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Analysis and Research of Urban Public Transport Network Based on ArcGIS

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Abstract

With the continuous growth of urban populations and vehicles, traffic issues have become increasingly severe. The layout of public transport networks requires scientific planning, with evaluation analysis serving as the foundation for optimization. To address this, this study utilizes Python to obtain open-source data on Kunming's bus network. By employing spatial analysis and statistical methods in ArcGIS, we conducted evaluations at three levels—station, route, and network—based on established assessment criteria, providing a basis for public transport network planning in Kunming. The research employs Python code to acquire bus network data, overcoming challenges such as data accessibility and sample scarcity. The code is scalable to support nationwide urban studies. Results indicate: At the station level, 100% coverage rate within 500 meters and 89.47% coverage rate within 300 meters were achieved in central urban areas, rated as Level 1, indicating close proximity to stations and high service quality. However, the station density of approximately 6 per square kilometer was rated as Level 5, reflecting low station density. At the route level, the repetition coefficient of bus routes in central urban areas reached 3.37 (Level 3), suggesting excessive route duplication and reduced travel efficiency. The non-linear coefficient of bus routes was 1.53 (Level 3), further indicating inefficient travel patterns. At the network level, the bus network density in central urban areas stood at 6.01 km2/km2 (Level 1), demonstrating high accessibility to bus routes and superior service quality. In general, the public transport resource allocation in the built-up area of downtown Kunming is not high, the development of urban public transport is not coordinated with the regional social and economic development, and the regional public transport service level needs to be further improved.

Keywords: Urban Bus; Geographic Information System; Network Index System; Spatial Analysis Method

1. Introduction

In recent years, with the rapid economic growth and accelerated urbanization in our country, the urban population and number of vehicles have been increasing, making urban transportation face increasingly challenging tasks. Issues such as traffic congestion, road safety, and environmental pollution are receiving growing attention from the public (Liu, 2012). Public transportation, with its high capacity and efficient use of road resources, offers a new solution to traffic congestion (Zhang et al., 2012). It is one of the key infrastructure projects for urban development (Sun, 2016). Early domestic research primarily focused on technical performance indicators of public transit networks, such as network density, repetition coefficient, and non-linear coefficient. As the "people-oriented" philosophy in public transportation systems deepened, studies gradually expanded to service dimensions including passenger accessibility, transfer convenience, stop coverage, and average travel time. Zhu (2022) established Anhui Province's public transport evaluation system encompassing three dimensions: operational capacity, service capability, and development potential. This framework innovatively incorporated government investment, new energy proportion, and intelligent dispatching into the evaluation criteria, marking an extension from "infrastructure" to "governance capability" in public transport assessment. Meng (2020) developed a three-tier evaluation index of "stop-route-network" based on GIS buffer zone and overlay analysis, revealing resource allocation disparities between Shenyang's urban core and peripheral areas. Wu et al (2022) applied Floyd-Warshall algorithm and GIS network analysis to dynamically assess passenger travel costs in Hanzhong City, achieving 31.88% improvement in stop coverage and 28.02% increase in route coverage after optimization.

Foreign scholars have conducted in-depth research on public transportation network systems. Evaluations of urban public transport networks have evolved from single-dimensional to multi-dimensional approaches, shifting from static to dynamic perspectives and qualitative to quantitative analyses, forming a systematic theoretical framework. Lin et al (2021) developed standardized evaluation tools to assess transit network performance in three cities including Stonington, establishing a four-dimensional standard matrix encompassing "infrastructure-service-economy-sustainability" dimensions. They applied the Analytic Hierarchy Process (AHP) model to quantify policy effectiveness. The findings indicate that local governments can conduct horizontal performance comparisons and dynamically adjust policies, though localized indicator weights are required. Zhang et al (2024) addressed route frequency and stop optimization challenges for multi-vehicle transit systems by developing an MILP model using real-time demand data collected via drones. This approach minimized passenger walking costs, construction expenses, and operational expenditures. Results showed that high-capacity parking solutions reduced overall costs by 9.09% compared to low-capacity alternatives under high-cost scenarios, necessitating budget-service balance. Sun et al (2018) quantified accessibility to evaluate fairness in public transport resource allocation. They improved London's PTAL system by incorporating off-stop walking time and stop spatial distribution, assessing transit opportunities across Shenzhen's districts. Their conclusion highlighted that accessibility disparities reflect uneven regional development opportunities, emphasizing priority improvements

