Article

Diversity and Influencing Factors of Public Service Facilities in Urban (Suburban) Railway Life Circle—Evidence from Beijing Subway Line S1, China

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Abstract: The urban (suburban) railway is a fast and convenient rail transit system connecting urban and suburban areas, and a refined analysis of the diversity of public service facilities around its stations can help to promote the intensive use of land around rail stations. However, the differences in the diversity of public service facilities in the railway life circle between urban and suburban railway stations and the factors affecting them are not clear. This paper takes the Beijing Suburban Railway Line Sub-center (Line S1) as a case study, uses the Shannon-Wiener index to measure the spatial diversity characteristics of public service facilities, and utilizes a multi-scale geographically weighted regression model to explore the influencing factors. The findings indicate that: (1) Centered on the stations, all six stations show a "less-more-less" ring or half-ring to the left distribution structure of the comprehensive diversity index of public service facilities within their study areas, with an increase followed by a decrease. (2) The influence of each influencing factor on the diversity of market-featured facilities exhibits significant differences. The most substantial spatial heterogeneity is observed in the distances to the nearest subway stations and bus stops. Distances to subway and urban (suburban) railway stations exhibit different spatial distribution characteristics within urban and suburban areas on Line S1. In urban areas, the closer the distance to the subway station or the further the distance to the railway station, the greater the diversity of public service facilities. Conversely, in suburban areas, the opposite is true. The conclusions of this research provide a scientific methodology and improvement measures to facilitate the construction of railway life circles in suburban regions of megacities.

Keywords: public service facilities; urban (suburban) railway; railway life circle; diversity; multi-scale geographically weighted regression (MGWR); Beijing

1. Introduction

Rail transport construction has become a strategic choice for transport development in numerous cities in the context of high-quality development. The Transit-Oriented Development (TOD) concept uses rail stations as hubs to create a comprehensive area with residential, commercial, cultural, and educational facilities [1]. This mode ensures that land development is supported by adequate transport, thereby making the construction of high-density life circles a reality [2]. As the urban scale expands, urban (suburban) railways have become an essential means of transportation, connecting the central city and suburban areas to meet the demand for work-life commuting. They have also become crucial in constructing an efficient and convenient life circle. In 2023, China’s urbanization rate reached 66.16%. The improvement of the construction of the life circle of the urban (suburban) railway station embodies the concept of new urbanization development that is not only people-centered but also significantly alleviates traffic congestion, environmental pollution, and other problems in urban development. Furthermore, the
urban (suburban) railway life area has a significant impact on the quality of life of residents, reducing the time spent commuting and increasing the opportunities for leisure and entertainment.

Urban public service facilities represent the core elements of railway life circle construction and meet residents’ daily material and spiritual life needs [3]. As China’s urbanization enters a new stage of comprehensive development, the focus of city and town development has shifted from merely maintaining balance to enhancing residents’ quality of life and satisfying their spiritual and cultural needs. Studies have demonstrated that within the 15-minute life circle, the diversity and richness of public service facilities have a significant positive impact on enhancing residents’ sense of fulfillment and happiness [4]. The convenience of suburban railway stations attracts people of different ages and occupations to choose to live in the surrounding area. Their needs for daily life present multi-dimensional and multi-level characteristics, which require us to provide more diversified and refined facilities and services in the construction of the urban environment [5–7].

However, most current studies tend to analyze the number and spatial distribution characteristics of public service facilities but often neglect the in-depth exploration of the diversity of facilities. In addition, studies on the life circle of rail transit mainly focus on subway stations and city center areas, and it is generally believed that facilities around these stations should follow a circular distribution pattern [8–14] (i.e., the number of facilities decreases as the distance from the station increases). However, existing studies have not yet provided clear explanations and in-depth analyses of the diverse characteristics of public service facilities and their influencing factors in urban (suburban) railways and suburban areas.

2. Literature Review

Research on urban public service facilities at home and abroad has evolved from initial explorations of spatial layout [15] and demand matching ability [16,17] to more detailed areas such as accessibility of facilities, coupling of transit-oriented development (TOD), and life areas [3]. In this research area, numerous scholars have focused on the equity of facility distribution and the accessibility of location choices. They have found that factors such as the distribution of population with different income levels [18], population density [19,20], green space [21,22], and educational resources [23,24] play a key role in achieving equity. At the same time, public health facilities [25,26], the urban walking environment [27], the allocation of public transport such as the subway [28–30], and the price of housing [31,32] are also significantly affected by the accessibility of facilities. In particular, scholars such as Ji Seong Chae and Chang Hyun Choi, based on the TOD concept and using data from Seoul, have pointed out that poor accessibility of residential infrastructure to public transport, especially the subway, will reduce access to these infrastructures [28]. Tainá A. Bittencourt et al. analyzed optimized accessibility metrics on the accessibility and availability of public services in São Paulo and Curitiba, Brazil. It was found that most public services in these cities are concentrated in the city center, making it difficult for most residents to access these services [29].

