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Research on Allocation of Residential Space and Public Service Facilities Using Beijing as an Example

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Facing the increasingly strong demand for quality urban residential space, we studied the temporal needs for and satisfaction with residential space and public service facilities in communities and residential districts. In this study, data sources including geographical data from remote sensing satellite sensors, point of interest (POI), area of interest (AOI), and Baidu Maps from mobile phone sensors were used, and multi-source data process and analysis technologies were studied. A multi-level analytical method was established, which included the overall analysis of the allocation of community public service facilities, the evaluation of three categories of public service facilities in residential districts, and the analysis of population mobility and characterizations of residents. A functional mix index and a coordinated development index were adopted, and an indicator evaluation system based on methods of computing coverage and compliance was proposed. Taking the core area of Beijing as an example, we analyzed detailed allocation conditions of public service facilities, including their spatial and temporal insufficiencies. Our results show that residential districts in the core area of Beijing should consider safe sites and park layouts within the walking range of living areas, improve the quality of property services, and create a multi-functional living environment. In this study, we offer methods of studying the distribution of small-scale urban population structures and evaluating the quality of urban residential space; we thereby provide useful information for the planning and management of urban public service facilities.

1. Introduction

High-quality living environments can increase the happiness and comfort of residents.(1) The COVID-19 epidemic has sounded an alarm bell for humanity. More attention should be paid to the conditions that support residents' living facilities and the integrity of layout at the level of residential spaces. Since the reform and opening up of China 44 years ago, population flow to cities has accelerated on a large scale as a result of urbanization. Owing to the fierce competition between population and resource factors, the spatial distribution structure and evolution trend of population have changed. Currently, research on the scale of countries, provinces, urban

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agglomerations, cities, and communities is the main level at which the characteristics of the spatial distribution of populations are assessed. Studies have tended to focus on large-scale population distribution differences, mesoscale mobility characteristics and network structure, and small-scale work to find a balance between housing and public facilities. The era of big data makes it possible now to study the spatial structure of the population. The characteristics of high precision, fast updating, and large sample size can make up for the traditional shortcomings of time-consuming and labor-intensive studies with small sample size and low spatial property.

Yao detailed the concept of street space and summarized the existing quantitative methods of assessing the quality of street space.(2) Wu elaborated the methods of improving spatial quality from the perspective of planning, aiming at two spatial levels of residential area and community.(3) Liang introduced the concept of the circle of life and evaluated the layout of community-friendly public service facilities from the perspective of efficiency and fairness.(4) Sun *et al.*(5) put forward countermeasures for the selection of resilient city indicators from three aspects: organizational resilience, health resilience, and basic resilience. Regarding the spatial structure of an urban population and influential factors, Yao and Shao(6) pointed out that China's population distribution presented a pattern of "large dispersion and small concentration." Characteristics of urban locations, especially the developed high-speed rail networks, were the main factors in population changes, and public services were the main welfare factors for attracting more people. On the basis of data from the sixth census of Nanjing and factor ecological analysis, Zhao *et al.*(7) found that housing prices, family situations, universities, and high-tech industry clusters can affect many aspects associated with population changes, including the urban social space, the renewal of old urban areas, population movement, planning, and construction. Using GPS data, Shen and Chai(8) compared the distribution of time between working and rest days, and studied the characteristics of the activity space of residents in a sample community. They found that residents depend on urban space during working or rest days, and the degree of dependence was affected by the location of a residence, regional consumption level, and employment location. Supporting facilities for promoting the balance between work and home still needs to be strengthened. With a continuously increasing number of applications of mobile big data in planning, Niu *et al.*(9) pointed out the advantages of the application to estimate "resident population." They also clarified the logic and method of four-level sample expansion and expounded on the necessity of testing the total amount of data, taking Wuhan City as the sample area for verification. Using mobile phone signaling data, Wang *et al.*(10) identified the residential and working places within 253 sample residential areas and visualized the distributions of employment core density and probable commuting distance. They also summarized the typical distribution pattern and impact factors of employment space in residential areas.

Currently, quantitative and applicable research results on the daily flow of population in residential areas are lacking. In addition, residential areas with high daily population mobility are vulnerable to urban emergencies. Paying more attention to these residential areas will help improve the quality of residential life and overall resilience. At the same time, it also provides a new perspective for refining residential area management, which is of practical significance for the path of big data to promote community governance and service innovation.

In this study, we explored the distribution characteristics of public facilities in residential spaces in the core area of Beijing, taking communities and residential areas as research units. Data sources including geographical data from remote sensing satellite sensors, point of interest (POI), area of interest (AOI), and Baidu Maps from mobile phone sensors were used, and multi-source data process and analysis technologies were studied for the analysis of coverage, supply and demand, and population mobility for public service facilities. With data on passenger flow (dynamic number of people) from Baidu Maps, the characteristics and commuting rules of the peak population in the morning and evening in 296 residential districts were analyzed. Our analysis revealed the current characteristics of age, income, consumption level, profession, and types of cars in different residential districts, and strengthens our ability to accurately and scientifically manage the classification of populations in residential districts. Our work thereby provides a method of studying the distribution characteristics of small-scale urban populations.

2. Study Area and Materials

The core area of Beijing, composed of the Dongcheng and Xicheng Districts, is China's political and cultural center and reflects the image of the capital. *The Regulatory Detailed Planning of the Capital Functional Core Area (at the block level)* emphasizes strengthening the supplementation of educational resources for kindergartens and primary schools, balancing the layout of the medical and health system, promoting the deep integration of property management and grassroots social governance, optimizing the combined use of the ground bus network and transportation terminals, enriching green spaces, organizing grassroots commercial networks, resolving the shortcomings of sports facilities, and improving the abilities for disaster prevention, mitigation, and relief.[11]

The big data used in this study included POI, AOI, website data on house rentals, and Baidu Map data. POI covers transportation, catering, sports, medical, and other categories; AOI is commonly used for commercial residential/residential areas; websites for house rentals may show details about residential areas; as can be seen from Fig. 1, Baidu Map data include population portraits, which can be understood as the characteristics of populations and views of passenger flow processed and analyzed from user information based on massive map services. The data volume within the core areas of Beijing (Dongcheng and Xicheng Districts) was more than 1 million records per day in TEXT format. The passenger flow population updated hourly refers to the people located at a specific location. Population portrait attributes include coordinate pair (X, Y), date, timestamp (per hour), portrait tag (category), and tag prediction estimated percentage. For analysis and research on residential districts, five labels were selected to depict the population of residential areas, namely, age range, income capacity, professional classification, consumption level, and vehicle use status. Taking residential districts as the research unit, a portrait of the passenger flow population was calculated from 19:00 to 21:00 on working days from July 15 to 31, 2019.

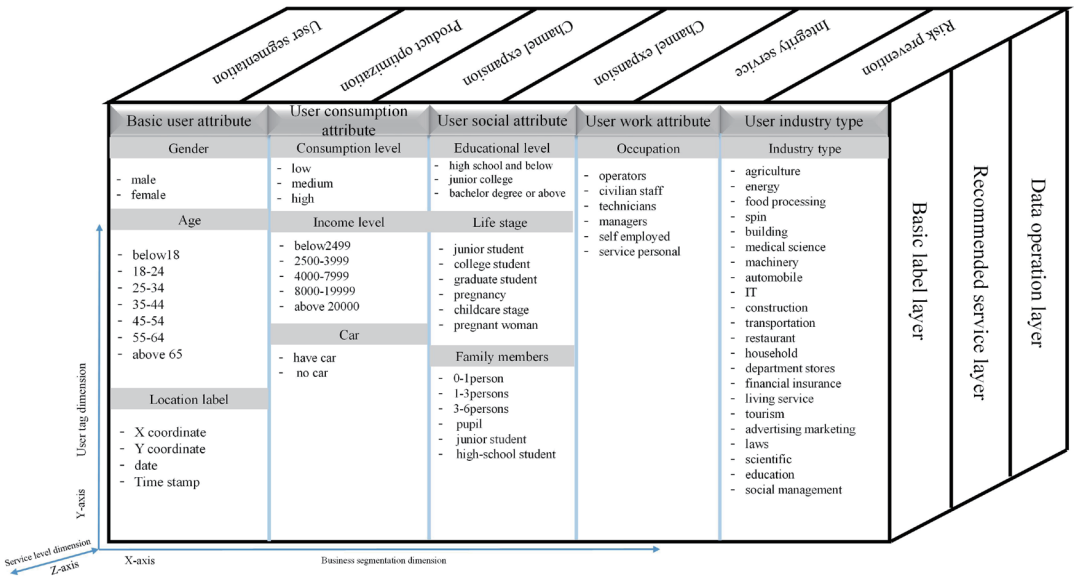

Fig. 1. Current population categories based on Baidu Map data.

