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An Improved Algorithm for Accessibility of Public Transport Stations Based on Two Step Moving Search Method

Zhifei Lei[1], Pengxiang Lei[2]

[1] School of Surveying and Mapping and Land Information Engineering, Henan Polytechnic University, China

[2] Qingciyao Coal Mine, Jinneng Holding Group, China

Abstract

In order to reflect the spatial configuration and supply and demand situation of bus stops, and to provide decision-making for resolving the contradiction between vehicle supply and passenger demand. This article takes the stations in the main urban area of Jiaozuo City as the research object, considers the surrounding public service facilities, and uses GIS spatial analysis and Gaussian two-step mobile search method to calculate the accessibility of the stations. The results indicate that: (1) the accessibility of stations in the study area shows a central diffusion towards the surrounding areas; (2) The accessibility at the intersection of the central urban area and the demonstration new area is good; (3) Presents a distribution pattern of high center, low north south edge.

Keywords

Accessibility; Bus stops; Two-step movement method.

1. INTRODUCTION

The demand for residents' travel is increasing, and the scale of buses is also expanding. Bus stops, as the link between passengers and bus services, are an important part of the public transportation system. Quantitative analysis of station accessibility is crucial for optimizing station layout and improving bus operation efficiency. Mobile search was first used for accessibility assessment in medical services, but later due to its superiority in multiple fields, Langford first applied the two-step mobile search method to measure the accessibility of bus stops [1]. XU gave the importance of time in modeling bus supply and demand, combining time tables and distance data to obtain accessibility for different time periods [2]. Wu Hongbo used the two-step moving method to analyze the distance accessibility of urban public transportation network coverage areas [3]. From domestic and international research, it is not common to consider the flow of parked vehicles at stations as a factor in the two-step mobile search method. Therefore, this article quantitatively estimates the accessibility of stations based on this, providing more detailed information for residents' travel.

2. MATERIALS AND METHODS

2.1. Overview of the research area

Jiaozuo is located in the northwest of Henan Province, bordering Jincheng City in Shanxi Province on the border between Shanxi and Henan. It is influenced by Zhengzhou and Luoyang in multiple aspects and has a unique strategic advantage. To the east is Xinxiang and to the west is Jiyuan; The overall terrain is high in the north and low in the south, mostly located in a plain area with a total area of about 4071km2. The geographical coordinates are between 112 º 43'31 "-13 º 38'35" east longitude and 34 º 49'03 "-35 º 29'45" north latitude. Jiaozuo is the throat

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area connecting North China, East China, and Central China to the northwest. Its main urban area is located in the central north of the city, including Shanyang District, Jiefang District, Macun District, Zhongzhan District, and urban-rural integration demonstration zone. As shown in Figure 1.

