The Impact of Road and Railway Transportation Networks on Suzhou's Urban Accessibility and Agglomeration Economy

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Abstract. In the year 2000, Guangzhou proposed the urban spatial development strategy of "Eastern Expansion, Western Integration, Southern Extension, and Northern Excellence." By 2010, the initial framework of the "Two Cores, Four Cities" urban spatial pattern was established. Subsequently, the strategy incorporated a "Central Adjustment" to further optimize the urban development layout, aiming to shape a multi-centered, cluster-based, network-oriented urban spatial structure by 2020. Against this backdrop, this study employs Geographic Information Systems (GIS) to divide and calculate the density of Guangzhou's railway and road networks. Furthermore, by combining the measurement of temporal accessibility of the rapid rail transit (metro) network, a comprehensive evaluation of urban accessibility in Guangzhou's central area is conducted. The study analyzes the spatial characteristics and investigates the effects of railway and road networks on urban accessibility and agglomeration economy through an examination of both the central and peripheral regions of Guangzhou.

Keywords: Accessibility; Transportation Infrastructure; Transportation Network; Agglomeration Economy; Guangzhou

1 Introduction

The essence of urban development lies in enhancing accessibility and fostering economic agglomeration. As a pivotal component of urban transportation, the railway transportation network holds profound influence on urban accessibility and agglomeration economy.

Accessibility, introduced by Hansen (1959), stands as a core concern in transportation geography. It serves as a key performance indicator in the fields of transportation network analysis, transportation planning, and land use[1] (Geurs and van Wee, 2004; Kim and Song, 2018; Östh et al., 2018). Accessibility is often defined as the potential for interaction opportunities (Hansen, 1959) or the ease of reaching any land use activity from a specific location within a given transportation system (Dalvi and Martin, 1976) [2].

However, variations exist in the definition of accessibility across multiple studies, leading to numerous measurement models being proposed [3] (Geurs and van Wee,

Z. Wang et al. (eds.), *Proceedings of the 2023 2nd International Conference on Public Service, Economic Management and Sustainable Development (PESD 2023)*, Advances in Economics, Business and Management Research 273,
https://doi.org/10.2991/978-94-6463-344-3_59

However, variations exist in the definition of accessibility across multiple studies, leading to numerous measurement models being proposed [3] (Geurs and van Wee, 2004; Alam et al., 2010; Geurs and van Wee, 2013; Malekzadeh and Chung, 2020). In this paper, accessibility is defined as the extent to which individuals or groups of passengers can reach their destinations within a particular urban transportation system[4].

Agglomeration economies constitute an economic concept that has been observed throughout various historical periods. It gradually developed within the realms of economic geography and regional economics, arising from the observation that when enterprises and populations concentrate in specific geographic areas, certain economic benefits emerge[5]. These economies describe the various economic benefits and scale effects that can be enjoyed when businesses and populations congregate in a specific location. Urban agglomeration economies represent a central driving force behind modern urbanization and economic development. As urban areas expand in size and economic activities increase, the accessibility between different regions plays a crucial role in the development of agglomeration economies.

In summary, regional accessibility is influenced not only by its geographical position within the transportation network but also closely correlated with factors reflecting the level of socio-economic development and infrastructure completeness (Geurs et al., 2004; Chen et al., 2011; Ahlfeldt et al., 2011; Chen et al., 2007; Liu Xianteng, 2007; Wang Guogang et al., 2013). Therefore, considering factors such as regional location, transportation infrastructure development, and utilizing regular grid cells to partition the urban area of Guangzhou, this study comprehensively evaluates urban accessibility based on indicators including subway network temporal accessibility, road conditions, and land use structure (spatial distribution of residential areas, public and commercial service locations), incorporating socio-economic perspectives[6]. The study conducts an analysis of its spatial characteristics, explores the interaction between location factors and accessibility, reveals the overall spatial pattern of accessibility, and highlights interregional differences within the research area. This provides a scientific reference for urban construction and development planning.

2 Data and Methods

Currently, Guangzhou covers a total area of 7,434.4 km^2 and administers 10 districts and 2 county-level cities, with the urban area accounting for 5,843.43 km^2, or 51.7% of the total area. The selected research areas are centered around the older districts of Yuexiu, Haizhu, and Liwan.

