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Research Article

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Research on the Accessibility of Rail Transit Line Network Based on Spatial Synta - Taking Qingdao as an example

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Abstract In order to reasonably and quantitatively evaluate the accessibility size of the urban rail transit network, this paper takes Qingdao Urban Rail Transit Phase 2 Construction Plan, Phase 3 Construction Plan and Visionary Construction Plan Rail Transit Plan as an example, and selects the degree of global integration, degree of local integration, degree of comprehensibility, and degree of spatial intelligence to construct four evaluation indexes, and utilizes the software such as AutoCAD, Depth map, and so on, to quantitatively analyze the overall structure and accessibility of the rail transit in Qingdao city based on the spatial syntactic theory and model to quantitatively analyze the overall structure and accessibility of Qingdao's rail transit. According to the output results of the software, Qingdao's rail transit network is improving, the global integration degree and local integration degree in the index system are increasing, and the comprehensibility degree and spatial intelligence degree are decreasing, which quantitatively describes the accessibility of Qingdao's rail transit network, and can provide a certain reference for the planning of urban rail transit line network.

Keywords Accessibility, Spatial Syntax, Rail Transit

1. Introduction

In order to comply with the global sustainable development goals and trends, China will formally incorporate "carbon peak" and "carbon neutrality" into the national strategy in 2020, and this year coincides with the opening year of the 14th Five-Year Plan and the accelerated construction of a transportation powerhouse. This year coincides with the opening year of the "14th Five-Year Plan" and the acceleration of the construction of a strong transportation country, and the public transportation industry is precisely one of the important carriers of practicing the "dual-carbon" strategy. Urban rail transit is the backbone of urban public transportation system and an important part of urban comprehensive transportation system [1]. In transportation research, we generally use accessibility to evaluate the level of urban public transportation services [2], the theory was put forward by Hansen in 1959, in the field of transportation, we believe that accessibility is the degree of convenience from one location to another in a given transportation system [3]. Summarizing the existing literature and research results, it can be seen that for different research purposes, different research objects and different evaluation needs, there are different methods of accessibility evaluation, and the current common methods of accessibility metrics mainly include: topological method, cumulative chance method, value line method, gravity model method, etc [4]. Accessibility is an important method of evaluating the level of public service, objective and accurate evaluation of rail transit accessibility issues, the urban rail transit system line network structure, planning and construction is of great significance [5].

2. Construction of rail transit accessibility evaluation system

2.1 space syntax

Spatial syntax was proposed and developed by Hillier of the University of London in the early 1980s, and its essence is a network accessibility model based on topological distance and spatial segmentation, with four basic

methods, namely, axial method, convex spatial method, field of view segmentation method, and line segmentation analysis, and Depthmap software is used to analyze the networked structure of the space, and to intervene in the analysis from the conformation of the space [6]. This method only considers the topological location relationship of the line spatial location [7], so the calculation results are stable and reliable. In this study, the axial method in spatial syntax is used, which is a common method in spatial syntax, is to utilize the longest straight line of the fewest number of purposes to draw the axial map, as shown in Figure 1.

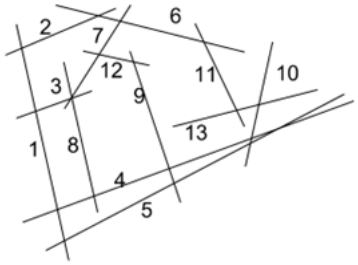

Figure 1: Axis connection relationship

The value of each axis syntactic variable can be calculated by using the axis diagram, and the size of each axis syntactic variable is indicated by different colors from red to blue, as shown in Figure 2.

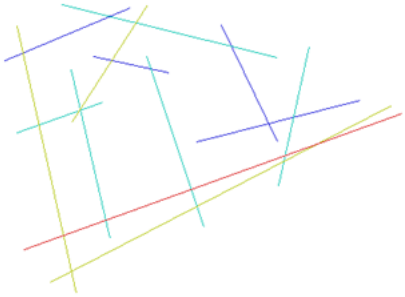

Figure 2: Schematic representation of axial syntactic variable values

2.2 space syntactic variable

Spatial syntax can be derived from the axial map connectivity relationships based on topological relationships, and the basic variables include average depth value, asymmetry, connectivity value, and integration.

(1) Connection value

The connection value indicates the number of spaces intersecting with the first unit space in the system space, and the higher the connection value, the better the permeability in the space.

$$C_i = k \qquad (1)$$

Where: C_i is the connection value of node i; k is the number of nodes connected to node i.

