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Research on the Spatial Agglomeration Characteristics of Commercial Service Facilities in the Osaka Metro Midōsuji Line Rail Transit Station Area

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ABSTRACT

With the rapid development of rail transit systems in developing countries, the problems of low adaptability of commercial facilities to stations and lack of commercial vitality in rail transit station areas have gradually emerged, which in turn hinders the conversion of station passenger flow into commercial flow and is not conducive to the sustainable development of commerce. The Japanese rail transit represented by Osaka Midosuji Line can be taken as a typical representative of the study due to its early construction, high density and large passenger flow. Based on the field research of Osaka Midosuji Line and POI-based multi-source big data, this paper comprehensively applies the methods of spatial data visualization and spatial statistics to firstly classify the stations into four types, namely, residential, transportation hub, public service, and commercial service, and then summarize the spatial characteristics and agglomeration patterns of commercial facilities around each station of the line, analyze the similarities and differences in the commercial spatial structure and proportion of the commercial facilities around the stations, and deeply analyzes the main factors affecting the spatial agglomeration of commercial service facilities. It is found that different functional types of stations show different spatial agglomeration characteristics, which are mainly influenced by factors such as pedestrian accessibility and functional diversity of land within the station area. It is also found that higher commercial diversity can effectively improve the service level of the station area and better promote sustainable commercial development. Finally, optimization suggestions are made for the commercial layout strategy of developing countries' rail transit stations.

1. Introduction

Over the past few decades, with the accelerated process of urbanization, rail transit systems have experienced rapid development globally, particularly in developing countries, and have become

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an integral part of urban public transportation. Rail transit systems not only effectively alleviate urban traffic congestion and improve urban operational efficiency but also play a crucial role in promoting the optimization of urban spatial structure and socio-economic development [1-2] However, with the increasing density of rail transit networks and a substantial increase in passenger volume, the adaptability and commercial vitality of facilities around stations have become pressing issues [3] Especially in developing countries, due to the lack of coordination between urban planning, commercial development, and transportation infrastructure, commercial service facilities around stations often fail to effectively attract and serve passing passengers, thereby missing the opportunity to convert large passenger flows into commercial flows. This phenomenon not only weakens the promotion of urban commercial activities by rail transit but also affects the sustainable development of commercial facilities and the vitality of urban economy [4].

Existing research has generally focused on the impact of rail transit on urban spatial structure and commercial activities, but there remains a lack of in-depth study on the spatial agglomeration characteristics of commercial facilities around rail transit stations and their influence on urban commercial vitality. Cervero *et al.* [5] explored the potential of rail transit to enhance commercial activities within urban areas, while Zhang *et al.* [6] analyzed the impact of subway stations on surrounding property prices. Litman, T *et al.* [7] extensively discussed how Transit-Oriented Development (TOD) centered around public transportation can improve economic performance and quality of life, including its effects on commercial activities and real estate markets. Curtis, C *et al.,* [8] analyzed the impact of commercial and residential locations on commuting behavior, providing empirical data on how rail transit stations and their surrounding commercial facilities attract pedestrian flows and alter travel patterns. O'Sullivan, D *et al.* [9] examined the actual pedestrian walking distances within public transit systems, offering empirical support for optimizing commercial vitality and urban transit system design. Gutiérrez, J *et al.* [10] emphasized the importance of transportation coverage, critical for providing service to passengers. While these studies lay the groundwork for understanding the relationship between rail transit and urban commercial development, further exploration is needed, particularly in terms of optimizing the commercial layout around rail transit stations to enhance commercial vitality, especially concerning spatial distribution characteristics.

To fill the abovementioned research gap, this paper conducted an examination of the spatial agglomeration characteristics of commercial nodes around the Midosuji Line in Osaka. Utilizing primarily open-source big data extracted from Points of Interest (POI) obtained through web scraping on Google Maps, Commercial service facilities (CSFs) were compiled and imported into ArcGIS 10.6 for spatial overlay analysis. This analysis revealed the spatial distribution of CSFs in the vicinity of the Midosuji Line, categorizing all stations along the line based on the surrounding land use types. Through this categorization, differences and similarities in commercial spatial structure, agglomeration level, and mix of businesses were analyzed across different station types, leading to preliminary conclusions. Furthermore, facility agglomeration was integrated with other influencing factors and subjected to correlation analysis using SPSS to discern the primary factors affecting the spatial agglomeration of CSFs. The main objectives are to: (i) Analyze the overall spatial distribution characteristics of CSFs along the Midosuji Line. (ii) Examine the similarities and differences in commercial spatial structure and business format combinations around four types of stations. (iii) Identify the factors influencing the degree of spatial agglomeration of CSFs.

2. Methodology

2.1 Study Area And Data Description

This study focuses on the spatial agglomeration characteristics of Commercial Service Facilities (CSFs) around subway stations, selecting all 20 subway stations along the Midosuji Line in Osaka, Japan, and further analyzing the factors influencing the spatial distribution of CSFs around these stations.

The Midosuji Line is operated by Osaka Metro, a public enterprise jointly established by Osaka Prefecture and Osaka City to manage the subway system within Osaka City (**Fig 1**). Spanning 24.5 kilometers, it is one of the earliest developed and busiest routes in Osaka, serving as a major transportation artery running from north to south through the city. The northern terminus of the Midosuji Line is at Esaka Station in Suita City, Osaka Prefecture, while its southern terminus is at Nakamozu Station in Kita Ward, Sakai City, Osaka Prefecture (**Fig 2**).

Fig. 1. Osaka Subway Lines

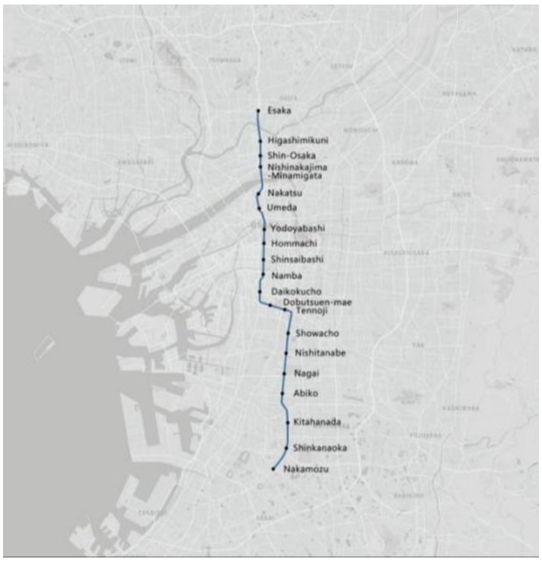


Fig. 2. Osaka Midosuji Line

By observing the urban land planning data provided by the Ministry of Land, Infrastructure, Transport and Tourism of Japan on the official website of Osaka City (http://www.mapnavi.city.osaka.lg.jp), and through statistical organization, it is evident that the commercial land structure of Osaka City is primarily concentrated along the north-south axis of the Midosuji Line, particularly around the central business district and transportation hubs. Notably, the Shin-Osaka Commercial District, Umeda Commercial District, Shinsaibashi Commercial District, and Tennoji Commercial District are the most bustling commercial centers in Osaka City [11]. These areas host numerous shopping malls, department stores, boutiques, restaurants, and entertainment venues, attracting a large number of consumers and tourists.

At the same time, the Midosuji Line, as a historically significant and heavily trafficked rail transit route, is located within the Osaka metropolitan area. Through the efficient integration of station-city commercial development, it effectively transforms rail transit stations into vibrant urban commercial centers, achieving the efficient conversion of passenger flow and commercial flow. This model not only enhances the commercial vitality of station areas but also promotes the rational utilization of urban space and sustainable economic development [12].

