ISSN 2616-7433 Vol. 5, Issue 2: 42-48, DOI: 10.25236/FSST.2023.050208

Research on the spatial coupling relationship between subway accessibility and commercial facilities in large cities—a case study of Xi'an city

Hu Lingling, Chen Xianxue, Zhao Qian

School of Tourism, Institute of Human Geography, Xi'an International Studies University, Xi'an, China

Abstract: *The coupling and mutual feedback between subway accessibility and commercial facilities is one of the important prerequisites for promoting the coordinated development of cities. This paper uses spatial syntax to measure the accessibility of Xi'an subway, and combines GIS kernel density analysis and bivariate spatial autocorrelation analysis to explore the spatial distribution of subway accessibility and commercial facilities, as well as the coupling and spatial structure between them. The study found that: 1)Subway accessibility presents the characteristics of multi-center spatial layout, and has spatial imbalance. 2)The commercial facilities present a center-periphery spatial layout, with the bell tower as the center and the core density gradually decreasing to the surrounding areas. 3)From the perspective of spatial correlation, the subway accessibility and the layout of commercial facilities have a high spatial correlation. The local spatial pattern is relatively stable. The High-High and Low-Low aggregation areas constitute the main spatial correlation mode, and the distribution proportion of High-Low and Low-High types is relatively low.*

Keywords: *subway accessibility, commercial facilities, kernel density, spatial autocorrelation*

1. Introduction

Under the policy background of the construction of "Transportation Power", the subway, as the backbone of public transport, plays an increasingly important role and advantages in urban development. Relying on its strong radiation ability, the subway has become an important magnetic center to attract the agglomeration of urban elements,[1] and its accessibility determines the agglomeration and reconstruction of urban spatial elements in a certain sense. With the penetration of TOD theory in urban development, the commercial space along the subway is expanding rapidly, and the subway accessibility will bring a large number of people to collect and distribute into commercial passenger flow, which provides an opportunity for the development of commercial facilities, and good commercial development has a driving feedback effect on the construction of the subway system. Therefore, there is a close internal relationship between subway accessibility and the development of commercial facilities. The regularity of this relationship should be thoroughly studied, which is of great significance to the urban commercial development and the reasonable layout of outlets, the promotion of commercial comprehensive competitiveness and the assistance of transportation network planning.

As the two key elements of urban development, the relationship between rail transit and commercial facilities has always attracted the attention of scholars at home and abroad. Relevant foreign research is mainly based on the land use change under transportation construction to indirectly explore the impact of subway development on the commercial agglomeration along the line. For example, Lucia Mejia Dorantes and others used spatial statistical technology to explore the impact of the expansion of Madrid Metro Line 12 on the spatial agglomeration of many commercial activities such as urban retail, finance, catering and hotels,[2] David King pointed out that the expansion of the rail transit network is more inclined to the areas of commercial prosperity, which does not always play an active role in guiding commercial development;[3] The attention to relevant research in China is relatively late, but there have been relatively rich research results in many aspects, such as the impact of rail transit on the urban commercial space structure, the mode and type of commercial development of subway stations and surrounding areas, and the development of underground commercial space at stations, For example, Chen Weishan and others found that with the development of urban rail transit, the evolution of the commercial space of the transfer hub has experienced three stages of point-like, face-like and radial structure[4]; Fang Xiangyang and others divided the types of ground and underground retail business clusters near the station entrance from three aspects: Form, hierarchy and business format[5]; Xu Yajie

ISSN 2616-7433 Vol. 5, Issue 2: 42-48, DOI: 10.25236/FSST.2023.050208

and others found that traffic accessibility is significantly related to the vitality of space, and is the core factor affecting the vitality of underground commercial space in the metro station area[6].