in low-accessibility areas' stop layouts. Lin et al (2021) applied complex network theory to optimize the public transportation network efficiency in Nanguan District, Changchun City. By incorporating passenger travel impedance and path probabilities, they developed an optimization model with network efficiency as the objective function. Using ant colony optimization algorithm for solution, the study achieved an 8.5% improvement in network efficiency post-optimization, demonstrating the applicability of complex network theory in urban transit planning for medium and small cities.

With the acceleration of urbanization, urban public transportation systems have become crucial for alleviating traffic congestion, reducing carbon emissions, and enhancing urban operational efficiency. The scientific and rational layout of these networks has gained increasing attention. Public transport network evaluation not only serves as a prerequisite for network optimization and planning, but also provides vital references for governments to formulate transportation policies and enterprises to adjust their operational strategies. This paper uses Python to scrape bus routes and bus stops in the central built-up area of Kunming from Gaode Map. By integrating spatial query and analysis functions, as well as spatial overlay analysis capabilities within Geographic Information Systems (ArcGIS), this study examines, analyzes, and evaluates the indicators of the bus network in the central built-up area of Kunming, providing insights for urban public transportation planning and design.

2. Data Sources and Analytical Methods

2.1. GIS Data and Tools

Geographic Information System (ArcGIS) refers to the application of systems engineering analysis and methods for collecting, storing, entering, querying, modifying, deleting, and analyzing basic geographic spatial data. This is used to provide planning, management, and decision-making research on population distribution, road distribution, infrastructure distribution, service levels, and regional travel characteristics (Zhao, 2017). With the rapid development of urban construction, ArcGIS-based cartography not only improves drawing speed and accuracy but also reduces errors caused by external environments. It further enriches map types and usage methods, enabling timely responses to changing needs within limited time frames, which facilitates information sharing (Li, 2020).

In this study, the use of arcgis software is as follows:

Data Import and Cleaning: Import the urban bus routes and stops data obtained from python into arcgis, using the coordinate projection function for coordinate system conversion. Since the latitude and longitude data of the obtained bus stops are duplicated, clean the duplicate bus stop data to ensure that the bus stop data matches and is complete with the actual bus route data.

Data statistics and integration: Use data statistics tools, such as summary statistics (summary statistics) and table statistics (table statistics), to calculate the density of bus stops and the length of bus network.

Data visualization: By establishing a buffer zone, the coverage area of bus stops 300 meters and 500 meters is drawn. The bus stop map and bus route map are drawn using drawing tools.

The geographic information system is used to complete data processing and data visualization, and the bus network indicators are further analyzed. Before the indicator analysis, the evaluation indicators need to be determined.

2.2. Evaluation Indexes of Urban Bus Network

Based on the complexity and extensive nature of urban public transportation systems, it is essential to establish a multi-level, unified, and comprehensive evaluation index system for urban public transport networks under the principle of overall completeness (Liu, 2016). To ensure that the selected indicators can objectively assess the development level of urban public transport, the selection should adhere to principles such as representativeness, objectivity, ease of acquisition, and calculability (Zhu, 2022). Given that the evaluation research and analysis of urban public transportation systems involve numerous complex factors, including population flow, route distribution, stop rationality, and network density, and considering that arcgis technology divides graphic elements into three categories—points, lines, and surfaces—the paper categorizes the evaluation indicators for urban public transport into three hierarchical structures: site level, route level, and network level (Liu, 2016).

Principal Component Analysis (PCA) is a statistical method used for dimensionality reduction and data analysis. The core idea of this method is to simplify the complex relationships in raw data into several principal components. Each principal component is a linear combination of the original variables, capable of reflecting most of the information in the raw data, and these components are mutually independent. By doing so, it is possible to retain important features of the original data while reducing its dimensionality, simplifying problems, and improving the efficiency and accuracy of data analysis. In this paper, PCA is used to divide the influencing factors of bus networks into three principal components: stop level, route level, and network level. The principal components are divided into five indicator layers. See Table 1(Liu, 2016) for the evaluation index system of urban bus networks.

