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Method of Improving the Service Capacity of Public Facilities in Smart Communities

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The Beijing Urban Master Plan and the Communist Party of China's "Nineteenth National Congress" report both sought to "raise and improve people's living standards" and "build a high-quality and balanced public service system covering urban and rural areas, as well as to achieve full coverage of the quarter-hour community service circle". In this study, we propose a calculation method for increasing the service capacity of community public facilities, starting with the quarter-hour community service circle and taking into account factors such as population density, road network walking time, and facility scale. Public facilities have a 15-min service circle model and a capacity calculation model. The proposed method provided results that are both accurate and reasonable. In addition, this study also compares the difference between the actual population size and the service population size for public facilities within a community service circle within a 15-min walk. In addition, the reasons for the disparity were analyzed so that the deficiencies and shortcomings in community public services could be identified, allowing for an accurate assessment of the facility gaps in community public services and the establishment of a solid foundation for further adjusting and optimizing the function settings of the facilities of the community life service industry and the informed construction of a layout of the space of life service facilities to ensure comprehensive coverage.

1. Introduction

The "quarter-hour community service circle" means that starting from the community, the residents can enjoy convenient, fast, and comfortable community services within a 15-min walk. The following types of services are provided for community residents: first, convenient services provided by market mechanisms, such as vegetable markets, breakfast spots, supermarkets/convenience stores, beauty salons, end delivery services, laundry, housekeeping, and maintenance; second, the essential public services provided by the government, such as community service stations, community health service centers, and stations, nursing homes, and

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centers for education, recreation, and sports; third, the voluntary mutual aid services provided by social forces and individual residents, such as community party organizations, community neighborhood committees, and community volunteer service stations.[1] With the rapid development of the economy and society, residents have put forward new demands for community public services. To solve the outstanding contradictions and problems in supply, demand, and quality, it is necessary to promote further the development of facilitation, refinement, and quality of the life service industry.[2] The Beijing Urban Master Plan (2016–2035)[3] requires the current quarter-hour community service circle to achieve coverage of approximately 80% of urban communities by 2020 and complete coverage of urban and rural communities by 2035.

The service capacity of the spots of the community service facility in the community service circle is influenced by the distance that residents can walk in a quarter of an hour, the spatial distribution of the population, and the service scale of the facility spots. Current urban planning calls for the development of a balanced and comprehensive network of convenient services, as well as the gradual implementation of a quarter-hour community service circle in urban and rural areas. There are many methods of calculating the availability of community public service facilities within the 15-min service circle. Chen *et al.*[4] analyzed the coverage rate of public service facilities through kernel density estimation to guide the optimization of layouts. Using buffer analysis and road path network analysis to compare the difference between using geographic distance as the radius and using walking distance as the radius to calculate the service scope of public facilities, Liu and Deng[5] and Xing *et al.*[6] discovered that the traditional method of calculating service scope using geographic distance as the radius may result in planning blind areas and gaps in the actual service scope in the layout of medical facilities. Wang and Chang[7] used point of interest (POI) data and navigation road network data to evaluate the service level of a 15-min community life circle by aggregating community life circles based on the central place theory. The service level and differences in the demand for facilities within each unit were assessed, and recommendations for facility configuration were put forward to provide a reference for effectively configuring community public services. Chen *et al.*[8] and Shen and Tong,[9] based on the Internet map platform, used dynamic location data from the map to ensure the timeliness, reality, and accuracy of the road network and reduce the analysis time and labor costs so that the results were more reasonable and accurate. Zhang[10] studied the process of equality evaluation for communities, hospitals, and elderly service institutions and designed a decision scheme for the space optimization of facilities. Gao *et al.*[11] and Wu *et al.*[12] used an analytic hierarchy process to construct and calculate a convenience index for urban life. They quantitatively analyzed a degree of convenience for obtaining public services in the quarter-hour community, interpreting the overall distribution characteristics of the municipal area in a macro way and analyzing the local deficiencies in distinct communities in a micro way. Zhang *et al.*[13] used three indicators, namely, "richness", "compactness", and "accessibility", to construct a system to evaluate the evenness of the configuration of convenience facilities and to empirically study the evenness of the configuration of the current convenience facilities of the Million-Zhuang community. By evaluating "richness" and "compactness," the types of convenience facilities can be enriched, and the service radius can be