(2) Average depth value

Average depth value is an important concept in spatial syntax, which refers to the minimum number of steps of a node in a system, as shown in equation (2). In the rail transit line network, the average depth value can compare the convenience of the location of this node in the line network.

$$D_i = \sum_{d_i=1}^{k} d_i \cdot N_i \qquad (2)$$

Where: D_i is the depth value of the node i; N_i is the number of nodes with the least number of steps to node i; d_i is the minimum number of steps from node i to another node. When k = 1, D_i is equal to the connection value of node i; When k < n 时, D_i is the local depth value of node i; When k = n 时, D_i is the global depth value of node i.

$$MD_i = \frac{\sum_{d_i=1}^{k} d_i \cdot N_i}{m-1} \quad (3)$$

Where: MD_i is the average depth value of node i; m is the total number of nodes in the space system, m >1.

(3) Degree of integration

Integration degree is used to indicate the degree of closeness between nodes in a system.

$$I_i = \frac{m\left[\log_2(\frac{m+2}{3}-1)+1\right]}{(m-1)(MD_i-1)} \quad (4)$$

Where: I_i is the integration degree of node i.

2.3 Accessibility evaluation indicators

Accessibility is an objective characteristic in space, using spatial syntax to analyze the morphological variables of space, through the literature analysis method and research related situations can be found, in the basic variables of spatial syntax reflecting the overall spatial or local spatial relationship is the degree of global integration and local integration, the degree of integration and the range of accessibility is directly proportional to the degree of integration; the degree of comprehensibility and the spatial intelligence degree reflect the spatial distribution pattern and the The comprehensibility and spatial intelligence reflect the spatial distribution pattern and structural rationality. Therefore, this paper mainly focuses on the four indicators of global integration, local integration, comprehensibility and spatial intelligence to evaluate the accessibility of traffic organization.

Comprehensibility is a ratio, which is the ratio between the global and local model analysis results, and its value is the regression coefficient of the linear regression equation, which expresses the correlation with the global integration degree, and is expressed in the scatter plot output by the software, and the larger the value is, the higher the comprehensibility is, and the more coordinated is the development of the local area and the whole area.

$$R^2 = \frac{[\sum_{i=1}^{m}(C_i-\bar{C})(I_i-\bar{I})]^2}{\sum_{i=1}^{m}(C_i-\bar{C})^2\sum_{i=1}^{m}(I_i-\bar{I})^2} \quad (5)$$

Where $\bar{C}$ is the mean of the connection values, I_i is the mean of the global integration, and

$$\bar{C} = \frac{1}{m}\sum_{i=1}^{m} C_i \quad (6)$$

$$\bar{I} = \frac{1}{m}\sum_{i=1}^{m} I_i \quad (7)$$

I_i is the global integration of node i.

Spatial intelligence is determined by the correlation between global integration and local integration, and spatial intelligence is proportional to reachability within range.

$$r^2 = \frac{[\sum_{i=1}^{m}(I'_i-\bar{I}')(I_i-\bar{I})]^2}{\sum_{i=1}^{m}(I'_i-\bar{I}')^2\sum_{i=1}^{m}(I_i-\bar{I})^2} \quad (8)$$

Where: r^2 is the spatial intelligence degree;

$\bar{I}'$ is the mean value of the local integration degree, and

$$\bar{I}' = \frac{1}{m}\sum_{i=1}^{m} I'_i \quad (9)$$

I'_i is the local integration of node i, I_i is the integration of node i.

3. Qingdao Rail Transit Accessibility Evaluation

3.1 Qingdao Rail Transportation Planning

Since the construction of Qingdao Metro started in 2010, the operation mileage has reached 246 kilometers, and six lines have been built and put into operation, with the highest passenger flow in a single day exceeding 1.2 million, which is among the top ten in China, and has become one of the fastest growing cities in the country in the past ten years. In 2016, in order to support Qingdao's overall urban development goals and promote Qingdao's economic development, it was agreed that the construction tasks and objectives of the Qingdao Urban Rail Transit Phase II construction plan (2013-2021) should be adjusted. Plan (2013-2021) to adjust the construction tasks and targets set out in the Plan.2021 In September 2021, the Qingdao Urban Rapid Transit Phase III Construction Plan (2021-2026) was formally approved, with a total of 139 kilometers of seven lines and a total investment of about 100 billion yuan. The Adjustment of Qingdao Urban Rail Transit Line Network Planning (2019) was approved by the Qingdao Municipal Government, which partially adjusted the original line network vision year scheme, and the adjusted Qingdao rail transit line network scheme for the vision year consisted of 19 lines (including 2 branch lines), with a total scale of 872 kilometers. According to the current Qingdao 2050 Vision Development Strategy, the future urban spatial structure of Qingdao is a multi-center, networked urban spatial layout structure with "one axis, one belt, six corridors, one bay, two wings and two pivot points".