Table 1. Evaluation index system of urban bus network

Top Class	Metric	Indicator Significance	Unit
Stop layer	Bus stop Coverage rate	Reflect the level of public transport services	%
	Bus stop density	Reflects the density of bus stops	units/km^2
Route layer	Bus route repetition coefficient	Reflect the number of bus routes in the section	/
	Bus route non-linear coefficient	Reflect travel time and distance	/
Network layer	Bus network density	Reflects the degree to which residents are close to bus routes	km/km^2

There are many methods to deal with the qualitative evaluation of indicators, such as analytic hierarchy process, Delphi method and five-level scale method, etc. Because the spatial coverage of urban public transportation is complicated, the five-level scale method is adopted for its simplicity and intuitiveness (Liu, 2016).

The evaluation index level of urban bus network is defined in Table 2 (Liu, 2016).

Table 2. Definition of evaluation index tier for urban bus network

Evaluation Tier	Rating	Description
Tier 1	Excellent	The index indicates a highly developed region with abundant resource availability
Tier 2	Good	The index reflects a well-developed region with sufficient resource availability
Tier 3	Average	The index suggests moderate development with basic resource availability
Tier 4	Marginal	The index shows underdevelopment with scarce resource availability
Tier 5	Poor	The index reveals critical developmental gaps with highly inadequate resource availability

2.3. Quantification and Classification of Urban Bus Network Indicators

The quantification of indicators plays a crucial role in the evaluation system for urban bus networks. The rationality of each indicator's quantification method directly affects the accuracy of the evaluation results(Liu, 2016). First, it is necessary to determine the nature of the city being studied and identify its type. For the classification of city types, see Table 3.

Table 3. Definition of urban type and grade

City Type	Tier Category	Permanent Urban Population (10,000)
Megacity	Category I	≥1000
Super-large City	Category II	500-1000
Large City	Category III	100-500
Medium City	Category IV	50-100
Small City	Category V	< 50

2.3.1. Bus Stop Coverage

Bus stop coverage is a crucial indicator for measuring the service level of the bus system, reflecting how close residents are to bus stops. The service coverage area for bus stops is calculated as follows: for medium and small cities, using a 200 m radius; for megacities and large cities, using a 300 m radius. It should not be less than 50% of the urban planning and construction land area; when calculated with a 500 m radius, it should not be less than 90%. To improve the spatial accessibility of bus services, in practice, the service area ratio within a 300 m radius can be appropriately increased based on different city and regional conditions.

Computational formula:

$$\boldsymbol{R = \left(\frac{C}{U}\right) \times 100\%} \quad (1)$$

In the formula:

R —— Bus stop coverage rate

C —— Public transport service coverage area

U —— Urban built-up area

The evaluation value of urban bus stop coverage rate is shown in Table 4(Liu, 2016).

Table 4. Evaluation criteria for urban bus stop coverage rate by city tier

City Category	Tier 1 (%)	Tier 2 (%)	Tier 3 (%)	Tier 4 (%)	Tier 5 (%)
Category I	> 95	90-95	85-90	75-85	< 75
Category II	> 90	85-90	80-85	70-80	< 70
Category III	> 85	80-85	75-80	65-75	< 65
Category IV/V	> 80	75-80	70-75	60-70	< 60

2.3.2. Bus Stop Density

The density of urban bus stops is the value obtained by comparing the total number of stops in the study area with the area of the study area.

Computational formula:

$$\boldsymbol{D = \frac{N}{A}} \quad (2)$$

In the formula:

D —— Bus stop density

N —— Total number of stops

A —— Area of study

The evaluation value of urban bus stop density is shown in Table 5 (Liu, 2016).

