EVALUATION OF SPATIAL FAIRNESS OF URBAN PUBLIC TRANSPORT SERVICE: A CASE STUDY OF WUHAN CITY

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Commission IV, WG IV/10

KEY WORDS: Wuhan City, Moran's I, Fairness, Public Transport, Population Density, Transportation System Optimization.

ABSTRACT:

Spatial equity of urban public transport service is an important index to evaluate the potential of sustainable development of urban transport. This paper, taking Wuhan as the study area, the use of public transport network data and population density of 1 km^2 grid data, using Moran's I reveals research area spatial correlation between different variables and the significance, in order to under different scales of whole and local area in Wuhan city public traffic service demand and supply of the current situation and problems of space fairness is analyzed. The research shows that there are significant differences in spatial fairness of public transport service in Wuhan, and the service configuration level of central urban areas is higher than that of non-central urban areas. According to the Moran's I, Huangpi District was the worst administrative district in spatial fairness, and Dongxihu District was the best administrative district. The evaluation based on spatial fairness can help to realize the rapid optimization of public transport service system, improve the spatial inequity of service supply and demand, and provide scientific basis for the optimization and upgrading of public transport system.

1 INTRODUCTION

Urban transportation is one of the basic functions of a city, and urban transportation system plays an extremely important role in the transfer of urban information and materials(Lu ,2021).Public transport network structure optimization of construction is to reflect the traffic demand and configure the service level and residents of the results, in the construction of the site, often can appear site service configuration level and residents near the site traffic demand does not match, this difference distribution results often lead to traffic congestion or waste of resources. With the rapid urbanization and motorization, the current major contradiction of urban transportation in China has been transformed into residents' increasing travel needs and uneven allocation of public transportation resources, which has become a practical problem that needs to be solved in the process of urban public transportation planning.

Fairness evaluation is one of the important indexes to measure the performance of urban public transportation network system. The research on the evaluation of spatial fairness of public transport services can be combined with the distribution of bus stops and residents' travel needs to evaluate, and the corresponding results are not only conducive to the rapid optimization of bus services, but also to improve the status quo of inequity. It can also provide theoretical basis for scientific evaluation of public transport construction planning scheme. Many scholars at home and abroad have done a lot of research in the field of public transportation. Evaluated the accessibility and fairness of public transport and car transport from the perspective of time cost of traffic travel（Xi ,2020）. Evaluated the scale effect and spatial effect affecting the spatial fairness mechanism of public transport（Li ,2019）. Studied the influence of spatial scale changes on bus fairness evaluation（Qiao, 2021）, bus system optimization (Bai, 2017) and (Ge, 2006) and (Wirasinghe, 1981) and (Li, Bertini, 2009), and public transport accessibility (Ribeiro, 2021) and (Gao, Zhang,2022) and (Liu, Wang, 2011). Public transport passenger flow analysis (Gutiérrez et al., 2020) and (Liang, 2007), multi-use space autocorrelation analysis（Zhang et al., 2012）, Gini coefficient（Liu et al., 2021）, kernel density analysis（Yu, Ai, 2012）and other research methods in relevant literature. To sum up, there have been many discussions on the supply and demand of public transport services in relevant literatures, but less attention has been paid to the analysis of the supply and demand matching degree of public transport services by using the Bivariate Moran's I. To sum up, the urban traffic fairness as the effective way to solve the problem of urban traffic, is more and more scholars pay close attention to, but now use Bivariate Moran's I on the research of the matching degree between supply and demand of the bus service does not see more, more studies focus on public transport resource allocation balance, such as start in eastern part（Ji，2016）the accessibility index, The traditional Moran' s I is used to measure the spatial balance of public transport resource allocation. The Bivariate Moran's I is a modification of the traditional Moran's I. The Bivariate Moran's I is a modification of the traditional Moran's I, which can be used to evaluate and study the spatial distribution

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characteristics of service demand and supply, so as to comprehensively explain and explore the potential relationship between them from the perspective of spatial agglomeration . Traditional Moran's I showed the same elements in the space between the relationship, and the double variable Moran's I can better reveal the bus service supply and the demand of different factors on the evaluation unit space matching degree, bus service by analyzing the evaluation unit space matching degree between supply and demand, to evaluate the public transport service space fairness.

