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Differences and Evaluation of the Development of Urban Rail Transit Interchanges in the Perspective of Multi-source Data

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KEYWORDS

Multi-Source Data,
Interchanges,
Service Facilities,
Real-Time Population Data

ABSTRACT

With the rapid development of urban rail transport, regional functional differences result in significant variations in service facilities and population growth around stations. A scientific assessment of station development can enhance the comprehensive benefits and sustainability of rail transit systems. Using Suzhou as a case study, this research analyzes the correlation between variables such as service facilities and population distribution utilizing POI data and Baidu heat map data. Interchanges were classified using clustering methods, and specific differences in service facilities among these stations were identified through analysis of variance (ANOVA).

1. Introduction

With the growing demand for convenient transportation and rapid urbanization, urban rail transit (URT) has become increasingly vital in urban development. URT facilitates population movement and regional growth. Despite China's late start in URT development, national policies and large-scale investments have led to significant achievements, with passenger flow surpassing other countries for years. However, high costs and challenges in achieving operational profitability remain. Nonetheless, URT's external benefits drive local economic growth and land use. Scholars have explored ways to balance URT losses through value capture and diversified business models. Classifying URT stations and aligning service facilities with population changes can support effective transit-oriented development (TOD).

Studies confirm URT's strong influence on population concentration and service facility development. A rich variety of service facilities attracts residents, businesses, and enterprises, driving local economic prosperity and enhancing property value. This concentration of services fosters urban expansion and population growth. The rise of urban multi-source data has enabled more precise research on urban environments at finer scales, facilitating real-time studies of URT stations. Research highlights URT's role in urban growth, with population as a key factor reflecting station characteristics. Comprehensive vitality assessments of station areas using multi-source data are essential for optimizing resource allocation and promoting spatial synergy.

This study uses multi-source data (Amap POI and Baidu Heat Maps) to analyze service facilities and real-time population data around Suzhou's URT interchange stations. By exploring the development characteristics and typological differences of these stations, the research aims to support urban development and improve transportation and citizens' quality of life.

2. Research Scope and Data Presentation

2.1. Research Scope

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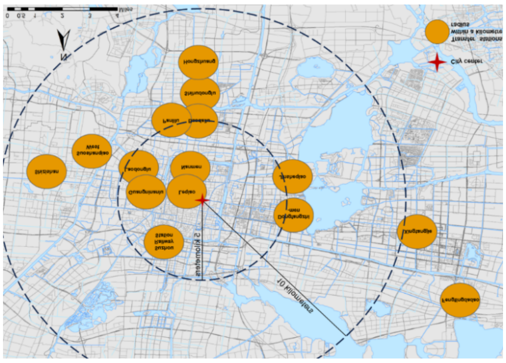

Figure 1 l Diagram of Suzhou Railway Interchanges

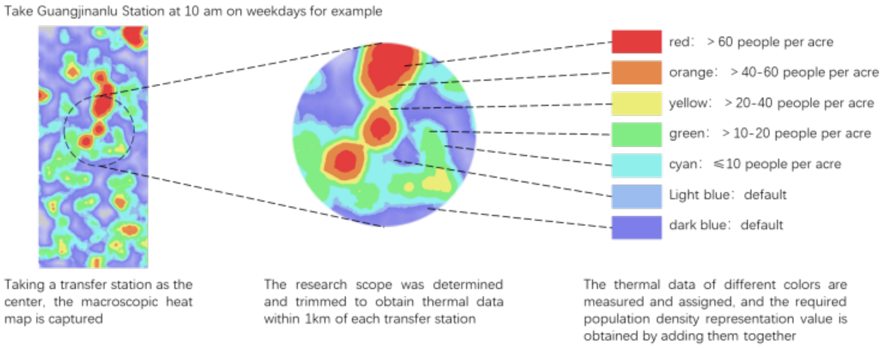

Figure 2 l Heat data extraction process

Suzhou is the first prefecture-level city in China to build and open a URT system. The first rail transit line, Suzhou Rail Transit Line 1, commenced operations on April 28, 2012. By 2023, Suzhou has a total of 7 lines in operation, with 197 stations, including 16 interchange stations. This study focuses on the 1km radius around these interchange stations, representing a 15-minute living circle. The research scope includes 15 interchanges (Figure 1). Huaqiao Station on Line 11 is excluded from the study as it is not under the city's jurisdiction.

2.2. Data Acquisition and Processing

There are three main types of data included in the study to represent the development of interchanges: service facility data, demographic data, and locational planning (Table 1).

The population data were sourced from Baidu Heat Maps and acquired in March and April 2024. Real-time heat maps for each interchange were regularly captured using a mobile phone, and the specific heat data within a 1-kilometer radius were cropped out. The number of pixels in different color classes was then calculated separately, and population values were assigned based on these color classes (Figure 2). The population data were categorized into two types: weekdays and weekends, covering the period from 6:00 to 23:00. By averaging the data from multiple weekdays and weekends, the specific population changes for each period were determined (Figure 3).