3. Methods

3.1 Data preprocessing

All data used in this study were processed into a dataset by data cleaning, data spatialization, and registration. By taking community and residential districts as the research units, information was calculated from the dataset.

3.2 Overall analysis of allocation of community public service facilities

3.2.1 Functional mix index

To study the mixed functions of community public service facilities, a mixed index was established, and information entropy was introduced to quantify mixed degrees of function. Information entropy was used to measure the size of changes in uncertainty. If the mixed degrees of function of the community are simple, the uncertainty is low and the entropy is small. In contrast, if the mixed degrees of function of the community are complex, the uncertainty is high and the entropy is large.[12] The equation for this calculation is

$$M = -\sum_{i=1}^{n}\left(S_i * LnS_i\right), \tag{1}$$

where S_i indicates the proportion of service facility type i in the total POI of all facilities (i = 1, 2, 3, ..., 9).

3.2.2 Coordinated development index

To measure the degree of coordination between the distribution of public service facilities and the population in a community, a formula that involves the types, total amount, and population distribution of facilities was introduced. The definitions are as follows:

$$index_{i,j,k} = \frac{F_{i,j,k} \Big/ \sum_i F_{i,j,k}}{Population_i \Big/ \sum_i Population_i}, \tag{2}$$

$$index_i = \sum_{j=1}^{9} \sum_{k=1}^{n_j} index_{i,j,k}, \text{ and}$$

$$i = 1,2,3,\ldots,430; j = 1,2,3,\ldots,9; k = 1,2,\ldots,n_j \tag{3}$$

where $F_{i,j,k}$ represents the total number of public service facilities in categories j and k of community i. $Population_i$ represents the number of permanent residents in community i. $index_{i,j,k}$ represents the coordinated development index of public service facilities in categories j and k of community i. n_j is the number of subcategories included in category j. $index_{i,j,k} > 1$ means a well-coordinated development and $index_{i,j,k} < 1$ means a poorly coordinated development. $index_i$ represents the coordinated development index of community i and the sum of coordination indexes of various public services.[13]

3.3 Analysis of residential space and public service facilities allocation by residential district unit

3.3.1. Indicator system

The construction principles of the indicator system include the principles of objectives, comprehensiveness, scientificity, and operability. The quality of residential space must be demonstrated by evaluation indicators, and the reasonable selection of indicators is very important. The study of the quality of residential space is comprehensive and integrated, so the construction of a research evaluation system must include all aspects of the quality of residential space, including infrastructure, residents' lives, urban security, and ecological environment. The research system is a technical means for the quantitative analysis and evaluation of the quality of residential space. To ensure that the research system enables an objective and comprehensive evaluation of the quality of residential space, it is necessary to ensure that the selected research indicators and calculation methods conform to basic science. If the research system seeks to achieve applicability and practicability, operability is an essential key requirement. The selection, measurement, and calculation of research indicators must not be very complex, and the

various parameters in the formulas of the research system must not be difficult to obtain. The reliability and credibility of the selected values must be ensured.

For analyzing the quality of urban residential space, an indicator system was studied and established, including infrastructure, health assessment, and urban quality. Considering the comprehensiveness, scientificity, and operability, the following indicators were selected:

(1) Infrastructure:

- Transportation: bus station, entrance, and exit from the subway station;
- Convenient commerce: supermarkets, fruit and vegetable markets, convenience stores, and restaurants;
- Education: kindergartens and primary schools;
- Medicine: first-class hospitals, health service stations, and pharmacies;
- Logistics: delivery outlets;

(2) Health assessment:

- Safety: emergency shelters, fire stations, and police stations;

(3) Urban quality:

- Science and education: museums, art galleries, children's places, libraries, and exhibition halls;
- Sports: sports venues and comprehensive gymnasiums;
- Parkland: city squares (communities) and flower beds/artificial green land (residential areas).

3.3.2 Indicator evaluation method

3.3.2.1 Coverage

If the residential area has public service facilities $F_{j,k}$, it means that the residential area has $F_{j,k}$ coverage. The equation used is

$$C_{i,j,k} = \begin{cases} 1, & \exists F_{j,k} \subset N_1\left(Community_i\right) \\ 0, & \text{others} \end{cases}, \tag{4}$$

where $Community_i$ represents Community i; $C_{i,j,k}$ reveals whether $Community_i$ has facilities in the radius of the living circle $F_{j,k}$; "1" means that facilities exist, indicating that it has been covered; otherwise, the value is 0.[14]

On the basis of the life service circle theory, each residential area was taken as a base point, and ArcGIS was used to establish buffer zones with radii of 300, 500, 800, and 1000 m as the range of the living circle of the residential area. Details of the service radius of various facilities are given in Table 1.

Table 1
Service radius of public service facilities in residential districts.

Evaluation category	Facility category	Facility name (service radius) (unit: m)
Infrastructure	Traffic	bus stop (500); metro entrance and exit (800)
	Convenience	convenience store (500); catering (300); supermarket (300); vegetable market (500)
	Education	primary school (500); kindergarten (500)
	Medicine	grade iii-A hospital (1000); health service station (500); pharmacy (300)
	Logistics	Express (500)
Health assessment	Security	safe places of refuge (1000); police station (800); fire station (800)
Urban quality	Science education	museum (1000); art museum (1000); children's place (1000); library (1000); exhibition hall (1000)
	Sports	sports venues (500); comprehensive gymnasium (1000)
	Green land	park (800); city square (1000); residential green space (either artificial green space or flower beds in residential district)

3.3.3.2 Rate of reaching a standard

The standard-reaching rate comprehensively reflects the substitutability of public service facilities in real life.[13] In this paper, we define the connotation of "reaching the standard" of public service facilities from three perspectives:

(1) "Reaching the standard" can be divided into mandatory items and achievable items. Only when mandatory items exist simultaneously can they be referred to as reaching the standard, and achievable items can be regarded as additional supplements to mandatory items.
(2) Some facilities can replace each other. For example, supermarkets and vegetable markets have similar functions, and either of them can be used. Primary schools and kindergartens are educational configurations for different ages, which are not mutually replaceable and indispensable. Only when they exist simultaneously can they be called "reaching the standard."
(3) For health, science, and education facilities, each subcategory can be equipped with one facility to meet the standard.

"Reaching the standard" is specifically defined as (1) "traffic" reaching the standards: either a bus or subway station is acceptable; (2) "convenience" standards: supermarkets, convenience stores, and fruit and vegetable markets are available, and at least one catering store is available; (3) "education" standards: primary schools and kindergartens are indispensable, and both must exist simultaneously; (4) "medical" standards: a first-class hospital, health service station, and pharmacy are all available; (5) "logistics" standards: at least one delivery outlet exists; (6) "safety" compliance: there shall be at least one emergency shelter, fire protection, and public security area; (7) "science and education" standards: museums, arts, children's places, books, and exhibition centers exist; (8) "sports" standards: sports venues and comprehensive gymnasiums can meet the requirements of either category; (9) "park" standards: parks and city squares are two types of outdoor sites, and at least flower beds or artificial green spaces are needed in the community.