Table 5. Evaluation criteria for urban bus stop density by tier

	Tier 1	Tier 2	Tier 3	Tier 4	Tier 5
Site density (units/km^2)	> 50	40-50	30-40	20-30	< 20

2.3.3. Bus Route Repetition Coefficient

In cities with well-developed public transportation, the repetition coefficient of bus routes is generally between 1.25 and 2.5. For a specific section, the repetition coefficient of public transportation routes refers to the number of bus routes set up on that section. Considering the even distribution of bus routes and the capacity of stops, the number of bus routes set up on a road should not exceed 3 to 5.

Computational formula:

$$B = \frac{T}{W} \tag{3}$$

In the formula:

B —— Bus route repetition coefficient

T —— Total length of public transport lines

W —— Network length

The formula reflects the density of bus lines running on major traffic roads in a city(Yuan, 2023).

The evaluation value of the repetition coefficient of urban bus lines is shown in Table 6(Liu, 2016).

Table 6. Evaluation criteria for urban bus route repetition coefficient by city tier

City Category	Tier 3	Tier 2	Tier 1	Tier 2	Tier 3
Category I	< 1.2	1.2-1.3	1.3-1.4	1.4-1.5	≥1.5
Category II	< 1.15	1.15-1.25	1.25-1.35	1.35-1.45	≥1.45
Category III	< 1.1	1.1-1.2	1.2-1.3	1.3-1.4	≥1.4
Category IV/V	< 1.0	1.0-1.1	1.1-1.2	1.2-1.3	≥1.3

2.3.4. Bus Route Non-linear Coefficient

In order to ensure the normal operation of public transportation and improve the service level of public transportation, the length of bus lines with different functional levels needs to meet the

requirements. If the line is too short, the transfer rate of passengers will increase; if the line is too long, the speed of the bus is not stable, the running is difficult to be punctual, and the normal interval between lines is difficult to be guaranteed.

The non-linear coefficient of the circular route is determined by the ratio of the actual distance between major collection and distribution points to the spatial straight-line distance. The non-linear coefficient should not be too high; generally, for bus routes, it should not exceed 1.4, and for main bus lines, it should be kept within 1.2 as much as possible. This helps reduce additional travel distances and travel time for passengers. For branch bus routes, settings can be flexibly adjusted according to actual conditions to expand the service coverage and enhance accessibility of bus services.

Computational formula:

$$E = \frac{G}{I} \tag{4}$$

In the formula:

E —— The non-linear coefficient of bus line

G —— The actual distance between the first and last stops of public transportation line

I —— Space linear distance

The formula reflects the degree of curvature of the specific driving path of urban bus lines (Yuan, 2023).

The evaluation value of non-linear coefficient of urban bus line is shown in Table 7 (Liu, 2016).

Table 7. Evaluation criteria for urban bus route non-linearity coefficient by city tier

City Category	Tier 3	Tier 2	Tier 1	Tier 2	Tier 3
Category I	< 1.10	1.10-1.20	1.20-1.30	1.30-1.40	≥1.40
Category II/III	< 1.05	1.05-1.15	1.15-1.25	1.25-1.30	≥1.30
Category IV/V	< 1.00	1.00-1.10	1.10-1.15	1.15-1.20	≥1.20

2.3.5. Bus Network Density

The density of urban public transportation network planning should generally reach 3-4 km/km^2 in the city center and 2-2.5 km/km^2 in the outskirts. According to surveys, residents within a 300 m radius on both sides of public transport routes are willing to use public buses. Beyond 500 m, the majority of residents prefer cycling, with very few choosing public buses (Wang, 2017). Therefore, the density of the public transportation network should not be too low.

Computational formula:

$$F = \frac{W}{U} \quad (5)$$

F —— Bus network density

W —— Network length

U —— Urban built-up area

The formula reflects the true degree of that urban residents arrive at or approach bus lines (Yuan, 2023).

The defined value of urban bus network density evaluation grade is shown in Table 8 (Liu, 2016).