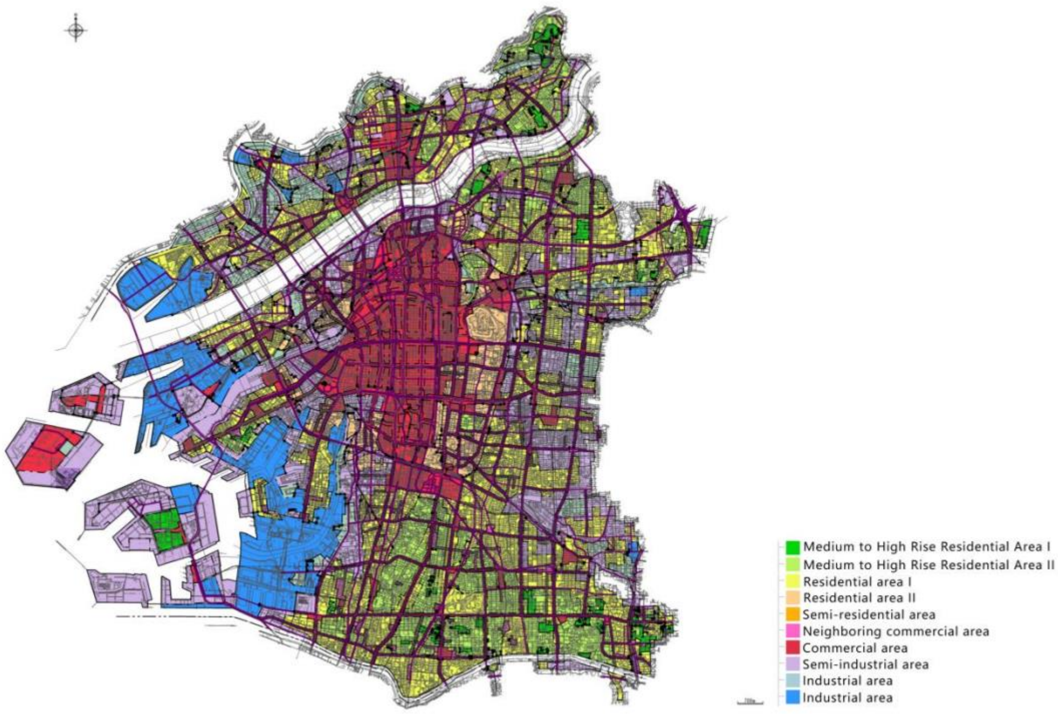


Fig. 3. Osaka Urban Land Use Planning

CSFs refer to operational venues [13] that provide goods and services for production, business, and residents' daily lives. For the sake of comparability in this study, individually operated entities in food and beverage, retail, and lifestyle (leisure and health) establishments are considered as a single CSFs. Similarly, individual food and beverage, retail, and lifestyle businesses within higher-level commercial complexes are also treated as a single CSFs, aiming to better identify the spatial distribution variations and characteristics of CSFs along the Midosuji Line.

Various classification methods have been used in previous studies to categorize commercial formats. Christaller's Central Place Theory primarily divides commercial formats based on centrality and hierarchy of commercial supply, including retail, wholesale, finance, enterprise, management, administration, professional services, education, and entertainment [14]. In recent years, Xia (2015) [15] categorizes commercial formats based on consumer behavior into six major categories: clothing and accessories, daily department stores, office services, dining and leisure, and others. Li (2018) [16] classifies formats based on target merchant data into ten major categories: retail and wholesale, hotels, restaurants, beauty salons, banks and finance, education and training, medical care, digital equipment, automotive maintenance, and building materials markets. In studies on commercial complexes and shopping centers, formats are typically divided into four major categories: retail, dining, leisure and entertainment, and lifestyle services [17-18].

This study integrates the aforementioned classification methods, combines Google Maps functional classification with the characteristics of business formats in the Kansai region of Japan, and refers to scholars' classifications [19] to categorize CSFs along the Midosuji Line into six major categories: retail, dining, leisure and entertainment, lifestyle services, financial services, and tourism accommodation. The specific classification details are shown in the table below.

Table 1 Classification Details of Commercial Service Facilities

Type	
Retail	Supermarkets,Shopping mall,Comprehensive Stores and other Comprehensive Retail
Catering	Special catering bread dessert drinks (in), bread dessert drinks (not in), snack food (not in), snack food (in), etc
Leisure and entertainment	massage/health club, fitness/sports, KTV/ dance hall, cinema/theater, bar, teahouse room chess and card room, Internet cafe, amusement/video games, etc
Life service	Learning and training, pet service, beauty salon and body beauty, medical service, printing service, daily maintenance, consulting/intermediary service, cultural service, convenience service, washing and cleaning,etc
Financial service	Business halls of banks, securities institutions, etc
Tourist accommodation	Hotel, Inn, Residential hostel, etc

This study primarily utilizes data surrounding the Midosuji Line in Osaka, Japan, including Points of Interest (POI), road networks, and population data :

(i) POIs data: Points of Interest (POI) are derived from an open-source internet map database and include information such as facility types, coordinates, and specific locations. They exist in the form of point data, where each facility represents a POI point with multiple spatial data attributes, representing entities like companies, shops, supermarkets, squares, and parks. Internet mapping companies collect POIs worldwide through human effort and technology, marking them on maps for easy access. Urban planners can utilize ArcGIS to incorporate POI data, including coordinates and names of various enterprises, into corresponding urban enterprise distribution maps, enabling analyses related to urban planning based on basic information derived from point data.

The POI data used in this study were obtained through Google Maps using an open-source web crawler framework called Scrapy, programmed in Python. A total of 231,435 data points were collected using this method. Google POI data include various functional types of facilities within the city, such as CSFs, Public Service Facilities (PSFs), factories, residential areas, etc., covering nearly all types of urban facilities encountered in daily life. Google POI data mainly consist of attributes such as name, type, latitude and longitude, detailed address, public rating, etc. For example, the attribute fields for a certain residential POI data point include "HANASTAY Hanakei-inn (SONO), Japanese inn, 34.6409563, 135.49677359999998, 1 Chome-9-16 Hanazonominami, Nishinari Ward, Osaka, 557-0015, Japan, 5 (score)." Among these attributes, latitude and longitude coordinates facilitate precise facility location, while name and type aid in filtering and classifying POIs based on function and industry. Due to the large volume and complexity of the data collected from Google Maps, and considering the research requirements of this study, field selection was initially performed to retain only four valid fields: name, type, latitude, and longitude. Moreover, since the study focuses on commercial nodes within a radius of 800 meters centered on rail transit stations, data within the research scope needed to be selected based on latitude and longitude coordinates, followed by further classification of commercial nodes according to facility types. In Google POI data, the "type" attribute can be used to filter out CSFs points.

(ii) Road network and Population data: The road network data for the year 2023 were downloaded from OpenStreetMap (https://www.openstreetmap.org/). After excluding highways and other roads unsuitable for walking, topological errors were corrected, and a road network was constructed in ArcGIS 10.6. Population grid data were downloaded from Worldpop (https://hub.worldpop.org/). The data are presented in 100m*100m grid format, and after defining the study area, the spatial distribution of the population can be more intuitively understood using the natural break points classification method.