The service facility data were obtained from amap POIs on April 9, 2024. Based on the Urban Residential Code Design Standards and considering the availability and practicality of the data, the POI data were classified into 10 categories of facilities: automobile repair-related services, food and beverage services, shopping services, living services, sports and recreation, health care, governmental

Table 1 l Specific variables and data acquisition methods

Typology	Specific variables	Sources of data
Population data	Total population (S_A)	Sum of real-time headcount by time period
	Real-time population peaks (S_{MAX})	Maximum real-time headcount from 6-23 p.m.
	Population fluctuation (σ_n)	Standard deviation of real-time population
Planning condition	Interchange completion time (T)	Official operating time of the line
	Entrances and exits (W)	Number of entrances/exits in amap
	Distance from the city center (D)	Straight-line distance from the interchange site to the city center
Service facilities	Auto Service (K_1), Food & Beverages (K_2), Shopping (K_3), Daily Life Service (K_4), Sports & Recreation (K_5), Medical Service (K_6), Governmental Organization & Social Group (K_7), Science/Culture & Education Service (K_8), Transportation Service (K_9), Finance & Insurance Service (K_{10}), Total Services and Facilities (K_A)	Number of pois within 1km of the interchange
	Service facility imbalance (H)	Information entropy of different services in the vicinity of the interchange

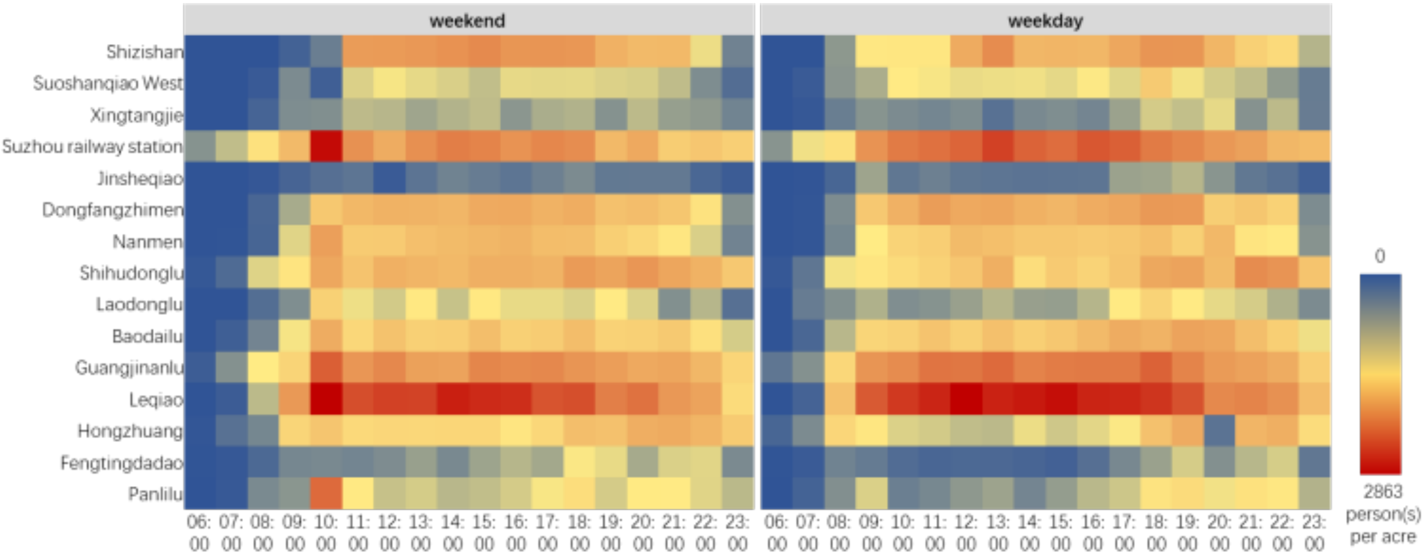

Figure 3 | Real-time population of the interchanges at different times of the day

institutions, science, education and culture, transportation, and financial and insurance services. The KEY was acquired through the amap Open Platform's WEB service, and the POI data within a 1km radius of each interchange were further retrieved using Python, resulting in a total of 32,037 nodes.

2.3. Research Indicators

Several specific variables are selected for this study. S_A represents the total population in one day at the interchange, which is obtained by summing up the real-time population (S_i) ross the 18 study periods at the interchange. S_i is derived by multiplying the number of color pixels (A_{color}) in different study periods by the weights of the corresponding colors. This study focuses on a relatively active population, so only the color range from red to cyan is selected, and the minimum weight value is used:

$$S_i = 60A_{red} + 40A_{orange} + 20A_{yellow} + 10A_{green} + A_{cyan}$$

The population fluctuation (σ_n) is used to measure the daily population activity at different interchanges. A larger value indicates a higher level of population vitality at the interchange on that day. σ_n is the standard deviation of the real-time population (S_i), where $\bar{S}$ is the average real-time population at the interchange for a single day. The calculation formula is as follows:

$$\sigma_n = \sqrt{\frac{\sum_{i=6}^{23}(S_i - \bar{S})^2}{18}}$$

Service facility imbalance (H) represents the degree of disarray in the number of various service facilities around the interchange. A higher value indicates a greater imbalance among different types of service facilities. H is the information entropy of different types of service facilities, where P_{K_i} represents the overall proportion of a certain type of service facility. The calculation formula is as follows:

$$H = -\sum_{i=1}^{10} P_{K_i} \log_2 P_{K_i}$$

3. Analysis of Data Results

The study first used SPSS to process and analyze the data, explored the correlation relationship between various variables through correlation analysis, found a more stable and conducive to explaining the developmental differences in the variable groups, and then further carried out clustering and analysis of variance (ANOVA). On this basis, the data were imported into ArcMap, and the spatial distribution of the variables was combined to obtain the developmental differences of each site.