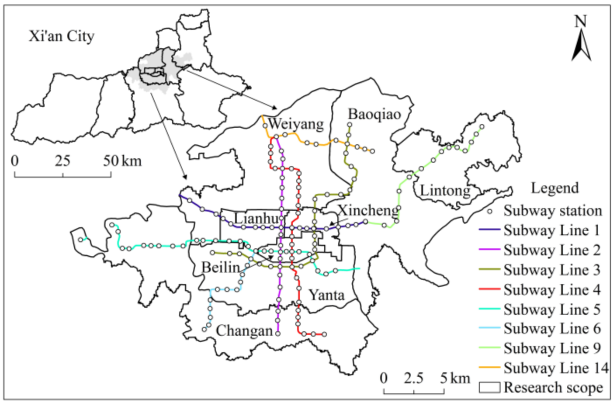

Figure 1: Xi'an subway line and station map

The research on the relationship between rail transit and commercial facilities has formed relatively rich results, but the research on the coupling relationship between traffic accessibility and commercial facilities is relatively scarce. In the existing research, the main focus is on the analysis of the coupling between rail transit and commercial facilities in spatial form/quality,[1] without considering the structural attributes of rail transit and in-depth analysis of the correlation between them. However, the research on the coupling relationship between subway accessibility and commercial outlets[7] does not consider the station's own attribute, namely connectivity. Therefore, in order to enrich the theory and method of measuring the coupling relationship between rail transit and commercial space, this paper takes Xi'an as an example, quantifies the accessibility of subway stations through spatial syntax and Baidu map data, and combines GIS kernel density analysis and bivariate spatial autocorrelation analysis to explore the spatial distribution law of subway accessibility and commercial facilities, as well as the coupling and spatial structure between them. It is expected to provide scientific reference for exploring the development law of urban commercial agglomeration and carrying out the practice of commercial and rail transit construction.

2. Research objects and methods

2.1. Research object

This paper takes Xi'an as the research object, which is located in the middle of Guanzhong Plain, and is the largest central city in the northwest inland region. As the starting point of the ancient capital of the thirteen dynasties and the ancient Silk Road, Xi'an has a long history of commercial form. In addition, Xi'an is the first city in northwest China to open subway. As of June 2021, there are 8 subway lines in operation, including Line 1, Line 2, Line 3, Line 4, Line 5, Line 6, Line 9 and Line 14. The total operating mileage is 252.6km, basically forming a mature network covering the main urban areas and urban development axis.

At present, 159 subway stations have been opened in Xi'an (since the data in this paper were collected in April 2022, so the subway stations opened before this time). This paper only studies the subway stations in Xi'an, a total of 145. The distribution of subway lines and stations in Xi'an is shown in Figure 2.

2.2. Research sources

The research data mainly includes Xi'an rail transit line and station data and commercial facilities data.

The data of rail transit lines and stations in Xi'an is derived from the schematic diagram of subway lines recently published on the official website of Xi'an Metro. The data are preprocessed by ArcGIS software and combined with manual interpretation to build a traffic network data set. The data of commercial facilities in the eight districts of Xi'an comes from the POI data of Gaode Map captured through the network in April 2022. A total of 254762 POI data were obtained after the data were de-duplicated, corrected and verified by field investigation. Finally, according to the different functions of the city and in combination with the POI classification system of Gaode Map, the POI data is divided into the following seven categories: Catering service, shopping, accommodation, business residence, financial insurance, life service, leisure and entertainment.

2.3. Research methods

2.3.1. Space Syntax

This paper draws on the research ideas of Zhou Qun,[8] two types of morphological variables, global integration and global traversal, which are widely used in spatial syntax, are adopted. The specific meanings of these two types of syntactic morphological variables are as follows:

Global integration reflects the accessibility between one node and all other nodes in the whole system. The calculation of the global integration degree is closely related to the depth value. Depth can express the accessibility of nodes in the topological sense, and the calculation formula of global integration degree can be obtained by extending it.[9]

$$md_i = \frac{\sum_{j=1}^{n} d_{ij}}{n=1}, I_i = \frac{D_n(n-2)}{2(mdi-10}, D_n = \frac{2n\left[\log_2(\frac{n+2}{3})\right]}{(n-1)(n-2)} \quad (1)$$

$md_i$is the average depth of node i; $I_i$is the global integration of node i; n represents the total number of nodes; d_{ij} refers to the number of steps, namely the depth, between nodes i and j; D_n is used to further standardize the degree of integration, which originates from the diamond model.