decreased; by evaluating the "accessibility," the accessible routes can be optimized. In response to the one-sidedness of the implementation and assessment of traditional planning, which only focused on the attributes of the "engineering blueprint" of the plan, Li and Ma[14] proposed to reconstruct the method and process of the implementation and assessment of the planning from a new perspective of public policy attributes. According to the objectives of public cultural facility planning regarding the efficiency of resource allocation of urban public spaces and the effectiveness of public-oriented services, a multi-dimensional assessment system and a feedback mechanism based on the assessment results were constructed, and the specific contents of each dimensional assessment were specified. Several related studies[15–21] have explored the planning and construction of essential public service circles, taking different cities in China as examples. These methods have some shortcomings: first, either the accuracy of the calculations needs to be improved or the spatial distribution density of the surrounding residents was not considered; second, the issue of the service capacity of community service facilities in the actual scale must be considered. These capacities need to be more robust to satisfy the need to accurately assess the gaps in the community public service facilities so that the service capacity of the community service circles can be ensured.

2. Study of the Technical Route

Owing to the shortcomings of the methods described, we explored a new method to improve the service capacity of public facilities for smart communities. This method breaks the administrative boundaries of street communities. It analyzes the reasons for the disparity using the actual service capacity of community service facilities as a starting point and compares the disparities between the population size within the 15-min service circle of community services and the population size of the actual service capacity to identify the deficiencies and shortcomings in the community service industry. In this way, reasonable planning suggestions can be put forward. Therefore, by analyzing and planning, a scientific layout of community service facilities in space with comprehensive coverage can be proposed, and the service capacity of the community service circles can be improved. Such an analysis can accurately assess the need for community service facilities with gaps and provide constructive suggestions for constructing community service circles to improve the service capacity of community service circles. Figure 1 shows the technical route of the method including the following steps.

Step 1: Calculate the range of the 15-min service circle of community service facilities: by calculating the distance matrix from the facility to all single buildings, then selecting the distance matrix to be reached by walking for 15 min, and planning appropriate walking paths, the range of the 15-min service circle of a facility can be obtained.

Step 2: Calculate the range of actual service capacity of the community service facilities: by sorting the coverage area of the facility from small to large according to walking distance and determining the resident population covered by the circle of maximum service capacity of the facility according to the relevant standards and norms and the requirements for actual service capacity, a range map of the maximum actual service capacity of the facilities can be drawn.