Considering that rapid rail transit (subway) operates as a fast, point-to-point, and leap-frogging system, and the spatial distribution of the subway network exhibits characteristics such as extensive coverage and long distances between stations, analyzing small-scale network densities may not adequately reflect their impact on overall accessibility. Therefore, a distinct approach is employed for assessing subway network accessibility as opposed to other transportation facilities, ensuring operational feasibility. The evaluation of subway network accessibility is carried out using a matrix analysis-based approach. The convenience of spatial connections in transportation networks, as well as the ease of inter-node communication, reflects their degree of connectivity (Wang et al., 2009). Given that the subway network is fully connected, meaning any two stations (nodes) are interconnected through rail lines, time is selected as the measure of inter-station connectivity based on rail line connections. Initially, by utilizing the subway travel planning query function provided by Guangzhou Metro Company's website, the time required for a station to reach another station via rail lines is obtained, constructing a time matrix T with the following formula[7]:

$$T = \left[t_{ij}\right]_{m\times n}$$

The smaller the sum of the time required for a station to reach various other stations through rail lines, the better the level of accessibility for that station. Based on the time matrix T, the temporal accessibility of station i is defined as follows:

$$T_i = \sum t_{ij}$$

To further assess the relative accessibility levels of various stations within the rail transit network, the average accessibility value of all stations is used as a benchmark. The time accessibility coefficient of a station is then calculated by comparing its accessibility value to this benchmark. The expression is as follows:

$$m(i) = \frac{T_i}{(\sum T_i)/n}$$

The smaller the value, the better the relative accessibility of station i. When the value is less than 1, it indicates that the station's accessibility level is higher than the network-wide average. Conversely, when the value is greater than 1, it signifies that the station's accessibility level is below the network-wide average.

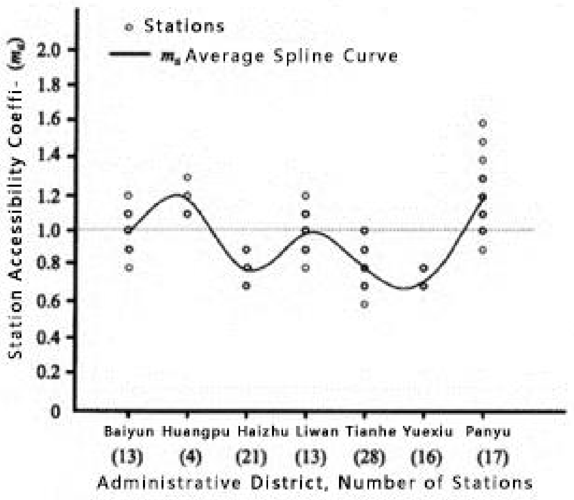

Fig. 1. Scatter plot of time accessibility coefficients of metro stations in Guangzhoue

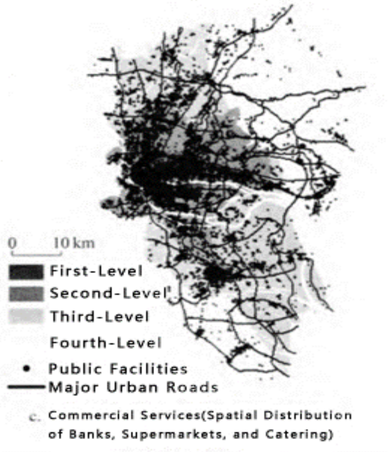

Fig. 2. Spatial distribution of infrastructures in the urban area of Guangzhou

Table 1. Number and density of urban infrastructures in different areas in Guangzhou

Zoning	Area/km^2	Public Facilities		Commercial Service Facilities		Residential Areas	
		Number/Units	Density (Units/km^2)	Number/Units	Density (Units/km^2)	Number/Units	Density (Units/km^2)
First-Level	105.5	2574	24.3	12418	117.6	1955	18.5
Second-Level	425.5	2732	6.4	13912	32.6	1588	3.7
Third-Level	884.6	2010	2.3	8977	10.1	427	0.5
Fourth-Level	1027.2	513	0.5	821	0.8	52	0.1
Total	2442.8	7829	/	36128	/	4022	/

3 Results and Analysis

In Fig. 1, the application of the formula to calculate the time accessibility coefficients of various subway stations in Guangzhou reveals that the station with the highest temporal accessibility is Tiyu Xi Station, with a coefficient of nearly 0.5. In Fig. 2, a scatter plot displays the distribution and dispersion of accessibility coefficients for subway stations within each administrative district, with the spline curve representing the average values within each district. The results indicate that stations with lower values (higher accessibility) are concentrated in the districts of Yuexiu, Haizhu, and Tianhe, among which Yuexiu has the lowest average value (reaching 0.7), followed by Haizhu and Tianhe (0.8). This is attributed to the denser distribution of lines and stations within these three districts (65 stations in total, accounting for 58% of the total). On the other hand, Baiyun, Liwan, Huangpu, and Panyu districts have average station values greater than 1.0, indicating poorer overall subway network accessibility in these areas.