Table 8. Evaluation criteria for urban bus network density by tier

City Category	Tier1(km/km^2)	Tier2(km/km^2)	Tier3(km/km^2)	Tier4(km/km^2)	Tier5(km/km^2)
Category I	≥4.5	4.0-4.5	3.0-4.0	2.5-3.0	< 2.5
Category II/III	≥4.0	3.0-4.0	2.5-3.0	2.0-2.5	< 2.0
Category IV/V	≥3.5	3.0-3.5	2.5-3.0	1.8-2.5	< 1.8

3. Results and Discussions of Urban Bus Network

In the evaluation and research of urban bus network, Kunming's central built-up area is selected as the research object. The city has a permanent population of 8.68 million and an area of 428 square kilometers, which belongs to a second-class city. arcgis is used to analyze the bus network indicators in this area.

3.1. Stop Layer Analysis

From the site level, analyze the coverage and density of bus stops. Import the data crawled by python into arcgis, use the buffer function to draw area circles with a radius of 300 m and 500 m respectively, and calculate the coverage of bus stops at 300 m and 500 m through software.

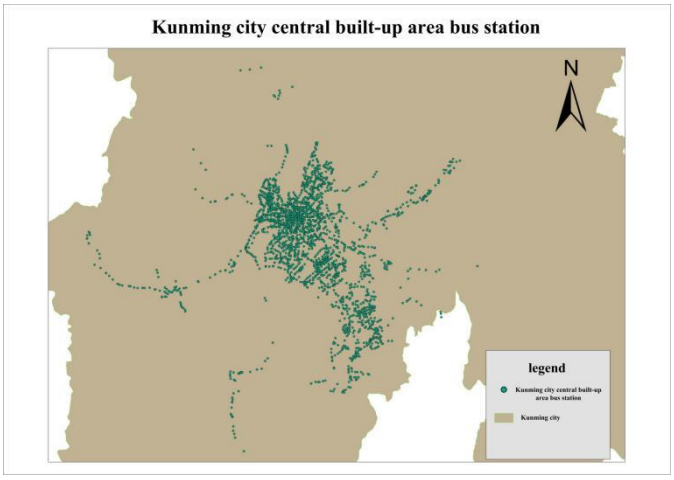

Figure 1. Distribution of bus stops in the built-up area of Kunming city center

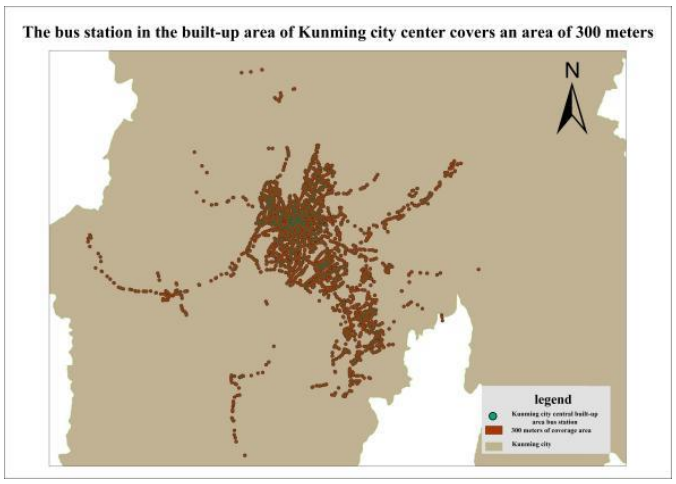

Figure 2. Coverage area of bus stops within 300 meters

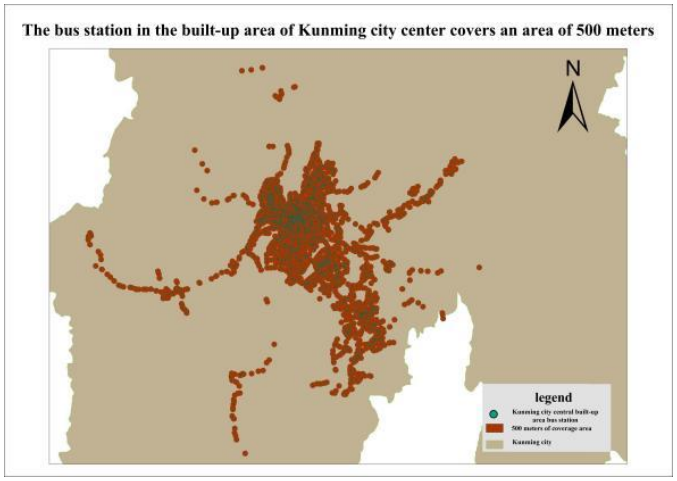

Figure 3. Coverage area of bus stops within 500 meters

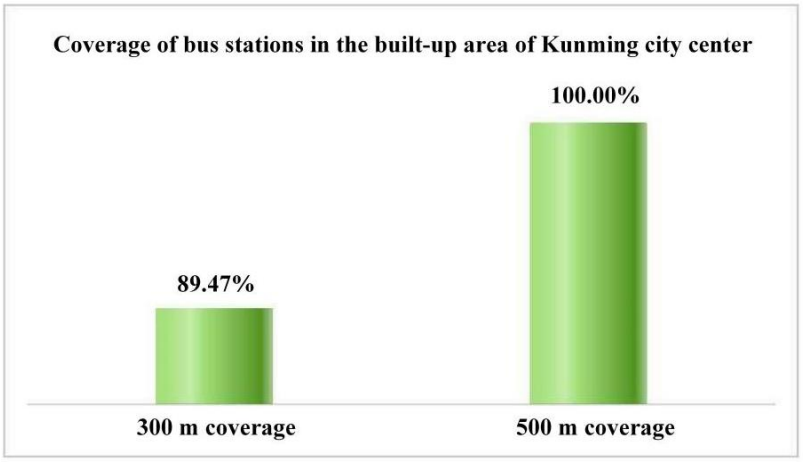

Figure 4. Bus stop coverage in the built-up area of Kunming city center

As can be seen from the figure, the coverage rate of bus stops in the built-up area of Kunming city center is 100.00% at 500 m and 89.47% at 300 m. According to the evaluation grade of bus stop coverage rate, the evaluation grade of bus stop coverage rate in the built-up area of Kunming city center is level 1, indicating that residents are close to bus stops and the service level is high.

Table 9. Bus stop density in the built-up area of Kunming city