3.1. Correlation Analysis

Correlating the specific variables of the interchange (Table 2), it can be observed that the total service facilities (K_A) show a highly stable positive correlation with the total population (S_A), the real-time population peak (K_{MAX}), and the population fluctuation (σ_n), (p-values$<$0.1). This suggests that an abundance of service facilities positively impacts the mobility of the population around the interchange. Simultaneously, active demographic changes prompt the presence of a considerable number of service facilities. Although further research is needed to analyze the influence mechanism between these two factors, their relationship is notably close at the macro level.

Additionally, the total population (S_A), the real-time population peak (S_{MAX}), and the population fluctuation (σ_n) on weekdays and weekends are all negatively correlated with

Table 2 | Correlation and significance between different variables

r \ p		Total Services and Facilities (K_A)	Service facility imbalance (H)	Weekday			Weekend			Distance from the city center (D)	Interchange completion time (T)	Entrances and exits (W)
				Total population (S_A)	Real-time population peaks (S_{MAX})	Population fluctuation (σ_n)	Total population (S_A)	Real-time population peaks (S_{MAX})	Population fluctuation (σ_n)			
Total Services and Facilities (K_A)			0.889**	0.760**	0.802**	0.747**	0.777**	0.787**	0.690**	-0.703**	0.565*	0.5
Service facility imbalance (H)		0		0.600*	0.564*	0.561*	0.579*	0.566*	0.569*	-0.750**	0.499	0.575*
weekday	Total population (S_A)	0.001	0.018							-0.658**	0.549*	0.246
	Real-time population peaks (S_{MAX})	0	0.028							-0.586*	0.518*	0.323
	Population fluctuation (σ_n)	0.001	0.03							-0.629*	0.535*	0.21
weekend	Total population (S_A)	0.001	0.024							-0.592*	0.556*	0.255
	Real-time population peaks (S_{MAX})	0	0.028							-0.582*	0.572*	0.49
	Population fluctuation (σ_n)	0.004	0.027							-0.628*	0.556*	0.408
Distance from the city center (D)		0.003	0.001	0.008	0.022	0.012	0.02	0.023	0.012		-0.336	-0.34
Interchange completion time (T)		0.028	0.058	0.034	0.048	0.04	0.031	0.026	0.031	0.221		0.397
Entrances and exits (W)		0.058	0.025	0.377	0.24	0.453	0.359	0.063	0.131	0.215	0.142	

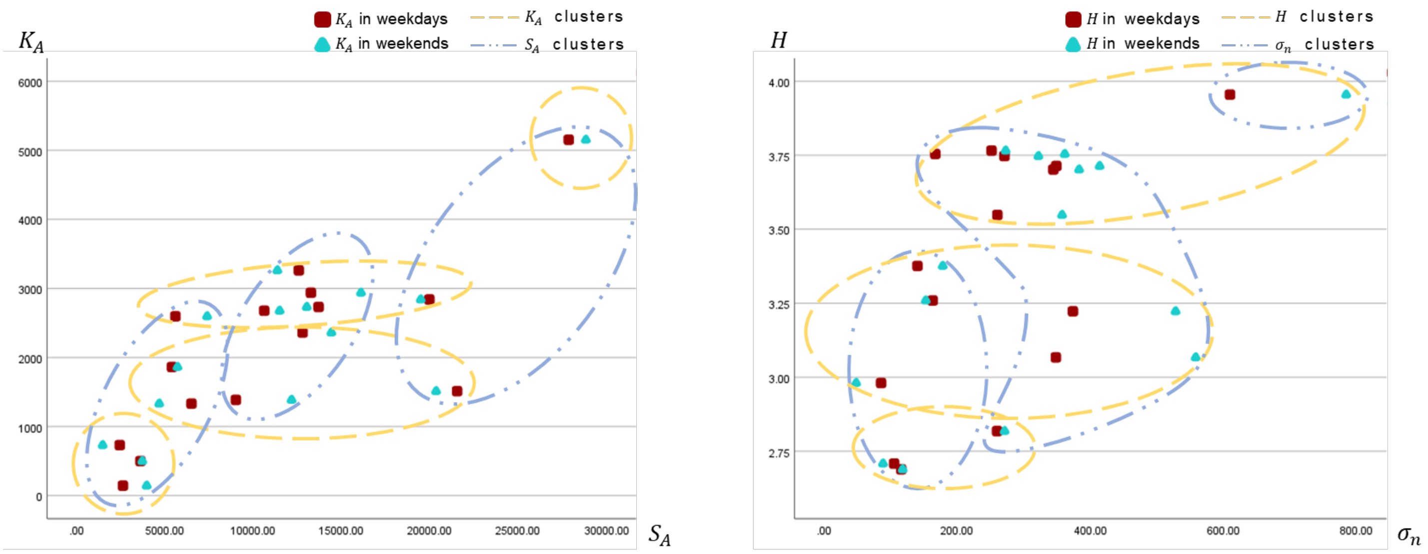

Figure 4

the distance from the city center (D). This partly reflects that interchanges farther from the city center have lower total population, less vigorous surrounding populations, and lower single-day real-time headcount maxima. The imbalance of service facilities (H) and the distance (D) from the interchange to the city center show a high negative correlation, indicating that the closer the interchange is to the city center, the more imbalanced the distribution of various types of service facilities. Conversely, the further the station is from the city center, the more balanced the distribution of service facilities.