2.2 Research Process

The spatial data of each station was imported into ArcGIS 10.6 and projected to the EPSG:6690 - JGD2011/UTM zone 53N coordinate system. Buffer zones of 300m, 500m, and 800m were then established around each station, starting from the geometric center of the station, following the method outlined by Cervero and Kockelman [20]. Duplicate station names were manually removed from the original dataset in the open-source Geographic Information System ArcGIS. Subsequently, Commercial Service Facilities (CSFs) located within each station area were extracted. The spatial distribution of CSFs, the composition of business categories, and the diversity index of facilities were analyzed based on the number of facilities in each subclass.

The Kernel Density Estimation (KDE) method was employed for visual analysis of the spatial distribution characteristics of different CSFs. KDE, proposed by Rosenblatt and Emanuel Parzen, estimates the density of points or line patterns using a moving window. It measures spatial distribution features such as point location and density by constructing a continuous probability density function based on discrete sample points, making it an important tool for studying uneven spatial distributions. The formula for the kernel density function is as follows (Dong et al., 2022) [21].

$$f(x,y) = \frac{1}{nh^2}\sum_{i=1}^{n} k\left(\frac{d_i}{h}\right) \tag{1}$$

- *f(x,y)* is the density function at point *(x, y)*.
- d_i is the distance between point *(x, y)* and the ith observation point.
- *n* is the number of observation points.
- *k* is the kernel function.
- *h* is the bandwidth, set to 800 meters based on the spatial scale radius of the station area.

Due to the varying daily passenger flow at stations, ranging from several hundred to over 1.5 million, it is expected that the number and composition of facilities near the stations will be diverse. After using the KDE method to assess spatial distribution characteristics, correlation analysis will be conducted. Correlation analysis is a method used to determine the relative relationship between simple objective phenomena, commonly using scatter plot discrimination and correlation coefficient measurement methods. This study chooses to use Pearson's simple [22] correlation coefficient to measure the degree and strength of the relationship between various indicators pairwise. The judgment criterion is based on the absolute value of the indicator correlation coefficient (the correlation coefficient itself has positive and negative attributes, where a positive number indicates positive correlation, and a negative number indicates negative correlation). The greater the absolute value, the stronger the correlation between the two indicators. The study will analyze the degree of aggregation of CSFs and the richness of business formats within an 800-meter radius around the stations, as well as the correlation between multiple influencing factors. The calculation formula for Pearson correlation coefficient is as follows:

$$r = \frac{\sum_{i=1}^{n}(x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum_{i=1}^{n}(x_i - \bar{x})^2 \sum_{i=1}^{n}(y_i - \bar{y})^2}} \tag{2}$$

In the above formula, n represents the total number of samples, x^i and y^i represent the attribute values of the two variables respectively, $\bar{x}$ and $\bar{y}$ and represent the mean values of the variables x and y respectively. To demonstrate the scientific rigor and integrity of the analysis process, it is necessary to conduct a reliability test on the correlation coefficient to prevent potential biases resulting from issues such as sample size and data manipulation. Firstly, the extracted CSFs data will be exported, exported to Excel in batches, and then inputted into SPSS [23] to calculate the intrinsic spatial characteristics of business sites through the Pearson correlation coefficient, providing an internal association analysis of the commercial sites.

3. Results

3.1 Spatial Agglomeration Analysis Of Commercial Service Facilities
3.1.1 Spatial agglomeration characteristics of different types of stations

The study combined the urban land planning data provided by the Japan Ministry of Transport website, referring to previous research that considered the functional classification of urban areas as the basis for categorizing the location of railway stations in the city and the dominant functions of the surrounding land use at the stations [24]. Based on the composition ratio of urban major functional land in the station area, the 20 stations along the Midosuji Line were classified into residential stations, commercial service stations, public service stations, and transportation hub stations (**Fig 4**). Specifically, there are currently seven residential stations, four public service stations, five transportation hub stations, and four commercial service stations along the Midosuji Line (**Table 2**).

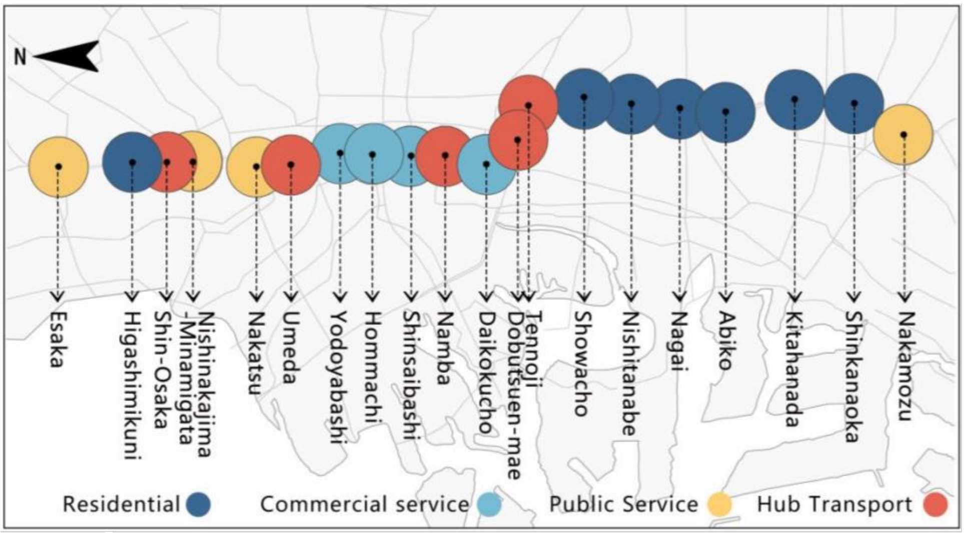


Fig. 4. Classification of Station Types along the Midosuji Line Rapid Transit

Table 2 Classification of Midosuji Line Metro Stations

Station Categories	Station Names
Residential	Higashi-Mikuni,Showachō,Nishitanabe,Nagai,Abiko,Kitahanada,Shin-Kanō
Transportation Hub	Shin-Osaka,Umeda,Namba,Dobutsuen-mae,Tennoji
Public Service	Esaka,Nakatsu,Nishinakajima-Minamigata,Nakamozu
Commercial Service	Yodoyabashi,Homamachi,Shinsaibashi,Daikokuch

Currently, residential-type stations along the Midosuji Line are mainly distributed on the northern side of the line, near Suita City and Yodogawa Ward in Osaka City, as well as on the southern side near Sakai City, Abeno Ward, and Minami Ward in Osaka City, at a considerable distance from the main commercial centers within Osaka City. These stations are predominantly surrounded by residential areas with high population density and relatively fewer commercial facilities. Residential-type stations along the Midosuji Line are primarily located on the outskirts of the city, relatively far from the main commercial centers. This distribution pattern may reflect certain specific trends and influencing factors in urban development. For example, urban population growth and expansion may lead to increased demand for residential areas in the suburbs, attracting more people to live in these areas. Additionally, the relatively fewer commercial facilities around residential-type stations may be related to the land use planning and commercial development strategies in these areas. Urban planners may focus more on developing commercial facilities in the central urban areas, while emphasizing residential area construction and development in the outskirts. This distribution pattern may also be related to transportation and infrastructure development, with transportation in the outskirts potentially being relatively inconvenient, limiting the development of commercial facilities to some extent. Additionally, there is a certain correlation between residential-type stations and surrounding land prices, with residential-type stations more likely to be located in areas with lower land prices. This may imply that developers and urban planners consider factors such as land costs when selecting station locations, tending to choose areas with lower land prices for constructing residential-type stations. This choice may affect the development and diversity of commercial facilities around the stations, as the construction of commercial facilities is also restricted by land costs. Taking these factors into consideration, it can be inferred that the commercial development around residential-type stations may be subject to certain limitations, with the development of commercial facilities relatively slow, mainly focusing on meeting the basic needs of surrounding residents. The two residential-type stations near Suita City are classified as compound stations, surrounded by public service and commercial service-type stations, but they have not formed distinct overlay areas, indicating a general lack of spatial correlation. Considering these observations, it can be inferred that residential-type stations have relatively low commercial diversity and moderate development levels, but with relatively complete public service facilities.