Urban built-up area of Kunming (km^2)	Total number of bus stops (units)	Bus stop density (units/ km^2)
428	2433	5.68

As can be seen from the table, the bus stop density in the built-up area of Kunming city center is about 6 per square kilometer. According to the evaluation grade of bus stop density, the bus stop density in the built-up area of Kunming city center is graded as level 5, indicating that the density of bus stops is low and the distribution is unreasonable.

3.2. Route Layer Analysis

From the perspective of routes, analyze the repetition coefficient and non-linear coefficient of bus routes. Bus routes are divided into upbound and downbound routes. When calculating the repetition coefficient of bus routes, it is necessary to measure the lengths of both the upbound and downbound routes. To calculate the non-linear coefficient of bus routes, the actual distance between the starting and terminal stops must be measured using the computational geometry function in arcgis, which involves obtaining the latitude and longitude coordinates of the starting and terminal stops, and then using conversion formulas to output the actual distance.

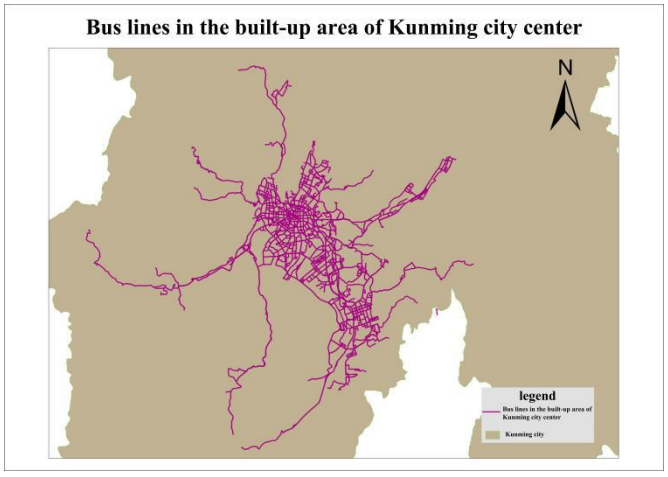

Figure 5. Bus route distribution map in the built-up area of Kunming city center

Table 10. Coefficient of bus line duplication in the built-up area of Kunming city center

Total length of public transport lines (km)	Line network length (km)	Bus line repetition coefficient
8660.56	2571.02	3.37

As shown in the table, the bus route repetition coefficient in the central built-up area of Kunming is 3.37. According to the evaluation criteria for bus route repetition coefficients, if the coefficient exceeds 1.45, the evaluation grade is set at level three. This indicates that there are many bus routes on the road sections, with severe repetition, significantly increasing traffic load and leading to congestion.