3.4 Characteristics of residential populations

The above analysis was conducted from the perspective of space configurations of residential areas and public service facilities, but the actual demand for public service facilities changes markedly with the specific type and activity characteristics of residents. The public service demands of floating populations in residential districts are the focus of the government. In previous studies, more attention was paid to the registered residence population and permanent residents, because it was difficult to obtain the data on the floating population. For Beijing, the research significance of the floating population is far more significant than that of the permanent population. Particularly after the outbreak of the COVID-19 epidemic, the characteristics and mobility of the floating population have affected policy formulations by government staff and the allocation of public service facilities.

A population portrait is equivalent to dividing people into detailed categories, a process that assists accurate population management. The population portrait can be used to analyze the trend of population age, gain insight into residents' interests and preferences, monitor trends in public opinion, and identify characteristics of a population to improve the depth and accuracy of management. For example, an aging community may need more elderly care facilities; the demand for actual parking spaces is not only related to the number of cars but also to the specific times of demand during the day; the management of residential districts with large floating populations needs to be improved; the allocation of parking time can be optimized to meet the needs of residents in a limited space. Therefore, in this study, we further analyze the characteristics of population mobility in residential areas and explore the satisfaction of residents with residential areas and public services.

3.4.1 Characteristics of population mobility

Average passenger flow means the dynamic population in the region, "passenger" being understood as "hourly people", which can be used to assist in analyzing the mobility of population.

Average passenger flow refers to the average population in a region at a given time within the specified time frame of the study, reflecting average dynamic population per hour.[15] The equation is

$$M_{P_{i,j}} = \frac{\sum^{n} p_{i,j}}{n}, \tag{5}$$

where $M_{P_{i,j}}$ represents the average population in residential area i at time j; $p_{i,j}$ represents the population in residential area i at time j; and n represents days on which the research was carried out: (j = 0, 1 ,2, 3, …, 23; n = 13).

People flow is a ratio and not a specific value, which refers to the average movement of people in and out of an area during a period. The equation is

$$Fl_i = \frac{Max_{M_{P_{i,j}}} - Min_{M_{P_{i,k}}}}{Max_{M_{P_{i,j}}}}, \tag{6}$$

where Fl_i represents the people average movement in residential area i; $Max_{M_{P_{i,j}}}$ represents the maximum population in residential area i at time j; $Min_{M_{P_{i,k}}}$ represents the minimum population in residential area i at time k (j = 20, 21, 22, 23; k = 8, 9, 10, 11).

3.4.2 Characteristics of population portrait

Five labels were selected to depict the population portrait of a residential area, namely, age range, income capacity, professional classification, consumption level, and vehicle use status. The portraits based on the size of the community enable the analysis of the social attributes of residents in detail.[16] The age range of the resident population enables the identification of communities with a large proportion of aging members; the elderly care facilities in such communities may then be supplemented and improved. The income level reflects the quality of life.[17] Professional classification can measure the complexity of the owner structure of residential areas. For residential areas with a large proportion of self-employed and service industries, population mobility is relatively large, and this mobility is usually the focus of epidemic prevention and control in residential areas. The number of cars in a residential area can be calculated, which is of scientific significance for the construction of parking spaces.

Seven age groups defined in the study were as follows: below 18, 18–24, 25–34, 35–44, 45–54, 55–64, and 65 years and above.[18] The income capacity was divided into five categories: less than 2500 yuan, 2500–3999 yuan, 4000–7999 yuan, 8000–19999 yuan, and more than 20000 yuan a month. Professions were divided into six categories: production operators, civil servants, professional technicians, managers and entrepreneurs, self-employed, and service personnel.[19] The level of money consumption was divided into low, medium, and high. The use of vehicles was indicated as one of the two types: with a vehicle and without a vehicle.

4. Results

4.1 Community results

4.1.1 Results of functional mix index

From each sub-item, as can be seen from Table 2, the functional mix index of community M_1 is the highest, both higher than the next highest average of 1.13 and with the highest maximum of 1.78. The average mix index of the community is 1.47, which is much higher than those of other types of communities, but only accounts for 10.93% of the total number of communities in the core area. It is characterized by the highly mixed and balanced distribution of various facilities. M_3 and M_4 communities with medium functional mix indices account for 48.13% of the total number of communities. The mix of parks and sports facilities in such communities is

Table 2
Grading list of the mixed index of community public service facility functions.

Type	Average functional mix index
M_1	1.47 (max = 1.78)
M_2	1.13 (max = 1.27)
M_3	0.91 (max = 1.01)
M_4	0.70 (max = 0.80)
M_5	0.43 (max = 0.57)
M_6	0.00

low, and residents' outdoor sports venues are limited. There are seven communities with a functional mix index of zero, which have no public service facilities in their areas.

4.1.2 Results of the coordinated development index

As can be seen from Fig. 2, an average coordinated development index of less than 0.5 accounts for 23.48% of the total number of communities, and the lowest coordinated development index in the San Li He Community is 0.06. The average coordinated development index is between 0.5 and 1, accounting for 35.82% of the total number of communities. The coordinated development index overall is at an intermediate level. The per capita coverage of such communities with regard to places of refuge and scientific, educational, and cultural facilities needs to be strengthened. The average coordinated development index greater than one accounts

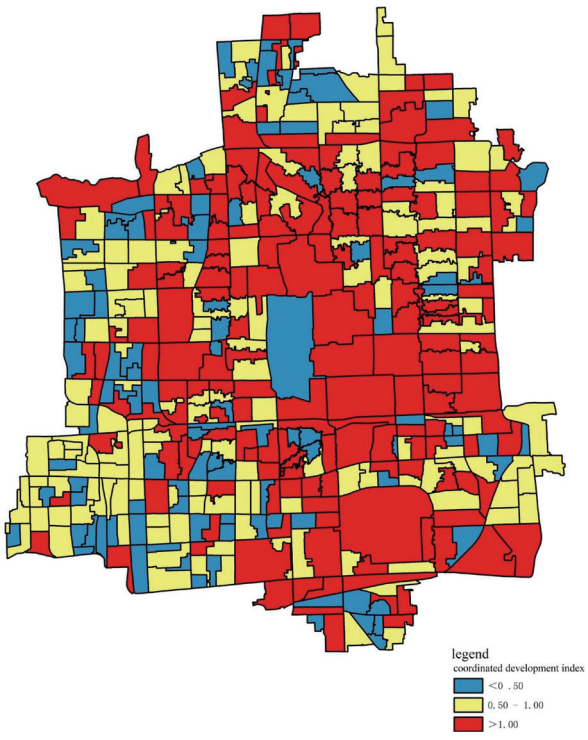

Fig. 2. (Color online) Spatial distribution map of coordinated development indices.

for 40.70% of the total number of communities, which indicates that these communities have advantages over other communities. From the perspective of spatial distribution, as can be seen from Fig. 3, the average coordination index of Dongcheng District has clear advantages compared with that of Xicheng District. The development of Xicheng District is relatively comprehensive. Compared with Dongcheng District, Xicheng District has disadvantages in terms of fire stations, parks, and kindergartens.

4.2 Residential district results

4.2.1 Results of coverage

From the perspective of Dongcheng and Xicheng, as can be seen from Fig. 4, 36% of the 25 indicators have very high residential area coverages, all exceeding 85%. In particular, the coverage of catering, convenience stores, bus routes, and police stations is 100%, indicating that the overall level of residents' living facilities is good. A total of 53% of residential areas have a coverage of 71–85%, and the coverage of public facilities is at an intermediate level. The sports venues, children's places, and flower beds in such areas need further improvement. Their coverage rate is 55–70%, accounting for 9% of residential areas. The coverage of safe shelters and fire stations in such areas also needs improvement,[20] as it is only 1% of the residential areas. The coverage of each sub-item of residential quarters needs to be further strengthened from the coverage rates of sports venues, emergency shelters, and urban squares. Particularly during the pandemic, the emergency shelters within the walking range of the residential areas are particularly important.