Commercial service stations along the Midosuji Line exhibit a certain degree of spatial agglomeration, primarily clustering in the central urban area of Osaka City, with most of them being stations built in the early stages of the line's construction. This distribution pattern may reflect the synergistic relationship between the development of urban commercial centers and the construction of rail transit lines. Around these commercial service stations, a higher diversity of commercial facilities and services is observed, with more complete basic service facilities, attracting more passengers. This agglomeration phenomenon may be influenced by factors such as urban development planning and transportation convenience. Urban planners and developers may prefer to construct commercial facilities in the central urban areas, and the construction of rail transit further enhances the commercial vitality of these areas. Therefore, the development of commercial facilities around commercial service stations is relatively comprehensive, with more complete service functions, attracting a large volume of passenger flow. Additionally, commercial service stations have relatively large and stable passenger flows, with no significant peak periods in the morning or evening, which may be related to their location and function. Most commercial service stations are located in the main commercial centers of the city, with convenient transportation, attracting a large number of residents and tourists. Due to the diversity and high level of service of commercial facilities around these stations, passenger flows remain relatively stable on both weekdays and weekends, and may even increase further on weekends. This phenomenon also reflects the significant importance and attractiveness of commercial service stations in the urban commercial system.

Public service stations along the Midosuji Line are relatively dispersed, mainly located in suburban areas or densely populated residential areas. These stations are mainly surrounded by public service facilities such as leisure and entertainment, education, and research, with relatively few commercial facilities. Since the primary function of these stations is to serve the public needs of urban residents, the development of commercial facilities is not their main feature. People usually visit these stations for leisure, entertainment, or service enjoyment rather than for business or shopping purposes.

The development of commercial facilities around public service stations is relatively limited, but basic service facilities are relatively complete, meeting the basic needs of citizens.

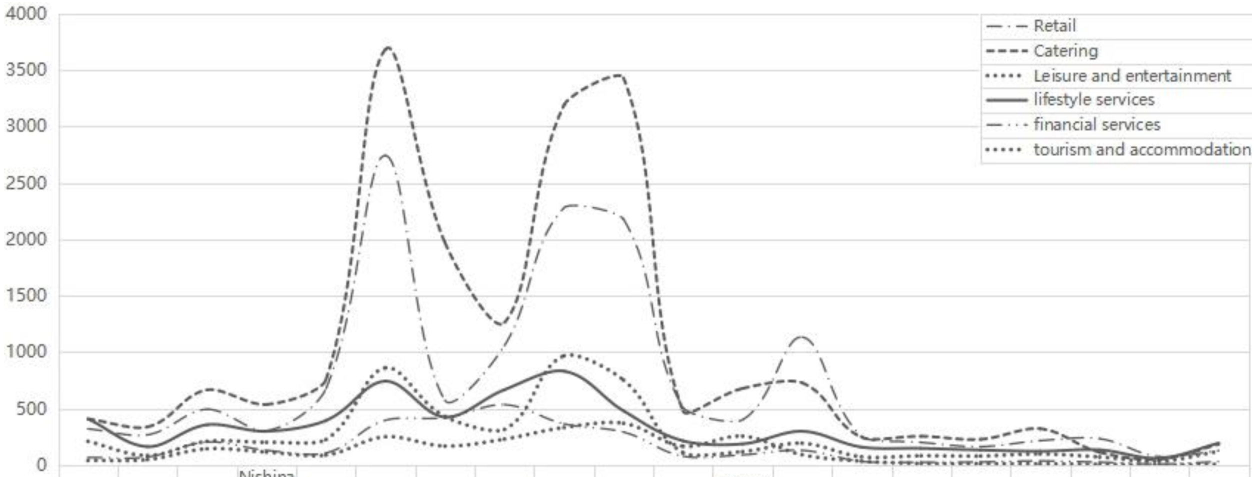
The transportation hub stations on the Midosuji Line are mainly located at Shin-Osaka Station, Umeda Station, Namba Station, Dobutsuen-mae Station, and Tennoji Station, playing crucial interchange roles within the subway network. These stations are surrounded by a wealth of commercial and service facilities, attracting a large population flow and exhibiting high commercial vitality. Strictly speaking, they are also commercial service-oriented stations, belonging to compound stations, but due to their outstanding transportation attributes, they are defined as transportation hub stations in this study. In addition to subway services, the transportation service facilities in these station areas are also well-developed, making travel more convenient. Moreover, these stations also benefit from their proximity to urban expressways, providing them with greater advantages in logistics and transportation, resulting in a dense distribution of large shopping facilities and other major commodity trading service facilities in these areas. Considering the relatively high accessibility of transportation hub stations, there is a significant advantage in pedestrian traffic in their surrounding commercial spaces. This leads to a predominance of shopping services in these areas, attracting a large number of shoppers. Besides shopping services, due to the increased foot traffic, these station areas also offer a certain amount of accommodation, dining, and leisure services to meet the needs of different demographics. It is worth noting that the commercial development of these station areas may be influenced by factors such as urban planning and land use policies, so the future development direction may be subject to adjustments.

3.1.2 Spatial agglomeration characteristics of overall commercial service facilities

From the distribution of CSFs quantity, it is evident that the distribution along the Midosuji Line exhibits a significant non-uniform pattern. The number of CSFs peaks at Umeda Station and Namba Station, while reaching a valley at southern suburban stations like Shin-Kano Station. Overall, the quantity of CSFs along the line shows an initial increase, followed by a decline, and then a subsequent rise before decreasing again.

Looking at the variation trend of CSFs quantity from north to south along the 20 stations on the line (**Chart 1**) , distinct differences in CSFs aggregation are observed along different sections of the line. It can be broadly divided into five segments:

From Esaka Station to Nakatsu Station: This segment represents a relatively low aggregation zone, with CSFs quantity generally at a moderate to lower level. The stations are located in the northern suburban area of Osaka. From Nakatsu Station to Yodoyabashi Station: This segment exhibits a highly concentrated zone, with CSFs quantity increasing as it approaches Umeda, the first major transportation hub and commercial center. The development intensity for commercialization is extremely high in Umeda. From Yodoyabashi to Daikokucho Station: In this segment, the CSFs quantity experiences a second increase. This area constitutes the second largest commercial district in Osaka, with intense commercial development around Namba Plaza, located south of Shinsaibashi Station. From Daikokucho to Showacho Station: Passing through Tennoji Station, this segment maintains a stable level of CSFs quantity, with a slight decrease compared to the previous two increases. There are notable development projects in the vicinity, such as Abeno Harukas, a famous landmark in Japan. From Showacho to Nakamozu Station: In this segment, the CSFs quantity continues to decline, reaching a valley at Shin-Kano Station, which is relatively far from the city center and situated in suburban areas.