3.2 Accessibility Evaluation

The object of accessibility evaluation in this paper is the urban rail transit network of Qingdao. According to the 2nd phase construction plan, 3rd phase construction plan and visionary construction plan of Qingdao urban rail transit, the road network in the master plan is used as the base map, and the collected planning data are transformed in AutoCAD software, and then the axial maps are extracted according to the requirements of the theory of spatial syntax. According to the principle of visibility analysis, a point in a subway line in the line network is selected, and from this point, the furthest visible point within the line is searched for to complete the first axis, and then from this point, the next furthest point is searched for to complete the axis, and so on involving the entire line network, the axial map is plotted, and then it is imported into the Depthmap Spatial Syntactic Analysis Software, and the Node Count is utilized to make a test of the model before generating the topological model. Before generating the topology model, Node Count is used to check the model, and if the axes are all in green, it means that there is no independent axes, which is mainly to prevent errors in the manual drawing process. After that, the spatial syntactic axial map is constructed for relevant analysis, and finally the research conclusion of spatial syntactic method in rail transit line network planning is drawn.

(1) Global integration degree

Line Length is used as the weight for topological operations, and k=n is selected to represent the global spatial integration degree, and the results of the global integration degree calculation for the three construction planning periods are shown in Table 1.

Table 1: Global integration degree

Global Integration	Planning Construction Cycle		
	Phase 2 construction planning	Phase 3 construction planning	Visionary construction planning
Maximum value	0.397681	0.388526	0.443383
Minimum value	0.13461	0.132345	0.158478
Mean Value	0.275613	0.266101	0.340082

In order to represent the global integration degree of the line network more intuitively, it is also possible to change the color of the integration degree according to the color of the integration degree, from cold to warm

color represents the value of the global integration degree is increasing, the warmer the color of the line, the higher the value of the integration degree. The global integration results are shown in Figures 3 through 5.

Figure 3： Phase 2 construction planning line network global integration

Figure 4： Phase 3 construction planning line network global integration

Figure 5： Visionary construction planning line network global integration degree

It is generally believed that when the integration degree is between 0.4 and 0.6, the spatial distribution is more decentralized. The spatial aggregation of the line network in the above three construction planning periods is relatively decentralized, among which, the integration degree of the line network in the 2nd and 3rd construction planning periods shows the shape of center aggregation and dispersion, which is similar to the distribution characteristics of the general rail transit line network; the global integration degree of the line network in the visionary construction plan is slightly improved.

(2) Local integration degree

The syntactic variables are calculated with the number of steps as 3, 5, 7, 9 and 11, and the integration degree of all 3 steps, 5 steps, 7 steps, 9 steps and 11 steps are obtained respectively, and the results of the local integration degree of the line network are shown in Table 2.

Table 2: Local integration degree

Global Integration		Planning Construction Cycle		
		Phase 2 construction planning	Phase 3 construction planning	Visionary construction planning
3-Step Integration Degree	Maximum value	1.66667	1.73077	1.73077
	Minimum value	0.333333	0.333333	0.333333
	Mean Value	0.949385	1.01114	1.06553
5-Step Integration Degree	Maximum value	1.2771	1.25225	1.24689
	Minimum value	0.349023	0.349023	0.349023
	Mean Value	0.762972	0.813863	0.867844
7-Step Integration Degree	Maximum value	1.02275	1.02832	1.05456
	Minimum value	0.328368	0.328368	0.328368
	Mean Value	0.657256	0.702742	0.754546
9-Step Integration Degree	Maximum value	0.885401	0.915445	0.90979
	Minimum value	0.35556	0.305556	0.305556
	Mean Value	0.585599	0.625975	0.673935
11-Step Integration Degree	Maximum value	0.79704	0.844079	0.837249
	Minimum value	0.277474	0.280208	0.281223
	Mean Value	0.532353	0.568402	0.612186

With the improvement of the rail transit line network, the 3-step integration, 5-step integration, 7-step integration, 9-step integration and 11-step integration of the line network have been improved, among which the integration of the 3rd phase construction plan is the highest, which is due to the fact that the vision plan proposed in 2019 is lagging behind compared with the current rapid development of Qingdao city in general, and the recently announced 3rd phase plan is based on the overall coordination of the rail transit construction and the development of Qingdao city. Completed rail transit lines, in-depth study of the planning line selection, in which Line 2, Line 3, Line 5, Line 7, Line 15, Line 4, Line 8 in the global integration degree and local integration degree of the value are relatively high, the 3 phase construction planning line network of local integration degree appears in the characteristics of the global characteristics of the network is similar to the global characteristics.