Based on the above considerations, this paper uses Wuhan public transport network data and 1km^2 population density data to establish an evaluation unit of 1km^2 grid. The number of stops of bus and subway lines is regarded as the service supply of public transport, and the population density data is regarded as the service demand. Reveal the spatial autocorrelation analysis of Wuhan public transport services demand and supply of spatial correlation and significance, through the analysis of evaluation unit public transport relative numerical gap between demand and supply, to study the supply and the demand of two variables match degree, thus to reveal the global and local area in Wuhan city public transport services under different scale space fairness difference, Thus, it is helpful to realize the rapid optimization of public transport service system, improve the spatial inequity of service supply and demand, and provide scientific basis for the optimization and upgrading of public transport system.

2 OVERVIEW OF THE STUDY AREA AND DATA PRETREATMENT

2.1 Overview of The Study Area

Wuhan is located in the east of Jianghan plain in central China (113°41'-115° 05'E, 29°58'-31° 22'N), with an altitude of 19.2-87.37m. It has a north subtropical monsoon climate, with an average annual temperature of 16.5℃-17.5℃ and annual precipitation of 1205mm. Covering an area of 8576. 41km^2, the city has jurisdiction over 7 central districts including Jiangan District, Jianghan District, Qiaokou District, Hanyang District, Wuchang District, Qingshan District and Hongshan District, and 6 new districts including Dongxihu District, Hannan District, Caidian District, Jiangxia District, Huangpi District and Xinzhou District.

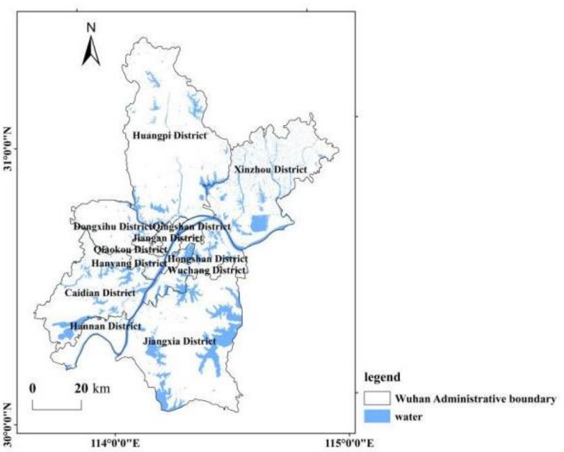

Figure. 1 Location diagram of Wuhan

2.2 Data Source and Pretreatment

Use crawler technology to obtain bus and subway stop and route data from amap open API by the end of 2021. The data includes the name of the site, longitude, latitude, the location of the city and other information. Consolidate bus stops of the same name on opposite sides of the street into one stop. The total number of bus and subway stations in the dataset is 3157. The data of public transportation lines were meshed by GIS, and the number of stations in 1km^2 grid was counted. A grid of 1 km^2 of population spatial distribution data was obtained in the Resources and Environment Science and Data Center, which reflected the detailed spatial distribution of population data in the whole country. A grid of 1 km^2 was selected as an analysis unit, and the number of stops of bus and subway lines in the analysis unit was regarded as public transport service supply, and population density data as public transport service demand.

3 METHODS

In this paper, the spatial correlation and significance of the supply and demand variables of public transport services are revealed by the method of spatial autocorrelation analysis, namely the Analysis of Moran's I. Based on the numerical matching relationship between the demand and supply of public transport service in the evaluation unit, the spatial fairness of local public transport service was evaluated, and the results of the overall scale evaluation were supplemented. First of all, the percentage of demand and supply variables are processed, and then the corresponding evaluation analysis is carried out. The GeoDa tool is used to measure the matching degree of the demand and supply space of bus service in the region.

3. 1 General Spatial Equity Analysis Method

Bivariate global Moran's I（Li et al., 2021) and (Liu , 2019）can reveal the spatial correlation and significance among different variables in the study area. The greater the absolute value of this index is, the higher the spatial matching degree of factors is. The higher the matching degree of bus service demand and supply value is, the better the regional spatial fairness is. The corresponding calculation formula is as follows:

$$I = \frac{N \sum_{i=1}^{n} \sum_{j=1}^{n} W_{ij} Z_{xi} Z_{yj}}{\sum_{i=1}^{n} \sum_{j=1}^{n} W_{ij} \sum_{i=1}^{n} Z_{xi} Z_{yj}} \qquad (1)$$

Where, I= the Bivariate Moran's I, and its value is between [-1, 1]. The positive, negative and zero values respectively represent the spatial positive correlation, negative correlation and spatial independence. In addition, the greater the absolute value of this index is, the greater the spatial proximity of elements is.