The global selection degree refers to the frequency of the shortest topological distance between two nodes of an element in the space system, reflecting the possibility of space being traversed. In the rail transit system, the higher the choice of the station, the higher the probability that it will be passed by the passenger flow, and the greater the chance of consumption in the station area. The calculation formula is:

$$ch_i = \frac{\sum_{j=1}^{n}\sum_{k=1}^{n}\delta(j,i,k)}{(n-1)(n-2)} \quad (2)$$

$ch_i$is the global selectivity of node i; n represents the total number of nodes; j、k and i are arbitrary spatial nodes;$\delta(j,i,k)$represents a count of node i passing by when nodes j and k pass each other.

2.3.2. Kernel density estimation

Kernel density estimation is a widely used method in spatial analysis of point data[10,11]. The calculation method takes a specific point as the center, and the estimated density of the point is the highest, which will decline with the increase of the outward distance. When the distance center reaches a certain range, the density is 0. Calculate all points and stack at the same position to get the final kernel density distribution map, and reflect the difference of space position.

2.3.3. Spatial autocorrelation

Spatial autocorrelation[12,13] is the core of spatial statistics, which is used to show whether a certain surface phenomenon has a special spatial form. It aims to describe the spatial characteristics of a certain phenomenon or attribute value in the whole region, and test whether it has the characteristics of agglomeration, dispersion or randomness in space.

3. Kernel density estimation

The kernel density analysis method is used to measure the subway accessibility and the spatial distribution characteristics of commercial facilities. The search radius adopts the default value and is output in the size of 1000 m pixels. The natural breakpoint grading method is used for hierarchical display. According to the density value, it is divided into one to five levels from low to high. The visual image is shown in Figure 2 and Figure 3.

3.1. Spatial distribution characteristics of subway accessibility

The kernel density distribution of subway station accessibility presents a "multi-center" spatial

ISSN 2616-7433 Vol. 5, Issue 2: 42-48, DOI: 10.25236/FSST.2023.050208

layout (Figure 2), which is uneven. Yongningmen-Xiaozhai, Hepingmen-Dayanta stations form the largest core area, Beidajie-Wulukou Station forms the secondary core area, Shuangzhai Station forms the three-level core area, and the administrative center and Kejilu station form the fourth and fifth core areas. These stations are mostly transfer stations. The area with low nuclear density has the widest coverage.

3.2. Spatial distribution characteristics of commercial facilities

The kernel density of seven types of commercial facilities, including catering services, shopping, accommodation, business, financial insurance, life services, entertainment and leisure, is superimposed through the geographic information system (GIS) overlay analysis technology, so as to calculate the distribution characteristics of the density of commercial space facilities.

In general, the kernel density of commercial facilities presents a center-periphery spatial layout, with the Zhonglou as the center, and the kernel density gradually decreases to the surrounding areas (Figure 3). It can be seen from Figure 3 that the core circle is a five-level gathering area with the highest density. This is the traditional commercial center area of Xi'an (Zhonglou-NanShaomen area and the area around the Wulukou and Kangfulu stations). The density of commercial facilities is much higher than other areas, and it becomes the core area of commercial facilities gathering; The three、fourth level expands in circles on the basis of the fifth level. Xiaozhai and Tonghuamen stations, as transfer stations, have a great impact on their surrounding areas, becoming the "rising star" of the business district, and forming a "enclave" in the peripheral area (Huaqingchi-Dongsancha section); The secondary circle begins to spread along the track line, but the coverage is small, forming scattered "enclaves" in the edge area, and the primary circle has the widest coverage.