(3) Understandability

Using Depthmap analysis software, the global integration degree and connection value are selected for correlation analysis, and the results of line network comprehensibility calculation are shown in Table 3.

Table 3: Comprehensibility

comprehensibility	Planning Construction Cycle		
	Phase 2 construction planning	Phase 3 construction planning	Visionary construction planning
R^2	0.167098	0.17571	0.142346

The comprehensibility of Qingdao's construction planning line network in different periods is shown in Figure 6 to Figure 8. In the figure, the horizontal axis is the connection value and the vertical axis is the global integration degree.

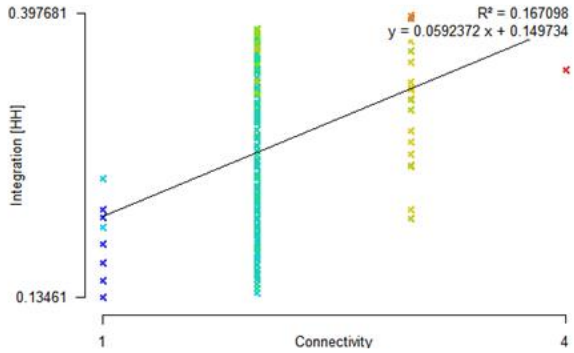

Figure 6：Phase 2 construction planning line network comprehensibility

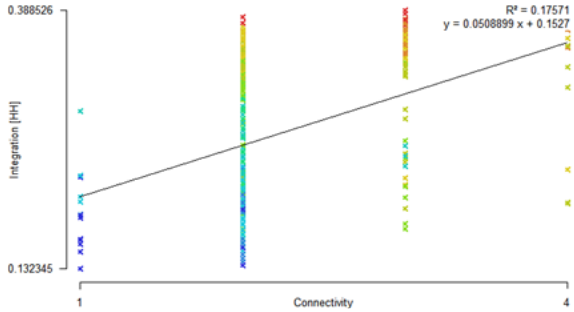

Figure 7：Phase 3 construction planning line network comprehensibility

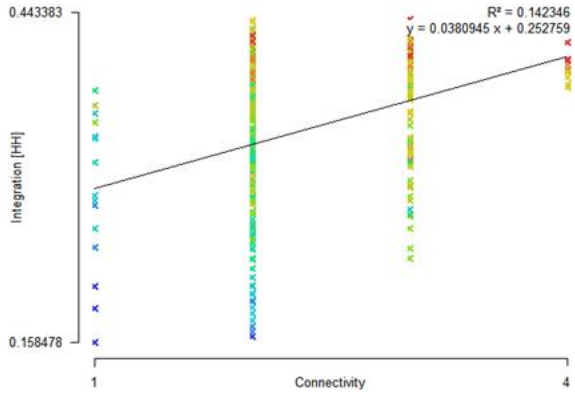

Figure 8: Comprehensibility of the line network of the visionary construction plan

Generally speaking, the R^2 value R^2 is less than 0.5, which indicates that the correlation is weak. The comprehensibility of the rail transit line network in different periods is average, which indicates that the network structure of Qingdao is relatively weak, and with the continuous improvement of the line network, the comprehensibility is decreasing, which is due to the continuous expansion of the line network scale and the development of the city from the central urban area to the outside, which reduces the comprehensibility of the whole line network.

(4) Spatial Intelligence Degree

Using the Scatter Plot function of the analysis software, the calculation results of the spatial intelligence of the construction planning line network are shown in Table 4.

Table 4: Spatial Intelligence

Spatial Intelligence	**Planning Construction Cycle**		
	Phase 2 construction planning	Phase 3 construction planning	Visionary construction planning
r^2	0.346953	0.351614	0.303869

The spatial intelligence of Qingdao's 3-phase construction planning line network is shown in Figure 9 to Figure 11, with the vertical axis as the 3-step integration degree and the horizontal axis as the global integration degree.