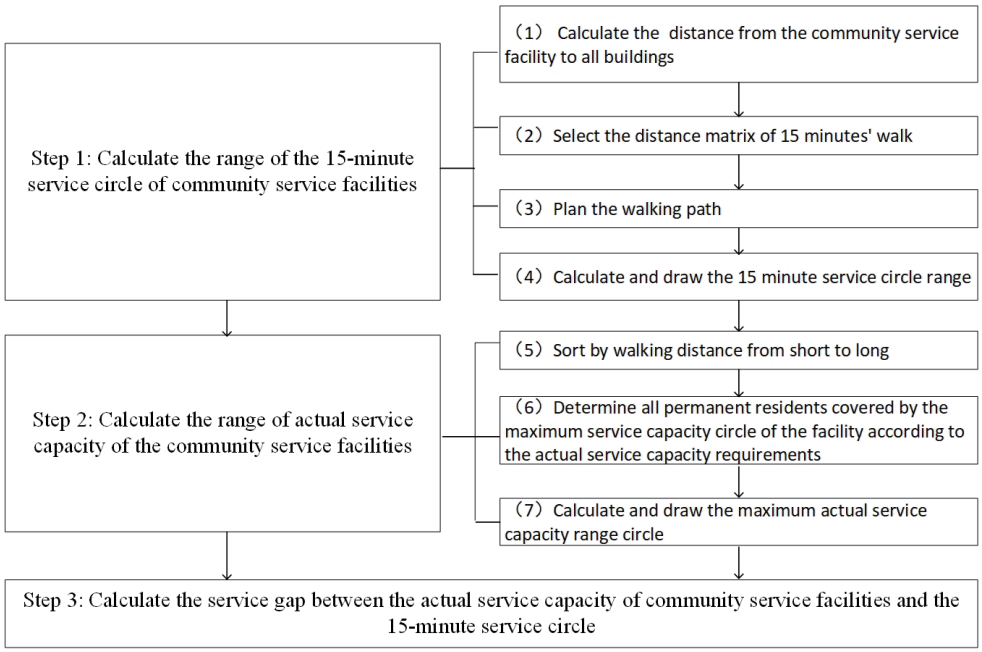

Fig. 1. Technical flow chart of method for public facility service capacity improvement for a smart community.

Step 3: Calculate the service gap between the actual service capacity of community service facilities and the 15-min service circle: by analyzing the reasons for the gap between the service and the circle, reasonable planning suggestions can be put forward.

2.1 Calculate the route for 15-min service circle (Step 1)

(1) Calculate the distance from the community service facility to all buildings in an area of 2000 m around that facility and create a distance matrix.
(2) Set the threshold value of distance, then screen out the buildings whose distance to this community service facility is less than the threshold value and generate a collection T of buildings.
(3) Use the navigation road network to calculate the walking time, and the walking path from this community service facility to the building point Ti is planned to obtain the walking distance and walking time to the building Ti: $Ti \in T$. The navigation road network considers influential factors such as the connectivity and grade of roads and the presence of viaducts and traffic lights at the intersections.
(4) Calculate the range of the 15-min service circle of this community service facility based on the value of walking time, and draw a map of the navigation road network of the 15-min isochronous circle.

Repeat steps (1) to (4) to calculate the ranges of the 15-min service circle of all community service facilities and the sum of all ranges.

2.2 Calculate the route of actual service capacity (Step 2)

(5) Sort each building in the building set T from short to long according to the walking distance from the community service facility to the buildings.
(6) On the basis of the attributes of the size of the spatial distribution of the resident population at each building and the actual service capacity requirements of each building, the resident population that resides in all single buildings that comprise the maximum service capacity circle is determined for each building.
(7) Calculate the range of the maximum actual service capacity of each building and draw a circle for its maximum actual service capacity on the map of the navigation road network.

- Repeat steps (5) to (7) to calculate the maximum actual service capacity of all community service facilities and add up the ranges of actual service capacities of all community service facilities. The actual service capacity of the buildings should include the configuration standards for vegetable markets, breakfast spots, small commercial services, recycling stations, and other commercial service facilities such as community health service centers, community health service stations, community cultural facilities, outdoor sports fields, indoor sports facilities, kindergartens, nursing homes, and community management service facilities.

2.3 Calculate the route of service gap (Step 3)

As shown in Fig. 2, the specific process is to superimpose the spatial distribution maps of the actual service capacity of community service points and that of a 15-min service circle, then