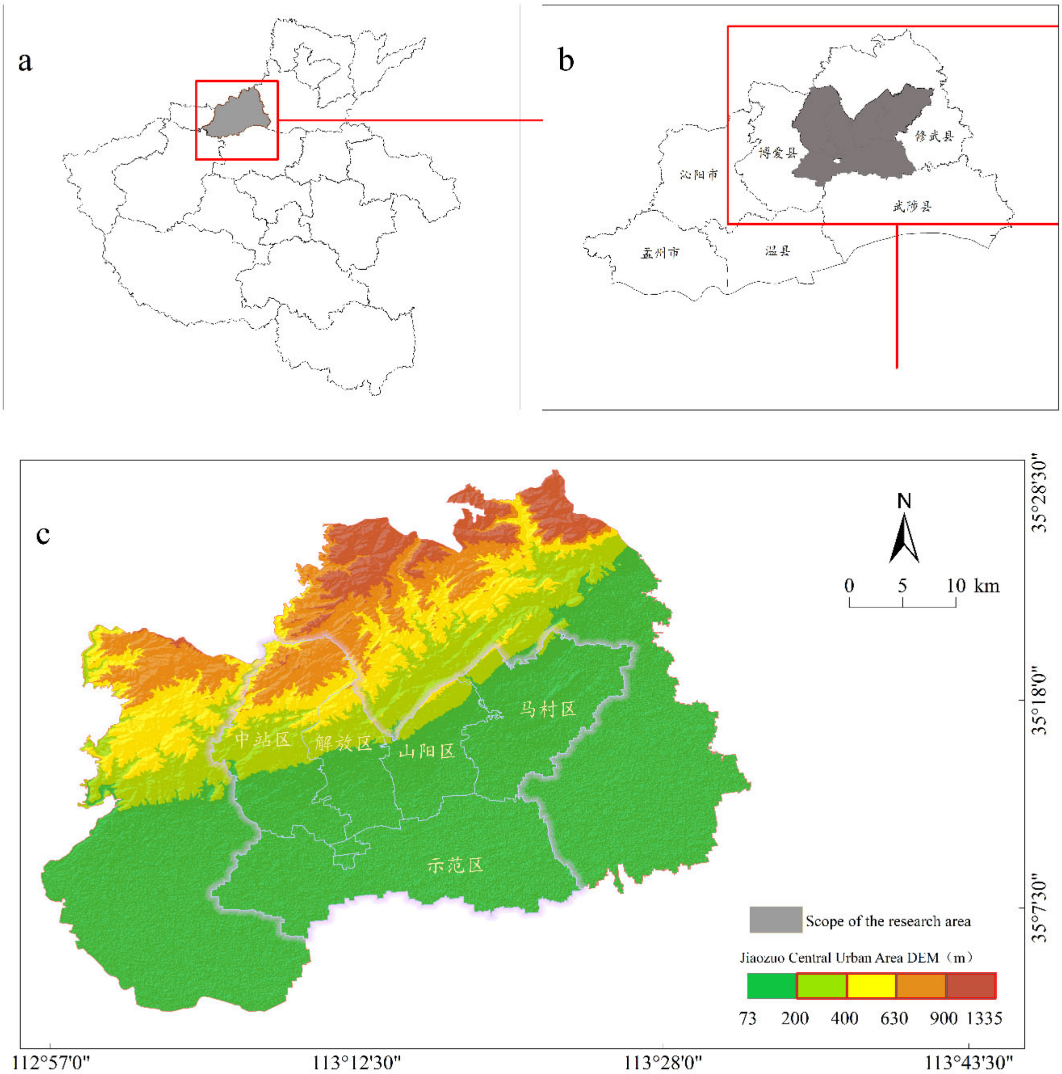

Figure 1. Research Area Map

2.2. Data Source and Preprocessing

As a location for passengers to get on and off the bus route, bus stops are an important component of the bus route, determining the direction of the bus route. The bus route network is formed based on bus stops and the urban road network. Table 1 describes the structure of bus stops in the database.

Table 1. Bus stop property sheet

field	data type	Description	Remarks
ObjectID	Object ID	834	Site number, primary key
Longutite	Double	113.230705	Station longitude
Latitute	Double	35.240262	Site latitude
Name	Text	Youth intersection	name

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Stations are connected through routes, and the strength of the relationship depends on two aspects: one is the running time of the section between stations, and the other is whether the location of the station has a strong attraction. Therefore, obtaining the spatial coordinates of urban bus stops is particularly important. Using Baidu Maps API to obtain bus stop data [4-7], JavaScript can be run in a web browser, and the operation process is as follows:

(1) Modify and save. Save the JavaScript code that connects to Baidu Maps API with an HTML suffix name to open a webpage named "Get Bus Stop" in the browser.

(2) Query conversion. Input the corresponding line for query to obtain its station coordinates, and use coordinate conversion tools to convert the data into the WGS-84 coordinate system.

(3) Compare and choose. Referring to the Jiaozuo bus data crawled by Python, select a more accurate bus stop location based on the geographic coordinates of the included stations.