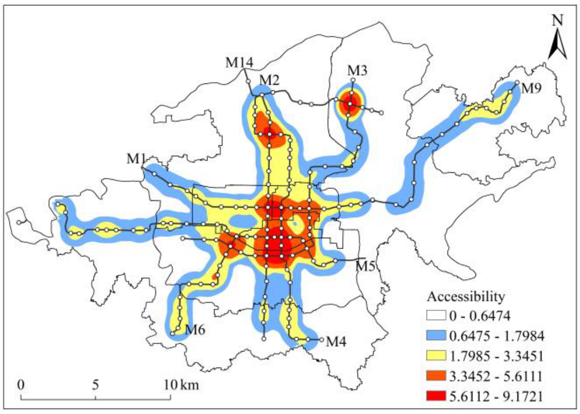

Figure 2: Spatial distribution characteristics of subway accessibility kernel density

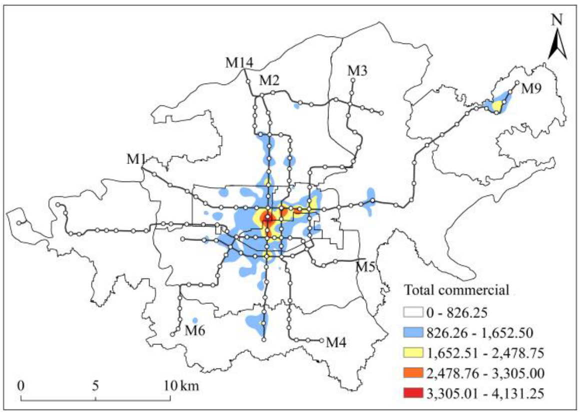

Figure 3: Spatial distribution of kernel density of commercial facilities

4. Spatial coupling correlation analysis

This paper uses ArcGIS software to build fishing net (200m × 200m), extract the kernel density values of subway accessibility and commercial facilities of each grid, and calculate the global and local

ISSN 2616-7433 Vol. 5, Issue 2: 42-48, DOI: 10.25236/FSST.2023.050208

Moran's I index of bivariate based on the kernel density values of both.

4.1. Two-variable global autocorrelation

As shown in Figure 4, On the whole, subway accessibility and commercial facilities have a high spatial correlation, high-high and low-low aggregation areas constitute the main spatial correlation mode, and the distribution proportion of high-low and low-high types is low.

Among them, the Moran's I index of the coupling between subway accessibility and commercial facilities is 0.635, the z value is 250.240, and the p value is 0.001. Through the 1% significance level test, it shows that there is a significant positive spatial correlation between subway accessibility and commercial facilities in Xi'an, that is, subway accessibility and commercial facilities show a highly concentrated distribution phenomenon. According to the bivariate Moran's I scatter diagram (Figure 4), the spatial autocorrelation index of subway accessibility and commercial facilities kernel density values are distributed in all four quadrants, mostly in the first and third quadrants, belonging to the "high-high" and "low-low" type cluster area, accounting for 79.40% of the total sample size, showing a significant positive spatial correlation; The stations located in the second and fourth quadrants, namely "low -high" and "high-low" type cluster areas, are less, accounting for 20.6% of the total sample, indicating that the high value and low value areas tend to be bipolar cluster distribution.

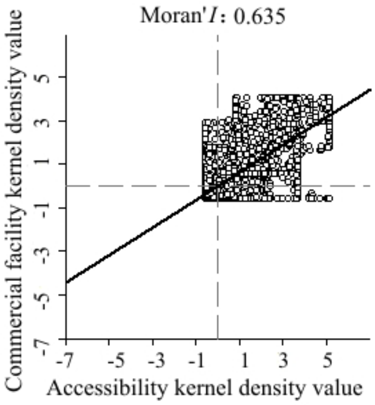

Figure 4: Metro accessibility and commercial fac-ilities global autocorrelation scatter distribution