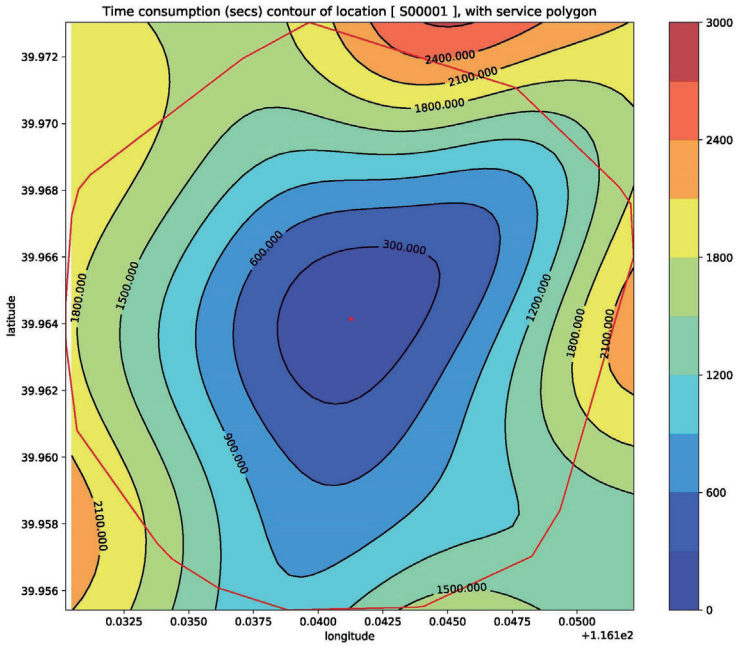

Fig. 2. (Color online) Program automation computing service circle and actual service capability.

calculate the gap in the range of services of community service points and draw that range on the map of the navigation road network.

The beneficial effects of this technical solution may be as follows: the method of improving the service capacity of community public facilities breaks the administrative division boundaries of street communities and analyzes the reasons for the gaps by taking the actual service capacity of community service facilities as the basis and comparing the gaps between the population size within the 15-min service circle of community services and the population size of actual service capacity so that the shortcomings and debts in the community service industry can be identified and reasonable planning suggestions put forward. Therefore, by analyzing and planning, a scientific layout of the community service facilities in space with comprehensive coverage can be created, and the service capacity of community public facilities can be improved.

3. Case Study

To illustrate the technical features clearly, the details were elaborated using a specific case. Figure 3 shows a flowchart for the improved method of assessing the service capacity of public facilities for smart communities. The method includes the following steps.

In step (4), the process of drawing the range of the 15-min service circle includes the following steps:

Rasterization of walking time: divide the rectangular box enclosing the building set T into 50*50 rectangular grids, followed by interpolating the walking time values from the community

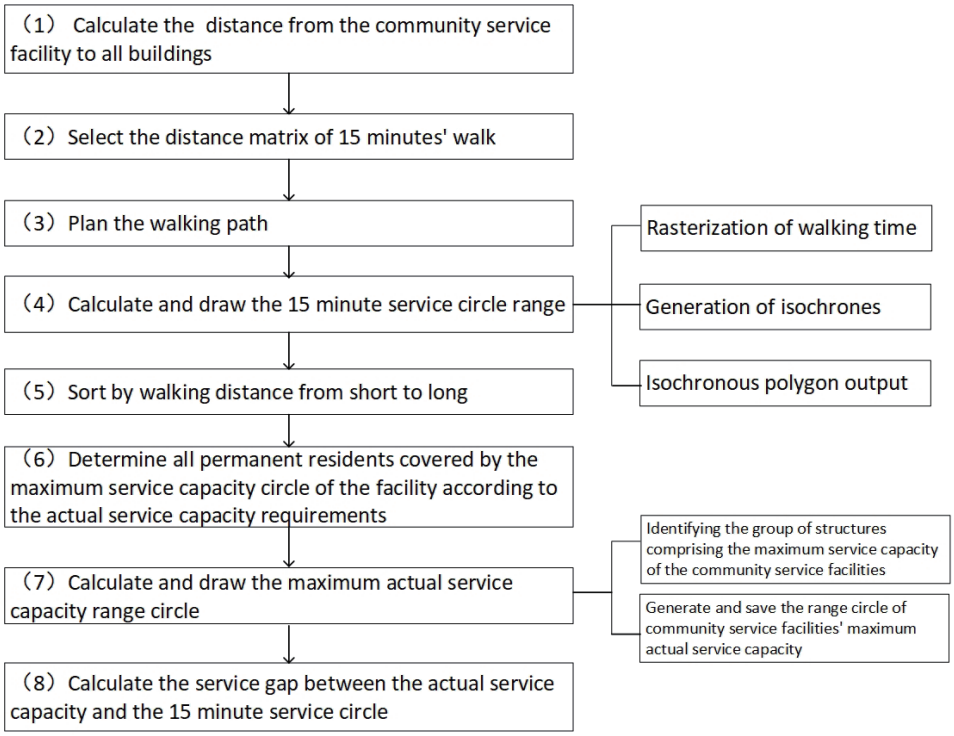

Fig. 3. (Color online) Schematic diagram of the range of a 15-min service circle.

service facilities to all buildings Ti in the building set T onto the grid points using the ordinary kriging interpolation algorithm (a Gaussian function is used for the variation function).
Generation of isochrones: specify the time indicator values for walking in isochronous circles as 5, 10, and 15 min. Find the points where each indicator value is located by interpolation according to the walking time values on the grids. Connect the points with equal walking time values with a smooth curve.