In reality, there are several large bus stops in the public transportation system, called bus hubs. These stations have strong appeal and have a large number of bus routes, such as the Second Hospital and Department Store; Other stations are influenced by it and connected to it through road sections, forming small station clusters, which are reflected in the public transportation network as preference attachment. Although the public transportation system is complex and diverse, it still follows the topological foundation of "point line surface" from the real world abstraction to the network, where the point is the source, and Figure 2 shows the bus stop diagram.

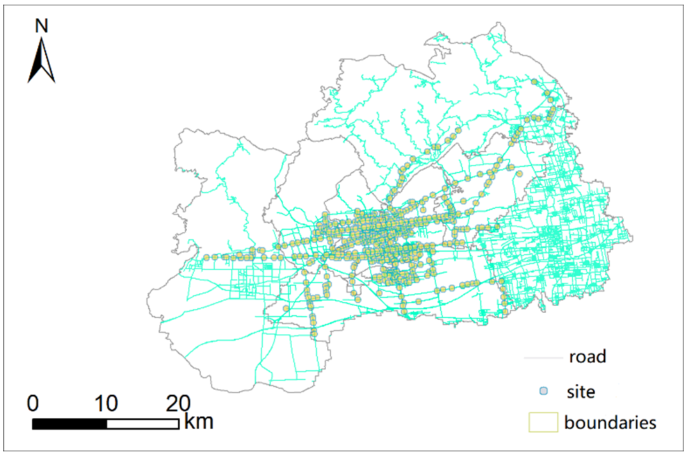

Figure 2. Bus stop map of Jiaozuo urban area

2.3. Research Methods

2.3.1 Classic two-step mobile search method

Early mobile search methods assumed that all supply services within the search domain were available to demand points. By summing up the number of supply points within the search radius, the accessibility value of the service could be obtained. This assumption leads to overly idealized initial mobile search, with suspicion that the actual distance between the demand and supply points exceeds the radius threshold for service provision. To meet the reality, 2SFCA conducts two mobile searches based on supply and demand respectively, reflecting the configuration of the facility through the supply-demand ratio. Combining the gravity model of obtaining service potential from demand points with the mobile search method of providing service capabilities from supply points. 2SFCA comprehensively considers the impact of facility supply scale, demand scale, and distance between supply and demand on accessibility. Each time, a threshold is used as the search radius to obtain the sum of the supply to demand ratios of the supply points obtained by the demand points. The larger the value, the higher the accessibility. As shown in Figure 3.

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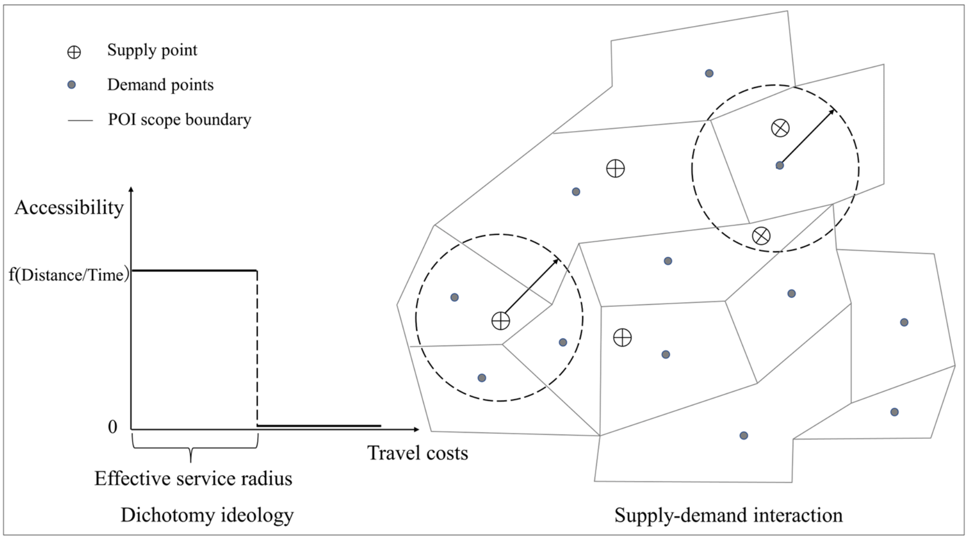