According to research on the factors affecting the diversity of public service facilities, it can be found that in real cities, the demand for public service facilities is relatively low, especially in places with small populations. Therefore, population size affects the diversity of facilities to a certain extent [33]. Compared to urban areas, suburban stations are surrounded by a less dense road network, with fewer and more widely spaced bus stops and subway stations [34,35]. In addition, many of the facilities around the stations follow a circled distribution pattern with distance decay characteristics. Therefore, we have considered these possible influences in our subsequent analyses.
In terms of research methods, geographically weighted regression (GWR) [36–38], multi-scale geographically weighted regression (MGWR) [31,39,40], and propensity score matching-double difference (PSM-DID) [41,42] have become common tools. Although these methods have different techniques and indicators, they all consider public service facilities’ relevance and spatial heterogeneity. In addition, some scholars have proposed the 2FSC improvement method to analyze the accessibility of multiple facilities to balance equity and efficiency better [43]. In the railway life circle research, many studies have focused on the coupling effect between TOD and the life circle. For example, Singapore’s new town community construction mode [44,45] and Japan’s synergistic construction of TOD and urban function [46,47] are considered successful railway life circle construction cases.

In addition, based on existing studies on passenger flow and building density of suburban stations, it can be found that urban and suburban stations are different in terms of scale and development patterns [48]. For example, the station halls of suburban stations tend to be smaller in size compared to those of city center stations. Subway rail stations are more likely to have a single form of land development, insufficient occupational and residential capacity, and low passenger flow than urban areas [49]. Suburban stations have fewer crossing facilities, transfer routes, and travel options than urban areas [34,35,50]. In addition, urban stations mostly open and operate before suburban stations, and railway systems may need to operate for a more extended period before affecting land use [51]. Therefore, this paper argues that the above factors may lead to differences in the diversity of public service facilities in the life circle around rail stations in urban and suburban areas and that it is necessary to analyze the possible influencing factors.

Given the above, the Beijing Suburban Railway Line Sub-center (now called “Line S1”) was selected as a case study, and urban public service facilities were included in the research field. In this study, the point-of-interest (POI) and mobile phone signaling data were used to reveal the spatial diversity of public service facilities by applying the Shannon-Wiener index. Furthermore, the effects of different factors on the diversity of public service facilities were quantitatively assessed using multiscale geographically weighted regression (MGWR).

The paper is structured as follows: Section 2 details the definition of the study area, the data sources, and the research methodology used. Section 3 presents the study’s results, analyzing the characteristics of public service facilities’ diversity and the factors influencing it. Section 4 provides an in-depth discussion of the findings, exploring their logic and possible explanations. Section 5 is the concluding part, summarizing the study’s main conclusions and proposing policy recommendations.

3. Research Design
3.1. Study Area

This study focused on the six stations of the Beijing Suburban Railway Line S1—Beijing West Railway Station (A1), Beijing Railway Station (A2), Beijingdong Railway Station (A3), Liangxiang Railway Station (B1), Tongzhou Railway Station (B2), and Qiaozhuangdong Railway Station (B3)—as the research subject. Line S1, a vital commuter artery in Beijing, is 63.7 km long, connecting the city’s center with the suburban areas, exhibiting significant differences in public service facilities around the stations (Figures 1 and 2). Based on the actual situation of Beijing’s economic layout, population distribution, and transportation network, this study drew on the research area division method of Wang Caiyan et al. [52], which divides A1, A2, and A3 into urban stations. At the same time, B1, B2, B3 are defined as suburban stations. Among the urban stations, A1 is located between the 2nd and 3rd Ring Roads on the west side of Beijing. A2 is located in the 2nd Ring Road of Beijing, about 2 km from Tian’anmen Square. A3 is located between the 3rd and 4th Ring Roads on the east side of Beijing. Among the suburban stations, B1 is located on the west side of Beijing, with a straight-line distance of about 27 km from the city center. B2 and B3 are located on the east side of Beijing, with B2 having a straight-line distance of about 23 km from the city center and B3 about 25 km.
As a megacity, Beijing has problems such as uneven spatial allocation and insufficient diversity of public service facilities, which also exist in other megacities, and the research on them is universal and typical. At present, there are nearly 40 urban (suburban) railways in the Tokyo metropolitan area in Japan [53–55], almost 20 in London, UK [56,57], and nearly 10 in Paris, France [58], and these urban (suburban) railways pass through the city center and suburbs like the S1 line. Therefore, Line S1 was selected to analyze the diversity of public service facilities within the living area of urban and suburban stations and the differences between urban and suburban stations, which is also a reference for allocating public service facilities in supercities and megacities in other countries.
In this study, a rectangular area of 3 km × 3 km was delineated as the study area of a railway life circle based on 15-minute cycling accessibility, centered on each station, following the norms of the TOD model, the definition of the life circle, and the relevant literature. To deepen the precision of the spatial analysis, we further divided these areas into 144 grid cells of 250 m × 250 m, each of which is studied in detail as an independent spatial statistical unit.

3.2. Data Sources and Data Processing

The data that this study was based on covers two types of crucial information: point-of-interest (POI) data of public service facilities and demographic data within the area of each study station (Table 1). The POI data were mainly obtained through the Baidu Big Data platform, covering various dimensions such as business, sports, culture, and leisure and entertainment. The demographic data was derived from the Smart Steps mobile signaling data provided by Big Data Corporation. Its data serves more than 30 countries and over 200 cities in China. The mobile phone signaling data used covered the whole area of Beijing at this time, with a total data volume of 1,048,576 items. The dataset recorded the key social indicators in detail, such as the distribution of residents, the working population, and the age composition of the study area, which is representative.

Table 1. Statistics on data sources.

