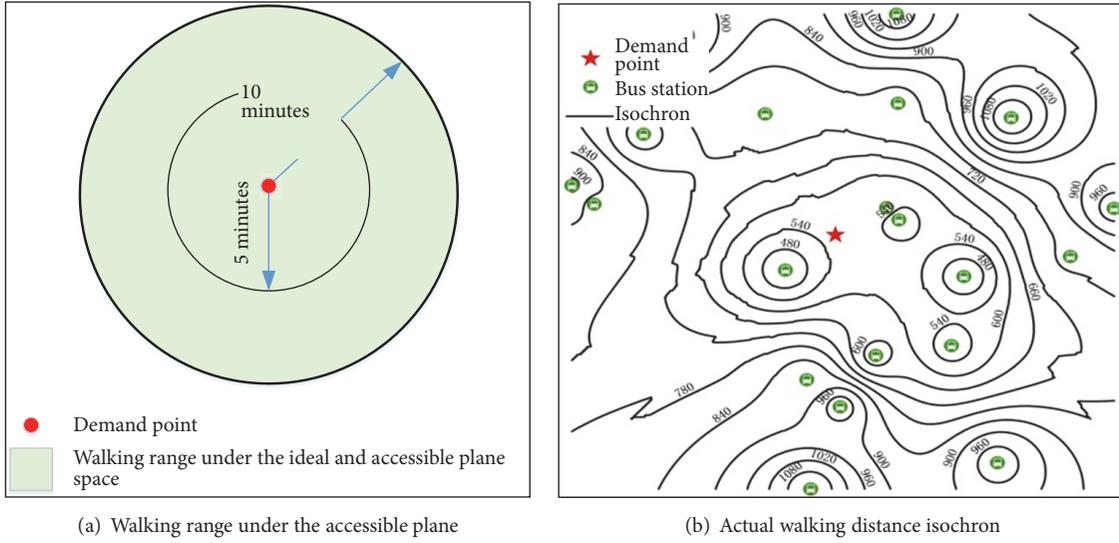


FIGURE 5: Walking distance calculation.

transfer capacity of the station, and the research defines a station serving less than 10 lines as a common station and a station serving more than 10 stations as a transfer station. The weights of the common station, the transfer station, the subway station, and the railway station are set to 0.1, 0.2, 0.3, and 0.5, respectively. The equation shows that the station accessibility is in direct proportion to station weight and the number of public transport lines, and the accessibility is inversely proportional to walking time to the station.

Therefore, the accessibility of passengers from the demand points equals the sum of accessibility of all bus stops in the walking range:

$$A_i = W_i \times R(o, d)_j = \sum_m^k \sum_j^n \partial_m \times L_i \times \frac{R(o, d)_j}{T_w} \quad (3)$$

where $R(o, d)_j$ can be used to judge whether station j is in the walking range of demand point i , and only the bus stations in the walking range of demand point need to be considered if the walks start from the demand point.

2.3.3. Calculation of Public Transport-Private Cars Travelling Time Ratio. The public transport-private cars travelling time ratio equals the ratio of public transport travelling time and private cars travelling time from the initial point A and end point B, which is an important indicator to reflect the accessibility competitiveness of public transport compared to private cars. Success of public transportation in international cities shows that public transport can be competitive against cars if the total travelling time of public transport is limited to 1.5 times of that of cars. The overall Singapore land traffic planning indicates that the door-to-door travelling time of

public transport in Singapore will be reduced to less than 1.5 times of the door-to-door travelling time of cars in 2020 [35].

$$E_i = \frac{T(AB)_{PTi}}{T(AB)_{cari}} \quad (4)$$

where E_i is the public transport-private cars travelling time ratio from initial point A to end point B, $T(AB)_{PTi}$ is the public transport travelling time from initial point A to end point B, $T(AB)_{cari}$ is the private cars travelling time from initial point A to end point B, and this paper obtains the index based on the network map.