Figure 3. Schematic diagram of 2SFCA

In the first step, the ratio of supply to demand at the supply point is calculated. Take any supply point j as the centre and the limit service distance d_0 of the supply point as the search radius, establish the spatial domain, find the demand point k contained in this search range, and calculate the ratio R_j between the supply point and the demand point in the effective domain.

$$R_j = \frac{S_j}{\sum_{k\in\{d_{kj}\leq d_0\}} D_k} \tag{1}$$

In the equation:

J——supply point;

K——supply point j establishes demand points within the search area;

R_j——The supply-demand ratio at point j is also the service capacity of the supply point;

S_j——the supply scale of point j;

D_k——Potential demand at point k;

d_{kj}——the travel cost (time or distance) between k and j;

d_0—— search radius.

In the second step, the accessibility of demand points is calculated. For each demand point i, search all supply points j within the radius d_0 where the demand point is located, and sum the supply-demand ratios R_j of the supply points to get the accessibility of demand point i.

$$A_i = \sum_{j\in\{d_{ij}\leq d_0\}} R_j \tag{2}$$

In the equation:

i——demand point;

A_i——Accessibility of demand point I;

d_{ij}——The travel cost (time or distance) between i and j.

The two-step mobile search method evaluates the ability to obtain public service facilities through the interaction between points in space. The classic 2SFCA model can better evaluate spatial accessibility considering both travel costs and supply-demand ratio. However, the model

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failed to consider the impact of distance attenuation on obtaining supply services, believing that the accessibility of all demand points within the threshold range is the same; Because it uses dichotomy to explain distance attenuation, the reachability is the same within the search radius threshold range, while the reachability at any location above the threshold is 0; The traditional form of 2SFCA defines the distance attenuation function f(d_{ij}) as a constant, while the extended form defines f(d_{ij}) as different functions. Based on the attenuation trend of the function and the specific actual situation, the function form is selected to achieve a reasonable evaluation of the accessibility of the supply and demand sides. In order to improve the limitations of traditional methods, in addition to introducing a distance decay function, there are also considerations for expanding the search radius, competition between supply and demand, and travel modes.

For the optimization of traditional 2SFCA in four aspects and the following three shortcomings, a focused analysis direction is provided for the description of the relationship between bus stops and POIs in this section.

(1) Due to only considering the linear distance between the supply point and the demand point, and ignoring the actual transportation cost consumed by the road network, the calculation results have a significant gap with reality.

(2) At the supply point within the extreme search threshold, access to services is equal for any demand point at any location, ignoring the impact of distance attenuation on access ability, especially in sparsely populated areas.

(3) The impact of supply point size on search radius was not considered, and the reality is that the search range will vary with the size of the supply point. At the same time, the differences in the location attributes of the demand point will also affect the demand for supply services, thereby affecting the accessibility results.

Due to the limitations of the classic 2SFCA, it is not possible to accurately describe the accessibility of both supply and demand sides. In order to illustrate the service capacity of bus stops and the relationship between residents' demand points at different locations, it is necessary to optimize the classic method.