<table>
<thead>
<tr>
<th>Data Property</th>
<th>POI for Public Service Facilities</th>
<th>Population</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time</td>
<td>2021</td>
<td>2–15 April 2021</td>
</tr>
<tr>
<td>Source</td>
<td>Baidu Maps</td>
<td>Smart Steps</td>
</tr>
<tr>
<td>Specification</td>
<td>Excel</td>
<td>Excel</td>
</tr>
<tr>
<td>Name of facility</td>
<td>Date</td>
<td>Date</td>
</tr>
<tr>
<td>Main Fields</td>
<td>Classification of facilities (small, medium, and large)</td>
<td>Number of inhabitants</td>
</tr>
<tr>
<td></td>
<td>Coordinate</td>
<td>Number of workers</td>
</tr>
<tr>
<td></td>
<td>Facility address</td>
<td>Age groups</td>
</tr>
</tbody>
</table>

This paper comprehensively re-systematizes the collected POI data based on an in-depth analysis of the classification of existing urban public service facilities. The classification framework, which contains two major categories of public welfare and market-featured facilities, nine intermediate classifications, and forty subcategories (Table 2), was constructed concerning the public welfare spectrum classification system established by Xu Gaofeng et al. [59]. A public service facilities database was based on the ArcGIS (version number 3.0.36056) platform through precise data screening and integration. This database covers 864 grid cells centered on the six stations of Line S1 in Beijing and reflects the distribution of public service facilities around each station (Table 3). Furthermore, this study employed the Smart Steps mobile signaling data between 2 and 15 April 2021. To ascertain the population data, the median of the daily average population data within the grid range of each station was selected as the basis for the study, based on the analysis of the residential population data during two consecutive weeks.
Table 2. Classification of urban public service facilities.

<table>
<thead>
<tr>
<th>Main Class</th>
<th>Public Welfare</th>
<th>Market-Featured</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Medium category</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Medical services</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Specialized hospital</td>
<td>Secondary school</td>
<td></td>
</tr>
<tr>
<td>Hospital</td>
<td>Primary school</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Kindergarten</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Subtype</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- **Medical services**: Medical Clinic, Specialized hospital, Hospital
- **Educational services**: Secondary school, Primary school, Kindergarten
- **Open space**: Park, Square
- **Transportation services**: Bus stop, Subway station
- **Cultural and recreational**: Museum, Art museum, Library, Exhibition hall
- **Sports services**: Comprehensive gymnasium, Basketball gym, Table tennis gym, Badminton hall, Natatorium, Soccer field
- **Leisure and entertainment**: Movie theater, Karaoke bar, Bar, Cybercafé, Beauty salon, Bath and massage, Billiard room
- **Business Services**: Convenience store, Supermarket, Integrated market, Shopping mall, Catering, Pharmacy, Fitness center
- **Commercial affairs services**: Bank, Insurance facility

- **Business Services**: Convenience store, Supermarket, Integrated market, Shopping mall, Catering, Pharmacy, Fitness center
- **Commercial affairs services**: Bank, Insurance facility
Table 3. The overall number of different public service facilities at each station.

<table>
<thead>
<tr>
<th>Stations</th>
<th>Public Welfare Facilities</th>
<th>Market-Featured Facilities</th>
<th>Add Up the Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Medical Services</td>
<td>Educational Services</td>
<td>Open Space</td>
</tr>
<tr>
<td>Beijing West Railway Station (A1)</td>
<td>56</td>
<td>43</td>
<td>16</td>
</tr>
<tr>
<td>Beijing Railway Station (A2)</td>
<td>112 **</td>
<td>59</td>
<td>19 **</td>
</tr>
<tr>
<td>Beijingdong Railway Station (A3)</td>
<td>60</td>
<td>41</td>
<td>6 *</td>
</tr>
<tr>
<td>Liangxiang Railway Station (B1)</td>
<td>30</td>
<td>26 *</td>
<td>7</td>
</tr>
<tr>
<td>Tongzhou Railway Station (B2)</td>
<td>44</td>
<td>61 **</td>
<td>7</td>
</tr>
<tr>
<td>Qiaozhuangdong Railway Station (B3)</td>
<td>26 *</td>
<td>29</td>
<td>9</td>
</tr>
<tr>
<td>Add up the total</td>
<td>328</td>
<td>259</td>
<td>64</td>
</tr>
</tbody>
</table>

Note: In the table, * denotes minimal values, and ** denotes tremendous values.
3.3. Research Methodology

3.3.1. Shannon-Wiener Index

This study employed the Shannon-Weiner index, a widely recognized measurement method. The information entropy measure proposed by Shannon is predominantly utilized domestically and internationally to assess the degree of land mixing and the diversity of plant and animal species, among other applications. The core of this index is to quantify the degree of mixing between different functional elements, which aligns with this study’s objective to calculate the diversity of public service facilities [33,60]. This study aimed to comprehensively assess the level of diversity of different types of public service facilities. To this end, the following formula is employed:

\[
H_j = -\sum P_{ij} \ln P_{ij} \tag{1}
\]

\[
h_j = -\sum p_{mj} \ln p_{mj} \tag{2}
\]

In this formula, \(H_j\) is the comprehensive diversity index, which refers to the diversity index of small types of public service facilities within unit \(j\), with a value range of \([0, \ln40]\). \(P_{ij}\) indicates the ratio of the number of public service facilities of type \(i\) within unit \(j\) to the total number of facilities in unit \(j\). \(h_j\) is the diversity index of different types of facilities, assuming that each medium type of facility contains \(N\) small types of facilities, then \(h_j\) indicates the diversity index of the medium type of public service facilities within unit \(j\), with a value range of \([0, \ln N]\). \(p_{mj}\) denotes the ratio of the number of the \(m\) subcategory public service facility within unit \(j\) to the total number of medium-category facilities to which the subcategory facility belongs within unit \(j\). The more the diversity index tends to 0, the greater the proportion of the facility in the unit, the more homogeneous the type of public service facility, and the lower the diversity. The closer the diversity index \(H_j\) is to \(\ln40\) and \(h_j\) is to \(\ln N\), the richer the variety of public service facilities within the unit and the higher the diversity.