Esaka	Higashi-Mikuni	Shin-Osaka	Nishinakajima-Minamigata	Nakatsu	Umeda	Yodoyabashi	Homamachi	Shinsaibashi	Namba	Daikokucho	Dobutsuen-mae	Tennoji	Showachō	Nishitanabe	Nagai	Abiko	Kitahanada	Shin-Kanō	Nakamozu
320	267	493	303	678	2743	572	1059	2280	2178	510	400	1133	254	200	162	215	232	73	127
408	337	665	536	758	3685	1969	1263	3191	3431	477	678	728	245	254	227	321	112	50	183
209	83	209	201	225	861	428	315	968	752	107	118	192	72	81	79	97	70	32	120
408	162	356	298	394	742	424	667	831	479	213	186	298	158	147	132	121	133	59	193
65	70	203	129	106	396	419	534	364	291	77	89	129	31	23	26	35	24	8	29
39	47	143	114	87	250	167	229	332	369	165	255	90	33	13	11	9	5	0	5

Chart 1: Statistics of CSFs Quantity around Each Station on the Midosuji Line

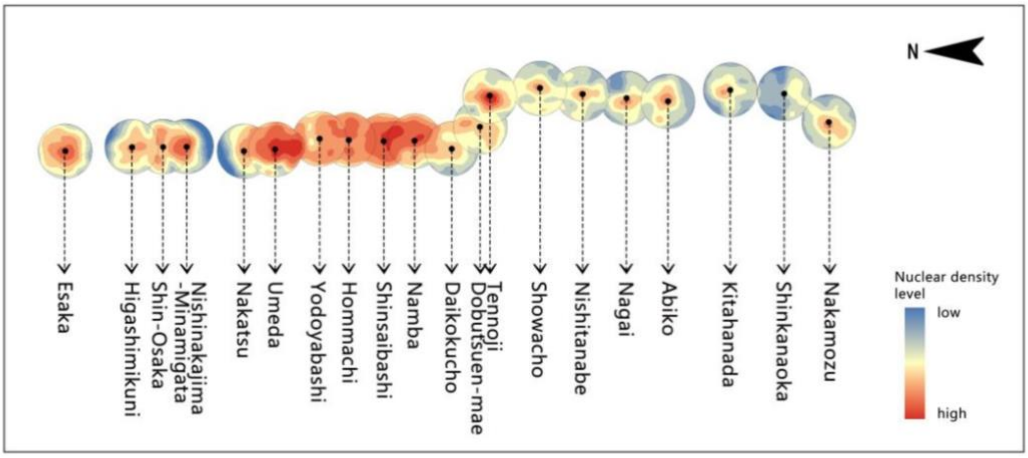


Fig. 5. Kernel Density Distribution of CSFs around Each Station on the Midosuji Line

3.1.3 Spatial agglomeration characteristics of various types of commercial service facilities

After extracting and categorizing the POI data according to the seven major categories of CSFs, kernel density analysis was performed separately in ArcGIS 10.6. The geometric interval classification method was adopted, utilizing the geometric properties of spatial distance to classify the data. This method provides intuitiveness and interpretability, effectively capturing the spatial distribution patterns of geographic data, which helps in understanding the spatial characteristics and correlations of geographic phenomena. The results from **Figures 6** reveal the following characteristics regarding the spatial aggregation of various types of CSFs:

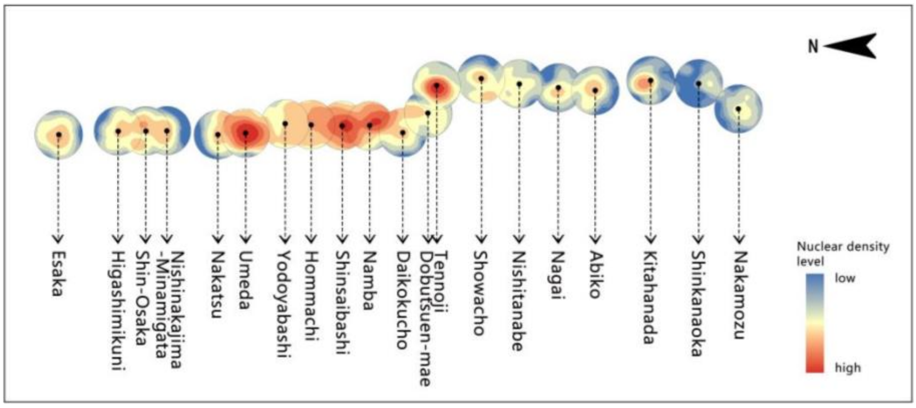
CSFs along the Midosuji Line in Osaka exhibit significant spatial agglomeration characteristics by type. These CSFs show high-density clustering in major commercial centers such as Umeda, Shinsaibashi, and Namba, while clustering in peripheral areas varies, demonstrating a significant linkage effect between rail transit and commercial development.

Retail and catering CSFs display a trend of decreasing clustering moving outward from the station centers. When overlaying the kernel density analysis results with station center locations, it can be observed that areas of high kernel density coincide with station centers, with the densest distribution in the central urban areas, gradually decreasing outward. The most significant clustering areas of retail and dining services closely match the high-density areas within the station influence zones, indicating that the substantial passenger flow generated by station construction strongly influences the layout of dining facilities.

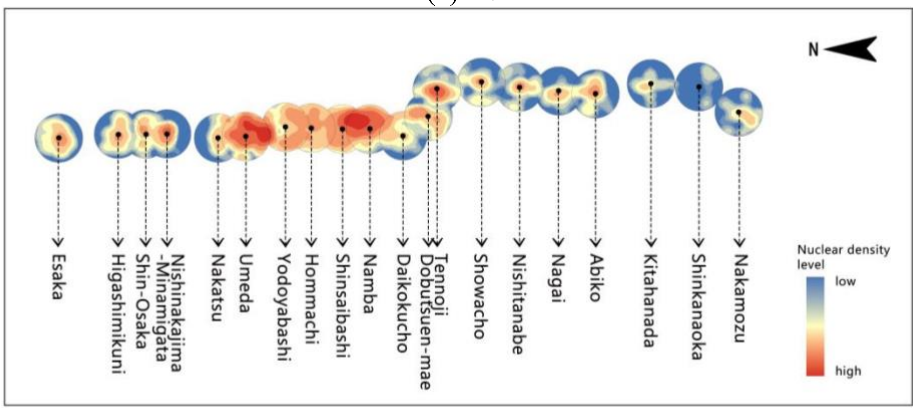
Lifestyle service CSFs along the line exhibit a "single-core area + multiple-core area" pattern. Lifestyle service CSFs, in addition to being concentrated in core commercial areas like Umeda Station and Shinsaibashi Station, also show higher clustering at more peripheral stations such as Shin-Osaka Station, Tennoji Station, and Nakamozu Station, achieving comprehensive coverage of each station's influence area.

Leisure and entertainment CSFs exhibit overall uneven distribution, with aggregation decreasing outward from the station center. High-density aggregation areas mostly appear within the 450m range centered around the rail transit stations, specifically overlapping areas at Umeda Station, Shinsaibashi, and Namba Station. Additionally, leisure and entertainment service facilities are relatively concentrated around six stations, including Esaka Station, Yodoyabashi, Hommachi, Tennoji, and Nakamozu, with less significant aggregation observed in other station areas.