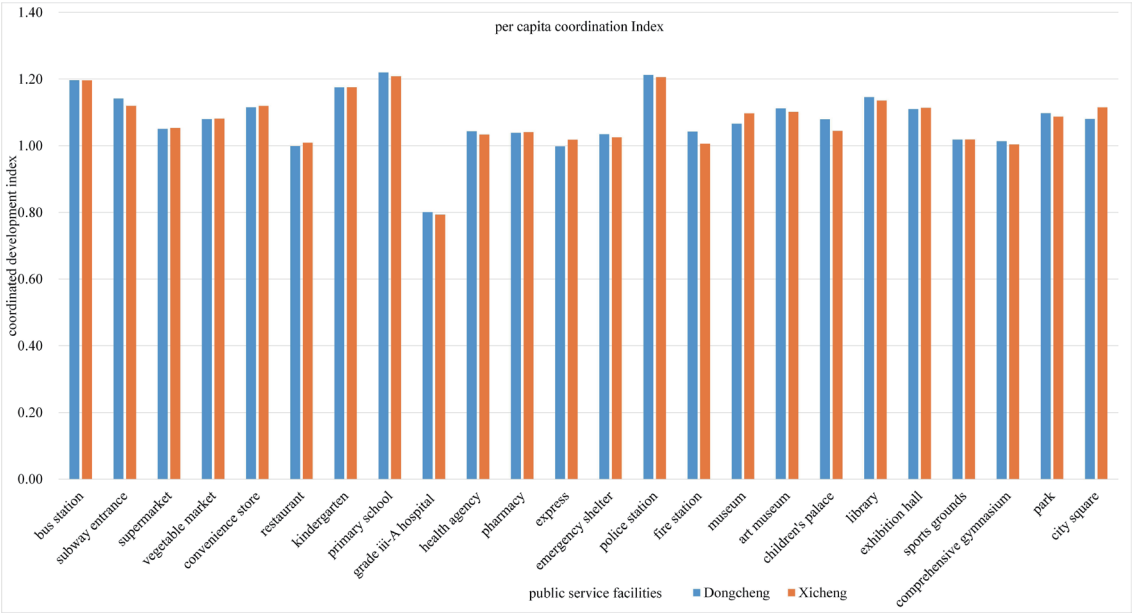

Fig. 3. (Color online) Per capita coordination index of various public facilities of Dongcheng and Xicheng Districts.

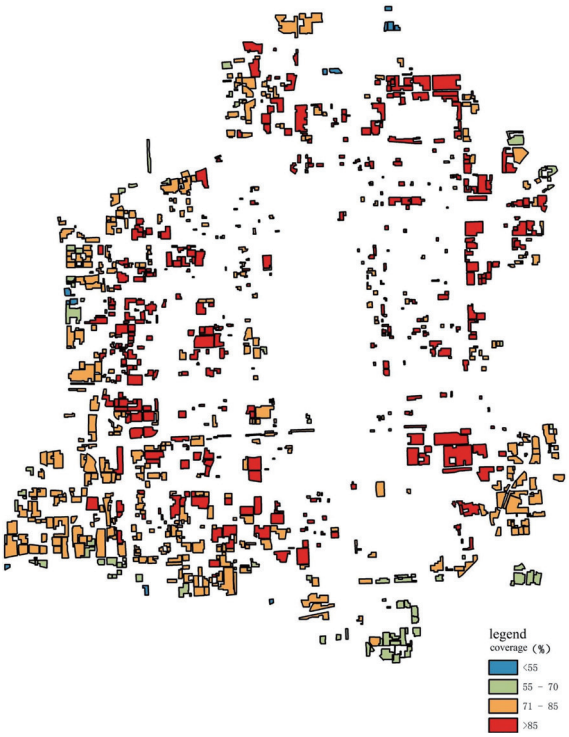

Fig. 4. (Color online) Spatial distribution map of coverage of residential areas.

4.2.2 Results of reaching a standard rate

Among the nine major public service facilities, the average rate of reaching the standard in residential areas is 91.51%, and 67.45% of residential areas are above the average level. In terms of sub-items, the complete percentages of transportation, convenience, education, medical care, and logistics are 99.38, 99.79, 78.06, 98.97, and 92.58%, and the complete percentages of safety, science and education, sports, and parks are 62.82, 99.59, 85.38, and 75.70%, respectively. Thus, security facilities and parks need to be strengthened. In addition, according to the information from websites such as Linkhome, the properties of residential communities in core areas are roughly divided into those with or without clear property companies. The proportion of property companies with specific information is 60.66%. It is not clear if the property companies can be divided into four categories, namely, the properties managed by units, the properties managed by housing management offices, street offices (the properties managed by committees), and the properties managed by owners, accounting for 13.18, 1.65, 8.44, and 16.07%, respectively.

4.3 Characteristics of populations

We analyzed the population of large residential areas (area > 1000 m^2) having the same population mobility characteristics. The spatial distribution map of residential districts is shown in Fig. 5. There are 296 residential districts, and they are distributed among 198 community neighborhood committees, which reflect the characteristics of residential population attributes

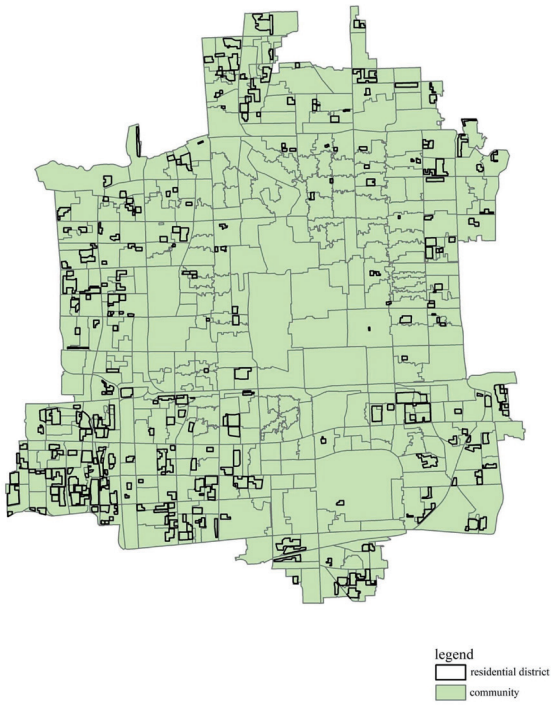

Fig. 5. (Color online) Spatial distribution map of residential districts.

in different districts. There is a relatively uniform distribution and sufficient number of the flowing population in these districts. The peak flowing population (20:00–23:00) has 40 more people than the low flowing population (8:00–11:00), and the shortfall population between peak and low time is greater than 20% of the peak population.

4.3.1 Results of hourly characteristics

The hourly population fluctuations in a residential area were calculated from the passenger flow data. All the recorded points in the period from 0:00 to 23:00 for each residential quarter on a given day were calculated and summarized, and the operations on the data over 13 days were repeated to obtain the hourly population of the residential quarter during the study period. The average passenger flow population at the corresponding time point is regarded as the hourly characteristics of the average passenger flow in the residential area. The maximum population at the time interval from 8:00 to 11:00 over the 13 days was regarded as the early peak population, and the maximum population at the average time interval from 20:00 to 23:00 over the 13 days was considered as the late peak population.[21]

As can be seen from Figs. 6–8, at 5:00 in the morning, residents gradually get up, which causes the increase in population, and the peak passenger flow population gradually appears from 6:00 to 8:00. On working days, the population gradually falls back and fluctuates steadily. After work, from 17:00 to 18:00, the population gradually increases, and a peak appears between 20:00 and 22:00. It can be seen from the change in hourly passenger flow population in the

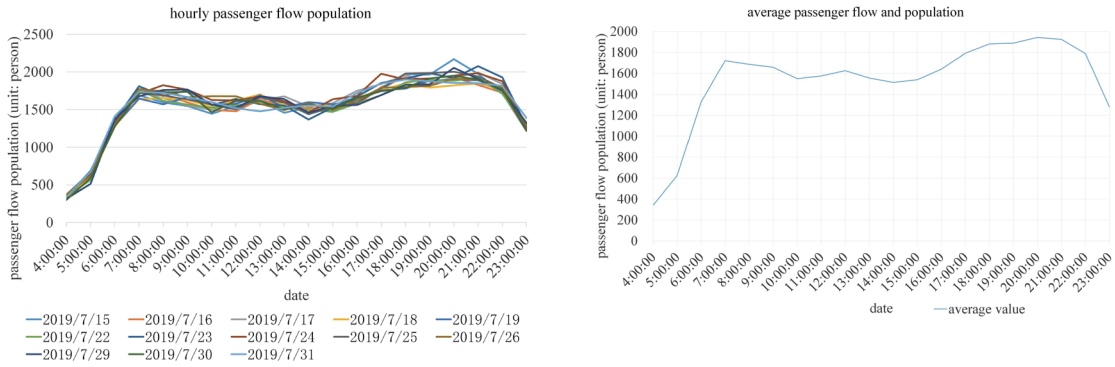

Fig. 6. (Color online) Hour by hour change in population flow in the residential district of Xin Feng Jie 1.