Table 11. Non-linear coefficient of bus lines in the built-up area of Kunming city center

Field distance between the first and last stops of public transport lines (km)	Spatial straight-line distance (km)	Bus line non-linear coefficient
8660.56	5672.647	1.53

As can be seen from the table, the non-linear coefficient of bus lines in the built-up area of Kunming city center is 1.53. According to the evaluation level of non-linear coefficient of bus lines, the non-linear coefficient of bus lines in the built-up area of Kunming city center is greater than 1.3, which indicates that the travel time and distance of residents increase and the travel efficiency decreases.

3.3. Network Layer Analysis

From the perspective of network, the density of bus network is analyzed.

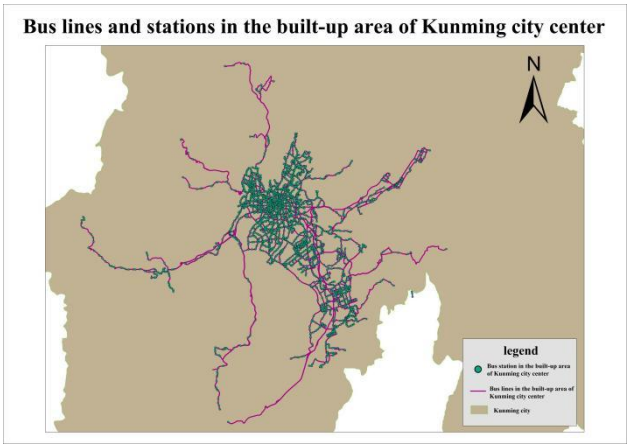

Figure 6. Distribution map of bus network in the built-up area of Kunming city center

Table 12. Bus network density in the built-up area of Kunming city center

Urban built-up area of Kunming (km^2)	Line network length (km)	Bus network density (km/km^2)
428	2571.02	6.01

As can be seen from the table, the bus network density of the built-up area in downtown Kunming is 6.01 km/km2. According to the evaluation grade of bus network density, the bus network density of the built-up area in downtown Kunming is grade I, indicating that residents have a greater degree of access to or proximity to bus lines and a higher service level.

3.4. Result Analysis

The evaluation of urban public transportation development should adhere to the principles of comprehensiveness, objectivity, and guidance (Zhu, 2022). By collecting and organizing data on the bus network in the developed area of Kunming's city center, quantifying indicators, and defining levels, we conduct a comprehensive analysis of the spatial distribution status and

characteristics. This allows for both quantitative and qualitative analysis of the developed area of Kunming's city center, leading to basic evaluation results of the bus network in the study region.

Table 13. Evaluation index level determination results of bus network in central built-up area of Kunming

Metric	Excellent	Good people	Average	Marginal	Poor
Bus stop coverage	√				
Bus stop density					√
Bus line repetition coefficient					√
Bus line non-linear coefficient					√
Bus network density	√				

As shown in the table, the bus resource allocation in the central built-up area of Kunming is not high, especially the bus stop density, the repetition coefficient of bus routes, and the non-linear coefficient of bus routes are all at low levels, indicating that public transportation resources in this area are relatively scarce. The development of urban public transportation is less coordinated with regional socio-economic development, and the level of public transportation services within the region needs to be further improved.

Suggestions for the optimization of bus network in central Kunming:

(1) Increase the density of bus stops; increase the number of bus stops, on the basis of existing bus stops, through data analysis to determine the densely populated areas, and add bus stops in these areas.

(2) Optimize bus routes; adjust or add bus routes through research and data analysis to cover more residential areas, commercial areas and important facilities.