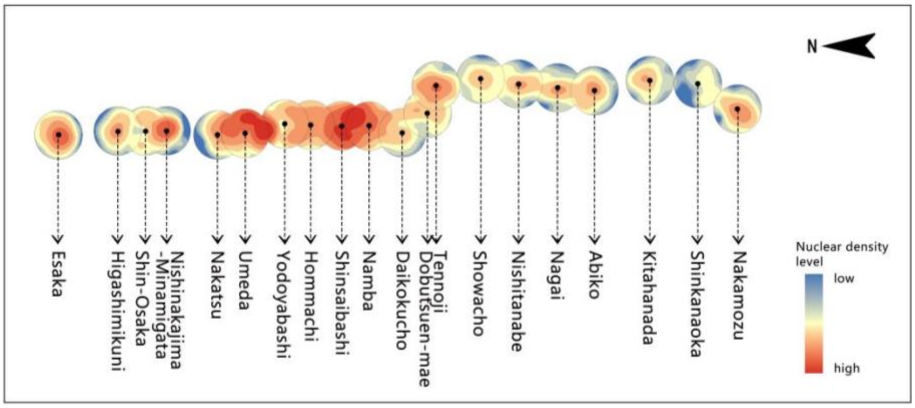
Financial service and tourism accommodation CSFs exhibit uneven distribution, with high aggregation areas located around commercial and transportation hub-type stations. These facilities mainly aggregate within the station's core influence area. The highest aggregation of tourism accommodation CSFs is found in the core influence areas of Namba Station and Dobutsuen-mae Station, followed by areas around Umeda Station and Hommachi Station.



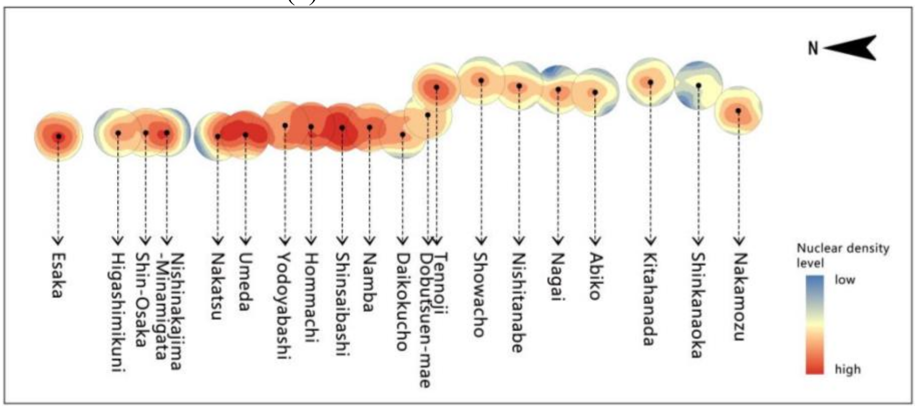
(a) Retail



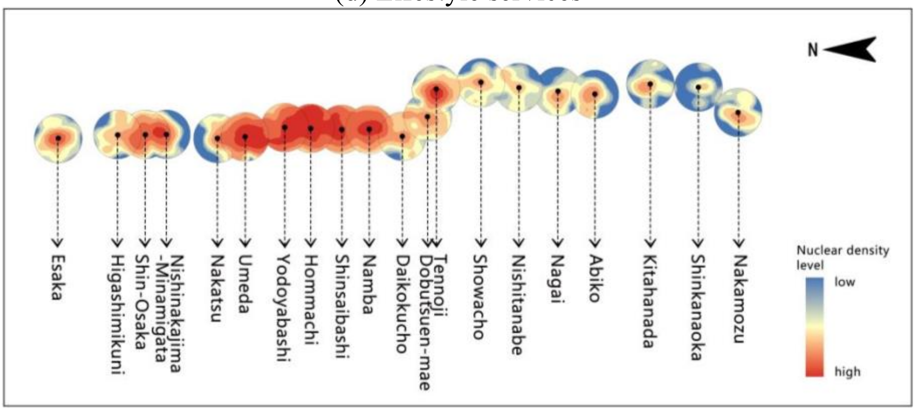
(b) Catering



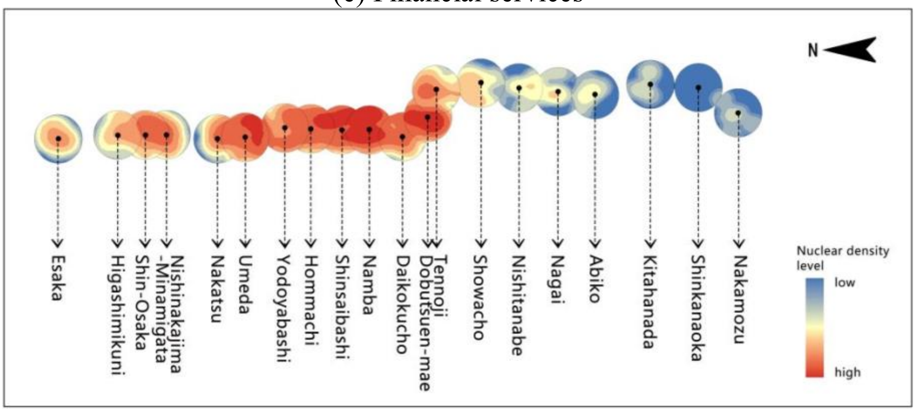
(c) Leisure and entertainment



(d) Lifestyle services



(e) Financial services



(f) Tourism and accommodation

Fig. 6. Kernel Density Analysis of Various Commercial Service Facilities

3.2 Analysis Of Factors Influencing The Spatial Agglomeration Of Commercial Service Facilities
3.2.1 Correlation analysis among commercial service facilities

According to the theory of commercial agglomeration, a large number of interrelated CSFs tend to agglomerate in space. Therefore, exploring the differences in agglomeration and the correlation between CSFs of different types of businesses is of great significance for understanding urban commercial space. CSFs of different types of businesses may attract or repel each other in spatial distribution, thereby affecting the spatial distribution of commercial facilities. Through the use of POI statistical data for each business service facility at each site as samples imported into SPSS, calculating the Pearson correlation coefficient between business service facilities of various types can help to explore whether there is a mutual influence relationship between the six types of CSFs and whether the correlation between facilities is significant. The final output results are shown in the **Table 3** .

Table 1 The correlation analysis matrix of various commercial service facilities

	Retail	Catering	Leisure and entertainment	Lifestyle services	Financial services	Tourism and accommodation
Retail	1(0.000***)	0.949(0.000***)	0.943(0.000***)	0.848(0.000***)	0.711(0.000***)	0.806(0.000***)
Catering	0.949(0.000***)	1(0.000***)	0.977(0.000***)	0.838(0.000***)	0.778(0.000***)	0.847(0.000***)
Leisure and entertainment	0.943(0.000***)	0.977(0.000***)	1(0.000***)	0.889(0.000***)	0.755(0.000***)	0.812(0.000***)
Lifestyle services	0.848(0.000***)	0.838(0.000***)	0.889(0.000***)	1(0.000***)	0.873(0.000***)	0.761(0.000***)
Financial services	0.711(0.000***)	0.778(0.000***)	0.755(0.000***)	0.873(0.000***)	1(0.000***)	0.759(0.000***)
Tourism and accommodation	0.806(0.000***)	0.847(0.000***)	0.812(0.000***)	0.761(0.000***)	0.759(0.000***)	1(0.000***)