4.2. Two-variable local autocorrelation

In order to more clearly reveal the spatial distribution characteristics of the local spatial autocorrelation of the kernel density values of subway accessibility and commercial facilities, the local autocorrelation LISA aggregation map is drawn by ArcGIS software (Figure 5). ①High-High concentration area is mainly located in the central area of the main urban area, where the business district gathers, the population density is large, and the transportation facilities are perfect. There is a significant positive correlation between the subway accessibility and the commercial facilities. In addition, the section between Northwestern polytechnical university·Xi'an University of Science and Technology(Lintong Campus) Station and Yinqiaodadao Station of Line 9 presents a local high gathering area around the city, which is closely related to the existing tourist attractions Huaqingchi and Qinling, and tourism drives the development of commerce and transportation. ② High-Low concentration areas are mainly located in Chang'an District and Baqiao District, with relatively scattered spatial distribution. We should give full play to the radiation effect of high concentration areas and promote each other with the surrounding low concentration areas. ③Low-High concentration area is located at the edge of the main urban area. This type of area is adjacent to the "High-High" type of concentration area. Relatively high value areas such as economy, resources and transportation service facilities are weak, thus forming a valley area. ④Low-Low concentration areas are mainly distributed in the edge of the main urban area and the peripheral areas of the city. These areas have relatively lagged road access conditions, scattered population, less intensity of economic activity than the central area, and don't have good location conditions. Therefore, this area shows a low kernel density value of subway accessibility and a positive spatial correlation with the scattered distribution of commercial facilities. The abnormal state of local spatial correlation between the two shows that the layout and

ISSN 2616-7433 Vol. 5, Issue 2: 42-48, DOI: 10.25236/FSST.2023.050208

development of commercial facilities are not only affected by the traffic network.

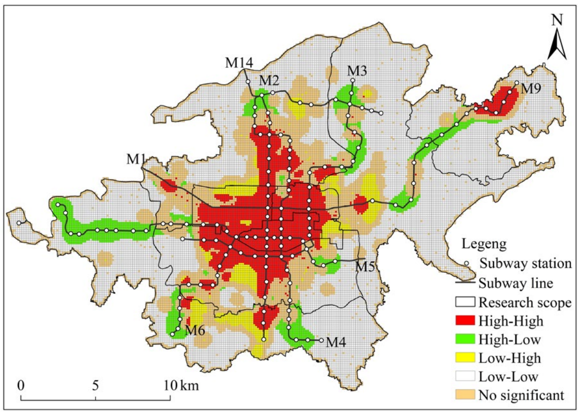

Figure 5: Metro accessibility and commercial facilities kernel densit Local spatial autocorrelation LISA agglomeration distribution

5. Discussion and Conclusion

5.1. Discussion

Based on the existing research on the relationship between rail transit and commercial space, combined with big data technology, this study deeply analyzes the spatial coupling between the two. The research conclusion is different from the conclusion of Wang Weili and others that the accessibility and convenience of the subway stations in the center of Tianjin and the vitality of the surrounding commercial space have a low degree of coupling development.[14] The high coupling between the accessibility of the subway in Xi'an and the layout of commercial facilities has verified the research of He Jianhua and others on the spatial coupling of the subway accessibility and catering outlets in Wuhan,[7] That is, there is a good global spatial positive correlation between the accessibility of subway stations and the dynamic coupling and coordination of commercial space, and there are four different types of spatial agglomeration locally. The research results have certain guiding value for urban rail transit planning and commercial functional area layout. However, this study also has some shortcomings. It only considers the subway transportation mode. In future research, we can try to add other transportation data, such as public transport, shared bicycle, etc., to make up for the shortcomings left by the spatial coupling between the subway transportation mode and catering outlets.

5.2. Conclusion

Through the study of Xi'an subway accessibility and the coupling of station commercial space, it is found that:

The subway accessibility presents the characteristics of multi-center spatial layout. Beidajie, Zhonglou, Yongningmen, Nanshaomen, Wulukou and other stations in the center of the city have the highest overall integration. The subway stations with high overall selection are mainly transfer stations, which are unevenly distributed in the main urban area, such as Xiaozhai, Dayanta, Beidajie, Wulukou and other stations are more concentrated in the center of the city, while Kejilu, Administrative Center, and Shuangzhai stations are scattered in the periphery. The stations with high overall selection are also stations with good subway accessibility.