It is worth noting that there is a strong positive correlation between the total service facilities (K_A) and the imbalance of service facilities (H) (p=0.000009 < 0.01). This also indicates that the higher the total number of service facilities around the interchange, the more serious the imbalance in service facility types. Combined with the distance to the city center (D), the closer the station is to the city center, the greater the number of service facilities, and consequently, the greater the imbalance in the types.

By transforming the above variables into scatterplots (Figure 4), it can be observed that the points display a basic linear distribution. However, due to the scattered nature of the distribution, it is difficult to draw clear and intuitive conclusions from the scatterplots alone. To more accurately and visually interpret their correlations, further cluster analysis is necessary to identify the specific differences among the relevant variables.

3.2. Cluster Analysis

Given that this study is based on big data, it continues to examine population dynamics and service facilities. Four

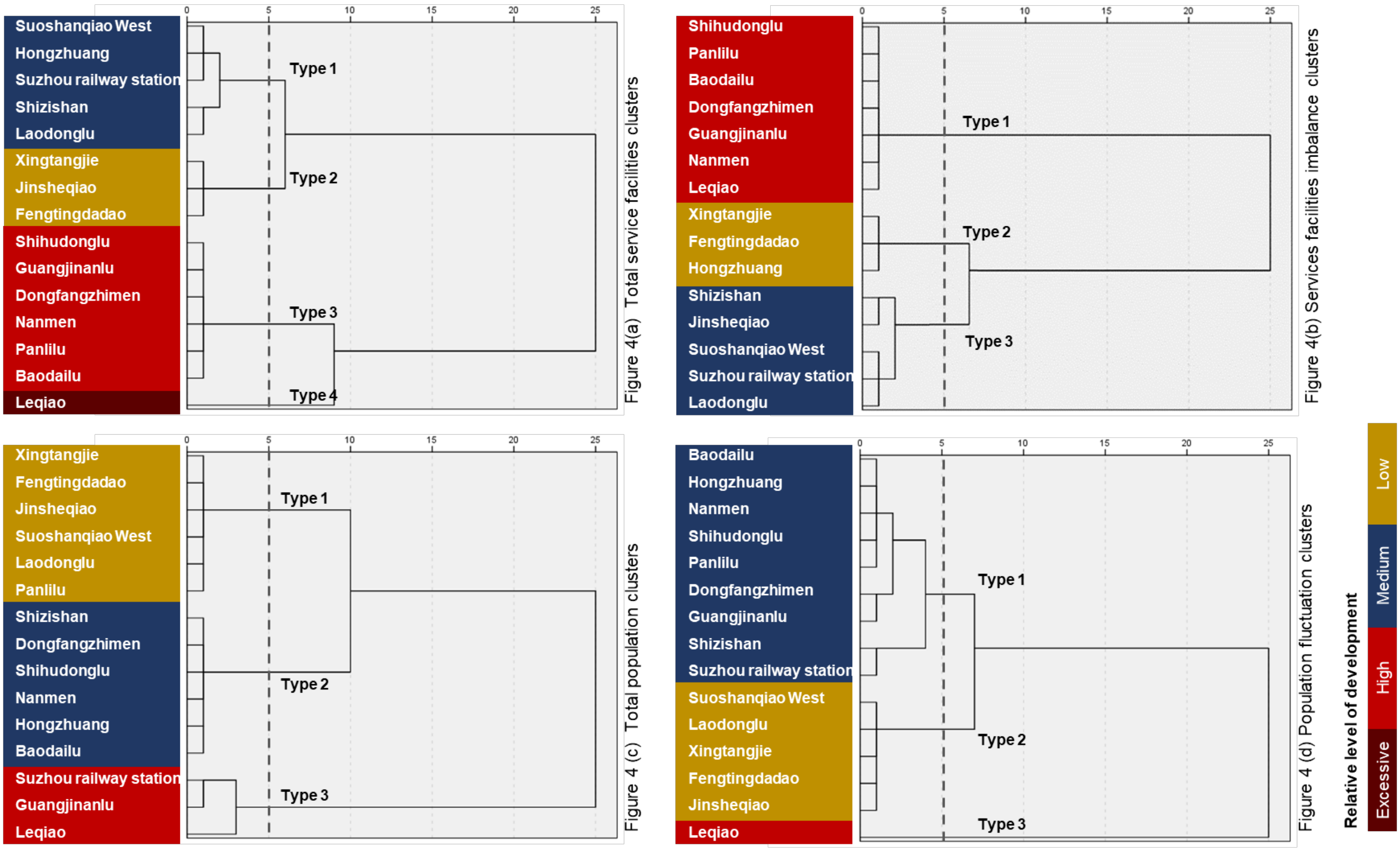

Figure 5 | Cluster analysis of S_A, σ_n, K_A and H

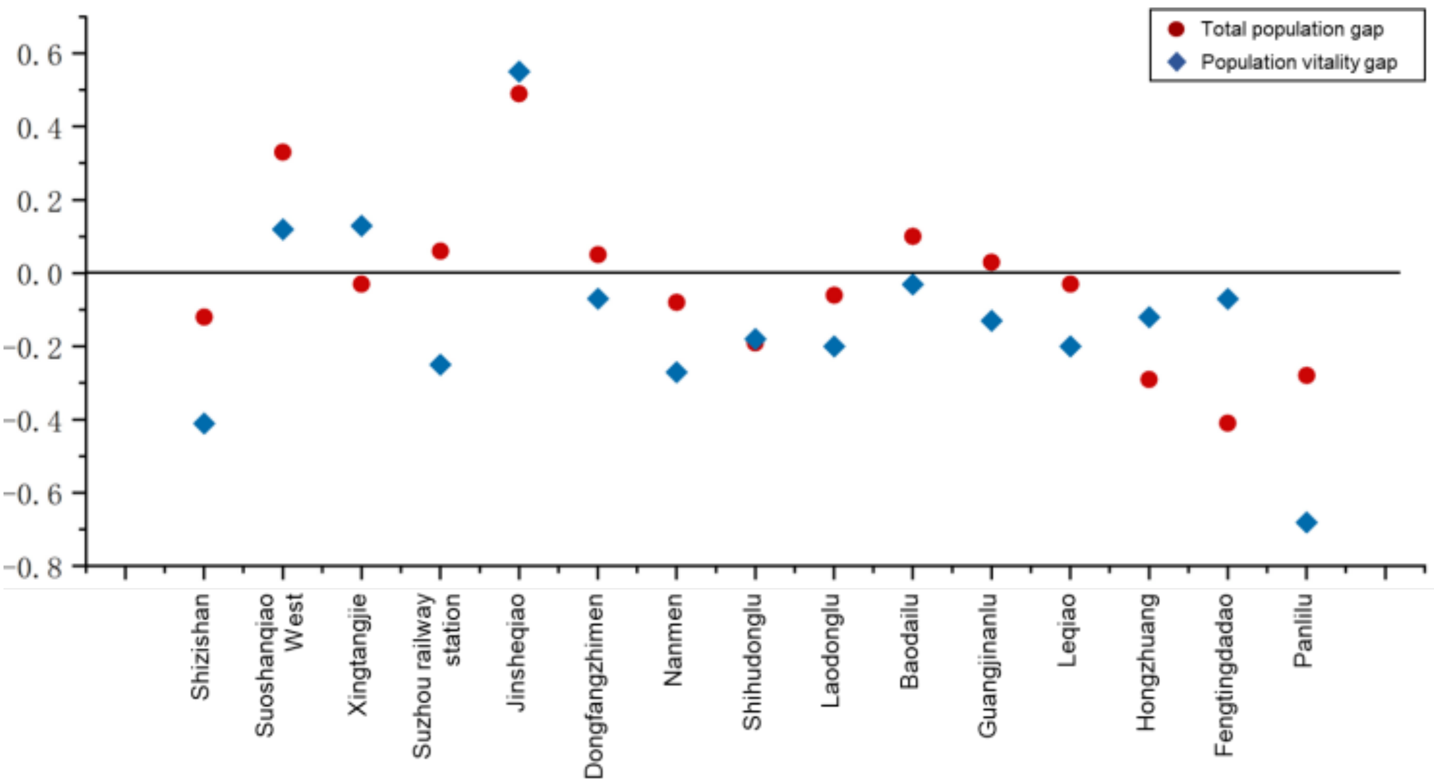

Figure 6 | Gap in total population and population vitality on weekdays and weekends

variables S_A, σ_n, K_A and H —are categorized and summarized to reveal the basic characteristics and differences in the development of interchanges. Using systematic clustering in SPSS, 15 interchanges were analyzed based on these 4 variables. The clustering method used was Wald's method, with the measurement interval being the squared Euclidean distance. Based on the clustering results, the different interchanges were classified into 2 to 8 categories. To compare the relative levels of these interchanges, the results of 3-4 categories were selected for comparative analysis (Figure 5).

Since the total population clusters on weekdays and weekends are similar, but considering the differences in their specific conditions, the gap situation is further plotted (Figure 6) to analyze the population characteristics of the interchanges in more detail. The specific calculation method for the gap situation involves the difference between weekday and weekend data. A positive difference indicates stronger population data on weekdays than on weekends, and vice versa. This difference is then divided by the average population data of the two periods to get the specific fallout of the total population at various interchanges. The circle represents the total population gap, and the diamond represents the difference in the population vitality gap.