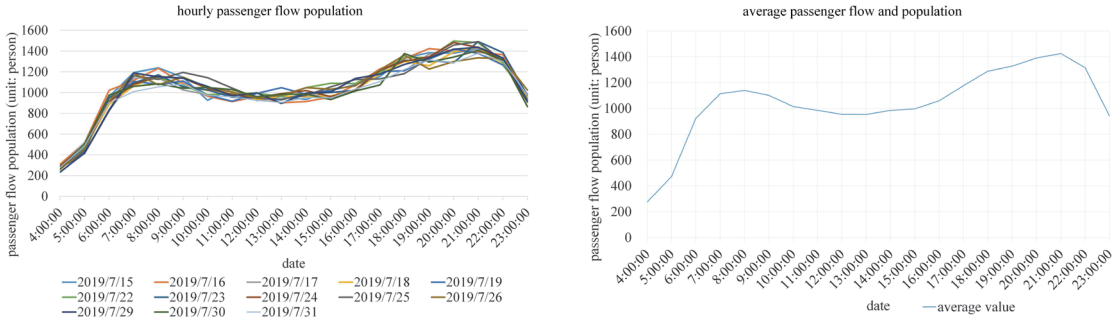

Fig. 7. (Color online) Hour by hour change in population flow in the residential district of Zhong Xin Jia Yuan.

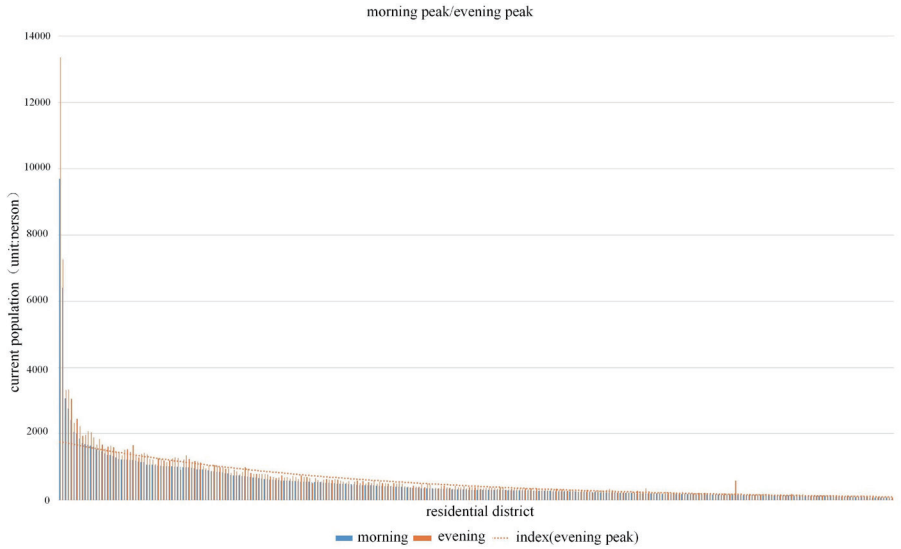

Fig. 8. (Color online) Population of morning and evening peaks.

residential areas that there are two passenger flow population peaks in a day, which is in line with the “double peak” feature of commuter travel on weekdays. In terms of population, the identified number of passengers in the late peak is more than that in the morning peak. The time

Table 3
Proportion of peak current population at time intervals.

	Time interval					
Morning peak	7:00	8:00	9:00	10:00	11:00	—
	54.70%	32.21%	2.68%	0.34%	10.07%	—
Evening peak	18:00	19:00	20:00	21:00	22:00	23:00
	7.38%	8.39%	12.75%	58.39%	12.75%	0.34%

points of the morning peak are relatively concentrated at 7:00 and 8:00. The passenger flow growth rate fluctuates considerably, while the late peak time points are relatively scattered, with small changes and fluctuations in growth rate, mainly appearing at 20:00, 21:00, and 22:00. More details are given in Table 3, the residential areas with morning peaks at 7:00 and 8:00 account for 54.70 and 32.21% of the population, whereas the residential areas with evening peaks at 20:00, 21:00, and 22:00 account for 12.75, 58.39, and 12.75%, respectively.

4.3.2. Average characteristics

The analysis of the changes in passenger flow and population in the residential area during corresponding periods depicts the population flow of residents in the residential area on working days. It can be seen from the daily hourly fluctuation of the passenger flow population that, after 8:00, the population gradually decreases because the residents go to work, and the size of the passenger flow population gradually reaches its lowest value in the morning. In other periods, the passenger flow population fluctuates slightly. After 20:00, with the residents returning home, the amount of passenger flow gradually reaches a peak. We calculated the low value of the morning passenger flow population (8:00–11:00) and the peak value of the evening passenger flow population (20:00–23:00) of the residential area during 13 working days to represent the mobility of the population.

In general, as can be seen from Fig. 9, the average mobility of the passenger flow population in all residential areas is about 30.89%. Specifically, residential areas with a passenger flow population mobility of less than 30% account for 49.66% of the total number of residential areas, residential areas with mobility between 30 and 40% account for 36.58% of the total number of residential areas, and residential areas with mobility greater than 40% account for 13.76% of the total number of residential areas. The mobility of passenger flow and population on weekdays reflects the regular travel frequency of residents; the dynamic tracking and supervision of residential areas with high mobility should be strengthened.

4.3.3. Portrait characteristics

The five portrait labels are age range, income capacity, professional classification, consumption level, and car use status. The current population portrait in the residential district of Xin Feng Jie 1 is shown in Fig. 10.

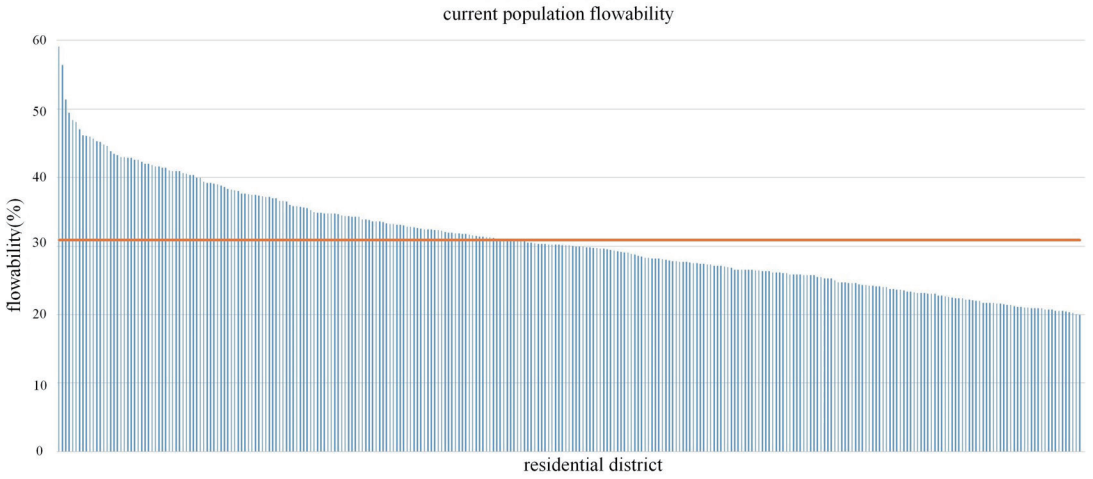

Fig. 9. (Color online) Liquidity ranking chart of populations in residential areas.