Note:*、**、***represent significance levels of 1%, 5%, and 10% respectively

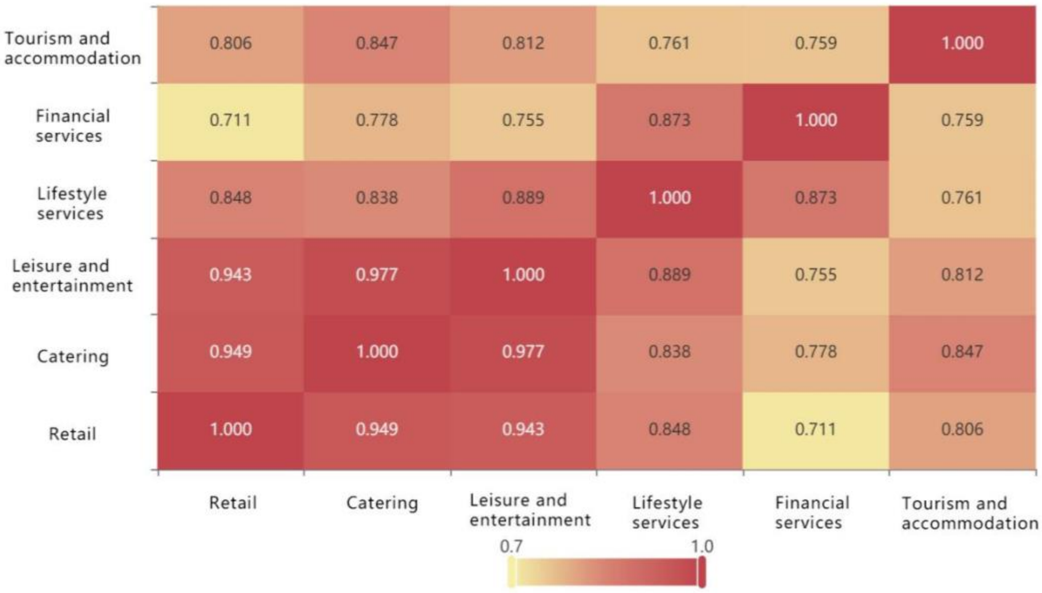


Fig. 7. Heatmap of Correlation Coefficients for Agglomeration of Various Types of CSFs

In **Figure 7**, the two types of CSFs marked in red show a significant positive correlation in distribution quantity, indicating a strong correlation between these two types of CSFs, suggesting that they tend to agglomerate interactively in the vicinity of rail transit stations. Conversely, the two types of CSFs marked in yellow also exhibit a positive correlation in distribution quantity, but the correlation is moderate, indicating a lower level of agglomeration interaction in the vicinity of stations. Therefore, the following conclusions can be drawn:

Firstly, various types of CSFs within the station areas of the Midosuji Line rail transit exhibit significant correlations, indicating different degrees of mutual attraction between different types of CSFs. Particularly, retail, dining, and leisure entertainment service facilities show a strong correlation, indicating a robust association. Conversely, financial services demonstrate relatively weaker correlations with CSFs other than lifestyle services.

Secondly, the most significant clustering interaction is observed between dining service facilities and leisure entertainment service facilities, followed by their relationship with other CSFs. This suggests that in areas of CSFs aggregation, dining service facilities tend to be the core attractors for other CSFs. Therefore, it can be inferred that the greater the richness and quantity of dining service facilities, the higher the diversity of commercial formats in the area. Thus, to activate a new commercial cluster, priority may be given to introducing dining service facilities.

Thirdly, there is also a noticeable correlation between lifestyle service facilities and financial services, indicating a certain degree of spatial clustering interaction between them. The correlation between lifestyle service facilities and financial services may reflect changes in urban residents' quality of life and consumption habits, as people increasingly demand higher quality of life and leisure entertainment. Therefore, the clustering interaction between these service facilities may embody the diversification and personalization of urban lifestyles.

In summary, the similarity or complementarity of functions between different types of CSFs determines their mutual combination and layout in space. For example, functional complementarity leads to a strong synergistic effect between dining and leisure service facilities, while a stronger synergistic effect between dining and retail service facilities promotes their aggregation interaction in space. The central role of dining service facilities in commercial areas, the correlation between lifestyle service facilities and leisure & entertainment service facilities with financial service facilities, and the synergistic effect between dining service facilities and leisure & entertainment service facilities may have profound implications for the development of commercial areas. These speculative conclusions provide important references for further in-depth research into the development of commercial areas.

3.2.2 Correlation analysis between commercial service facilitiesand various influencing factors

Next, considering the external main factors influencing urban spatial agglomeration, such as pedestrian accessibility, land use, regional economic development level, and their influence on CSFs types and layout. The main driving force behind the agglomeration of CSFs in urban rail transit station areas is that the construction of stations improves the accessibility of station areas, attracting a large number of sustained and stable pedestrian flows, changing social, economic, and environmental conditions, thereby influencing pedestrian flows and commercial activities, which in turn affect the agglomeration of CSFs.

To study the main factors influencing commercial agglomeration around stations, the number of POIs is selected as the dependent variable. Meanwhile, combining with reference literature [25-27], these influencing factors are categorized into three main types: station social factors, economic factors, and built environment factors. In terms of station social factors, population size and residential scale are selected as consideration factors; in economic factors, business diversity and enterprise scale are selected; while in built environment factors, public transportation convenience, pedestrian accessibility, functional diversity, development intensity, and road network density are chosen. To conduct the analysis, relevant data around the selected stations are collected and normalized. The specific calculation standards are shown in the **Table 4** below:

Table 2 Measurement standards for various influencing factors

	Indicators	Calculation Method	Formula	Number
Social factors	Population density	Number of population inTAZ unit.	$S_1 = \frac{N_i}{S_i}$	(1)
	Residential scale	Residential andnon-residential balance (0-1).	$S_2 = 1 - \left\| \frac{\text{Re}\, s_i - Non\,\text{Re}\, s_i}{\text{Re}\, s_i + Non\,\text{Re}\, s_i} \right\|$	(2)
Economics factors	Commercial diversity	Shannon-Wiener index of commercial function.	$E_1 = -\sum_{i=1}^{n}(\rho_i \cdot \ln \rho_i)$	(3)
	Enterprise scale	Kernel density values for Companies.	$E_2 = \sum_{i=1}^{n} \frac{1}{r^2} k(\frac{x - x_i}{r})$	(4)
Built environment	Convenience of public transportation	Nearest distance of TAZ unitto adjacent publictransportation facilities.	$B_1 = D_0 - Min(D_{ip})$	(5)
	Walkability	Utility-based walking accessibility to a single POl	$B_2 = -\ln(\sum_{i \in C_m} \exp(-\overline{V_i})$	(6)
	Mixed land use diversity	Shannon-Wiener index of building function.	$B_3 = -\sum_{i=1}^{n}(\rho_i \cdot \ln \rho_i)$	(7)
	Construction intensity	Total building area inTAZ unit.	$B_4 = \frac{Q_i}{S_N}$	(8)
	Road network density	Total length of road centerline in TAZ unit.	$B_5 = \frac{L_i}{S_i}$	(9)

Table 3 Correlation analysis matrix of various influencing factors

	Overall agglomeration level	Retail	Catering	Leisure and entertainment	Lifestyle services	Financial services	Tourism and accommodation
Population density	0.674(0.001***)	0.561(0.010**)	0.784(0.000***)	0.66(0.002***)	0.676(0.001***)	0.495(0.026**)	0.632(0.003***)
Residential scale	-0.35(0.130)	-0.403(0.078*)	-0.549(0.012**)	-0.524(0.018**)	0.543(0.013**)	-0.713(0.000***)	-0.367(0.111)
Commercial diversity	0.84(0.000***)	0.847(0.000***)	0.83(0.000***)	0.869(0.000***)	0.949(0.000***)	0.868(0.000***)	0.871(0.000***)
Enterprise scale	0.445(0.049**)	0.65(0.002***)	0.487(0.030**)	0.409(0.073*)	0.499(0.025**)	0.572(0.008***)	0.528(0.017**)
Convenience of public transportation	0.633(0.003***)	0.816(0.000***)	0.639(0.002***)	0.707(0.000***)	0.746(0.000***)	0.8(0.000***)	0.686(0.001***)
Walkability	0.78(0.000***)	0.855(0.000***)	0.854(0.000***)	0.779(0.000***)	0.855(0.000***)	0.794(0.000***)	0.801(0.000***)
Mixed land use diversity	0.336(0.103)	0.309(0.185)	0.361(0.118)	0.314(0.177)	0.398(0.082*)	0.543(0.013**)	0.44(0.052*)
Construction intensity	0.531(0.016**)	0.512(0.021**)	0.538(0.014**)	0.507(0.022**)	0.538(0.014**)	0.542(0.014**)	0.666(0.001***)