In terms of K_A clusters, Type 3 has the largest share, with the total service facilities around its interchanges ranging between 2500 and 3500, symbolizing that these interchanges are at a relatively mature level of development, marked High. Additionally, since the total number of service facilities in Type 4 (Leqiao station) is significantly higher than the other types, it is classified as a separate category, indicating that its service facility situation is at an over-saturated development level compared to other interchanges, marked Excessive. Regarding H clusters, Type 1 > Type 3 > Type 2, are characterized as severe imbalance, moderate imbalance, and slight imbalance respectively. Most interchanges experience severe imbalance and combined with the total number of service facilities, there are significant developmental differences in service facilities among different interchange stations. The reasons for this imbalance will be further analyzed in the following section.

In terms of S_A clusters, Type 1 and Type 2 have the same number and both account for the largest proportion of the clusters. This indicates that the total population at most of the interchanges is small-sized (1469-7383) and medium-sized (9011-16093), with only three interchanges having a large-sized population (20345-28824). Figure 6 shows that the number of positive and negative values in the total population gap is approximately the same, and most of the absolute values of the gap are between 0 and 0.2. This indicates that the total population at these interchanges is relatively stable on weekdays and weekends. However, there are also cases with significant differences, such as Fengtingdadao station and Jinsheqiao station, which are -0.41 and 0.49 respectively. It shows that the difference in total population between weekdays and weekends is prominent, with people tending to gather at Fengtingdadao station on weekends and at Jinsheqiao station on weekdays. Combined with the real-time population data in Fig. 2, most of the interchanges in Type 1 show a high concentration of population during weekdays only during commuting hours, indicating that the main function of these interchanges is oriented towards daily commuting. Type 2 and Type 3 have significant population concentration throughout the day, indicating that these interchanges not only serve daily commuting but also accommodate various functions such as commerce and culture.

In terms of S_A clusters, Type 2 has the lowest population volatility, suggesting that these interchanges have a less vibrant population profile. Type 1, which is the most numerous, has moderate population volatility, indicating

Table 3 I Relative development and characteristics of different interchanges

Interchange \ Level \ Factor	Total service facilities K_A	Service facility imbalance H	Total population S_A	Total population gap ΔS_A	Population fluctuation σ_n	Population fluctuation gap $\Delta\sigma_n$	Distance from the city center D
Xingtangjie	Low	Low	Low	Negative	Low	Positive	11.3
Fengtingdadao	Low	Low	Low	Negative	Low	Negative	14.4
Jinsheqiao	Low	Medium	Low	Positive	Low	Positive	5.2
Laodonglu	Medium	Medium	Low	Negative	Low	Negative	3.7
Suoshanqiao west	Medium	Medium	Low	Positive	Low	Positive	6.1
Hongzhuang	Medium	Low	Medium	Negative	Medium	Negative	8.4
Shizishan	Medium	Medium	Medium	Negative	Medium	Negative	7.6
Suzhou railway station	Medium	Medium	High	Positive	Medium	Negative	2.5
Panlilu	High	High	Low	Negative	Medium	Positive	5.3
Dongfangzhimen	High	High	Medium	Positive	Medium	Negative	5
Nanmen	High	High	Medium	Negative	Medium	Negative	2.3
Shihudonglu	High	High	Medium	Negative	Medium	Negative	6.5
Baodailu	High	High	Medium	Positive	Medium	Negative	5
Guangjinanlu	High	High	High	Positive	Medium	Negative	2.6
Leqiao	Excessive	High	High	Negative	High	Negative	0.7

more distinct changes in real-time headcount. Additionally, there is only one interchange in Type 3, Leqiao station, which has the highest population volatility and the most dramatic population fluctuations. Combined with the data in Figure 2, it can be seen that the population build-up at Leqiao station becomes progressively more pronounced from 9:00 a.m. to 11:00 p.m. This suggests that Leqiao station is the most prominent in terms of demographic factors. It not only has high-intensity population activity values but also a stable continuation of population activity. This, to some extent, explains the excessive level of development in terms of the number of service facilities. The data in Figure 6 reflects the difference in population volatility between weekdays and weekends. Most interchanges have negative population gap values, indicating a higher intensity of population activity on weekends than on weekdays. For example, at Panlilu station, population activity from 10 a.m. to 10 p.m. on weekends is consistently high, while on weekdays from 10 a.m. to 3 p.m., there is less activity around the site, suggesting that people are more inclined to visit this interchange on weekends.

The above analysis provides the specific development differences for each interchange site (Table 3).

3.3. One-Way Analysis of Variance Analysis

The total service facilities and the total population can summarize the basic reasons for the differences in the development of interchanges, so the one-way analysis of variance analysis (ANOVA) was continued based on these two clusters to analyze the specific reasons for each of them to cause significant differences in the occurrence of interchanges (Table 4).

No significant between-group differences were shown between each of the above variables. In K_A clusters, 7 variables—Food & Beverages (K_2), Shopping (K_3), Daily Life Service (K_4), Sports & Recreation (K_5), Medical Service (K_6), Transportation Service (K_9) and Distance from the city center (D) —showed high significance. These factors are likely crucial in determining the differences in service facilities at interchange sites. Governmental Organization & Social Group (K_7), Science/Culture & Education Service (K_8), and Finance & Insurance Service (K_{10}) also contribute to the classification of the total development type of service facilities. The histogram of facility types (Figure 7) reveals a certain regularity in the proportion of each type of K_A: $K_3 > K_2$ or $K_4 > K_9$. This indicates that differences between various development types are concentrated in these four types of service facilities.