3. Case Study

Calculate the accessibility value from different demand points to bus stations under certain time-space limits with accessibility calculation model by taking Shenzhen as the example when above statistics processing is finished, and obtain the spatial distribution of public transport accessibility by using GIS analysis tools. The public transport accessibility, public transport, and private car travel time of this article refers to off-peak.

3.1. Evaluation on Public Transport Facilities Resource Supply Level of the City. The 500m coverage rate of Shenzhen public transport has reached 97%, but Shenzhen's public transport accessibility renderings (see Figure 6) calculated with the method proposed in this paper show that there are obvious regional differences in the distribution of Shenzhen's public transport facilities resource supply, which has the following three features: firstly, the overall Shenzhen public transport accessibility structure is highly identical to the railway line network and public transport corridor form; secondly, the public transport accessibility inside the original special zone is obviously superior to that outside the special zone, Luohu District, and Futian railway network in the original special zone is extensive, and its public transport accessibility is

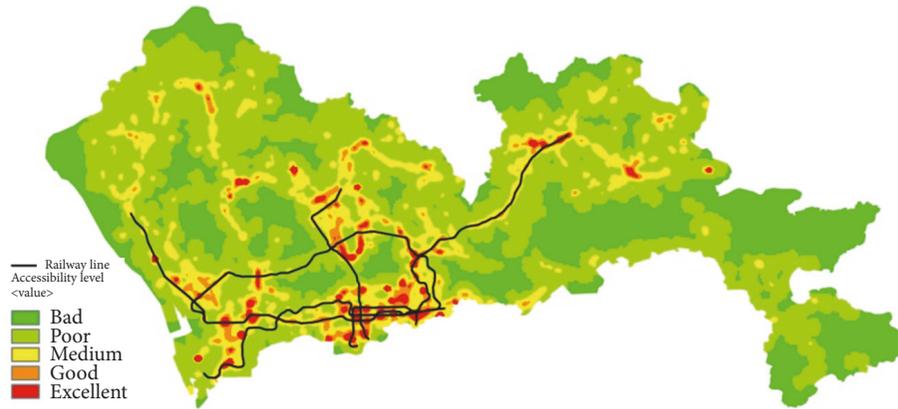


FIGURE 6: Shenzhen public transport accessibility evaluation.

TABLE 1: The correspondence between accessibility index and accessibility level.

| Accessibility Level | Accessibility Index | Color |
|---------------------|---------------------|---|
| Excellent | >25.01 |  |
| Good | 15.01-25.00 |  |
| Medium | 10.01-15.00 |  |
| Poor | 5.01-10.00 |  |
| Bad | 0.01-5.00 |  |

higher than that of the Nanshan District; areas with high public transport accessibility outside the original special zone are along railway and some public transport corridors, and the public transport accessibility of most areas is low; thirdly, local areas with high accessibility are near railway and public transport transfer stations as well as traditional commercial area and job centers, etc. The former includes Futian station, Shenzhen North Railway Station, and Buji Railway Station, and the latter includes Luohu Golden Triangle and the convention and exhibition center. The correspondence between accessibility index and accessibility level can be seen in Table 1.

3.2. Evaluation on the Public Transport Accessibility of Key Areas. In terms of accessibility, the average public transport travelling time from key areas such as Luohu District, Huaqiang North Commercial Area, Futian CBD, Che Kung Temple, five job centers in the science park, Longcheng Square in Longgang District, Longhua Bantian, the center of Pingshan District and the center of Guangming District to other places of the city is 118-183 minutes, and the average private cars travelling time is 58-69 minutes, so the overall accessibility of private cars is higher than that of public transport. Shenzhen key areas public transport accessibility can be seen in Figure 7.

