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GIS-based Road Network Analysis and Bus Route Evaluation in Futian District, Shenzhen

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Abstract— *Futian District is the central urban area of Shenzhen and one of the busiest and most dynamic urban areas. This article is based on the spatial analysis method (slop, density, road area); Simultaneously, using research methods such as average station distance, nonlinear coefficient, service area, and public transportation network repetitive coefficient, combined with national standards, this study analyzes and evaluates the urban road network and public transportation network in Futian District, Shenzhen. The results show that: firstly, the overall difference in road network density in Futian District is significant, with a characteristic of high density in the southeast and low density in the northwest. The transportation network is mainly distributed in the east, south, and west regions. Secondly, the shortcomings of the planning in this area were manifested in the non-compliance of the urban road area with national standards, the high nonlinear coefficient of bus routes, increased time and travel costs for residents' bus travel, and a bus service area within 500 m far below national standards. Reflecting on the sustainable development of urbanization in the area, we should address the shortcomings in road design and public transportation layout, explore our own advantages, and adjust planning strategies to seek new directions and strategies.*
Keywords— ***GIS-based, Road Network Analysis, Bus Route Evaluation, Density Calculation, Service Area***

I. INTRODUCTION

Futian District of Shenzhen is a national economic center and one of the core engine areas of the Guangdong-Hong Kong-Macao Greater Bay Area (GBA). In the process of urbanization, the diversity of production conditions in cities has promoted economic development. "Urban image" is its soul, and the transportation road network is its blood delivery artery, closely related to social pulsation, life dynamics, and economic development. Therefore, transportation is the fundamental, leading, strategic, and important service industry of the national economy and the urban foundation of public construction. It is an element that is related to the national economy and people's livelihoods (Wang, 2017). Among them, public transportation is an important component of urban transportation. In sustainable urbanism, density, rationality, and accessibility can quantitatively express urban sustainability indicators. Through the public transportation system, residents can overcome obstacles such as distance and time, participate in socio-economic activities, and obtain urban services, which is an indicator of urban expansion and vitality. It is also an effective indicator for judging the operational status and service capacity of the public transportation system, which can be used to measure the rationality of the spatial layout of urban public service facilities as well as the effectiveness and future of urban development.

In the 14th Five-Year Plan of China for Comprehensive Transportation (Cui, 2022), Futian District proposed to enhance the rationality of urban road construction, form a public transportation service system that meets demand, establish a sound public transportation service index system, and comprehensively promote "on-time public transportation". One of the high-quality performances of the urban service system lies in the comprehensive implementation of bus punctuality services on major routes and stations, the construction of a continuous network of bus lanes, and the standardized guidance of intelligent supervision and management of bus lanes. It is shown that in-depth research on public transportation accessibility is of great significance for improving the development level of urban public transportation, and the improvement of public transportation accessibility is based on the infrastructure and density of urban roads, which are closely related. Therefore, facing the future urban development of Futian District, the construction of urban roads and the setting of bus stops and routes have become important analysis and evaluation directions.

Based on the above viewpoints, it is important and necessary to analyze the road network and evaluate bus routes in Futian District (Yin & Yu, 2020). Thus, this article selects factors such as roads density, area, and slope for analysis of urban road networks. On the bus route network, there are many indicators for evaluating the bus route network. Based on the principles of scientific comparability and operability (Duan, 2014), factors such as the nonlinear coefficient, repetitive coefficient, average station distance, and service area range are selected for evaluation. There are two main objectives: firstly, through road network data, focus on analyzing the density, area, and slope of four types of roads and evaluating the rationality of road network layout in accordance with national standards. Secondly, based on relevant data on bus routes and national standards explain the relevant situation of bus accessibility in Futian District and conduct a quantitative evaluation.

II. STUDY AREA AND DATA SOURCES

2.1 Study Area

Futian District is located in the southern part of the central axis of Shenzhen City, between 113° 59 ′ -114° 06′ E and 22° 30′ -22° 36′ N. Futian District is the central urban area, with 10 streets, including Yuanling, Huafu, and Xiangmihu, under its jurisdiction (Figure 1). The green coverage rate in this area reaches 42.5%, with a total of 135 parks. The park green space has basically achieved full coverage within a 500-meter radius. Awarded as the "Most Beautiful County in China", it is the only central urban area in China that has won the title of "National Ecological Civilization Construction Demonstration Zone".

Focusing on the functions of the central urban area, Futian District will create an urban development pattern of "one core, three poles integration circle". One core is the Futian Central District; three poles refer to the development poles of the three new engines, specifically the Hetao Shenzhen-Hong Kong Science and Technology Innovation Cooperation Zone, the Xiangmi Lake New Financial Center, and the Central Park vitality circle; Rong Circle refers to four composite vitality circles of "business creation, residence, and tourism", namely the Hetao Shenzhen-Hong Kong Science and Technology Innovation Circle, Xiangmi Lake Chegongmiao Vitality Circle, Huan Central Park Fashion Innovation Circle, and Meilin Livable and Industrial Life Circle (Xu & Liao, 2021). As the earliest developed area in Shenzhen, Futian District has the leading infrastructure in the city, with many roads presenting a grid-like network. The Huanggang Hub, a road hub, is composed of multiple intercity and urban tracks, forming a composite hub. Chegongmiao and Xiangmi Lake integrate multiple urban rail lines to form a subway hub radiating throughout the city. Combined with the renovation of Huangmugang Interchange, seamless transfer of tracks, buses, and cars will be achieved.