N = the total number of analysis units, x and y are the results of percentage of supply and demand of public transport service

Z_{xi} , Z_{yj} = the results of the ratio of service demand and supply value to the total amount of analysis units respectively.

W_{ij} = the adjacency matrix and its construction rule is the queen adjacency weight rule.

The normalized statistic Z (I) can be used to test the significance level of spatial autocorrelation for the global Moran index.

Z (I) = (I-E(I))/Var(I)

Var (I) = The theoretical variance of Moran index

E(I) = -1/ (n-1). It's the theoretical expectation of the exponent

The spatial fairness of the regions with weak numerical agglomeration degree and strong spatial agglomeration degree of bus service demand and supply is better.

3. 2 Local Spatial Fairness Evaluation Method

Bivariate local Moran's I（Li ,2019） can better reflect the degree of regional spatial agglomeration and mainly explore the spatial heterogeneity of each evaluation unit on the LAN. It can complement the analysis of global spatial autocorrelation. The calculation formula is as follows:

$$Local\ Moran's\ I = Z_{xi}\sum_{j\neq i}^{n} W_{ij}Z_{yj} \quad (2)$$

Where, if the value of the local space autocorrelation coefficient is positive, it indicates that the elements of the same type of attribute value are spatially adjacent. x、y、Z_{xi}、Z_{yi}、Z_{yj} and W_{ij} as above 3.1, $\sum_{j=1,\ j\neq i}^{n} W_{ij}Z_{yj}$ is called spatial lag value. The obtained value can reflect the public transport supply of the evaluation unit. Z_{xi} and $\sum_{j=1,\ j\neq i}^{n} W_{ij}Z_{yj}$ are used to plot the moran scatter plot of supply and demand for public transport services. According to the moran scatter diagram, the gap between the relative supply and demand of public transport is judged, and the scatter points in the four quadrants are divided into four categories, namely high-high, high-low, low-low and low-high. According to the difference between the relative supply and demand of public transport service, it can be considered that the scatter point of high-high classification, the relative supply is greater than the average, and the relative demand is also higher than the average level. The scatter of low-high classification, its relative demand is higher than the average level, relative supply is lower than the average level; For the scatter of high-low classification, the relative demand is lower than the average level and the relative supply is higher than the average level; A scatter of low-low classifications, where relative demand and supply are both below average.

Calculating relative difference between supply and demand in the public transport service, in order to avoid the evaluation unit and the number of sites within the population density data cannot compare, need to calculate the number of sites in each evaluation unit and percent of total population density values, for the convenience of data visualization, the results of both subtraction magnified 10^6 times.

4 RESULTS

4. 1 General Spatial Fairness Evaluation Analysis

Figure 2 and 3 are obtained through $1km^2$ grid of population density and public transport line base map data of Wuhan, which show the demand and supply of public transport service in each evaluation unit of Wuhan. According to the population density value and the distribution number of bus stops in each evaluation unit, it can be seen that the Yangtze River is the boundary, The hot spots of public transport service configuration and population activities are mainly concentrated in the central urban areas. That is, Jiangan District, Jianghan District and Qiaokou District in the northwest of the Yangtze River, and Wuchang District and Hongshan District in the southeast of the Yangtze River. The former is the financial, commercial and trade center of Wuhan, with various banking and financial outlets, commercial streets and large enterprises and institutions scattered in this area. The latter is Wuhan politics, higher education and high-tech RESEARCH and development center, Hubei Provincial Party Committee, provincial people's government and many universities, scientific research institutions are located here. The population density of Qiaokou District, Jianghan District and Jiangan district is higher than that of the rest of the country. Moreover, public transport service distribution is mainly distributed in the central urban area, where public transport service supply and population density are statistically higher than those of non-central areas. According to the statistical data, the analysis unit of the five central built-up areas, which accounts for 36% of the total supply, gathers about 48% of the total population. Moreover, the supply of public transport stations also gathers in the central urban areas, while the population distribution density and the supply quantity of stations in the evaluation units located in non-central cities are less than that in the central urban areas on the whole. It can be seen that the central urban area is the agglomeration of population distribution and traffic station distribution in Wuhan, indicating that there is a certain inequity in the overall distribution of public transport services in Wuhan.