In terms of public transport-private cars travelling time ratio, the average ratio from key areas such as Luohu District, Huaqiang North Commercial Area, Futian CBD, Che Kung

Temple, five job centers in the science park, Longcheng Square in Longgang District, Longhua Bantian, the center of Pingshan District, and the center of Guangming District to other places of the city is 1.79-3.09, which is above 1.5, so the public transport service competitiveness should be improved further. For areas with a public transport-private cars travelling time ratio of more than 1.5, Luohu District, Huaqiang North Commercial Area and Futian CBD are larger than other areas, and their public transport competitiveness in the 1-hour public transport coverage area is also higher than that of other areas; in addition, the public transport service level of areas outside the original special zone, especially Guangming District and Pingshan District, shall be improved greatly. Shenzhen key areas public transport-private cars travelling time ratio can be seen in Figure 8.

Above accessibility research on key areas of the city can be used to analyze public transport travelling time, private cars travelling time, and the public transport-private cars travelling time ratio, which is the basis to assess public transport facilities resource supply level and select proper travel mode. Shenzhen key areas public transport accessibility analysis can be seen in Table 2.

3.3. Further Discussion of Application. The accessibility calculation method proposed in this paper can directly reveal the spatial distribution characteristics of public transport facilities resource supply and can be used to

TABLE 2: Shenzhen key areas public transport accessibility analysis.

| Calculation Index | Area | | | | | | | | | |
|---|-------------------------|---|------------|------------------------|----------------------|---------------------------|---------------------------------------|---------------------------------|----------------------------------|--|
| | Luohu Commercial Center | Huaqiang North Commercial Area in Futian District | Futian CBD | Futian Che Kung Temple | Nanshan Science Park | Huawei in Longhua Bantian | Longcheng Square in Longgang District | The Center of Pingshan District | The Center of Guangming District | |
| Average public transport travelling time (min) | 127 | 121 | 117 | 118 | 134 | 143 | 129 | 169 | 183 | |
| Average private cars travelling time (min) | 59 | 69 | 60 | 66 | 67 | 61 | 58 | 69 | 63 | |
| Average public transport-private cars travelling time ratio | 2.18 | 1.79 | 1.97 | 1.92 | 2.11 | 2.42 | 2.39 | 2.77 | 3.09 | |