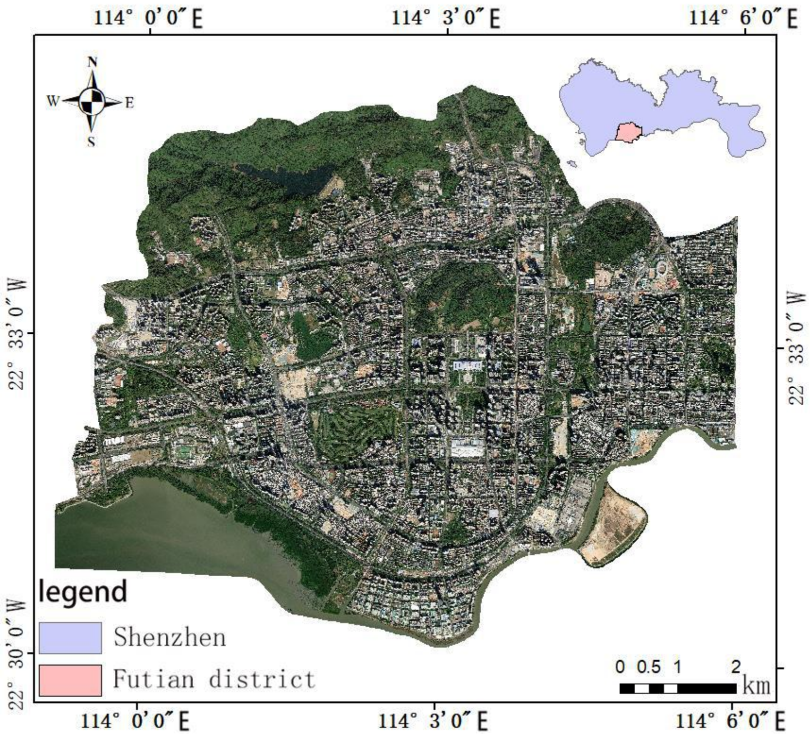


Fig.1 Study Area Map

2.2 Data Sources

This article mainly uses three types of data: one is the vector boundary range data of Futian District, the other is DEM elevation data, and the third is road network data. The road network data includes bus stop and route data (Table 1).

Table 1 Data Sources

Data type	Data sources
Vector boundary range data	Resource and Environmental Science and Data Center（https://www.resdc.cn/）
DEM elevation data	Geospatial Data Cloud (GDC)（https://www.gscloud.cn/）
Road network data	Open Street Map (OSM)（https://www.openstreetmap.org/）

III. METHODOLOGY

This study uses vector, DEM, and road network data as the analysis materials and is based on spatial analysis methods (slope, density, and road area). Meanwhile, using research methods such as average station distance, nonlinear coefficient, service area, and bus network repetitive coefficient, combined with national standards, the urban road network and bus network of Futian District, Shenzhen, were analyzed and evaluated (Figure 2).

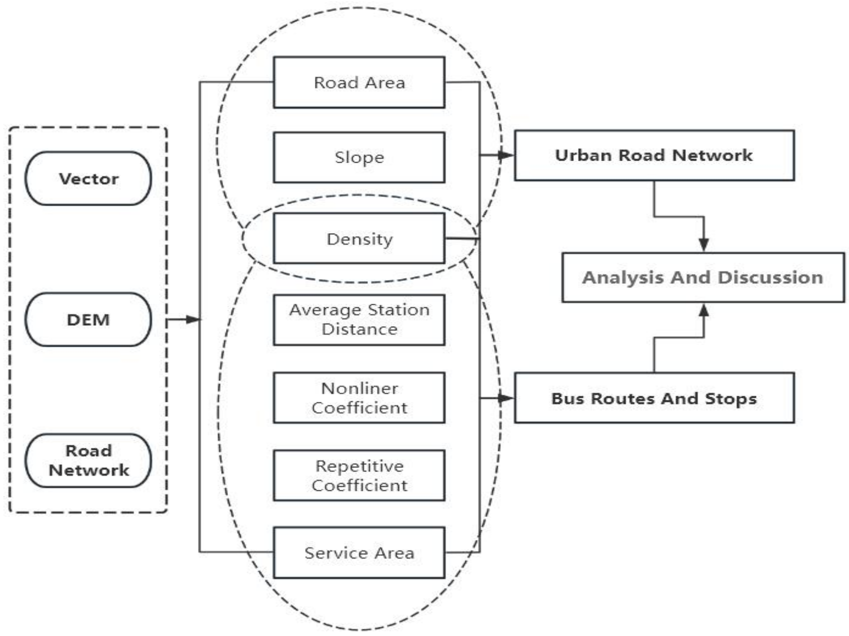


Fig.2 The Schema of The Study

3.1 Density Calculation

Road network density, reflecting the activity level of regional economic activities and other factors, is an important indicator for measuring regional development (Kong & Zheng, 2021). The density calculation in this article is divided into urban road network density and bus route density, but the essence of both road network densities is calculated based on the length of the road network/land area. The difference is that the density of the urban road network requires the overall length of the city's roads, while the density of the bus route network only requires the length of the road network that the bus travels on. The formula is as follows:

Road network density=length of road network/area (1)

3.2 Slope Calculation

Slope refers to the ratio of the height difference between two points on the same slope section of a route to their horizontal distance. The meaning of its measurement is that the road slope represents the quality index of the city's construction level, the government's behavior, and its vision. The percentage method is the most commonly used method for measuring slope, which is the percentage of the elevation difference between two points to their horizontal distance. The calculation formula is as follows (Yan, 2021):

Slope = (elevation difference/horizontal distance) x 100% (2)

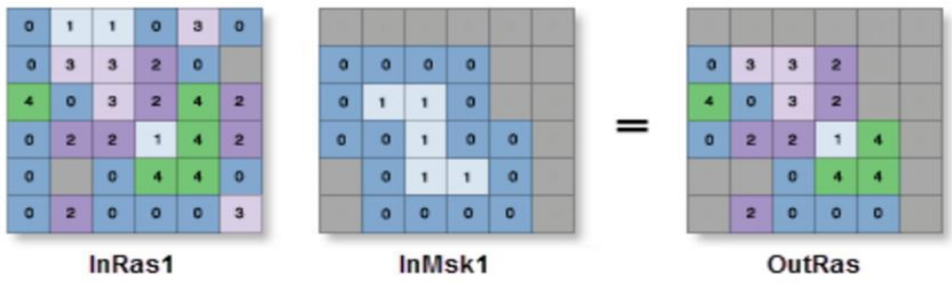
The idea of calculating slope in GIS (Figure 3) is to obtain the elevation difference of the road, divide it by the length of the road, and calculate the slope of each section of the entire road to obtain the slope value of a road. Main approach:

(1) Using the "Mask Extraction" tool, DEM grid data is extracted from road vector lines, and corresponding grid pixels within the defined area of the mask are extracted to obtain DEM values along the road.