3.3.2. Multiscale Geographically Weighted Regression (MGWR) Model

Following the calculation of the diversity index of public service facilities, this study employed a multi-scale geographically weighted regression (MGWR) model. The objective was to ascertain whether population distribution and road network density significantly influence the size of facilities and their diversity index and to identify the potential distance decay characteristics of facility distribution. The MGWR model’s strength lies in its capacity to adapt the optimal bandwidth for each independent variable, thereby accurately capturing the specific impact of factors such as proximity to the nearest bus stops, subway stations, and population size on the diversity of facility assignments. This was calculated as follows:

\[
y_j = \sum_{j=1}^{k} \beta_{byj}(u_i, v_i)x_{ij} + \epsilon_i \tag{3}
\]

In this formula, \(\beta_{byj}\) denotes the regression bandwidth of variable \(j\), and \(x_{ij}\) refers to the observed variable \(j\). \((u_i, v_i)\) are the coordinates of each variable. In this paper, the center of mass coordinates of the 250 m × 250 m unit were used as the variable coordinates and \(\epsilon_i\) is the error term. The study used MGWR 02.02.00.00 software for regression analysis, and further visualization was conducted using ArcGIS Pro 3.0.36056 software.

4. Results of Study

4.1. Statistical Characteristics of the Diversity of Public Service Facilities

The Shannon-Wiener index was employed to standardize the composite diversity index of the units. The results demonstrated that over half of the units, or approximately 60.85 percent, exhibited diversity indices above the mean value, with a notable concentration of 0.5 to 0.8. Units with lower-than-average values were predominantly distributed in the intervals of 0.0 to 0.1, 0.2 to 0.3, and 0.4 to 0.55 (Figure 3a). This suggests a significant
stratification of facility diversity across Line S1 stations and a tendency for many units to be monolithic regarding facilities.

Further, stacked bar charts were used to analyze the diversity of each type of facility to analyze the richness of different types of facilities within each unit (Figure 3b). Regarding configuration patterns, open space, leisure and entertainment, and sports service facilities are in the low diversity range within each unit. Healthcare, education, transportation, and commercial affairs service facilities have a low diversity index in most units and a high diversity index in a few units, showing a clustered configuration. Leisure and business service facilities have the highest diversity zones among the nine types of facilities, and their distribution is relatively homogeneous.

From the broad categories of facilities, except for transportation services, the number of above-average diversity units in the market-featured facility categories is higher than that of the public welfare facility categories, and the degree of richness is higher. This indicates that the current facilities around each station are mostly market-featured and are more influenced by economic external forces. In contrast, there is a lack of diversity in all categories of public welfare facilities. The explanation may be that these locations have certain special characteristics. The high volume of pedestrian traffic in the area and the varying needs of people for facilities make it easier to attract a concentration of facilities oriented towards serving the functional needs of the market. In contrast, the necessary demand for public goods facilities, such as cultural, recreational, and sports services, is relatively low.

4.2. Characteristics of the Spatial Distribution of the Diversity of Public Service Facilities

Based on the results of the calculations, The spatial configuration diversity of public service facilities is categorized into five types, as illustrated in Figure 4. It can be observed that, with each rail transit station as the core, the comprehensive diversity index of the surrounding public service facilities generally follows a distribution pattern of “less-more-less”, forming a unique ring or semi-ring structure. This distribution is primarily attributable to the fact that the initial diversity of the area surrounding the stations is relatively low due to the presence of railroad facilities and the barrier effect. Diversity gradually increases as it expands outward. Conversely, the marginal area situated at a distance from the stations is subject to a reduction in diversity due to the weakening of the radiation capacity of the stations. Notably, this ring structure’s radius varies according to the station’s size.
Figure 4. Spatial distribution of integrated diversity of public service facilities at Line S1 stations.

A comparison of Beijing reveals that high-diversity units are more widely distributed in urban stations across various functional districts, in contrast to suburban stations where high-diversity units are more concentrated in residential areas. Furthermore, even in areas with limited facilities, high diversity can be achieved when there is a diverse range of facilities, indicating that facility diversity is not solely dependent on quantity. A detailed analysis of each station reveals that A2 has the highest proportion of high-diversity units, predominantly situated on both sides of the subway lines in the area. In urban stations, high-diversity units tend to cluster around shopping malls; whereas, in suburban stations, they are often located near supermarkets. The two types of facilities are closely related to residents’ daily lives. They are frequently consumed, reflecting the differences in the configuration of facilities in regions with varying levels of economic development.