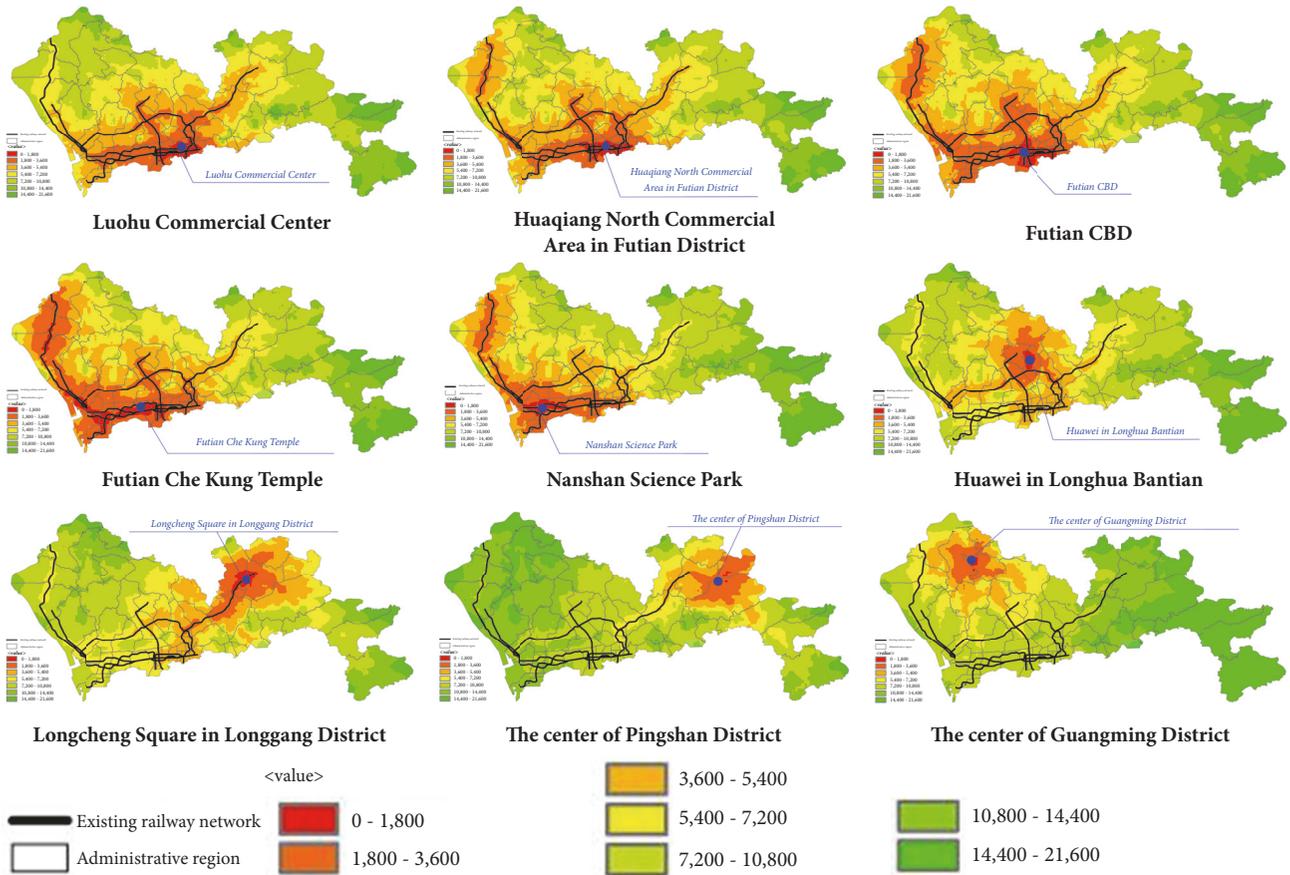


FIGURE 7: Shenzhen key areas public transport accessibility (unit: seconds).

effectively analyze the arrangement of spatial elements and preparation of spatial development policy. The method is highly useful in the preparation of urban public transport policy and traffic demand management of key areas.

3.3.1. Preparation of Public Transport Development Policy of the City Based on Population Density. Public transport resource distribution reflects the difference of regional development opportunity to some extent; the public transport accessibility evaluation method proposed by this paper is combined with population density and structure distribution, which can provide decision-making support for balanced development of public transport. Figure 9(a) shows that Shenzhen population is evenly distributed; both central urban area and peripheral streets such as Fuyong, Buji, Longcheng, and Bantian have high population density. Figure 6 shows that public transport resource in peripheral areas is not evenly distributed; the public transport accessibility level of some highly populated areas is low, which shall draw more attention. Of course, more attention shall be paid to the difference of population structure and public transport demand in addition to population density. From Figure 9(b) we can see that large number of people with junior high school degree and lower degree (most of them are peasant-workers) are distributed in areas outside the

Airport-He'ao expressway outside the original special zone; the public transport demand of such areas is greatly different from that of areas inside the Airport-He'ao expressway, and a differentiated public transport development policy shall be made.

3.3.2. Preparation of Demand Management Policy Based on Traffic Operation State. The traffic demand management policy can be made based on public transport accessibility level of the area and the actual traffic operation state. According to the 2015 Shenzhen frequently congested road diagram, roads such as Luohu District Binhe Road, Shennan East Road, and Aiguo Road are heavily congested (see Figure 10). Shenzhen public transport accessibility calculation result shows that the public transport accessibility level of Luohu District, especially the Luohu Golden Triangle Central Business District, is very high. It is possible to carry out congestion charging and increase parking charge in some areas of Luohu District to ease traffic jam and improve traffic operation state. But in the science park with severe traffic jam and livelihood issues, the substitutability of public transport shall be evaluated before traffic demand management policy is prepared, in order to prevent decreasing the overall residents benefit level, because current public transport accessibility level of this area is low.