(3) Improve the repetition coefficient of bus lines; reduce the repetition of bus lines, through reasonable planning, so that a line can serve more areas, reduce the waste of resources.

(4) Adjust the non-linear coefficient of bus lines; optimize the direction of bus lines, reduce unnecessary detours, improve the line straightness, so as to shorten the travel time of passengers.

3.5. Discussions

Through comparison with relevant domestic and international studies, this research exhibits certain commonalities in the construction of its evaluation framework and the application of analytical methods. Specifically, the evaluation indicator system and analytical techniques employed in this study—such as the Principal Component Analysis (PCA) and Geographic Information System (GIS) analysis—align with mainstream research practices. This ensures the scientific validity and comparability of the evaluation foundation.

The innovation of this study lies in the acquisition of public transportation data. Existing research predominantly relies on internal operational data such as bus IC cards and mobile payments, which are typically non-public and have limited accessibility(Xiao and Li, 2024). Additionally, methods like utilizing Baidu Maps API or ArcGIS secondary development to obtain route network data require high technical thresholds and face significant implementation challenges (Lu et al., 2021). This study innovatively employs Python code to directly retrieve the latest bus route network data for Kunming City. This method effectively overcomes the prevalent obstacles of data acquisition and sample scarcity in Kunming's bus network analysis, providing a reliable foundation for a comprehensive and direct analysis of the city's bus network. Furthermore, the developed Python code exhibits strong scalability, enabling the convenient acquisition of bus route network data for other cities across China. This offers a powerful data support tool for broader bus network research.

The limitations of this study and key areas for future development are as follows: On one hand, this study focuses on Kunming's bus network, employing static topological indicators to evaluate its structural characteristics. However, numerous cutting-edge domestic and international studies have demonstrated that incorporating dynamic analysis—such as utilizing bus GPS data for operational speed simulation and spatiotemporal distribution analysis of passenger flows—is crucial for comprehensively assessing a network's real-time operational efficiency, congestion levels, and service reliability. Therefore, to more accurately and authentically reflect the operational performance of Kunming's bus network and align the research depth with advanced domestic and international standards, subsequent research must urgently integrate a dynamic analysis perspective. On the other hand, regarding the scope of the research object, this study currently concentrates solely on the conventional ground bus network. With the rapid development and expansion of Kunming's urban rail transit network, rail transit has become an indispensable backbone within the city's public transportation system. Solely analyzing the conventional bus network neglects critical aspects such as the transfer efficiency and convenience between bus and rail networks, as well as the overall synergistic effects of a multimodal network. This makes it difficult to fully grasp the service capacity and layout rationality of Kunming's integrated public transportation system. Future work intends to incorporate the rail transit network, constructing a multimodal "bus + rail" composite network. By overlaying dynamic passenger flow assignment results, the study will assess accessibility and robustness under different network states. This approach aims to provide quantitative evidence with greater practical relevance for Kunming's transportation planning and design.

4. Conclusion

First, this study establishes the evaluation index system for the urban bus network based on Principal Component Analysis (PCA) and the five-point scale method. Subsequently, bus network data for the central built-up area of Kunming is collected using Python. This data, along with fundamental geographic information, is integrated into a spatial database using ArcGIS. Next, the spatial distribution characteristics of the urban bus system are analyzed. Leveraging ArcGIS

functionalities—including spatial analysis, spatial query, and spatial computation—the quantitative methods established for each evaluation indicator are applied to calculate all relevant indices within the study area. Following this, the cartographic rendering and visualization output capabilities of ArcGIS are utilized to qualitatively present the calculation results for each indicator. This qualitative output is based on the predefined grading standards within the urban bus network evaluation index system. Finally, the evaluation results of all indicators are comprehensively analyzed to derive the overall assessment of the bus network in Kunming's central built-up area. This assessment provides valuable insights for urban transportation planning and design in Kunming.

Author Contributions:

Conceptualization, methodology, software, validation, formal analysis, data curation, writing—original draft preparation, writing—review and editing, funding acquisition, D.Y. and Y.D. All authors have read and agreed to the published version of the manuscript.

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