In addition, based on the diversity index of different facilities in each unit, the diversity of high-value zones of 9 types of public service facilities was studied. It can be found that the distribution of high diversity zones for business, transportation, and recreational facilities is highly similar, and they are distributed in the second circle outside the station. Among them, transportation facilities are mostly attached to large shopping malls and evenly distributed in the area. On the other hand, business and leisure facilities are more often connected to the surrounding supermarkets, which shows a more obvious phenomenon of centralized arrangement around large-scale facilities. Commercial affairs and sports facilities are clustered around subway stations, shopping malls, and large corporate buildings. Open space, education, and medical services are mainly located around shopping malls or community centers. On the other hand, the diversity of cultural service facilities in the high-value areas and other types of facilities are not very well connected, and their distribution is relatively even but scattered. These findings reveal the existence of dependencies between public service facilities. In addition to the spatial layout, railway stations are more attractive to market-featured facilities, while community centers and shopping malls are more attractive to public welfare facilities.
4.3. Factors Influencing the Diversity of Public Service Facilities

4.3.1. Model Comparison

The influencing factors were calculated using the GWR and MGWR models, respectively. As Table 4 illustrates, the MGWR model exhibits superior overall fit R$^2$ values for public welfare and market-featured facilities compared to the GWR model. Additionally, the AICc is more minor, indicating that the MGWR model’s results are more accurate than those of the GWR model in this study. Therefore, the multi-scale geographically weighted regression model was employed to analyze the abovementioned issues for public welfare and market-featured facilities.

Table 4. Comparison of GWR and MGWR models.

<table>
<thead>
<tr>
<th>Model Indicators</th>
<th>Public Welfare Facilities</th>
<th>Market-Featured Facilities</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>GWR</td>
<td>MGWR</td>
</tr>
<tr>
<td>Goodness of Fit (R$^2$)</td>
<td>0.106</td>
<td>0.178</td>
</tr>
<tr>
<td>Calibrate R$^2$</td>
<td>0.101</td>
<td>0.154</td>
</tr>
<tr>
<td>AICc</td>
<td>2368.85</td>
<td>2334.34</td>
</tr>
</tbody>
</table>

4.3.2. Public Welfare Facilities

The spatial heterogeneity of public welfare facilities around each station is minimal, with a balanced distribution (Table 5). The R$^2$ value for public welfare facilities in the MGWR model is 0.178, indicating a poor fit, and the correlation between each influencing factor and the diversity index of public welfare facilities is low. The bandwidth indicator describes the spatial scale at which the spatial relationship of the influencing factors is smooth [61]. The bandwidths of each influence in the public welfare facilities are extensive and essentially close to the global scale, so no further analyses of each impact factor in the public welfare facilities will be conducted.

Table 5. Statistics on the regression results of the MGWR model for public welfare facilities.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Mean</th>
<th>STD</th>
<th>Min</th>
<th>Median</th>
<th>Max</th>
<th>Bandwidth</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intercept</td>
<td>0.085</td>
<td>0.307</td>
<td>−0.541</td>
<td>0.149</td>
<td>0.630</td>
<td>140</td>
</tr>
<tr>
<td>Distance to the nearest bus stop</td>
<td>−0.279</td>
<td>0.033</td>
<td>−0.325</td>
<td>−0.266</td>
<td>−0.223</td>
<td>636</td>
</tr>
<tr>
<td>Distance to the nearest subway station</td>
<td>0.181</td>
<td>0.113</td>
<td>0.051</td>
<td>0.185</td>
<td>0.300</td>
<td>636</td>
</tr>
<tr>
<td>Road network density</td>
<td>0.012</td>
<td>0.035</td>
<td>−0.027</td>
<td>0.001</td>
<td>0.063</td>
<td>720</td>
</tr>
<tr>
<td>Distance to the station</td>
<td>0.043</td>
<td>0.014</td>
<td>0.023</td>
<td>0.047</td>
<td>0.059</td>
<td>863</td>
</tr>
<tr>
<td>Population size</td>
<td>−0.007</td>
<td>0.014</td>
<td>−0.025</td>
<td>−0.010</td>
<td>0.013</td>
<td>863</td>
</tr>
</tbody>
</table>

4.3.3. Market-Featured Facilities

The more significant the bandwidth, the softer the spatial impact. The statistics of the coefficients (Table 6) show that the scale of action of different variables varies greatly. Therefore, the “public service facilities” mentioned below are all market-featured facilities. Among the variables, the bandwidths of distance to the nearest subway station and distance to the closest bus stop are 104 and 144, respectively, representing the smallest role scales among all the variables and exhibiting the strongest spatial heterogeneity. The bandwidths of population density and distance to the urban (suburban) stations are 179 and 281, respectively, which show less spatial heterogeneity. The bandwidth of the density of the road network is 854, which represents a global scale and exhibits essentially no spatial heterogeneity. The distance to the nearest bus stop and road network density negatively affected the diversity of public service facilities. The remaining three factors exhibited polarization in their effects. In the MGWR regression results, the road network density variable did not pass the 5% significance test, which may be related to the area of the divided cell. This paper will explore the spatial differences of the other four variables in the diversity of public service facilities.
Table 6. Statistics on the regression results of the MGWR model for market-featured facilities.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Mean</th>
<th>STD</th>
<th>Min</th>
<th>Median</th>
<th>Max</th>
<th>Bandwidth</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intercept</td>
<td>0.395</td>
<td>0.747</td>
<td>−0.952</td>
<td>0.311</td>
<td>2.720</td>
<td>30</td>
</tr>
<tr>
<td>Distance to the nearest bus stop</td>
<td>−0.218</td>
<td>0.112</td>
<td>−0.442</td>
<td>−0.186</td>
<td>−0.064</td>
<td>144</td>
</tr>
<tr>
<td>Distance to the nearest subway station</td>
<td>2.109</td>
<td>4.368</td>
<td>−0.490</td>
<td>0.102</td>
<td>13.586</td>
<td>104</td>
</tr>
<tr>
<td>Road network density</td>
<td>−0.034</td>
<td>0.005</td>
<td>−0.042</td>
<td>−0.036</td>
<td>−0.025</td>
<td>854</td>
</tr>
<tr>
<td>Distance to the station</td>
<td>−0.022</td>
<td>0.124</td>
<td>−0.264</td>
<td>−0.020</td>
<td>0.174</td>
<td>281</td>
</tr>
<tr>
<td>Population size</td>
<td>0.1395</td>
<td>0.150</td>
<td>−0.048</td>
<td>0.122</td>
<td>0.440</td>
<td>179</td>
</tr>
</tbody>
</table>