(2) Extract the highest and lowest elevations along the road and calculate the elevation difference of the road by interpolating the two.

(3) Using ArcGIS's attribute table tool to calculate geometry to obtain the length of the road.

(4) Calculate the percentage slope of a certain road using a table and formula.

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OutRas = ExtractByMask(InRas1, InMsk1, "INSIDE")
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Fig.3 Schematic Diagram of Calculating Slope Using Grid Pixels in GIS (data source: network)

3.3 Road Area Calculation

The urban road area ratio, also known as the "urban road area density," is expressed as the percentage of the road area within the urban built-up area to the built-up area. The urban road area ratio "is an important economic and technical indicator that reflects the ownership of urban roads within the urban built-up area. Through data comparison, the roads in Futian District are compared with the width limit for analysis and evaluation and used to distinguish road grades (Table 2).

Table 2 Road Class and Width Range

Road class	Total width of road
Expressway	35 - 80
Main road	30 - 50
Secondary trunk road	26 - 35
Branch road	16 - 25

3.4 Calculation of Average Station Distance

The average distance between bus stops is the average value of the distance between bus stops and the nearest bus stop. Using QGIS software, the main method is:

(1) Select the vector data of the bus stop in the "Input Point Layer" and "Input Target Point Layer", and select the name of the bus stop in both "Fields".

(2) The default output matrix type selection is a linear distance matrix.

(3) Since only the closest site is considered, fill in '1'. The concept is that it is possible to choose to calculate the distance (0) to all points in the target layer or limit it to the feature that is closest to a number (k).

(4) The final output data points contain vector layers for the distance calculation of each input feature. Its characteristics and attribute table depend on the selected output matrix type.

3.5 Nonlinear Coefficient Calculation

The ratio of the length of a bus route to the straight-line distance between the starting and ending stations is called the nonlinear coefficient of the route. The nonlinear coefficient of a circular route is measured between the main hub points (or the farthest two nodes) on the route. The nonlinear coefficient can more reasonably reflect the degree to which the bus route deviates from the shortest path of the road network and the detour situation of the bus route. The calculation formula is as follows:

Nonlinear coefficient=length of the line/linear distance between the starting and ending points of the line (3)

This study directly obtains the length of bus routes through the length field of the bus route layer, and the key to calculation is to calculate the spatial straight distance between the initial and final stations of the route.

3.6 Repetitive Coefficient Calculation

By using the length field of the bus route layer and road route layer, the length of the bus route and road route can be directly obtained, and the repetition coefficient of the public transportation route network can be obtained by substituting it into the formula. The calculation formula is as follows:

Repetitive coefficient of public transportation lines=total length of public transportation lines/length of line network (4)

3.7 Service Area Calculation

With the continuous improvement of living standards, the gradual change in driver and passenger demand, and the continuous construction of infrastructure, in order to better serve the public, leverage the advantages of infrastructure, and improve the level of service area construction, it is necessary to conduct an accessibility analysis of the service area range (Liu Yang et al., 2023). The basic elements of service area research can be divided into two categories: service points and transportation routes

Service area analysis considers only the resource allocation of network arc resistance between the supply and demand sides without considering the supply and demand of central resources. When conducting network service area analysis, there are three parts: the selection of service area analysis direction, service area overlap processing, and surface generation. First, service area analysis and direction setting: starting from the service point and not starting from the service point, it is necessary to determine the extension direction of the service point. Second, handling overlapping service areas: by setting the analysis direction, there is a certain degree of overlap between the generated service areas, and adjacent parts can be analyzed. Overlap removal processing can be selected. Third, generation of faces: in the process of generating service areas, the analysis results will simply outline the surface contour based on the nodes, which contain un-generated routing segments.

3.8 Evaluation Criterion

This article mainly uses the "Code for Urban Road Traffic Planning and Design GB 50220-95" as the evaluation standard and adopts the relevant provisions on urban public transportation and urban road systems.

3.8.1 Regulations on Urban Public Transportation

The density of the public transportation network planned in the city center should reach 3–4 km/km^2, and in the urban fringe areas, it should reach 2–2.5 km/km^2.

As a transportation method with high capacity, energy conservation, environmental protection, safety, and convenience, the importance of public transportation has gradually been recognized by people. Due to the fact that nearly 20% of the running time of buses is spent entering and exiting bus stops (Chen & Ji, 2018), it is important to evaluate the average station distance. The service area of public transportation stations, calculated with a radius of 300 m, shall not be less than 50% of the urban land area; calculated with a radius of 500 m, it should not be less than 90%.

The nonlinear coefficient of public transportation lines should not exceed 1.4. The average nonlinear coefficient of the entire national railway network should be between 1.15 and 1.2, which is too high, resulting in long detour distances and increasing travel time costs for passengers, which is not conducive to attracting bus passenger flow (Zhang & Chen, 2016).

3.8.2 Regulations for Urban road Systems

The urban road land area should account for 8% to 15% of the urban construction land area, and for large cities with a planned population of over 2 million, it should be 15% to 20%. The planning indicators for various types of roads in large and medium-sized cities should comply with the provisions of Table 3.

Table 3 Road Network Planning Indicators for Large and Medium Cities

Item	City size and population (10000 people)		Expressway	Main road	Secondary trunk road	Branch road
Design speed of motor vehicles	Metropolis	> 200	80	60	40	30
		≤200	60～80	40～60	40	30

(km/h)	Medium-sized city		-	40	40	30
Density of road network (km/km²)	Metropolis	＞200	0.4～0.5	0.8～1.2	1.2～1.4	3～4
		≤200	0.3～0.4	0.8～1.2	1.2～1.4	3～4
	Medium-sized city		-	1.0～1.2	1.2～1.4	3～4
Number of motor vehicle lanes in the road	Metropolis	＞200	6～8	6～8	4～6	3～4
		≤200	4～6	4～6	4～6	2
	Medium-sized city		-	4	2～4	2
Road width (m)	Metropolis	＞200	40～45	45～55	40～50	15～30
		≤200	35～40	40～50	30～45	15～20
	Medium-sized city		-	35～45	30～40	15～20

IV. ANALYSIS AND RESULTS

4.1 Analysis of Urban Road Network

4.1.1 Traffic Network Density

According to the density map of the transportation network in Futian District, the overall difference in road network density is significant, with a high density in the southeast and a low density in the northwest. The distribution of the transportation network is mainly distributed in the east, south, and west regions (Figure 4). Based solely on the analysis results of road network data:

1. The area with a road network density of 0-1.018720747 has a larger overall distribution area, distributed in the northern and southern regions, as well as in some urban centers such as forest parks.