2.3.2 Two step mobile search method based on service capability

Analyze the accessibility of bus stops using the two-step mobile search method, and use the calculated accessibility values to calculate the service capacity of bus stops. At the same time, service capacity is also an important manifestation of meeting people's needs for bus travel. 2SFCA is based on supply points and demand points, and moves and searches twice within the same threshold range to obtain the cumulative supply demand ratio of demand points, which is called accessibility. Based on the consideration of station service capacity in real life, comparing the attenuation curves of different functions, it is found that the Gaussian function attenuates more slowly when approaching the search threshold, which better simulates residents' travel situations. Therefore, the Gaussian equation is introduced as the distance attenuation function to improve the two-step mobile search method. Taking the accessibility evaluation of public transportation stations in Jiaozuo urban area as an example, the specific steps are as follows:

First of all, set the spatial threshold d_0 (the service area of the site) for each site in the study area, taking into account the effect of accessibility with the travelling distance attenuation, so for the spatial threshold range, Tyson polygon surrounded by the number of population of the various settlements using Gaussian equations to assign weights, and then summing up the population of each area after the weighting, to get the potential number of people travelling to all the small districts and administrative villages served by the site J.; and then dividing the traffic flow passing through the site by the number of people potentially served by the site to get the ratio of demand and supply R_j, which is the site's service capacity, and the bigger the ratio of supply and demand is, the more the site will have a greater impact on the residents.

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$$R_j = \frac{S_j}{\sum_{k\in\{d_{kj}\le d_0\}} G(d_{kj},d_0)D_k} \quad (3)$$

In the equation, D_k is the population of the polygonal area centered on residential area k within the spatial threshold of station j, d_{kj} is the spatial distance from residential area k to station j, expressed in time; S_j is the service capacity of a bus stop, expressed in terms of the flow of vehicles passing through the stop; $G(d_{kj}, d_0)$ is a Gaussian equation, calculated by the formula

$$G(d_{ij}, d_0) = \frac{e^{-\frac{1}{2}\times\left(\frac{d_{ij}}{d_0}\right)^2} - e^{-\frac{1}{2}}}{1-e^{-\frac{1}{2}}}, \quad d_{ij} \le d_0 \quad (4)$$

Using a continuous function to characterize distance decay within a certain threshold range, f(d_{ij}) represents the Gaussian decay function

$$f(d_{ij}) = \begin{cases} G(d_{ij}), & d_{ij} \le d_0 \\ 0, & d_{ij} > d_0 \end{cases} \quad (5)$$

The Gaussian function curve resembles a normal distribution and can better simulate the attenuation of actual distance. Adding Gaussian attenuation reduces the calculation error of reachable lines. G [d_{ij}, d_0) takes into account spatial friction and distance attenuation, and the reachability decreases slowly at the beginning of distance attenuation. As the distance from the starting point gets further away, the downward trend begins to accelerate, and the attenuation speed gradually slows down near the endpoint, similar to the decreasing part of the normal distribution curve, As shown in Figure 4.

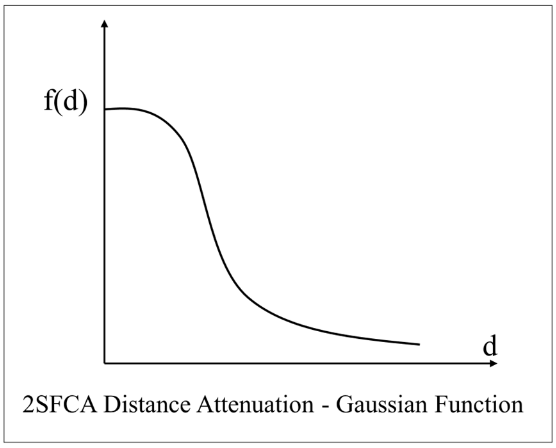

Figure 4. Gaussian function image

(2) For each demand point i, within a certain spatial distance d_0, assign the weight of the Gaussian function to the spatially scaled supply-demand ratio, and then sum it to obtain the accessibility value of bus stops in the residential area A_i

$$A_i = \mathrm{f}(\mathrm{d}_{ij})R_j = \sum_{j=1}^{n} \frac{S_j f(d_{ij})}{\sum_{k=1}^{m} D_k f(d_{kj})} \quad (6)$$

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where R_j is the supply-demand ratio of stop j in the spatial sphere of action of settlement i, and the value of A_i is the calculated accessibility value, which can be interpreted as the per capita occupancy of the bus service.