Where the bandwidth in the regression results of the MGWR model indicates the action scale of each influencing factor and the number indicates the number of units in the cell. The rest of the numbers indicate the influence coefficients of each influencing factor; positive numbers indicate that the influencing factors have a positive impact on the diversity size distribution of public service facilities, and negative numbers indicate a negative impact. For both positive and negative numbers, the larger the number, the greater the intensity of influence [40,62].

In the first place, the distance to the nearest subway station demonstrates significant differences between urban and suburban areas on a spatial scale, with a notable variation in the degree of influence (Figure 5). The impact of urban areas on the diversity of public service facilities is largely negative, indicating that the closer the subway station, the greater the diversity of public service facilities. Conversely, in suburban areas, the opposite is true. Among the stations, A2 demonstrated a contrasting impact effect within the study area on the east and west sides. The closer proximity to the subway station on the west side resulted in a decline in the diversity of public service facilities. This is primarily attributed to the proximity of Tian’anmen Square on the west side, which has influenced the orientation of the subway stations towards single-demand transportation to and from the station. The three suburban stations were constructed after the urban expansion, resulting in a weaker integration of public service facilities with the subway stations and a poorer diversity of public service facilities near the subway stations. The influence coefficient of the distance to the nearest subway station exhibited a range of values between −0.490 and 13.586, with a mean of 2.109 and a standard deviation of 4.368. This indicates that, on average, the diversity of public service facilities increases by 2.109 for every 1 m increase in distance. However, this influence factor varies considerably by station. Regarding the absolute value of the coefficient, the strength of its influence is the largest among all variables.

Figure 5. Spatial correlation between the diversity of amenities at Line S1 stations and the distance of units from the nearest subway stations.
Secondly, the distances to the nearest bus stop have a significant negative effect, the closer the bus stop is, the greater the diversity of public service facilities (Figure 6). The intensity of impacts showed an east-west difference within the study area of each station. It reflects that the accessibility of bus stops within the study area of each S1 line station significantly contributes to the diversity of public service facilities. The high-value area is mainly concentrated in B2, followed by A1. The coefficient of distance from the nearest bus stop takes values between $-0.442$ and $-0.064$, with a mean of $-0.218$ and a standard deviation of $0.112$. This means that for every 1 m decrease in distance, the diversity of public services increases by 0.064 to 0.442, with an average increase of 0.218. In terms of the absolute values of the coefficients, the strength of their effects is in the middle of all the variables.

![Figure 6. Spatial correlation between the diversity of amenities at Line S1 stations and the distance of units from the nearest bus stops.](image)

Thirdly, the effect of distance from the station on the diversity of public service facilities is both positive and negative, with the scale of the effect showing differences between stations and little variation within stations (Figure 7). Of these, A1 and A2 positively influence the diversity of public service facilities, i.e., the further away from the station, the greater the diversity; conversely, the opposite is true for the remaining stations. The A1 and A2 are large in scale, making it challenging to arrange commercial and other facilities within a certain radius around them. The difference between the railroad and the subway, which gives rise to the neighbor avoidance effect, is more pronounced, leading to greater disturbances to residential and commercial facilities close to the stations and lines. Consequently, the diversity of public service facilities around the stations is lower. The influence coefficient of distance from the station takes values between $-0.264$ and $0.174$, with a mean value of $-0.022$ and a standard deviation of $0.124$. This indicates that, on average, for every 1 m away from the station, the diversity of public service facilities decreases by 0.022. However, the overall strength of the influence is weak.
Figure 7. Spatial correlation between the diversity of amenities at Line S1 stations and the distance of units from stations.

Finally, the population size is positively correlated with the diversity of public service facilities. The high-value areas are mainly located in A2 and B3, indicating that there is indeed an apparent correlation between the diversity of public service facilities and population distribution (Figure 8). The west side of B2 and B1 show a weak negative correlation, indicating that less populated areas do not necessarily lead to low diversity of service levels. The impact coefficient of the number of people takes values between $-0.048$ and $0.440$, with a mean of $0.140$ and a standard deviation of $0.150$. This indicates that, on average, for every additional person, the diversity of public service facilities will increase by $0.140$, with a medium strength of impact.