2. The area with a road network density ranging from 1.018720748 to 2.35089403 has a relatively uniform distribution and a relatively large proportion of the overall area, distributed in the area of road traffic construction land along the transportation route.

3. The road network density ranges from 2.350894031 to 4.231609255, distributed in the central and surrounding areas of the construction land of the Ring Road (Beijing-Hong Kong-Macao Expressway), along the main roads and expressways.

4. In areas with a road network density ranging from 4.231609256 to 6.974318957, the distribution is scattered and the concentration is low, distributed along transportation roads such as Binhe Avenue, Huanggang Road, Qiaoxiang Road, Beihuan Xiangmi Interchange, and Futian Interchange.

5. The area with a road network density between 6.974318958 and 9.991299629 is a red grid point area, with a more dispersed distribution and a smaller area.

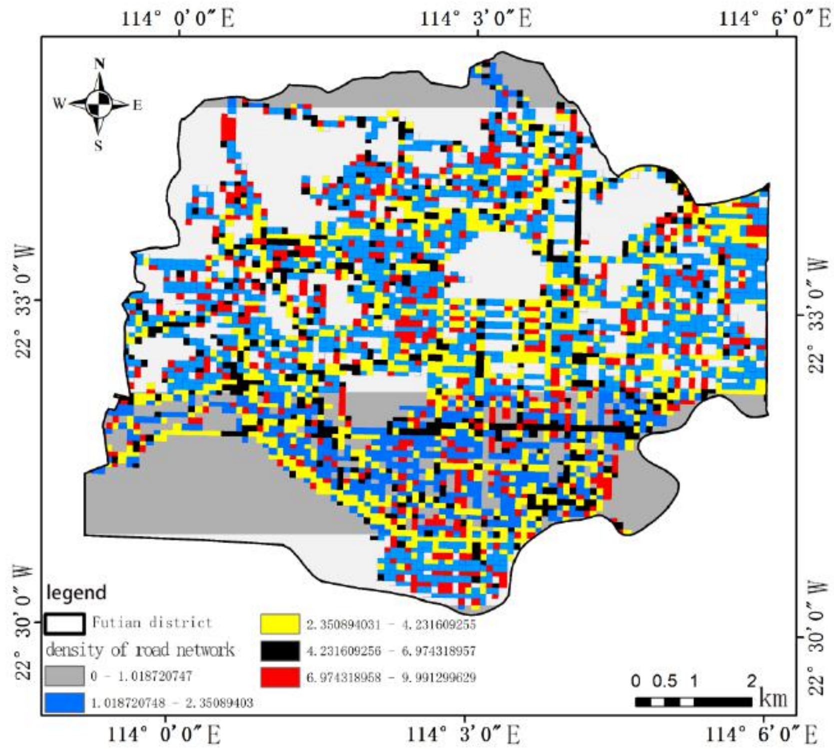

Fig.4 Road Network Density Map

In addition, combining elevation and road network data, the spatial distribution of density was analyzed, and the results showed that (Figure 5):

1. The road network density is distributed in the area of 0-1.018720747, mainly in the northern Tanglang Mountain Park and Yinhu Mountain Park, and the terrain is relatively high compared to the city center area, with fewer roads and low road network density. To the west of the south is Shenzhen Bay, and to the east is the boundary area between Hong Kong and Shenzhen, which belongs to the port area with low traffic demand and a sparse road network.

2. The area with a road network density between 1.018720748 and 2.35089403 is the distribution area of main roads within the urban area. The main roads account for about half of the total road area, so there are more blue grid points.

3. The areas with a road network density ranging from 2.350894031 to 4.231609255 are the North Ring Road auxiliary road, the Beijing-Hong Kong-Macao Expressway, and the areas near the Shenzhen Municipal Government in the city center. These areas surround the city center but are also at a certain distance from the city center, resulting in high and concentrated travel demand. Therefore, there are relatively few blue grid points (city main roads), mainly expressways with relatively small traffic volumes.

4. The road network density ranges from 4.231609256 to 9.991299629, distributed along relatively high-traffic main roads such as Binhe Avenue and Huanggang Road. These traffic lines pass through the urban area, have high traffic volume, and connect important industrial and commercial areas, so the traffic network density is relatively high.

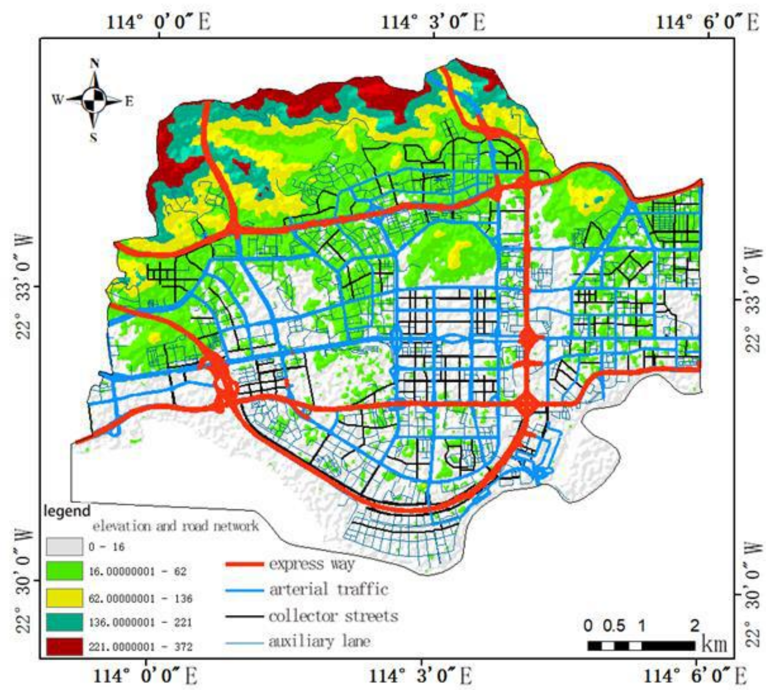

Fig.5 Elevation and Road Network Distribution Map of Futian District

In addition, the analysis of the data of four kinds of traffic lines of the Class I to fourth-class highway in Futian District shows that the total area of the area is 79.928048 km², the total length of the road is about 978.140659 km, and the total density of the road is about 12.23776488 km/ km² (Table 4).