In S_A clusters, only K_2 showed high significance, indicating that Food & Beverages are the most critical among the various service facilities and are the key factor influencing population size changes. Following K_2, K_4, K_5 K_8 and K_9 also impact population growth. However, the surprisingly low significance of shopping services suggests the grow-

Table 4 | One-way ANOVA for K_A and S_A

ANOVA	K_A		S_A	
	F	*P*	*F*	*P*
Auto Service (K_1)	0.980	0.404	0.235	0.794
Food & Beverages (K_2)	8.823	0.004	7.315	0.008
Shopping (K_3)	9.445	0.003	3.050	0.085
Daily Life Service (K_4)	13.513	0.001	4.626	0.032
Sports & Recreation (K_5)	7.840	0.007	5.151	0.024
Medical Service (K_6)	9.615	0.003	1.625	0.237
Governmental Organization & Social Group (K_7)	5.357	0.022	1.579	0.246
Science/Culture & Education Service (K_8)	4.990	0.026	4.838	0.029
Transportation Service (K_9)	23.080	0.000	4.842	0.029
Finance & Insurance Service (K_{10})	4.938	0.027	1.806	0.206
Distance from the city center (D)	12.173	0.001	3.439	0.066
Interchange completion time (T)	1.406	0.283	1.750	0.215
Entrances and exits (W)	3.699	0.056	0.162	0.852