Figure 8. Spatial correlation between facility diversity and population size at Line S1 stations.
5. Discussion

5.1. Statistical and Spatial Distribution Characteristics of the Diversity of Public Service Facilities

This study begins by exploring the spatial distribution of the diversity of public service facilities within the track living area of urban (suburban) railway, and the conclusions obtained show remarkable consistency with the findings of some scholars. As mentioned in the introduction, by analyzing the accessibility and availability of public service facilities, scholars such as Tainá A. Bittencourt found that in some cities, such as São Paulo, Brazil, facilities are primarily concentrated in the city center, which makes it difficult for the majority of the population to access these services [29]. This conclusion is consistent with that obtained in the second paragraph of Section 4.2 of this paper. That is, the high diversity units at the urban stations generally exceeded those at the suburban stations in terms of geographic extent. In addition, a previous study of Seoul City by Ji Seong Chae and Chang Hyun Choi pointed out that if the accessibility of living infrastructure to the subway is poor, the access to these facilities will also be reduced [28]. This aligns with the view that “distance from subway stations has a significant impact on the diversity of public services” as highlighted in the third paragraph of Section 4.3.3 of this study.

5.2. Spatial Heterogeneity of Impact Factors in Market-Featured Facilities

Further, the MGWR model was used in this study to analyze and reveal the spatial heterogeneity of the influences. That is, they show very different effects in urban and suburban areas, and even within certain stations, they show east-west variability due to the specificity of their geographical location. The conclusions obtained confirm our hypothesis, in which the two influencing factors, population size, and distance to the nearest bus stop, do not show significant differences between urban and suburban areas. We will discuss the different influencing factors separately in the following section.

5.2.1. The Distance of Units from the Nearest Subway Stations

Due to the attraction of subway stations to passenger flows and the widespread proposal of the TOD model, most studies tend to assume that public service facilities are biased towards clustering around rail transit stations [28,49]. However, most existing studies have selected maturely developed subway stations, which are relatively homogeneous in type, and have not paid attention to the spatial heterogeneity of public service facilities. This difference may stem from the fact that subway stations in urban areas benefit from early development, dense population, and favorable economic conditions and are more integrated with the subway stations during the planning and development process, which promotes the diversity of public service facilities. On the contrary, due to the late planning of subway lines, the surrounding areas have mostly completed the division of functional areas and have failed to promptly carry out adaptive development. This has resulted in a weaker correlation between public service facilities and subway stations and a relatively low diversity index. This has led to the realization that land development in the suburbs follows a different logic than in urban areas and that the TOD development model has not yet been fully realized. Although Line S1 passes through the city center and the suburbs, the configuration of public service facilities for the railway life circle at stations on the same line varies considerably. This study begins by exploring the spatial distribution of the diversity of public service facilities within the track living area of the urban (suburban) railway; railway stations need to be balanced with the intensification of neighboring land use.

5.2.2. The Distance of Units from the Nearest Stations

Furthermore, the study revealed that while proximity to urban (suburban) stations is less significant in terms of spatial heterogeneity than subway stations, it still exhibits variability across stations and has an opposite trend to the role of subway stations. For instance, A1 and A2 have larger station halls and more tracks, which makes it challenging to situate public service facilities in the areas immediately adjacent to the stations. Consequently, within the proximity of these stations, the diversity is lower. As the distance increases, the
diversity initially rises and then gradually declines. Nevertheless, other stations exert a less pronounced influence on the configuration of public services due to the smaller footprint of the station halls and the lower number of tracks. Consequently, within these railway life circles, the closer the station, the greater the diversity of services. This phenomenon can also be seen in the use of the Shannon-Wiener index to assess the level of diversity of public service facilities. It can be seen that the distribution of diversity of public service facilities around urban (suburban) railway stations does not entirely follow the generally accepted pattern of decreasing circle distribution [8–14]. The diversity distribution will show different spatial heterogeneities in the station life circle based on different factors such as location, station size, and surrounding environment. This finding makes us recognize that the configuration of public services around urban (suburban) railway stations is more challenging than subway stations. While expanding the scale of urban (suburban) railway stations, focusing on diversified land use is essential. The conflict between the increase in the scale of the station and the configuration of public service facilities should be reasonably adjusted. For example, consider building above the railway tracks and providing more facilities of the same type to create a clustering effect. Or to increase the diversity of facilities such as urban farms, pocket parks, indoor stadiums, etc., which are less sensitive to the sound environment, and to improve the diversified land use near the station.

5.2.3. The Distance of Units from the Nearest Bus Stops

Buses account for about 44% of Beijing residents’ trips by public transport [63]. Although the traveling speed is not as fast as the subway, they also have a more significant passenger flow due to the greater number of stops and smaller spacing, a major factor influencing the configuration of public service facilities. This study uses the widely recognized MGWR model for analysis, and it can be found that there is no significant difference in the distribution of the diversity of public service facilities in urban and suburban areas, both of which are greater the closer they are to bus stops. However, there is less spatial heterogeneity within the living circle of each station. It may be because the number and distribution of bus stops within the railway life circle of both urban and suburban stations of Line S1 are very similar, which is not consistent with the previous hypothesis that the number and spacing of bus stops in the suburbs are more significant than those in the urban areas as suggested by the studies of Yi, R et al. [34], and Moon, H [35]. It can be seen that the bus stops in Beijing are more complete and travel-friendly for suburban residents. In addition, due to the smaller size of bus stops, the choice of stop location is more accessible than that of subway stations so that it can be better associated with public service facilities, and there is no difference between urban and suburban areas.