The advantages of the two-step move search method are: ① In the calculation of accessibility, the nearest facilities and multiple service points are considered; ② The accessibility metric can be intuitively understood as the supply-demand ratio; and ③ It is easy to implement using the ArcGIS platform. Under the effect of spatial distance, the service capacity of the site shows non-uniform distance decay, and the willingness of residents to go to the site will also gradually decay with the increase of spatial distance, and the decay curve conforms to the Gaussian distribution, so Gaussian two-step movement is used to analyse the service capacity of the site's accessibility.

3. RESULTS AND ANALYSIS

Site accessibility analysis, using a two-step mobile search method, within the search radius with a Gaussian function as the distance decay function; in order to supply and demand as the centre, moving the search area in two times to calculate the accessibility of public service facilities. This method takes into account the interrelationship between the supply and demand of the research object, making the measurement of accessibility more precise and clear. It can both measure the site accessibility of the residents' starting place and identify the spatial differences in accessibility within the service area of the site. The selection of spatial thresholds is key in the calculation; time is used to characterise distance, and 15 minutes is used as the service threshold for bus stops in the paper.

It has been explained that the construction of network datasets solves the time problem of bus travel and pedestrian walking. In the process of calculating station accessibility, the network analysis tool of ArcGIS platform is still used to analyze the actual road network, and the OD cost matrix is used to replace the linear distance between supply and demand points. The specific attribute fields include road grade, distance, driving speed, etc. Please refer to Table 3-3 to set the road grade and speed. This table is combined with various factors of road traffic in the main urban area of Jiaozuo and is set comprehensively. For the walking time, select a walking speed of 5km/h and calculate the time using the distance [8,9].

Based on the network dataset constructed by the road network, the accessibility of bus stops is analyzed, with a threshold setting of 15 minutes and a Gaussian two-step moving search method. The steps are as follows:

(1) Calculate the supply-demand ratio of bus stops in the spatial scope within the threshold range of bus travel time centered around the stop;

(2) Calculate the bus service capacity within the search range of residential areas based on traffic flow; The time spent in the two steps is calculated based on the speed of the road network and different modes of travel;

(3) According to the calculation formula of 2SFCA, the accessibility of each residential area center is obtained, and interpolation visualization is used to generate predicted accessibility values for unknown residential areas, thereby simulating the spatial distribution of accessibility continuous surfaces.

Two types of spatial interpolation algorithms, Tyson polygon and Kriging interpolation, are used in the article to obtain the population of residential areas and visual geographic analysis results, respectively. Tyson polygon, also known as Voronio diagram, is a commonly used method for calculating surface data using point data. Each polygon contains only one discrete data, and after dividing the spatial plane, the spatial influence range of the discrete point can be reflected. Firstly, divide the Tyson polygon based on the location of residential areas and

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administrative villages, and then obtain the population size of the designated service area and population grid density. Finally, based on the seventh population census data, the WorldPop population grid data was corrected to obtain the population of each small region.

The accessibility calculation results of Gaussian 2SFCA are assigned to residential areas. To obtain the accessibility of bus stops at any location, it is necessary to estimate the accessibility of other residential areas outside of discrete points. The population is an important influencing factor in the solution process, and the estimated values of unknown areas are simulated through spatial interpolation. Because the spatial distribution of population has spatial autocorrelation characteristics, and Kriging interpolation not only considers the spatial position between the estimated point and adjacent points, but also calculates the spatial correlation characteristics between the two; So this method is chosen to interpolate accessibility and population data to achieve geographic visualization expression. Figures 5 show the accessibility values of residents within the 15 minute threshold range and the population distribution of their corresponding areas. The data is divided into 5 categories using the natural breakpoint classification method.