Table 4 Four Traffic Routes in Futian District

Road network type	Route（km）	Area（km²）	Density
First-class highway (expressway)	143.951643	79.928048	1.801015
Second-class highway (main road)	381.849904	79.928048	4.777420
Third-class highway (secondary trunk road)	142.880595	79.928048	1.787615
Fourth-class highway (branch road)	309.458517	79.928048	3.871713
Total	978.140659	79.928048	12.237764

According to the requirements of the national standard GB50220-95, the density of expressways in large cities with a population of more than 2 million is 0.4–0.5 km/ km², while the density of expressways in Futian District, Shenzhen, is about 1.8, greater than 0.5, which meets the requirements of the national standard and is overfilled, with a density of 3–4 times that of the national standard.

The national standard requires a density of 0.8–1.2 km/km² for main roads, while the density of main roads in Futian District is about 4.78 km/ km², which is greater than 1.2. It also meets the requirements of the national standard and is over fulfilled, with a density of about 4–5 times that of the national standard.

The national standard requires a density of 1.2–1.4 km/km² for secondary roads, while the density of secondary roads in Futian District is about 1.79 km/km², which is greater than 1.2. This also meets the requirements of the national standard. Although it has been exceeded, it is not much, about 1.25–1.55 times the national standard, which is relatively small compared to the first two types of roads.

The national standard requires a density of 3–4 km/km^2 for branch roads, and the density of branch roads in Futian District is about 3.87 km/km^2, which is greater than 3 but less than 4. It also meets the national standard requirements, but there is no excess.

Overall, the density of roads at all levels in Futian District meets the requirements of national standards. This indicates that there are sufficient roads in Futian District to meet transportation needs. A road network with appropriate density can better disperse traffic and provide multiple selectable paths. This helps to reduce traffic congestion, alleviate traffic pressure, and ensure smooth traffic. By increasing road density, vehicles can more conveniently choose shorter driving routes, thereby reducing travel time. This is beneficial for both residents and businesses, as it can improve efficiency and save costs. Appropriate road density can also reduce the mutual influence and conflict between vehicles and the risk of traffic accidents. By providing spacious roads, good visibility, and reasonable traffic signs, drivers' alertness and road safety can be improved. Meanwhile, reasonable planning of road density can better meet the travel needs of residents and commercial activities. Citizens can easily reach their destinations, and commercial activities are more conducive to development.

4.1.2 Road Area

According to the analysis of road area data from level 1 to level 4 (Table 5), the total road area is 24.707697 km^2. According to Part 7, 7.1.4 of GB50220-95, it can be seen that the area of urban road land should account for 8%–15% of the urban construction land area, and for large cities with a planned population of over 2 million, it should be 15%–20%. In addition, according to the data of various land use areas in Futian District, the total area of various land uses is 75.534294 km^2, of which the total area of water bodies is 4.4 km^2 not included in the land area. In addition, the area of road land accounts for 32.71% of the urban facility area, while Shenzhen is a megacity with a population of tens of millions, and the selection criteria should be 15%–20%. 32.71% is greater than 20%, which meets the requirements of national standards and is about 1.5–2 times the standard.

According to the area data of the first to fourth level roads (Table 5), the width of the expressway is 0.035 km and the area is approximately 5.0 km^2, accounting for approximately 20.39% of the total area; the width of the main road is 0.03 km, with an area of approximately 11.4 km^2, accounting for approximately 46.38% of the total area; the width of the secondary main road is 0.025 km, with an area of approximately 3.57 km^2, accounting for approximately 14.45% of the total area; and the width of the branch road is 0.015 km, with an area of approximately 4.64 km^2, accounting for approximately 18.78% of the total area. According to the requirements of GB50220-95, the width of expressways in large cities with a population of over 2 million should be 40–45 m, the width of main roads should be 45–55 m, the width of secondary roads should be 40–50 m, and the width of branch roads should be 15-30 m.

Table 5 Data Table for Area of Fourth Class Roads

Road network type	Route（km）	Width（km）	Area（km^2）	Rate (%)
First-class highway (expressway)	143.951643	0.035	5.04	20.39
Second-class highway (main road)	381.849904	0.03	11.46	46.38
Third-class highway (secondary trunk road)	142.880595	0.025	3.57	14.45
Fourth-class highway (branch road)	309.458517	0.015	4.64	18.78

Total	978.140659	0.105	24.707697	24.707697

According to the comparison of the analyzed data, it can be seen that the width of the expressway is 35m<40m, which is 5m less than the minimum value of the national standard and does not meet the requirements of the national standard; the width of the urban main road is 30m<45m, which is 15m less than the minimum value of the national standard and seriously does not meet the requirements of the national standard. The width of urban secondary roads is 25m<40m, which is 15m less than the minimum value of the national standard, and it also seriously does not meet the requirements of the national standard. The width of the urban branch road is 15m, which meets the minimum requirement of 15m in the national standard and just meets the requirements of the national standard.