5.2.4. Population Size

In real cities, the demand for public service facilities is relatively low in less populated areas. Our conclusions align with those of Liu, H.L. et al. [33], who verified that areas with smaller populations cause fewer layers of allocation of public service facilities, leading to a low diversity index. However, spatial heterogeneity is the strength of this relationship. Since B1 is not located in a regional center but in a university concentration area with a large number of students, the diversity of facilities is negatively correlated with the population size, with more significant numbers but lower diversity. In addition, some areas of negative correlation are also seen to the west of the B2 railway life circle, reflecting that less populated areas do not necessarily result in low diversity of service levels. In subsequent applications, it is hoped that the relationship between stations and essential functional areas of the city can be considered so that public service facilities can serve more residents.
5.3. Development Proposal

This study can reflect the scale effects of diverse influencing factors and differentiate between public welfare facilities and market-featured facilities, thus revealing the differences between urban and suburban stations in terms of different influencing factors. The conclusions obtained make us realize that the allocation of public service facilities around urban and suburban railway stations, which is an essential implication for promoting fairness in the allocation of public service facilities and efficient land use in urban and suburban areas, needs to be paid more attention. It will also help the relevant decision-makers make reasonable investments in public service facilities allocation. To upgrade the allocation of public service facilities in the life circle of railway stations, we suggest that the following aspects can be tried. (1) Regarding policy, we believe that the relevant departments should recognize the importance of the diversified configuration of public service facilities and strengthen the attention paid to them to propose relevant policies to promote their development. (2) In actual construction, it is necessary to focus on improving the diversity of public service facilities in suburban stations compared to urban stations. It is possible to make full use of the advantages of tiny footprints and large commuter flows of suburban stations to actively combine urban (suburban) railway stations and subway stations with a variety of public service facilities and to develop them into community-type, urban-type, and other TOD modes according to the characteristics of the stations. (3) The development rate of land in the suburbs is often lower than that in the urban areas, so new design tools may be applied, such as the addition of pocket parks and the construction of stadium parks where a variety of sports are clustered, etc., to make use of every bit of space. Or continue the current benefits of clustering facilities around bus stops by adding restaurants, beauty salons, and other facilities. (4) Many stations in urban areas are simultaneously responsible for running urban (suburban) railways, high-speed railways, subways, and other modes of transport. Therefore, to make the best possible use of the extremely large passenger flow, the development of the station superstructure can be considered to reduce the disadvantage of the large size of the station halls, making it difficult to arrange facilities. (5) With the rapid development of new technologies such as AI, urban and suburban stations can use these technologies to build online platforms for efficient utilization of public service facilities and timely identification of the lacking public service facilities. Where possible, 3D simulations of the configuration of public services can also be attempted to find optimal configurations.

Like other megacities such as Tokyo, London, and Paris, Beijing promotes the formation of metropolitan areas by constructing urban (suburban) railways. Therefore, the above recommendations have solid references for optimizing public service facilities around the stations in these cities. In addition, the conclusions we obtained are replicable and generalizable for constructing urban (suburban) railways in other megacities. These findings allow us to recognize that constructing railway life circles in megacities requires considering the spatial heterogeneity of urban and suburban areas. There is also spatial heterogeneity in the strengths of different influencing factors, so targeted optimization strategies can be used based on this.

6. Conclusions

The present study selected six stations on Line S1 of the urban (suburban) railway as research objects. The diversity of public service facilities within the living area of each station was analyzed with the help of geographic information system (GIS) technology by integrating point-of-interest (POI) data and cell phone signaling data. The study further examines the effects of five key factors on the facility diversity index: distance to bus and subway stations, distance to the urban (suburban) station itself, population size, and road network density. The main findings of the study are as follows:

(1) The public service facilities at the stations on Line S1 exhibit a clear stratification of diversity, with a similar number of low- and medium-diversity units and the highest
number of high-diversity units, which show a concentrated configuration. The number and diversity of market-featured facilities exceed those of public welfare facilities. 

(2) From the perspective of spatial distribution, the comprehensive diversity of public service facilities at the six stations generally exhibits a distribution pattern of “less-more-less”, with a concentration centered on the station, an initial increase, and then a subsequent decrease, resulting in the formation of a specific ring or semi-ring structure. The high-diversity units of urban stations are more widely distributed around shopping malls, while suburban stations are mainly concentrated near supermarkets. 

(3) While the diversity of public welfare facilities is largely spatially homogeneous around each station, the diversity of market-featured facilities is influenced by several factors, with the strongest correlation with the distance to subway and bus stops, followed by population size and station distance. On the other hand, road network density has a more stable influence on the global scale. Notably, the distance to subway stations had the most significant effect of all factors on the diversity index.

The above findings meticulously analyze the spatial differences in the diversity of public service facility configurations, which can provide a reference for constructing urban (suburban) railway stations. However, this paper also has shortcomings. Firstly, the limitation of data acquisition leads to the failure to comprehensively consider critical factors such as house prices and demographic and social attributes, which will be given special attention in future studies in the hope that more comprehensive data can be collected to deepen our research work. Second, although this paper assumes that urban and suburban areas adhere to the same principles and objectives in the allocation of public service facilities, it is essential to note that there are differences in the specific objectives of living area construction between the two types of areas due to the differences in the service groups and local environmental conditions. These differences must be taken into full consideration in future studies. Finally, this study has analyzed the factors that influence the spatial dimension. However, the consideration of temporal changes is still insufficient. In the future, models such as geographic time-weighted regression (GTWR) can be introduced to explore further the factors influencing the diversity of public service facilities in both the temporal and spatial dimensions.

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