Obtained by general spatial autocorrelation of district in Wuhan city and urban public transport service supply and demand data, calculating traffic service evaluation index of the double variable Moran's I, and in 999 under the random permutation, available in table 1, The Moran's I of the 13 districtsis greater than zero, indicating that the supply and demand of public transport service in the 13 districts are in a positive spatial correlation. Huangpi District is the worst of the fairness, administrative region. Dongxihu District is one of the best administrative region. Dongxihu's Moran's I was 0.4819, compared with the other area I value, is the largest area in Moran's I in the 13 districts, can get the public traffic service demand and supply of two variables on the numerical gap is smaller, indicates that this area evaluation unit of space of public transport service demand and supply matching degree is highest, service configuration level and population distribution is more reasonable. The Moran's I of Huangpi District was 0.0729, which was the smallest among the 13 districts. There was a large gap between the demand and supply of public transportation service in the evaluation unit, indicating that the spatial coupling degree of demand and supply of public transportation service in the evaluation unit was the lowest, and the supply and demand of public transportation service in the evaluation unit was the most unfair. These evaluation units with obvious inequities are the focus of our research. To solve their inequities in the supply and demand of public transport service is the key to optimize and upgrade the structure of public transport network.

The Qiaokou district, a central part of Wuhan, has the largest population density and bus service distribution in the evaluation unit compared with the other six districts, while the bus supply is not outstanding compared with other districts. The Qiaokou District is located in Wuhan's well-developed central district and its development strategy shows an obvious gap between the supply and demand of public transport services. Due to its important geographical location, the Qiaokou District has the smallest Moran's I compared with the other six central urban areas. So upgrading the network is crucial to ensuring that Wuhan's public transport services are fair. Apart from Qiaokou District, the rest of Wuhan's central districts have better spatial fairness in public transport services.

From the numerical results, it can be seen that the public transport service supply and population density in the central urban area are not only highly concentrated, but also have a high matching degree, and the public transport service configuration is relatively fair. The spatial correlation analysis shows a difference from the numerical results. The Qiaokou district is an area with high population density and high public transport, but the moran index has a smaller value, and the supply and demand of bus services do not match well.