To sum up, except for the branch road (fourth-class highway), which meets the minimum requirements of the national standard, the other three types of Class I, II, and III roads in the area do not meet the requirements of the national standard; even some of them are seriously inconsistent. Road areas that do not meet national standards may have an impact on traffic smoothness, safety, and driving comfort. Especially during peak hours or busy areas, the width of the road is insufficient to accommodate a large number of vehicles, resulting in traffic flow exceeding the carrying capacity of the road and causing congestion and delay. Narrow roads can also easily lead to collisions and friction between vehicles, especially in situations of high traffic volume or fast speeds. In addition, the narrow space near the road may limit the field of view and increase the risk of blind spots and pedestrians. Moreover, insufficient road space may make the driving experience uncomfortable. Vehicles driving on narrow roads may be restricted and unable to maintain a stable speed and direction.

In addition, when the road area is insufficient, the distance between vehicles and other vehicles or obstacles will decrease, bringing unnecessary pressure and tension to the driver. Therefore, in order to ensure traffic safety and smoothness, the road area in Futian District, Shenzhen, should be reasonably planned and designed according to national standards and actual traffic needs.

4.1.3 Road Slope

In terms of road slope analysis, seven long and representative roads were selected as the main ones, namely Shennan Avenue, Binhai Avenue Auxiliary Road, Hongli Road, Xinzhou Road, Beihuan Avenue Auxiliary Road, Caitian Road, and Xiangmihu Road in Futian District. Due to the fact that the length of these seven main roads exceeds 4000 m, an average of 1000 m segments was used for analysis. Taking Shennan Avenue as an example, this road has a total length of 12,300 m and is divided into 13 sections within a range of 1000 m (with the last section of the road being 300 m). In addition, the average elevation of Shennan Avenue has a maximum value of 19.6m and a minimum value of 10.5, due to the relatively small slope fluctuations of roads in Futian District. According to the slope formula, the main road slope of Shennan Avenue is 0.07%.

According to the requirements of urban land suitability evaluation, the maximum longitudinal slope gradient of general highway design is inversely proportional to the speed per hour. According to the relevant records of China Railway Corporation, the maximum speed required for general expressways is 80 km/h, so the maximum longitudinal slope is 5%. The maximum speed required for the main road is 60 km/h, so the maximum longitudinal slope is 6%. The analysis of data related to the seven main roads (Table 6, Figure 6) shows that the slopes of all seven main roads meet the requirements.

Table 6 Data Table for Seven Main Roads

Title	Shennan avenue	Binhai Avenue Auxiliary Road	Hongli Road	Xinzhou Road	Beihuan Avenue Auxiliary Road	Caitian Road	Xiangmihu Road

Length (m)	12300	12500	9800	6100	7600	5500	4000
Highest elevation (m)	39	37	42	36	105	46	60
Lowest elevation (m)	-10	-5	-5	-6	14	-4	-10
Height difference (m)	49	42	47	42	91	50	70
Path length (m)	12300	12500	9800	6100	7600	5500	4000
Slope	0.00398	0.00336	0.00479	0.00688	0.01197	0.00909	0.0175
Slope（%）	0.398%	0.336%	0.480%	0.689%	1.197%	0.909%	1.750%