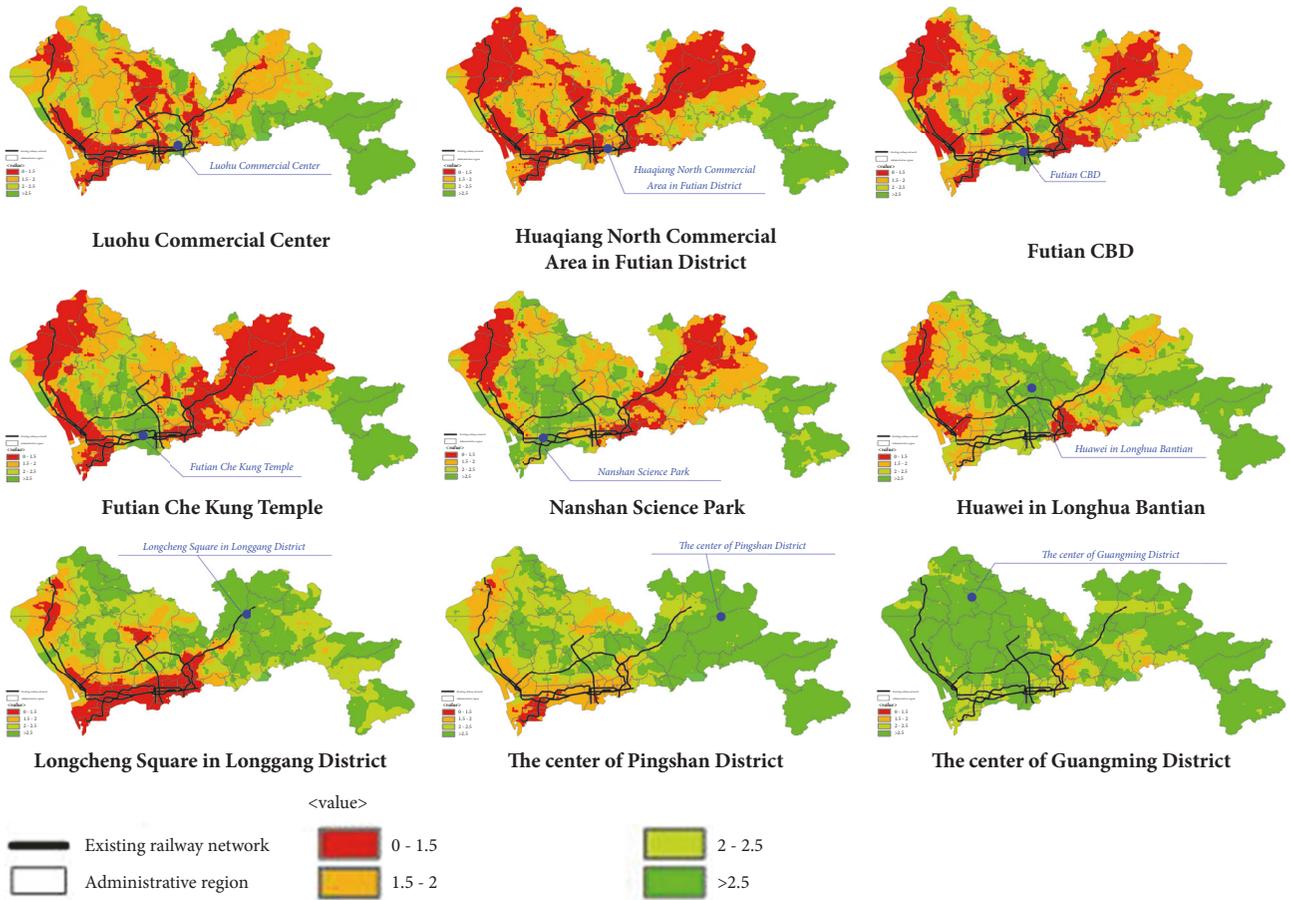


FIGURE 8: Shenzhen key areas public transport-private cars travelling time ratio.