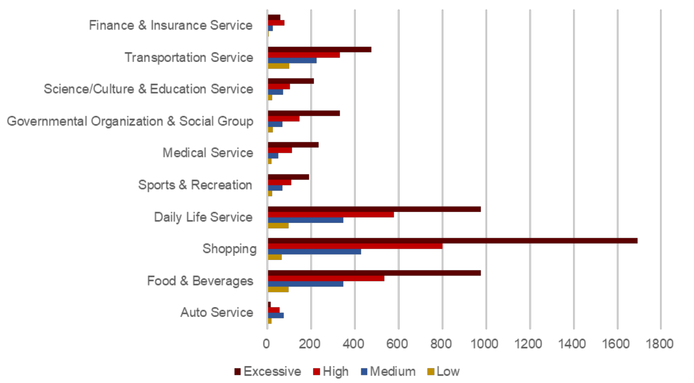

Figure 7 | Number of service facilities in K_A clusters

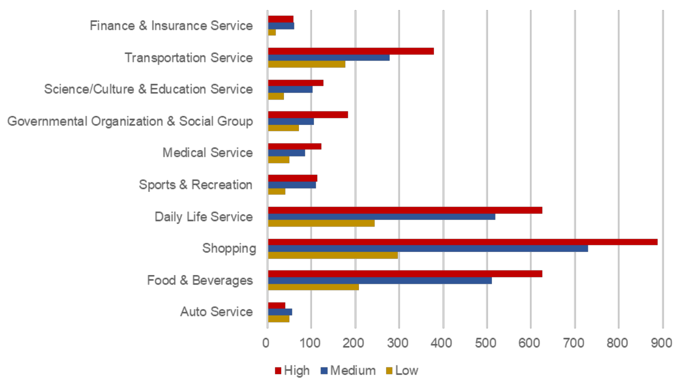

Figure 8 | Number of service facilities in K_A clusters

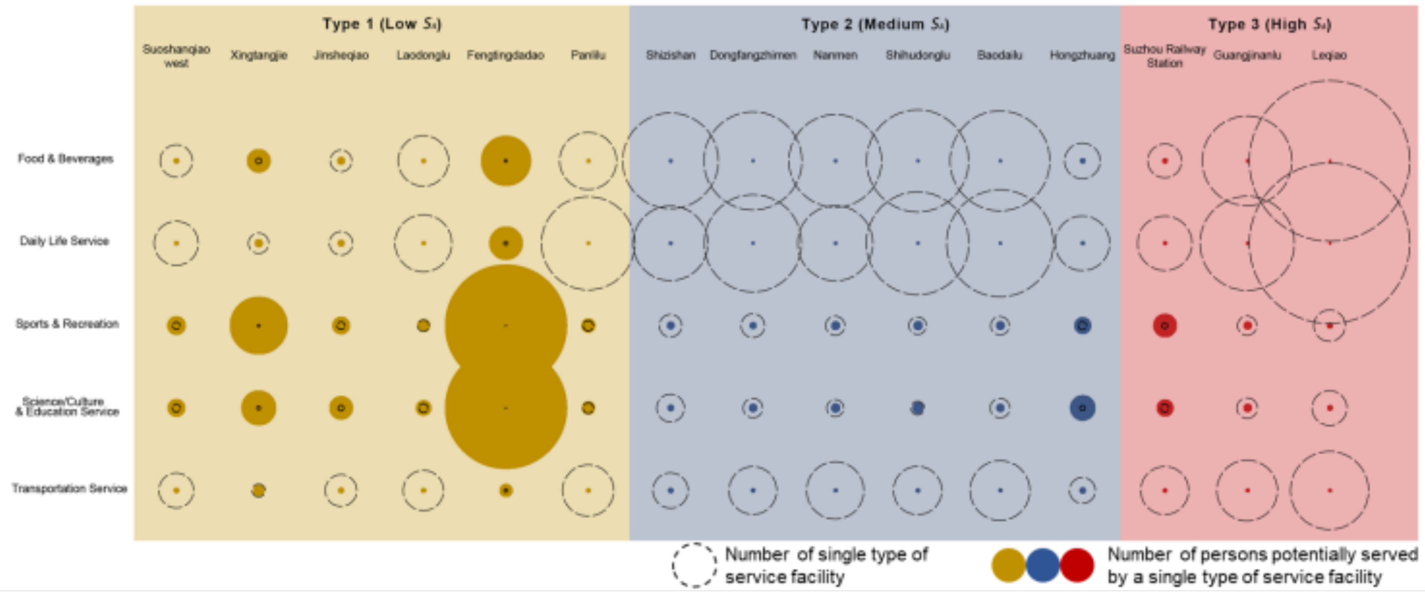

Figure 9 | Number of persons potentially served by a single type of service facility

ing popularity and convenience of online shopping, which reduces people's reliance on physical shopping places. The histogram of facility types (Figure 8) shows a consistent pattern with the previous section: $K_3 > K_2$ or $K_4 > K_9$.

The five service facilities with higher significance in the clusters were further analyzed and combined with the real-time S_{MAX} at their respective interchanges (Figure 2) to determine the specific number of people potentially oriented towards different service facilities at each interchange (Figure 9). In Figure 9, the coil size represents the number of each service facility, while the solid circle size reflects the number of potential users for each facility. Most coils surround the solid circle, indicating that the overall trend of the two is similar. However, in a few cases, the coils are smaller than the solid circles, suggesting that the configuration of the service facilities at these interchange stations is inadequate to meet the needs of the surrounding population, leaving room for further development and utilization. Conversely, if the solid circle is too small within the same type of service facility, it indicates that these facilities are under significant pressure and require better planning to enhance their comprehensive utilization rate.

4. Discussion

This study investigates the differences in development among Suzhou metro interchanges by examining service facilities and population data through multiple data sources. The findings highlight several patterns and relationships.

From the perspective of interrelationships, except for Suzhou Railway Station, there is a clear correlation between S_A and K_A. According to the relative development levels indicated in this study: low S_A - low/mid/high K_A, mid S_A- mid/high K_A, high S_A- high/very high K_A, the relative development level of service facilities is always greater than or equal to the total population. This indicates that the provision of service facilities is generally designed to meet or exceed the needs of the surrounding population, ensuring the functionality and service quality of the interchanges. It also reflects the foresight and redundancy in urban planning and service facility configuration to handle surges in population during holidays. The situation at Suzhou Railway Station is unique due to its dual function as a railway station, leading to an imbalance between service facilities and total pedestrian flow, and hence it is discussed separately.

Regarding σ_n and S_A, interchanges with mediumσ_n typically have medium to high S_A. This suggests that interchanges with medium S_A tend to attract more people. When considering the distance from the city center, Nanmen Station, which is relatively close to the city center, shows a trend of increasing to a high S_A. Similarly, Panlilu Station also exhibits a trend of rising to a medium S_A. In contrast, interchanges with low population volatility may need to develop multi-functional uses to enhance their overall attractiveness and utilization, thereby promoting population gathering and mobility, and driving the overall development of these interchange stations.

Moreover, there is a significant relationship among K_A, H and D. The closer an interchange is to the city center, the more service facilities it has, but also the more imbalanced the distribution of these facilities. In the city center, high population density and demand drive the development of commercial service facilities such as shopping, dining, and living services, while the quantity of other service facilities remains relatively stable, leading to resource over-concentration and supply-demand imbalance. The most typical example is Leqiao Station, where the excessive K_A

results in serious imbalance, leading to high pressure and competitive intensity among service facilities. To address this, government intervention is necessary to guide businesses and investors to build service facilities in peripheral areas, thereby alleviating the high-pressure environment of the city center.

5. Conclusion and Outlook

The development of URT interchanges is influenced by a multitude of factors, and cannot be inferred solely from service facilities and population factors. Land use types, local development policies, and per capita income levels all contribute to the comprehensive development of communities, creating a complex web of influencing factors. However, by combining pedestrian flow and service facility data, it is possible to monitor and track the development status and differences of interchanges in real-time. The study preliminarily demonstrates the potential for establishing a real-time development monitoring system for interchanges through this approach.

In the long run, the sustainable development of URT sites primarily depends on population density and the density of service facilities. High population density areas drive increased demand for commercial, educational, and medical facilities, which in turn fosters the clustering and development of these service facilities. This positive correlation ensures that the area surrounding a rail transit station is well-supported and functional. Adequate and diverse service facilities meet residents' daily needs, enhance the convenience and comfort of life, and attract more people, creating a virtuous cycle of "attracting population with service facilities." Moreover, the availability and quality of service facilities directly impact the attractiveness and utilization rate of the rail transit station. The richer and more evenly distributed the facilities around the station, the better they can meet diverse needs, increase passenger flow, and enhance the overall efficiency of the rail transit system. This interaction and synergistic development have a far-reaching impact on the sustainable development of cities, maximizing comprehensive benefits.

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