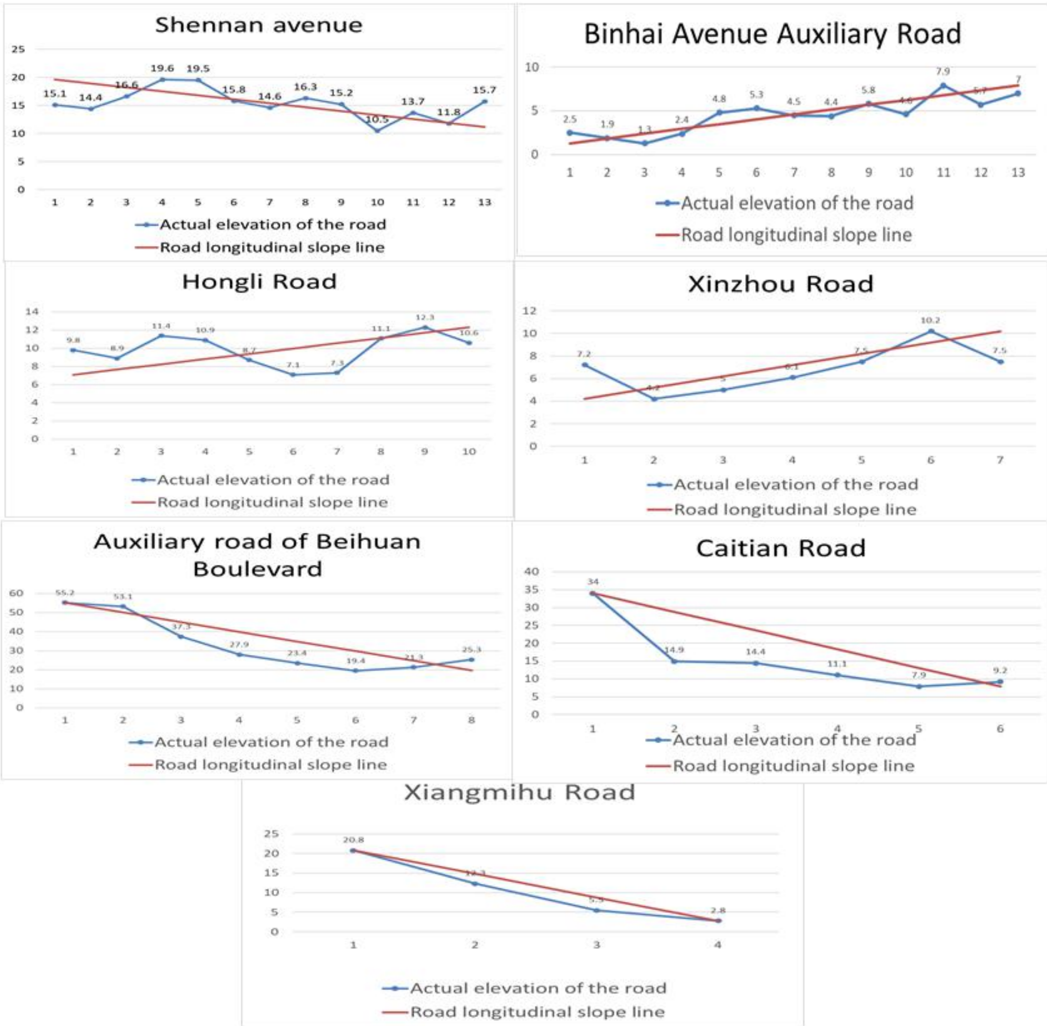

Fig.6 Slope of Seven Main Road

Divide the highest and lowest elevations of the seven main road-related data points by 100 meters and calculate the average data. Compared with the 1000-meter division method, the data is more accurate, and calculating the longitudinal ratio of the road will be more in line with the expected value. Taking Shennan Avenue as an example, the slope value calculated through the main road slope formula is 0.398%, which is in line with the expected value, while Xiangmihu Road has the largest difference in slope, which is 1.75%. However, no matter which road it is, its longitudinal slope ratio is far lower than the national standard. If the slope is too small, it will increase the burden of road maintenance because it is not conducive to drainage and is prone to water retention. Over time, it will lead to road deformation and sand formation, affecting the service life of the road.

Therefore, the slope construction of roads in Futian

District should comply with the road slope specifications. During road construction, the slope should be appropriately controlled to ensure vehicle safety, stability, and comfort, and to provide better services for driving customers.

4.2 Evaluation of Bus Route Network

4.2.1 Public Transportation Network Density

This study conducts a comprehensive evaluation of the public transportation network in Futian District, based on the route indicators of network structure, including repetition coefficient, nonlinear coefficient, station road network density, and nearest station indicators. The density of the public transportation network reflects the degree to which residents travel close to the line and is an important indicator for evaluating the level of public transportation service. The density specification for urban public transportation networks requires 3–4 km/km², while the density specification for public transportation networks in urban fringe areas requires 2–2.5 km/km². According to the analysis, the density of public transportation networks in Futian District is 3.056 km² (Table 7), which meets the national requirements for the density of public transportation networks in the main urban area. According to the analysis of spatial distribution, it is also shown that the bus stops are relatively dense (Figure 7).

Table 7 Public Transport Network Density in Futian District

Traffic network density	Total length of public transportation（km）	Area（km²）	Public transportation network density（km²）
	244.2	79.93	3.056

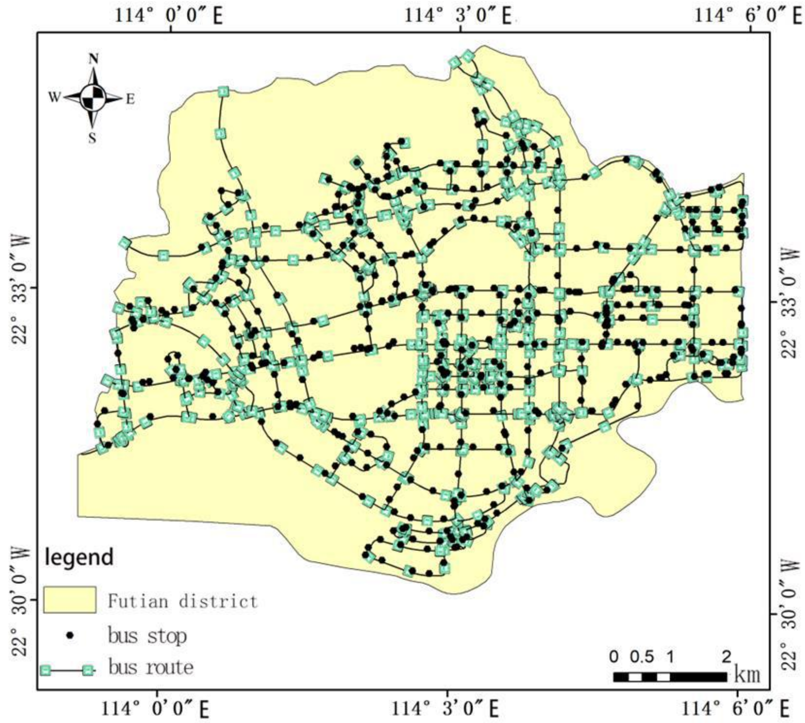

Fig.7 Spatial Distribution of Bus Routes and Bus Stops

4.2.2 Repetitive Coefficient of Public Transportation Lines

The coefficient of route repetition is the ratio of route density to network density, where route density refers to the ratio of the total length of bus operation routes to the area of urban land with bus services, and network density refers to the ratio of the road mileage of the routes laid out in the area to the area of urban land with bus services. Analysis shows that the repetitive coefficient of public transportation lines in Futian District, Shenzhen, is 7.74 (Table 8), which is greater than the standard of 1.25–2.5 in the "Transportation Engineering Manual" for the network repetitive coefficient. Thus, the number of public transportation lines in Futian District, Shenzhen, far exceeds the national standard, which can easily lead to resource waste of public transportation resources and urban traffic congestion, increase the occurrence of traffic accidents, but provide more options. To some extent, it has saved residents' travel time and costs. Thus, there is still a need for renovation in the construction of public transportation in Futian District, gradually reducing the repetitive coefficient and avoiding unnecessary resource waste.

Table 8 Repetitive Coefficient of Public Transportation Network in Futian District

Repetitive coefficient	Total length of bus routes（km）	Total length of public transportation（km）	Repetitive coefficient of public transportation lines
	1890.96	244.2	7.74

4.2.3 NonLinear Coefficient of Public Transportation Lines

Data shows that the nonlinear coefficient of public transportation routes in Futian District is 1.45, slightly greater than 1.4 (Table 9). Overall, the impact is not significant, but for residents in some areas, it will increase time and travel costs, as well as government and public funding and infrastructure construction costs. It is recommended to further adjust the public transportation routes in Futian District, reduce the nonlinear coefficient, and align with national standards.

Table 9 Nonlinear Coefficient of Public Transportation Network in Futian District

Nonlinear coefficient	Nonlinear coefficient of public transportation lines
	1.45

4.2.4 Public Transportation Service Area

According to the national standard GB 50220-1995, the service area of public transportation stations, calculated with a radius of 500m, shall not be less than 90% of the urban land area. Analysis shows that although the number of bus stops in Futian District can reach 86.9%, the coverage rate of bus stops at 500 meters is only about 33.7%, and the coverage rate of bus stops at 800 meters in the area is about 53.2% (Table 10). The bus service area within 500m is far below the national standard, and it is necessary to vigorously strengthen the service scope of bus stops.