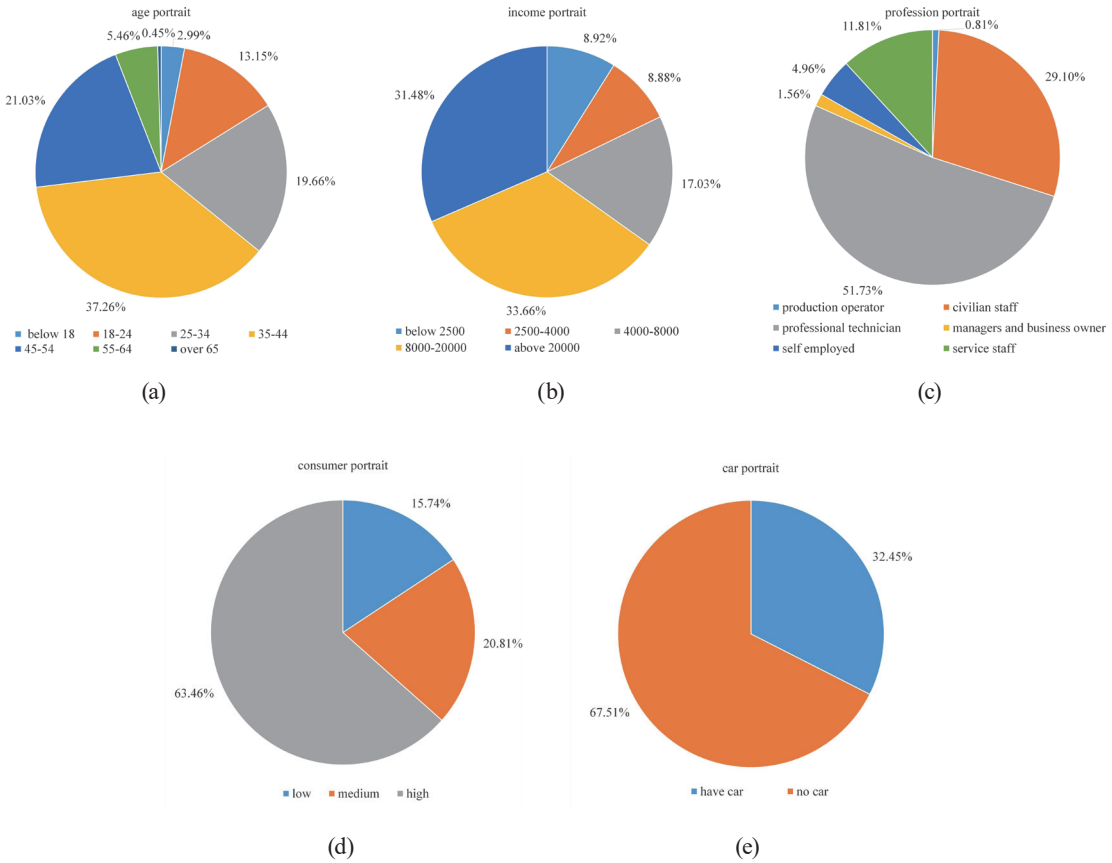

Fig. 10. (Color online) Current population portrait in the residential district of Xin Feng Jie 1. (a) Age range. (b) Income capacity. (c) Professional classification. (d) Consumption level. (e) Car use status.

4.3.3.1 Age portrait

As can be seen from Fig. 11, the ranges of 25–34 years, 35–44 years, and 45–54 years constitute the main age ranges of population concentration. These three age ranges are the main working groups. The sum of the estimated percentages of the group in the 25–54 year ranges and other age stages accounts for about 75 and 25% of the population of the communities, respectively. The total estimated percentage of 25–54 years old exceeds 60% in 97.30% of the residential areas.

The age above 55 is defined as the early aging period. In residential districts, the estimated percentage of the population having an average age between 55 and 64 and 65 or above is 5.48%. The estimated percentage of the average age below 18 is 3.21%, and the estimated percentage of the population with ages above 55 is higher than that below 18 in 247 residential districts. The top three residential communities with the highest percentages of the population over 55 years old are No. 21 Yard A of Bai Wan Zhuang Street, Dong Lang Xia Hutong Community; No. 7 Yard A of Yue; and Tan North Small Street, accounting for 14.96, 14.18, and 12.87% of the populations, respectively.

4.3.3.2 Income portrait

As can be seen from Fig. 12, the income profile of the passenger flow population is divided into five levels: less than 2500 yuan, 2500–3999 yuan, 4000–7999 yuan, 8000–19999 yuan, and

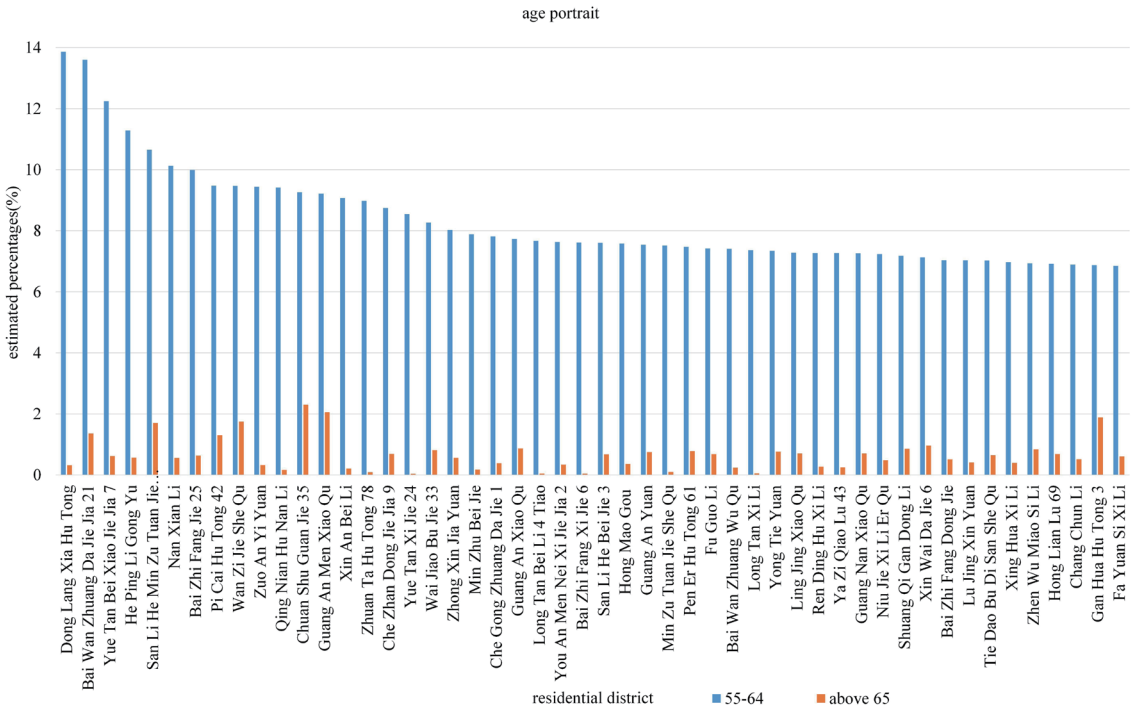

Fig. 11. (Color online) Ranking of residential districts by percent of population in the 55 to 64 age group.