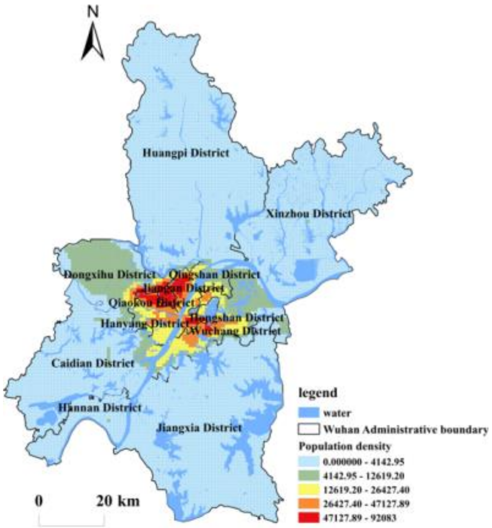

Figure.2 Distribution of population data

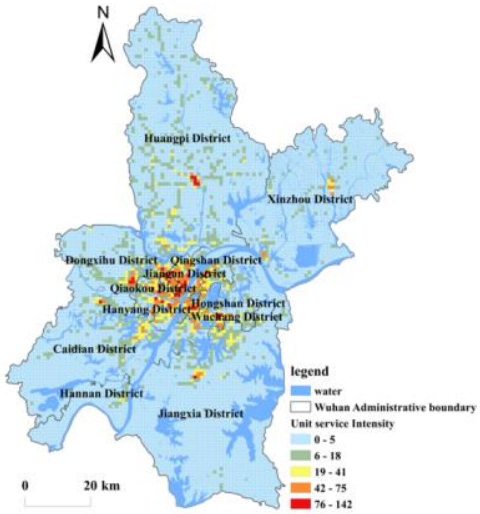

Figure 3 Public transport service configuration distribution

Area	Bivariate Moran's I	E（I）	Mean	Sd	Z-value	p
Wuhan	0.4869	-0.0001	0.0000	0.0058	84.0027	0.001
Hanyang District	0.4620	-0.0065	-0.0029	0.0507	9.1689	0.001
Qiaokou District	0.0846	-0.0154	-0.0085	0.0821	1.1334	0.143
Jiangan District	0.4192	-0.0088	-0.0062	0.0582	7.3061	0.001
Jianghan District	0.4230	-0.0667	0.0406	0.2096	1.8246	0.033
Wuchang District	0.3345	-0.0078	-0.0033	0.0560	6.0307	0.001
Qingshan District	0.2277	-0.0132	-0.0054	0.0741	3.1439	0.003
Hongshan District	0.4265	-0.0014	-0.0007	0.0227	18.8515	0.001
Dongxihu District	0.4819	-0.0018	-0.0016	0.0254	19.0579	0.001
Hannan District	0.1519	-0.0028	-0.0009	0.0280	5.4593	0.001
Caidian District	0.2320	-0.0008	0.0003	0.0159	14.6050	0.001
Jiangxia District	0.1821	-0.0005	-0.0005	0.0110	16.6219	0.001
Huangpi District	0.0729	-0.0004	-0.0009	0.0109	6.7948	0.001
Xinzhou District	0.1259	-0.0006	-0.0007	0.0128	9.8999	0.001

Table. 1 Calculation results of Bivariate Moran’s I for public transport service evaluation

4. 2 Regional Spatial Fairness Evaluation and Analysis

Local Moran’s I and using the double variable based on the classification of the relative demand supply gap between numerical results are bivariate LISA cluster map 4 and moran scatter diagram 5, as shown, from moran scatter diagram, standardized variables as the abscissa, spatial lag value as the ordinate, scattered data points in four quadrants, the first quadrant of the high - high classification evaluation unit, the second quadrant is low-high classification, the third quadrant is low-low classification and the fourth quadrant is high-low classification, and some points are not significant classification.

The demand for public transport service in the evaluation unit of low-high classification is higher than the average level, but the supply of public transport service is significantly lower than the average level. It can be seen that the demand for public transport service in the evaluation unit of this region is not matched with the supply, and these evaluation units are scattered in the periphery of the urban area, and a small number of them are distributed in the urban area. The demand for bus service in high-low evaluation units is lower than the average level, but the supply of bus service is significantly higher than the average level, and there are also differences in fairness. These evaluation units are mainly distributed in seasonal tourist attractions, and their service configuration has the problem of mismatch in the demand of tourists in off-season. The demand and supply of public transport service in high-high evaluation units are higher than average, mainly located in seven central urban areas, such as Qiaokou District, Jianghan District and Qiaokou District with high economic development level, Qingshan District with high industrial development level and Wuchang District, where universities are mainly distributed. The demand and supply of public transport service in low-low evaluation units are lower than the average level. There are few population distribution data and station supply in such evaluation units as a whole, which are mainly distributed in the periphery of Wuhan and do not belong to the core of urban development.

According to four different taxa of relative public transport services relative numerical gap between demand and supply, we can get the central city of Wuhan city in most parts of the supply of public transport services site and population density values were greater than average, and central city bus service supply and the demand value the degree of match between the two variables is higher, The public transport service configuration in the central urban area has good fairness, while the public transport service supply demand in the non-central urban area is mainly a low-low, low-high classification evaluation unit, mainly because the public transport service supply can't meet the needs of residents to travel.

To sum up, the classification of high - and low - low numerical evaluation unit of the public traffic service supply and the demand gap is smaller, the public transportation service level configuration and demand matching degree is higher, bus service level of configuration space of fairness, the basic supply of public transportation, has met the population of the area of traffic demand. There is a large gap between the supply and demand of public transport service in the analysis units of high-low classification and low-high classification, and there is spatial inequity in the allocation level of public transport service. These evaluation units are the key to optimize the public transport system.