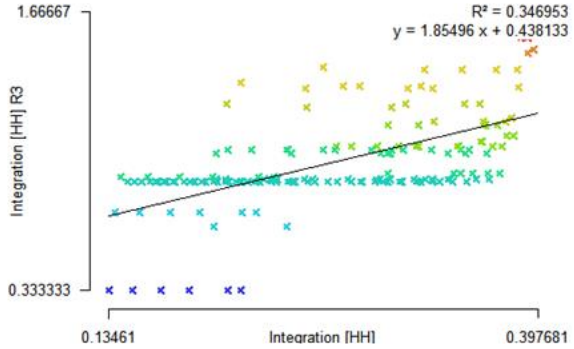

Figure 9: Phase 2 construction planning line spatial intelligence

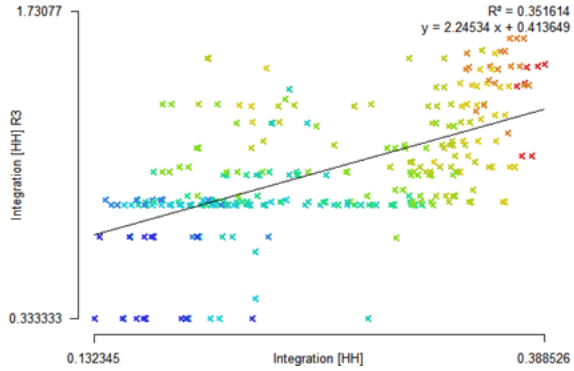

Figure 10: Phase 3 construction planning line spatial intelligence

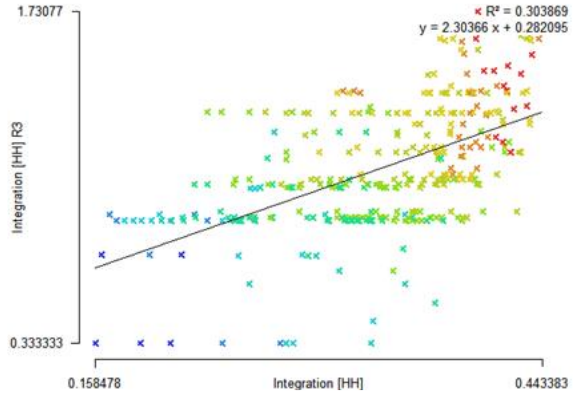

Figure 11: Visionary construction planning line network space intelligence degree

It is generally believed that an r^2 value greater than 0.5 means that the spatial intelligence is high, and an r^2 value greater than 0.7 means that the space is very intelligent. None of the spatial intelligence levels of the line network are high, which is due to the fact that Qingdao is still in a period of rapid development, and the spatial intelligence is still decreasing with the continuous improvement of the line network, and also due to the fact that the morphological structure of the developing city is changing drastically, and the scale is growing rapidly, which leads to the decreasing correlation between the localization and the whole.

4. Conclusions

Due to the complexity and diversity of the rail transit network structure, it is difficult to quantitatively analyze it by general mathematical and theoretical methods, and therefore it is difficult to provide empirical calculation methods and visualize images. In this paper, we use spatial syntax theory and model to quantitatively analyze the overall structure and accessibility of Qingdao's rail transit, and the analysis results are as follows:

(1) Combined with the global integration degree, it can be seen that the spatial aggregation of the line network in the three construction planning periods is relatively decentralized, among which the integration degree of the line network in the 2nd and 3rd construction planning periods shows the shape characteristic of center aggregation and dispersion around;

(2) With the improvement of the rail transit line network, the 3-step integration degree, 5-step integration degree, 7-step integration degree, 9-step integration degree and 11-step integration degree of the line network have been improved, and the 3-step integration degree can reach 1.66667, 1.73077, 1.73077, and the values of Line 2, Line 3, Line 5, Line 7, Line 15, Line 4, and Line 8 in the global integration and local integration degree are higher. are relatively high;

(3) The comprehensibility of the rail transit line network in the 3 different periods is average, which indicates that the network structure of Qingdao is relatively weak, and the comprehensibility decreases with the continuous improvement of the line network, which is due to the continuous expansion of the line network scale and the development of the city from the central urban area to the outside, which decreases the comprehensibility of the whole line network.

(4) The level of spatial intelligence of the rail transit network in the three different periods is not high. This is because Qingdao is still in a period of rapid development, and the spatial intelligence is still decreasing due to the continuous improvement of the line network, and also because of the rapid change of the form and structure of the developing city, and the rapid growth of the scale, which leads to the decrease of the correlation between the local and the whole.

According to the results of the accessibility analysis, different cities have different planning backgrounds. According to the current Qingdao 2050 Vision Development Strategy, the future urban spatial structure of Qingdao is more in line with the future vision of Qingdao as a multi-center, networked urban spatial layout structure of "one axis, one belt, six corridors, one bay, two wings and two pivot points". Based on the spatial syntax theory, the accessibility of the lines in the rail transit network is calculated, which will provide a reference for the future research to try to use the accessibility of the lines to determine the timing of the construction of rail transit lines.

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