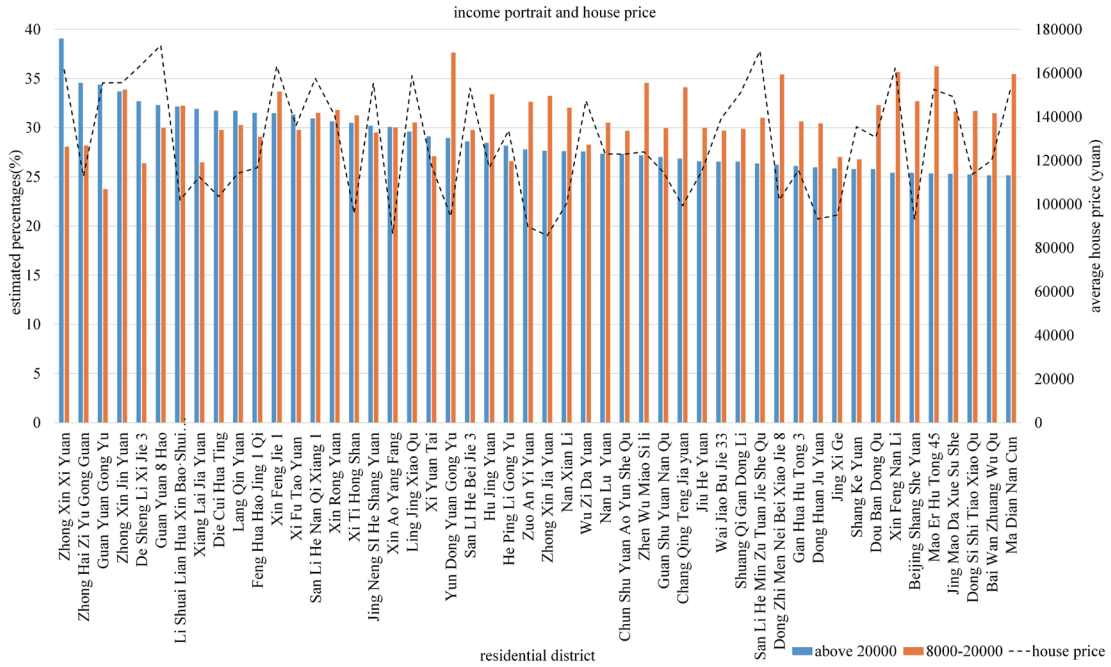

Fig. 12. (Color online) Ranking of residential districts in terms of house price and income level (top 50 with RMB 20000 and above).

20000 yuan and above per month. The average estimated percentages of the profile of the residential area for each income range are 15.51, 13.26, 20.96, 29.82, and 20.45%, respectively. On the whole, the estimated percentages of people's income levels are relatively balanced at a middle-income level, and the estimated percentage of people with an income level of 8000–19999 yuan is slightly higher. People with an income of less than 4000 yuan and more than 30% in residential areas are estimated to be 38% of the population, and people with an income between 4000 and 19999 yuan and more than 50% are estimated to be 57% of the population. People with an income of more than or equal to 20000 yuan are estimated to be more than 30% of the population, accounting for 6.08% of the residential area.

Web crawler technology using a LinkedIn mobile app was used to obtain information on house prices (August and September 2021) in the residential districts. A few missing pieces of house price data were supplemented by An Ju Ke, I Love My Home, and other website information. The comparison of the probable income levels with the average housing price shows that the overall trend of housing price is higher or close to the trend in the income of those at 20000 yuan and above, indicating that the purchasing ability of people with an income level of 20000 yuan and above is matched with the market price of housing.

4.3.3.3 Consumption portrait

The consumption level of the passenger flow population is divided into low, medium, and high, according to an average weekly consumption in the ranges of less than 110 yuan, 110–506

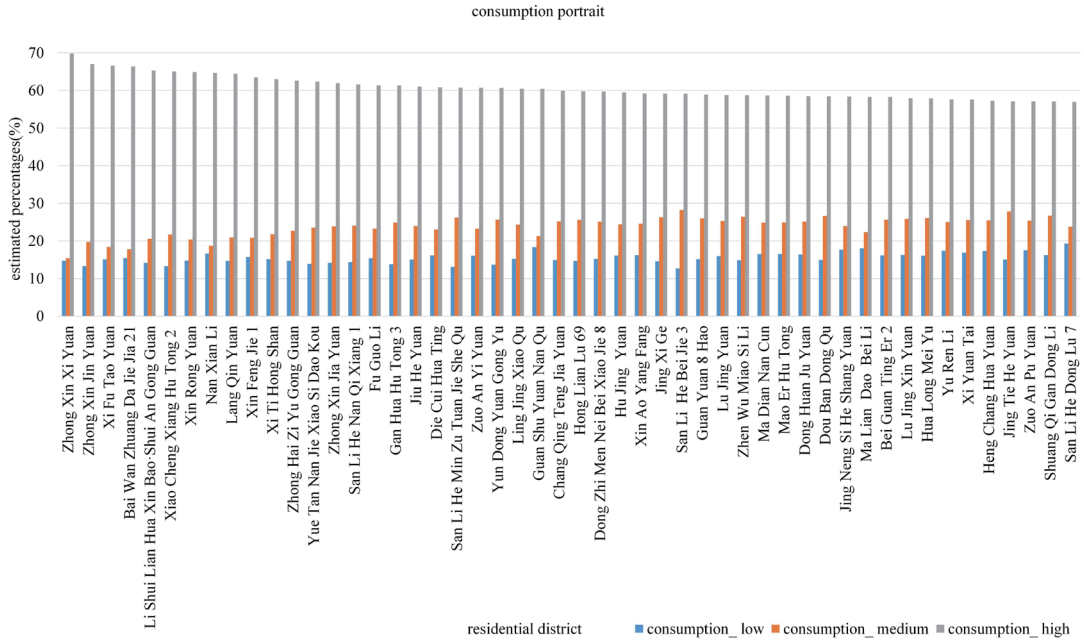

Fig. 13. (Color online) Consumption ranking of residential districts (top 50 areas in terms of high consumption level).

yuan, and more than 506 yuan. As can be seen from Fig. 13, the estimated percentages of the low, medium, and high average consumption levels are 19.30, 28.75, and 51.95%, respectively. The consumption portrait of the residential area reflects the differences between the low, medium, and high consumption groups, and the overall consumption level is biased towards the high consumption trend. The costs of living and survival expenditures account for a large proportion of consumption in Beijing.[22,23]

The estimated percentage of high consumption level, accounting for 66.21% of the residential districts, is greater than the sum of the estimated percentages of medium and low consumption levels. The top three residential districts with high consumption levels are the communities of Zhong Xin Xi Yuan, Zhong Xin Jin Yuan, and Xi Fu Tao Yuan, with estimated percentages of 69.79, 67.00, and 66.54%, respectively.

4.3.3.4 Professional portrait

Six professional portraits were defined: production operators, civil servants, professional technicians, managers and entrepreneurs, self-employed, and service personnel. As can be seen from Fig. 14, the average estimated percentages of the population in these categories are 1.60, 32.62, 46.48, 0.79, 5.64, and 12.87%, respectively. Civilians and professionals account for more than 70% of the population in 99.66% of the residential areas.

As for the professional structure of the populations in residential areas, more attention should be paid to service personnel and self-employed workers. The practitioners in these two professional areas are highly mobile and have a relatively large number of contacts daily.