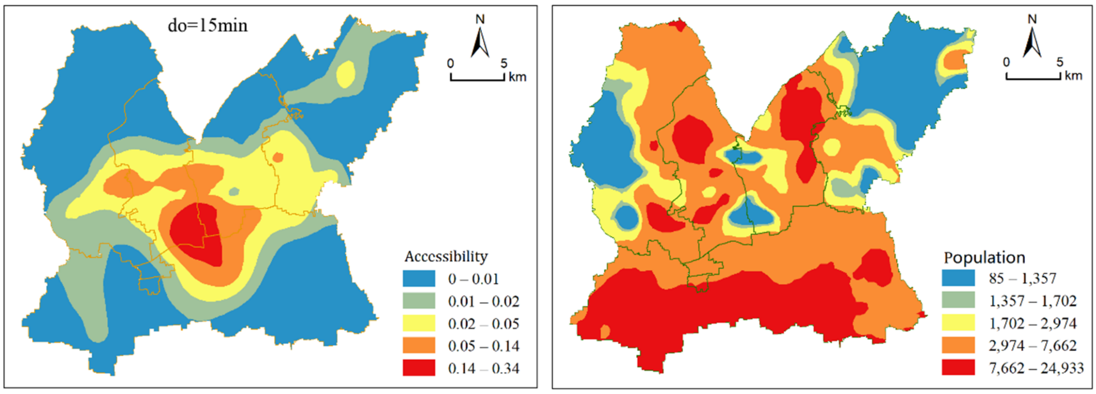

Figure 5. 15 minutes bus stop accessibility & worldpop corrects the population

As shown in the left figure, the accessibility of stations in the main urban area of Jiaozuo City shows a phenomenon of spreading from the center to the surrounding areas. The accessibility at the intersection of the central urban area and the demonstration new area is good, and gradually spreads to the surrounding areas, presenting a distribution pattern of high center, low north and south edges. Compared with the population interpolation graph (right), it has the following characteristics:

(1) The accessibility of Machun District is low in the north and high in the south, which is consistent with the terrain of the area being high in the north and low in the south, with a trend of tilting from northwest to southeast. Due to this terrain, the population of Ma Village is mostly distributed in the flat central and southern regions. The low population area of Zhongzhan District is formed by the intersection of the north-south Jinxin Expressway and the east-west Taihang Expressway. The accessibility of the corresponding bus stops here is relatively low, and the distribution of station accessibility is blocked by highways. The total population is small, and the number of administrative villages is scattered, resulting in low overall accessibility. Additionally, it is affected by terrain and population aggregation. The terrain of the Liberated Areas and Shanyang District is high in the north and low in the south. The northern part of the Liberated Areas has an elevation of 700 meters, and there are few villages in the north, with a population not concentrated.

(2) In the southern part of the demonstration area, there are many administrative villages with a dense population. However, the accessibility of bus stops within the 15 minute threshold here is relatively low, and the bus service capacity and residents' needs do not match. The reason is that the demonstration area has a wide range and limited bus stops extending to

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administrative villages, such as the barriers of Jinxin Expressway, Hebao Expressway, Liangu Line, Changji Expressway, Jiaotong Expressway, and Dashahe, which makes the accessibility of stops in this area poor, and residents receive less service in the 15 minute living circle. The extension of high-grade transportation roads in the western part of the Zhongzhan District and the southern part of the demonstration area has exceeded the range of public transportation trips, resulting in a decrease in the accessibility service level of public transportation.