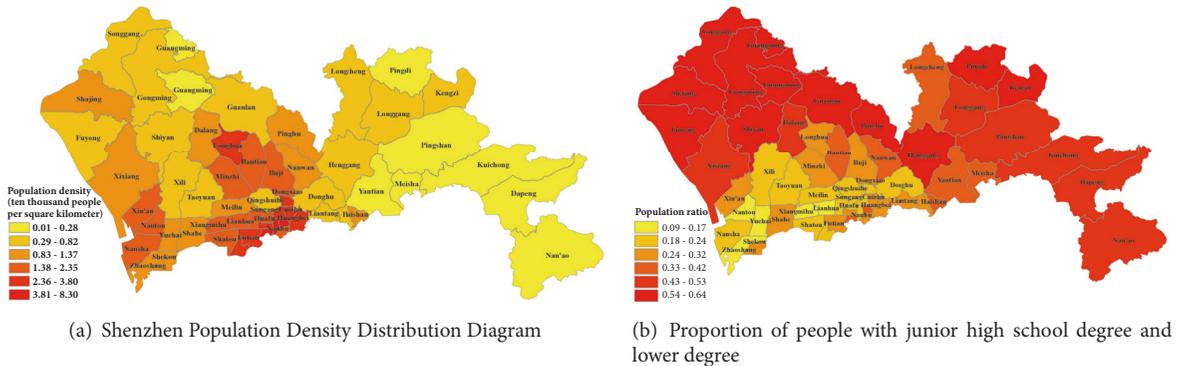


FIGURE 9: Shenzhen population distribution.

4. Conclusion

This paper considers walking time of passengers to stations as well as other factors such as property, class, and spatial distribution characteristics of station and proposes an urban public transport resource supply evaluation method based on the accessibility. Equity is an important principle of the sustainable urban traffic system. The method proposed in this paper essentially reflects the distribution of urban public transport facilities resource supply, evaluates the equity of

urban public transport facilities resource distribution based on the index of accessibility, calculates the public transport-private cars relative service competitiveness based on the index of public transport-private cars travelling time ratio, and provides conditions for the public transport accessibility evaluation of key areas. The proposed method is applied by taking Shenzhen as the example. The result shows that the method can truly reflect the spatial distribution characteristics of Shenzhen public transport facilities resource and can provide basis to assess travel mode in main areas, prepare

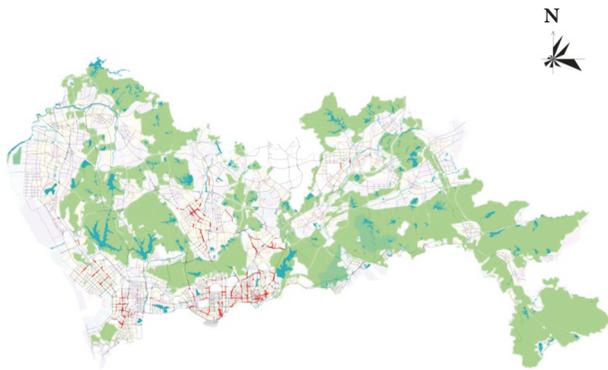


FIGURE 10: 2015 Shenzhen recurrent congested road map.

public transport development policy for the whole city, and make demand management policy for key areas. Further research shall consider more factors which may impact the accessibility, such as the departure frequency of the line and setting of station weight parameters, to establish a better calculation model. In addition, this paper only applies the method to the city and districts; subsequent research shall apply the method to more fields and further verify reliability and practicability of the method.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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