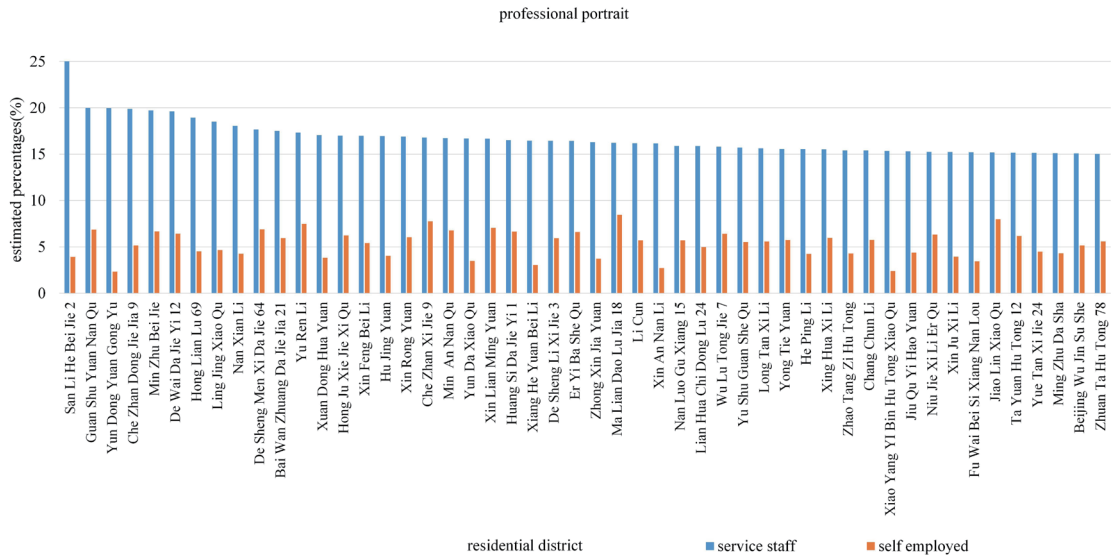

Fig. 14. (Color online) Ranking of the top 50 districts in employment in the service industry and self-employed.

Daily management usually does not focus on service personnel and self-employed workers, but these professionals will carry greater risks. From our analysis results, even though the service industry and the self-employed do not account for much of the profession in the residential area, they should be the focus of supervision. Understanding the professional portrait of the population in the residential areas has great significance for safety prevention, control, and issues of personnel management.

4.3.3.5 Car portrait

The problem of difficult parking is becoming increasingly prominent owing to the insufficient construction of parking spaces in the past and accelerated urbanization. The demand gap for parking was quantitatively analyzed using the car portrait of passenger flow and the movement of the population.[24] The average estimated percentages of having a car or not are 22.12 and 77.88%, respectively.

The average estimated percentages of having car can be divided into three levels: 10–20%, 20–30%, and >30%. As can be seen from Fig. 15, 31.76% of the residential districts have cars in the range of 10–20%, 64.19% of the residential districts have cars in the range of 20–30%, and 4.05% of the residential districts have cars in the range of >30%. To suggest effective methods to ease parking problems, it is necessary to determine the existing stock of parking spaces and the appropriate upper limit of possible capacity.

The research of Zhao *et al.*[13] involved a comparison between various districts and counties in Beijing with respect to the assessment of public service facilities, and they concluded that the core area was better than other districts on the whole. Our research has refined the scale of this research, compared the difference in the level of public service facilities between communities and residential districts in the core area, and expanded the analysis with respect to the commuter population. Our results should help improve the accuracy of the management of these issues.

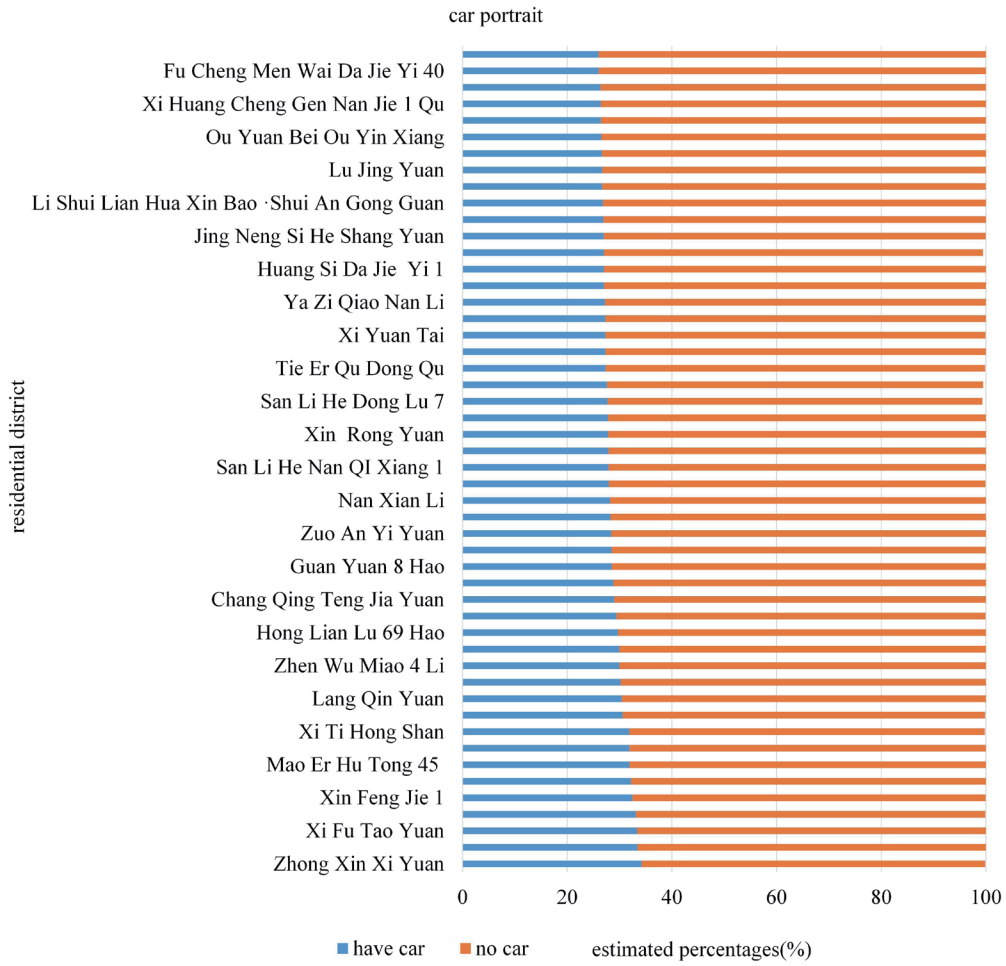

Fig. 15. (Color online) Portrait of car ownership in the top 50 residential districts.

5. Conclusions

Accurately estimating the demand for shared service facilities is the only way to insure their development scientifically.[25] We measured public service facilities across two dimensions of residential space: the community and the residential district, which represents further exploration of how to optimize the configuration of facilities. In this study, data sources including geographical data from remote sensing satellite sensors, POI, AOI, and Baidu Maps from mobile phone sensors were used, and multi-source data process and analysis technologies were studied. The use of multi-source big data diminishes the deviation between analysis using simulated data and real demands for public services. The overall level of facilities in the core area of Beijing is high. Communities should strengthen the construction of park sports and other supporting facilities to form diversified and independent living areas. The per capita supply capacity of safety facilities, such as shelters, should be improved to ensure a rapid response to various emergencies. Residential districts should comprehensively consider the layout of safe sites and parks within the walking distance of the residential circle, improve the quality of property

services, and create a multi-functional living environment. On the basis of passenger flow population and passenger flow portrait data from Baidu Maps, the spatial characteristics of population activities in the residential areas studied were enhanced using GIS spatial analysis and quantitative analysis methods. In addition, the hourly fluctuation, average mobility, and population attributes of individuals in residential areas during working days were explored, and the spatial structure and characteristics of the population were also analyzed. In this study, we provide methods of studying the characteristics of the structure within small-scale urban populations and evaluating the quality of urban residential spaces. The results provide useful information for the planning of urban public service facilities.

We evaluated communities and residential districts, but we did not carry out the comprehensive ranking of communities and residential districts because comprehensive and scientific scoring standards require long time periods for their demonstration. In future research, data from the communities will be further refined and analyzed, the satisfaction with and gaps in elderly care facilities will be probed, and electric bicycle charging piles, cultural activity centers, and community service centers will be analyzed by considering the requirements of a 15 min walking circle and the impact of the construction of digital communities.

Acknowledgments

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