(3) The central area of Shanyang and the northern part of Jiefang and Demonstration Zone have the highest accessibility, but there is a conflict between low population values and high station accessibility corresponding to low population numbers at the junction of Shanyang and Jiefang. This area has the Jiaozuo Municipal People's Government, the Chinese People's Political Consultative Conference, the Jiaozuo Education Bureau, the Judicial Bureau, the Shanyang District Government, and most government offices are located; Tai Chi Square and Longyuan Lake Park, green spaces for citizens' leisure life; Medical and health facilities such as Jiaozuo Shanyang Hospital and Jiaozuo Traditional Chinese Medicine Hospital are located north-south on Tanan Road and Zheng'er Street, and east-west on Fengshou Road and Renmin Road. Public service institutions or units that solve livelihood problems have a small resident population and a large floating population; Square Park public service land, population distribution center. Starting from the 15 minute living circle of the community, there are public welfare places with medical and green spaces around, which basically meet the goals of livable, suitable for work, suitable for travel, and suitable for maintenance for citizens. Renmin Road is a node connecting the new city and the old city, serving as an east-west main road. Tanan Road is a north-south urban main road, and both roads carry the vast majority of public transportation routes in the city. The accessibility of bus stops in this area is good. The northern areas adjacent to Shanyang and Jiefang also have low population values, resulting in a relative decrease in accessibility. Most of these areas are community health stations, community neighborhood committees, and administrative units such as Jiefang Urban Management Bureau and Shanyang Police Station. The population density of district level and community environment is low, and there are few functional units mainly responsible for living in small areas, so the accessibility of bus stops is relatively low. The analysis concludes that the urban land use function objectively guides the strength of public transportation accessibility.

In response to the uneven distribution of bus stops, suggestions for improving station accessibility are proposed. It is necessary to comprehensively consider the population density and layout of the bus network in each region, increase the number of stops in low accessibility areas, and ensure the supply of bus services.

4. CONCLUSION

Starting from the service capacity of the public transportation system, taking into account the number of people served, a two-step mobile search method is improved, and a accessibility evaluation method based on bus stops is proposed. The service capacity is characterized by the full day traffic flow of bus stops, and then population data is corrected, geographic blocks are segmented, and the population of each residential unit is estimated to represent the demand. The results show that the accessibility of stations in the main urban area of Jiaozuo City shows a phenomenon of spreading from the center to the surrounding areas. The accessibility at the intersection of the central urban area and the demonstration new area is good, and gradually spreads to the surrounding areas, presenting a distribution pattern of high center, low north south edge, and low south edge.

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REFERENCES

[1] fry R,Higgs G,Langford M. Measuring tranit system accessibility using a modified two-step floating catchment technique[J]. International Journal of Geographical Information, 2012, 26(2): 193-214.

[2] Xu W A,Ding Y,Zhou J. Transit accessibility measures incorporating the temporal dimension [J] Cities, 2015, 4655-66.

[3] Wu Hongbo, Guo Min, Yang Xiaoxiao.Accessibility of urban bus networks based on GIS network analysis. [J] Journal of Beijing Jiaotong University, 2021, 45 (01): 70-77.

[4] Guan Yibing Evaluation of the commercial center system in the main urban area of Nanjing based on big data [D] Southeast University, 2017.

[5] Wang Yuewen Research on the spatiotemporal characteristics and influencing factors of residents' leisure activities based on multi-source big data [D] Southeast University, 2021.

[6] Chen Enhui Research on Passenger Flow and Transfer Modes of Urban Rail Transit Stations under the Impact of Built Environment [D] Southeast University, 2021.

[7] Dan Xinhong A Study on the Spatial Characteristics of Nanjing Commercial Center from the Perspective of Spatiotemporal Behavior [D] Southeast University, 2020.

[8] Li Mengtong, Yang Lingbin, Wei Ye A Study on the Model of Gaussian Two Step Moving Search Method - Taking the Accessibility of Green Space in Shanghai as an Example [J] Progress in Geographic Science, 2016, 35 (08): 990-996.

[9] Yao Xuesong, Leng Hong, Yang Qingshan, etc Research on Park Layout in Changchun City Based on Accessibility Evaluation [J] Journal of Northeast Normal University (Natural Science Edition), 2016, 48 (3): 142-149.