The spatial agglomeration characteristics of the kernel density of commercial facilities show the trend of "center periphery" spatial structure. With the Zhonglou as the center, the core area is located in the traditional commercial center area of Xi'an (the Zhonglou-Nanshaomen section and the surrounding area of Wulukou and Kangfulu stations), and the outer area forms a "enclave" (Huaqingchi-Dongsancha section), which is closely connected with tourist attractions.

From the perspective of spatial correlation, the subway accessibility and the layout of commercial facilities have a high spatial correlation. The local spatial pattern is relatively stable. The High-High and Low-Low aggregation areas constitute the main spatial correlation mode, and the distribution proportion of High-Low and Low-High types is relatively low. The subway has a great impact on the

ISSN 2616-7433 Vol. 5, Issue 2: 42-48, DOI: 10.25236/FSST.2023.050208

commercial development of Xi'an, and the traffic accessibility plays a decisive role in the travel orientation of consumers. Therefore, the adjustment of the commercial space layout needs to be based on the distribution law of human space activities. For the local correlation anomaly, it indicates that the commercial development will be affected by other factors such as population density, consumption level, etc. in addition to the traffic conditions, In addition, other transportation modes should be supplemented to meet the needs of consumers to travel to commercial destinations.

References

[1] Yao, Q. A., Gong, T. W., Shi, J., (2019). "Coupling development of rail transit and commercial facilities based on public comment data: Taking Tianjin as an example, " Journal of Tianjin Chengjian University, 25(4), 239-245, .

[2] Dorantes, L. M., Paez, A., Vassallo, J. M.(2012)."Transportation infrastructure impacts on firm l-ocation: The effect of a new metro line in the suburbs of Madrid, " Journal of Transport Geography, 22, 236-250.

[3] King, D.(2011)."Developing densely estimating the effect of subway growth on New York city land uses, " Journal of Transport and Land Use, 4(2), 19-32.

[4] Chen, W. S., Liu, L., Liang, Y. T.(2015). "Characterizing the spatio-temporal evolution of retail business attransfer hubs of Guangzhou Metro," Acta Geographica Sinica, 70(6), 879-892.

[5] Fang, X. Y., Cheng, Z. N.(2005). "Agglomerate types of retail business around urban subway station: Taking Guangzhou as an example, " Economic Geography, 25(4), 525-527, 537.

[6] Xu, Y. J., Chen, X. S.(2021). "A study on the factors influencing the spatial vitality of underground commercial space in metro area and the strategies to improve the vitality, " Modern Urban Research, 12, 70-76.

[7] He, J. H., Cao, Z. Q., Li, C.(2018). "Space coupling research on accessibility of subway with catering services spot in Wuhan, " Geomatics &Spatial Information Technology, 41(2), 10-13.

[8] Zhou, Q., Ma, L. B., Chen, K., Cao, X. S.(2015). "An improved method of analyzing the accessibility of Guangfo subway evolution based on spatial syntax, " Economic Geography, 35(3), 100-107.

[9] Zhang, Y., Wang, J. G.(2004). "On 'Space Syntax', " The Architect, (6), 33-44.

[10] Wang, F. H.(2009). "Quantitative method and application based on GIS, " Beijing: The Commercial Press, 49.

[11] YU, W. H, , Ai, T. H., Yang, M., Liu, J. P.(2016). "Detecting "Hot Spot" of facility POIs based on kernel density estimation and spatial autocorrelation technique, " Geomatics and Information Science of Wuhan University, 41(2), 221-227.

[12] Li, Y., Yi, L., Zhou, Y., Zhu, X.(2012). "Investigation of a coupling model of coordination between urbanization and the environment, " Journal of Environmental Management, 98, 127-133.

[13] Zhan, X., Lin, A. W., Sun, C., Qiao, W.(2016). "Centrality of public transportation network and its coupling with bank branches distribution in Wuhan City, " Progress in Geography, 35(9), 1155-1166.

[14] Wang, W. L., Bai, Y. Q., Lu, J. D.(2019). "Activity classification and coupling of commercial space around subway stations based on Point of Interest (POI) data: A case study of the central city of Tianjin, " City, (5), 14-22.