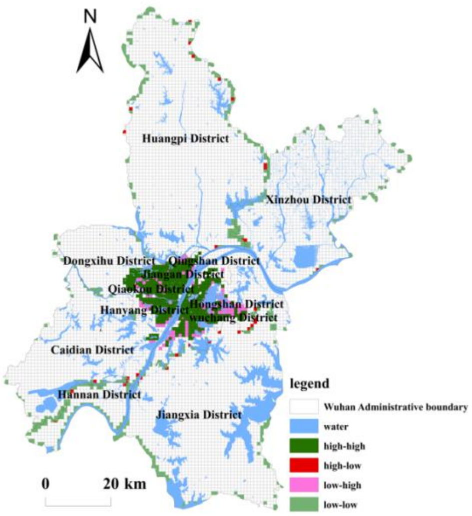

Figure. 4 Evaluation result at the local scale

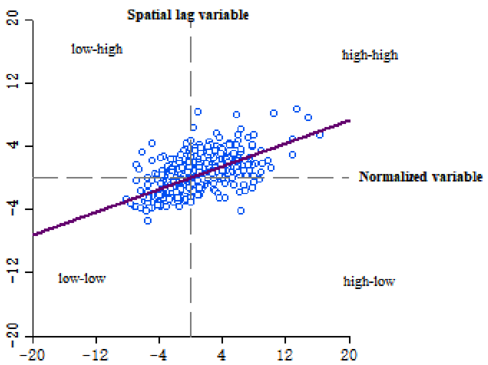

Figure. 5 Classification of bus service relative to supply and demand based on moran scatter diagram

5 CONCLUSIONS

With the rapid urbanization and motorization, the current major contradiction of urban transportation in China has been transformed into residents' increasing travel needs and uneven allocation of public transportation resources, which has become a practical problem that needs to be solved in the process of urban public transportation planning. The spatial fairness of urban public transport service is an important index to evaluate the sustainable development potential of urban transport. This paper, taking Wuhan as the study area, the use of public transport network data and population density of 1 km^2 grid data, using Bivariate Moran's I reveals research area spatial correlation between different variables and the significance, in order to under different scales of global and local area in Wuhan city public traffic service demand and supply of the current situation and problems of space fairness is analyzed. Bivariate Moran's I is a modification of the traditional Moran's I, considering the spatial distribution characteristics of the two variables of service demand and supply to carry out evaluation research, which can more comprehensively explain and explore the potential relationship between the two variables from the spatial concentration degree. The research shows that there are significant differences in spatial fairness of public transport service in Wuhan, and the service configuration level of central urban areas is higher than that of non−central urban areas. According to The Moran's I, Huangpi District was the worst administrative district in spatial fairness, and Dongxihu District was the best administrative district. The Qiaokou District was the least equitable of the seven central cities, mainly due to its high population density and inadequate transport services. The evaluation based on spatial fairness can help to realize the rapid optimization of public transport service system, improve the spatial inequity of service supply and demand, and provide scientific basis for the optimization and upgrading of public transport system.

By discussing numerical analysis and spatial agglomeration analysis, this paper carried out research on public transport service demand and supply equity. The results and observed values obtained from the values in the evaluation unit have no location attribute, so the spatial characteristics between the two variables cannot be studied. Spatial autocorrelation analysis is the analysis and consideration of spatial dimensions, which can combine the spatial characteristics of two different variables of public transport service supply and demand. The combination of the two methods can scientifically evaluate the fairness of public transport service in the evaluation unit from the perspective of numerical agglomeration and spatial agglomeration.

Through grid processing of population density data and bus line network data, the evaluation unit of 1km^2 grid can avoid the loss of some important but small areas or areas that are easy to be hidden.

To evaluate the spatial fairness of public transport according to the two different variables of supply and demand, the matching analysis of the two variables can be carried out, and then complete the in-depth understanding of the fairness of public transport service configuration level. According to the Bivariate Moran's I, Huangpi District has the worst spatial equity and Dongxihu District has the best spatial equity.

On the whole space of the public traffic service supply and demand in Wuhan equity analysis, 13 city of Wuhan Moran's I is positive, the supply and demand of public transportation, variable belongs to the space, central city of Wuhan city public transport demand and supply configuration level on average were higher than in the city center, according to the absolute value of Moran's I can be, Except Qiaokou District, the supply and demand level of public transport service in the other six central districts is relatively fair on the whole. According to the analysis of local scale based on the double variable local Moran's I of moran scatter diagram shows that belongs to the high - high and low - low classification evaluation units, this kind of unit match between supply and demand of the bus service is good, but some of the evaluation unit did not consider the matching problem between supply and demand of the bus service, such as low - high classification and high - low classification evaluation unit, To solve the mismatch between supply and demand of such evaluation units is the key to improve the public transport network. For example, the demand for bus service in the evaluation unit of high-low classification is lower than the average level, but the supply of bus service is significantly higher than the average level. It is suggested that the proportion of residential land should be appropriately increased according to the actual situation, so that more residents can enjoy better bus service in the corresponding area. For low-high classification units, the demand for bus service is higher than the average level, but the supply of bus service is obviously lower than the average level. Therefore, we can strengthen the construction of bus infrastructure to improve the overall strength of bus service configuration.