The preceding analysis focused on the spatial pattern of temporal accessibility within the subway network coverage area. However, due to the spatial scale and station coverage of the Guangzhou subway network, it is challenging to comprehensively reflect the accessibility and characteristics of the entire research area. Therefore, integrating the spatial distribution characteristics of transportation infrastructure density, a regional accessibility comprehensive evaluation and zoning are conducted based on subway network temporal accessibility analysis. Fig. 2 displays the continuous spatial distribution characteristics of road and public transit route densities generated using the Kriging interpolation method in ArcGIS. It is evident that there is a strong correlation between the density distributions of roads and public transit routes. From a location layout perspective, both road and public transit route density distributions exhibit concentric structures in space, extending towards the east and west wings. High and medium-density locations are concentrated in the urban core areas, indicating a strong centripetal location orientation of transportation infrastructure layout.

Building upon this, a comprehensive evaluation of overall accessibility is further conducted using the dual indicators of transportation infrastructure density accessibility index and subway network temporal accessibility index for each grid area. The regions are classified into accessibility levels using a natural breakpoint method, resulting in four major levels.

In Table 1, the first-level region covers an area of 105.5 km^2, accounting for 4.3% of the total research area. Its location layout corresponds with the urban core area of Guangzhou. This region boasts the most comprehensive transportation infrastructure construction and the highest level of regional transportation accessibility.

The second-level region covers an area of 425.5 km^2, constituting 17.4% of the region. Encompassing the first-level region, it extends north to Jiahe Town (including Baiyun New Town), south along Xinguang Expressway to Panyu Shiqiao, west to the boundary of Foshan Nanhai District (including Huadi New Town), and east to the Olympic Sports Center. The transportation infrastructure in the second-level region is relatively well-developed, resulting in a favorable level of regional transportation accessibility.

The third-level region covers an area of 884.6 km^2 and is divided into two parts by the first and second-level regions. The northern part is served by Metro Lines 2 and 3, while the southern part includes the University Town and Guangzhou New Town Center, also covered by Metro Lines 2, 3, and 4. The area has fewer subway lines with greater distances between stations (average exceeding 2 km), and several lines in the southern part lack transfer stations, leading to significantly lower subway network temporal accessibility (up to 1.8).

The fourth-level region covers an area of 1027.2 km^2 and lacks subway network coverage. The boundary lines between this region and other levels overlap with the subway network temporal accessibility dislocation lines. This region possesses the weakest transportation infrastructure and the poorest regional accessibility among all levels.

4 Conclusion

Transportation infrastructure density describes the degree of spatial distribution of transportation resources and is a crucial factor in characterizing urban transportation accessibility. It also indirectly reflects the level of regional socio-economic development. Taking Guangzhou's urban area as an example and combining spatial analysis of subway network temporal accessibility[8], this study achieved a comprehensive evaluation of urban accessibility using multiple indicators and improved specific calculation methods for different evaluation criteria.

The study results reveal that the temporal accessibility of Guangzhou's subway network and the spatial pattern of road and public transit route density distribution exhibit concentric circle structures. This pattern indicates a gradual decline in accessibility from the urban core area outward, reflecting the impact mode and degree of the spatial layout of transportation infrastructure in Guangzhou, which extends from the core area to the surrounding regions[9]. Simultaneously, the comprehensive evaluation of urban accessibility in Guangzhou reveals significant regional differences within the "Two Cores, Four Cities" framework. The city's spatial layout and architecture require further enhancement and optimization. Among these, the Tianhe New Town Center benefits from its advantageous location in the urban core area, resulting in the highest level of accessibility. The Olympic Sports Center, Huadi New Town, and Baiyun New Town lie at the junction between the urban core area and the outskirts, with relatively good transportation conditions. However, the University Town has weak connections with the outside world, leading to lower overall accessibility. Guangzhou New Town Center is spatially distant from the urban core area and lacks comprehensive transportation infrastructure, particularly a well-developed arterial road network and public transit network support, resulting in the lowest level of accessibility.

The accessibility index calculated using GIS tools demonstrates that accessibility in the central area of Guangzhou is significantly higher than that in the peripheral areas. This disparity arises from the well-developed railway transportation network in the city center, enabling residents to swiftly reach major commercial and office districts[10]. In contrast, private transportation networks in the peripheral areas are relatively underdeveloped, leading to longer travel times and lower accessibility.

By measuring the economic activity density in different regions, it can be inferred that there is a positive relationship between urban accessibility and agglomeration economy. When urban accessibility improves, economic activities tend to concentrate in the city center or areas with higher accessibility, thereby promoting resource concentration in specific regions.

Furthermore, the study analyzes the impact of railways and roads on accessibility and economic agglomeration. The results indicate significant differences in the influence of road and railway networks on urban accessibility. Specifically, railways contribute significantly to enhancing accessibility in the city's core area, while roads play a more crucial role in improving accessibility in the peripheral areas. Improvements in railway transportation lead to a considerable increase in economic activity agglomeration in the city's core area, with a notable agglomeration effect. On the other hand, improvements in road transportation highlight more pronounced dispersion effects within the city.

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