Table 10 Density of Public Transport Network Service Areas in Futian District

Service area density	500m Service area density	800m Service area density	Overall site density
	33.7%	53.2%	86.9%

Analysis shows that the 500m service area is only densely distributed on the southeast side of Futian District (Figure 8), and there are almost no 500m station service areas in the west and central west. This will be detrimental to the comprehensive development of Futian District. It is necessary to strengthen the number and area of 500m station service areas in the central and western regions and promote the coordinated development of transportation in the east and west. This is a direction that the Futian District government needs to consider and improve in the construction of bus station service areas.

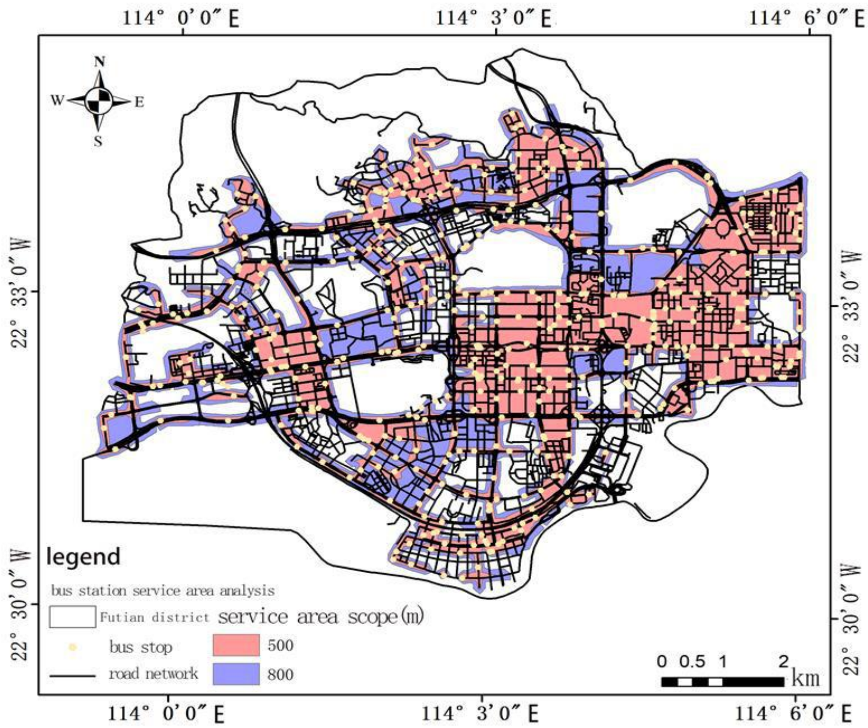

Fig.8 Scope of Bus Stop Service Area

4.2.5 Nearest Stop for Public Transportation

Calculate the average distance between the bus stop and its nearest bus stop (Table 11). The data shows that the average distance of the distribution of stations in Futian District is less than 500m, mostly within a reasonable range. Among the surveyed stations, only the distance from the exhibition center south to Dongfang Yayuan is more than 500m, which is basically in line with the national standard GB50220-1995. However, it is still recommended to adjust the distribution of some stations, improve the distribution network of public transportation stations, and make it more reasonable.

Table 11 Recent Sites Table (Screenshot)

Input ID	Target ID	Distance(m)	Average distance (m)
Xiasha 2	Xiasha 1	212.19	
Xiasha 2	Tairan 9th Road	209.04	214.38
Xiasha 2	Xiasha	221.90	
Exhibition Center South	Dongfang Yayuan	516.60	
Exhibition Center South	Yitian Middle Road	343.88	443.50
Exhibition Center South	Mintian Road Bus Terminal	470.02	
Union Square 2	Union Square	72.08	
Union Square 2	Union Square1	68.95	164.23
Union Square 2	Gaoxun Building	351.66	

V. CONCLUSION

This article uses factor analysis such as slope, average station distance, nonlinear coefficient, road area, service area, and public transportation network repetitive coefficient to obtain a series of evaluations on the road network and public transportation routes in Futian District, Shenzhen.

According to the analysis of traffic network density, the overall difference in road network density in Futian District, Shenzhen, is significant, with a high density in the southeast and a low density in the northwest. The traffic network is mainly distributed in the east, south, and west regions. Except for the branch roads (fourth level roads) that meet the national standard, the remaining first, second and third level roads in the urban road area do not meet the requirements of the national standard, and some even seriously do not meet the requirements and should be taken seriously and improved. In terms of the slope of the main roads, the seven representative roads selected all meet the requirements.

The public transportation network density of public transportation is 3.056km^2, which meets the national requirements for the density of public transportation networks in main urban areas. The repetitive coefficient of public transportation lines is 7.74, which is greater than the standard of 1.25–2.5 for the network repetition coefficient specified in the Transportation Engineering Manual. The nonlinear coefficient is 1.45, slightly greater than 1.4. The nonlinear coefficient of bus routes is too high, which can lead to a long detour distance and increase the travel time cost of passengers, which is not conducive to attracting bus passenger flow. In the long run, the increase in transportation costs will be detrimental to the cost-effectiveness of urban travel. In addition, the bus service area within 500m of Futian District is far below the national standard, and it is necessary to vigorously strengthen the service scope of bus stops.

Overall, based on the evaluation of the road network and bus routes in Futian District, Shenzhen, this article found that the planning of the district has shortcomings, mainly manifested in the fact that the urban road area does not meet national standards, the nonlinear coefficient of bus routes is too high, and the bus service area within 500m is far below national standards. If Futian District wants to further develop its city, it should face up to the shortcomings in road design and public transportation layout, explore its own advantages, and adjust its planning strategy to seek new directions and strategies. However, taking the shortage of urban land resources in Futian District as an example, the road network construction in the future of the city may need to develop in a three-dimensional direction, but this is not conducive to the landscape shaping of the city. Therefore, it is necessary to plan the corresponding measures as soon as possible.

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