Some of the evaluation units in Qiaokou District obviously have higher than average demand for stations and are densely populated areas, which are generally scattered in urban areas such as schools. In addition, some evaluation units are of higher than average transport service supply, so we should consider adding or reducing stations to optimize the layout of the bus system on the premise of improving the accessibility of the bus system or improving the coverage of bus stations

ACKNOWLEDGEMENTS

This research was financially supported by Key Laboratory of Surveying and Mapping Science and Geospatial Information Technology of Ministry of Natural Resources (2020-3-2). The authors would like to thank the funded project for providing material for this research.

REFERENCES

Bai Y., Liu W., 2017. Optimization of bus station layout based on GIS location allocation model: A case study of Wuhan Nanhu District. Urban public transport, (10):26-31.

Gao S G., Zhang B., 2022.Research on integrated transportation accessibility of hub airport based on WebGIS service. Surveying and mapping geographic information:1-7.

Ge H W.,2006. Study on Traffic Impact Analysis and Optimization technology of Urban Bus Stops. Southeast university.

Gutiérrez A., Domènech A., Zaragozí B., et al., 2020. Profiling tourists' use of public transport through smart travel card data. Journal of Transport Geography, 88:102820.

Ji X F., Ou S J., Chen F., 2016.Evaluation of balanced allocation of public transportation resources based on traffic equity. 2016 China Urban Transportation Planning Annual Conference Proceedings,1082-1093.

Li B W., Huang Z D., Kuai X et al.,2021 Evaluation of public transportation Service based on spatial equity Theory: A case study of Shenzhen city . Progress in Geography,40(06):958-966.

Li B W., Huang Z D., Liu W.,2019. Evaluation of Bus Station Layout based on matching degree of Bus Service Demand and supply: A Case study of Wuhan City . Modern Urban Studies(05):99-105.

Li H., Bertini R.,2009. Assessing a Model for Optimal Bus Stop Spacing with High-Resolution Archived Stop-Level Data. Transportation Research Record Journal of the Transportation Research Board, 2111(2111):24-32.

Li W.,2019. Research on the influence mechanism of built environment on spatial fairness of public transportation considering spatial scale . Kunming University of Science and Technology.

Liang G S.,2007. Uncertainty Analysis of Urban rail Transit Passenger Flow Forecast . Urban rail Transit Research,(05):1-3.

Liu C L., Xu J Q., Guo Q B.,2019. Spatial pattern of centrality of Major Cities in China based on railway network . Economic Geography,39(03):57-66.

Liu W., Dong A R., Deng L. et al.,2021. Accessibility Equity Measurement of Urban Public Transportation based on Network Open Data . Journal of Wuhan University of Technology (Transportation Science and Engineering),45(06):1045-1050.

Liu Z L., Wang M J.,2011. An empirical study on the impact of residential space dislocation on Commuting Behavior in Beijing. Journal of geographical,66(04):457-467.

Lu F T.,2021. Evaluation and optimization of urban public transportation accessibility based on POI.Hefei University of Technology.

Qiao P H.,2021. Study on the Impact of spatial Scale on bus fairness evaluation. Chang' an University.

Ribeiro J., Fontes T., Soares C., et al.,2021. Accessibility as an indicator to estimate social exclusion in public transport. Transportation Research Procedia, 52:740-747.

Wirasinghe S C., Ghoneim N S., 1981. Spacing of bus-stops for many to many travel demand. Transportation Science,15(3):210-221.

Xi D Q.,2020. Evaluation of urban traffic accessibility and fairness based on multi-source big data. Nanjing university.

Yu W H., Ai T H.,2015. Visualization and Analysis of POI points in network space supported by Kernel Density Estimation. Acta Geodaetica Et Cartographica Sinica,44(01):82-90.

Zhang W Y., Li H., Duan X J.,2012 Research on the Impact of urban rail transit on housing Price: A Case study of Beijing Metro Line 1. Economic geography,32(02):46-51+65.