	Overall agglomeration level	Retail	Catering	Leisure and entertainment	Lifestyle services	Financial services	Tourism and accommodation
Road network density	0.681(0.002***)	0.574(0.008***	0.724(0.000***)	0.808(0.000***)	0.712(0.000***)	0.658(0.002***)	0.73(0.000***)
Note:***、**、*represent significance levels of 1%, 5%, and 10% respectively							

According to the correlation coefficient (r values) results of the 9 indicator factors in **Table 5**, for the overall distribution of clustering along the line, the influencing factors are ranked in absolute correlation value as follows: Commercial Diversity > Walkability > Road Network Density > Population Distribution > Public Transit Accessibility > Development Intensity > Enterprise Scale > Residential Proportion > Functional Diversity. Commercial diversity and walkability are the primary factors influencing the overall clustering of commercial service facilities, with correlation coefficients greater than 0.75. Particularly in highly clustered areas with high development intensity, the correlation of walkability exceeds that of commercial diversity. This indicates that improved vertical transportation further promotes the clustering of commercial service facilities. Factors with correlation coefficients greater than 0.6 include Road Network Density, Population Distribution, and Public Transit Accessibility, while secondary factors include Enterprise Scale, Public Transit Accessibility, and Development Intensity. Functional Diversity also impacts the clustering of commercial service facilities but has a relatively weaker effect.

The density of population is positively correlated with the aggregation level of commercial service facilities. Higher population density implies a larger potential customer base, thus making it more likely for commercial service facilities to cluster in that area. In densely populated areas, commercial facilities are typically better able to meet people's needs, thereby promoting the development of commercial activities. Residential factors are negatively correlated with the clustering degree of commercial service facilities, indicating that these facilities tend to cluster in non-residential areas. However, this does not mean that commercial service facilities are completely independent of residential areas, as the clustering of commercial facilities is often influenced by the demand of surrounding residents. Enterprise scale is positively correlated with the clustering degree of commercial service facilities, possibly because larger enterprises have more resources and customer bases, making it easier for them to succeed in commercial clusters. Public transit accessibility is positively correlated with the clustering degree of commercial service facilities, likely because areas with convenient transportation can attract more customers, providing more potential customer bases for commercial service facilities. The correlation between Mixed Land-use Diversity and the clustering degree of commercial service facilities is relatively weak, suggesting that the spatial clustering relationship between Land mix-use of different functions is not significant, or that Mixed Land-use Diversity has a minor impact on the clustering degree of commercial service facilities. Development intensity is positively correlated with the clustering degree of commercial service facilities, possibly because areas with higher development intensity have better infrastructure and service support, which is more conducive to commercial activities. Road network density is positively correlated with the clustering degree of commercial service facilities. Areas with higher road network density are usually the central areas or transportation hubs of cities, which typically have higher population density and foot traffic, providing more potential customers for commercial service facilities. Additionally, areas with high road network density are often the centers of commercial activities and urban development, attracting more enterprises and investments, thereby increasing the clustering degree of commercial service facilities.

4. Conclusion

In recent decades, urban designers and policymakers have increasingly focused on the issue of spatial equity in cities. This study aims to explore how to achieve an organic integration of commercial vitality and transportation convenience in high-density urban environments, emphasizing the importance of diversity and inclusivity for urban development. By examining the Osaka Midosuji Line, the study combines web-scraped multi-source big data with field surveys to organize and categorize the data, creating a detailed dataset to analyze the overall characteristics of commercial service facilities (CSFs) along the line. Based on land use functions, the study summarizes the clustering characteristics of different types of station areas (residential, public service, commercial, and transportation hub) and provides preliminary analysis and discussion on the overall distribution, quantity distribution, and spatial clustering states of various commercial service facilities and their influencing factors.

The study first analyzes the spatial clustering characteristics of CSFs. The results show that the distribution of CSFs along the Midosuji Line exhibits uneven characteristics, with high-density clustering observed in major commercial centers such as Umeda, Shinsaibashi, and Namba, while clustering density varies in peripheral stations. This confirms the current multi-core structural pattern of point-axis development in Osaka, dominated by the Midosuji Line. CSFs in the station areas along the line decrease in density as they move outward from the station, with station areas and clustering centers being highly coupled. Additionally, life service CSFs show a "single-core + multiple-core" pattern, recreational and entertainment CSFs are mainly concentrated within a 300-meter radius of the station, and financial and tourism accommodation CSFs are more concentrated around commercial and transportation hub stations. There are significant differences in the spatial clustering characteristics of various types of stations: residential stations are primarily located on the urban fringe with fewer commercial facilities mainly meeting basic living needs; commercial and transportation hub stations are concentrated in central areas with diverse commercial facilities and high service levels, attracting large numbers of visitors; and public service stations are mainly located in suburban or densely populated residential areas with relatively few commercial facilities but well-developed basic service infrastructure.

The research results also preliminarily validate a significant spatial correlation among various types of commercial service facilities (CSFs) within the Midosuji Line's station areas, particularly a strong correlation among retail, dining, and recreational facilities, indicating a pronounced spatial clustering effect. Dining service facilities often play a central attracting role within these clusters, with their abundance and quantity significantly enhancing the commercial vitality of the area. Additionally, there is a noticeable clustering relationship between life service facilities and financial service facilities, reflecting urban residents' demand for high-quality living and diversified services. Analysis of the factors influencing the clustering of commercial facilities reveals that commercial diversity and walkability are the most significant factors (with correlation coefficients greater than 0.75), especially in highly clustered areas, where these factors markedly enhance the attractiveness and density of commercial facilities. Developing more user-friendly and efficient pedestrian and station-city connecting facilities can indirectly enhance the attractiveness of transit station areas, making them catalysts for urban economic development. Optimizing the business types around transit stations to diversify commercial services, and focusing on the balance of retail, dining, and recreational facilities can stimulate commercial vitality and promote the sustainable development of transit-related commercial areas in developing countries. Additionally, road network density, population distribution, and public transport convenience are important secondary factors that collectively drive the spatial clustering of commercial service facilities in transit station areas.

It is acknowledged that there are limitations in this study concerning the scope and data of commercial service facilities. The research only considered 20 stations, and a larger sample size is needed to clarify nonlinear and complex relationships and achieve statistical significance. However, since different target urban clusters may have varying levels of attractiveness and development pressures, it is necessary to use statistical methods to analyze these differences in the hypotheses. Moreover, differences between underground conditions and elevation conditions should also be considered. Future research could employ more detailed spatial grid analysis, optimize datasets, and focus on time dimensions and built environment factors. To fully understand the spatial equity of urban planning service facilities, it would be meaningful to consider various types of service facilities at rail transit stations in the Kansai region of Japan in future research, if more time and resources were available. This would provide valuable insights and support from an urban planning perspective to address the critical challenges of urban fragmentation and the diversity in urban design.

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