The output is a polygonal surface enclosed by isochronous circles and isochronous circles of adjacent indicator values: save the polygonal surface enclosed by isochronous circles with a walking time of 15 min and isochronous circles with walking times of 5, 10, and 15 min as GeoJSON files or Shapefile.

In step (7), drawing the range circle of maximum actual service capacity includes the following steps:

Identifying the group of structures comprising the maximum service capacity of the community service facilities: assuming that the maximum actual population served by the community service facilities is PA, add the resident population of each point in the building set T until the sum of the populations exceeds PA; the set formed by the added buildings is the building set Tsub, which is included in the maximum service capacity of the community service facilities.

Generate and save the range circle of the maximum actual capacity of the community service facilities and perform a convex hull operation on the building set Tsub. The circumscribed polygon obtained thereby is the range circle of the maximum actual service capacity of community service facilities. Save it as a GeoJSON files or Shapefile.

The following is a diagnosis of the service capacity of a 15-min community service circle of public facilities based on the requirements of the Beijing Urban Master Plan (2016–2035).[3]

3.1 Calculate the range of 15-min service circle

(1) Calculate the distance from the community service facility, Xinfa Di Vegetable Basket Convenience Direct-sale Store, to all buildings in the studied area and form a distance matrix.
(2) Assume the walking speed of a human is 1.111 m/s (approximately 1000 m walking distance in 15 min), and set the threshold value of distance as 1000 m. Screen the buildings at a distance less than the threshold value to the Xinfa Di Vegetable Basket Store to generate a new building set T.
(3) Use the navigation road network to calculate walking time and plan a walking route from the Xinfa Di Vegetable Basket Store to each residential building Ti, so that the walking distance and walking time of points Ti are obtained. The navigation road network takes into account influencing factors such as the connectivity and grade of roads, the presence of viaducts, and traffic lights at intersections.
(4) According to the walking times, calculate and draw the range of the 15-min service circle of the Xinfa Di Vegetable Basket Store. The rectangular box enclosing the set T can be divided into a 50*50 raster rectangular grid by rasterizing walking times. Subsequently, interpolate the values of walking time for all buildings Ti from the Xinfa Di Vegetable Basket Store to

the building set T onto the grid points using the ordinary kriging interpolation algorithm (a Gaussian function is used for the variation function). Specify the time indicator values for walking in isochronous circles (e.g., [5,10,15] min), identify the points where each indicator value is located based on the walking times on the grid points using interpolation, and then connect the points with equal walking times into a circular curve to generate the isochrones. Save the polygonal surface enclosed by the isochronous circles with a walking time of 15 min and the isochronous circles with walking times of 5, 10, and 15 min to form a 15-min isochronous circle, as shown in Fig. 4. Repeat steps (1) to (4) for each community service facility and add up the ranges of 15-min service circles for all facilities.

3.2 Calculate the range of actual service capacity

(5) Sort each point in the building set T by walking distance from small to large.

(6) Each point in the building set T has the attributes of its size and the resident population's spatial distribution. According to the actual service capacity of Xinfa Di Vegetable Basket Store, the resident population living in all single buildings that constitute the maximum service capacity circle of Xinfa Di Vegetable Basket Store is determined. The requirements for the actual service capacity of community service facilities are shown in Table 1.

(7) Calculate and draw the range circle of the maximum actual service capacity of Xinfa Di Vegetable Basket Store. As shown in Fig. 5, the resident population in the spatial ranges overlapped by two or more facilities of the same service type should be calculated only once. First, determine the set of buildings included in the maximum service capacity of Xinfa Di

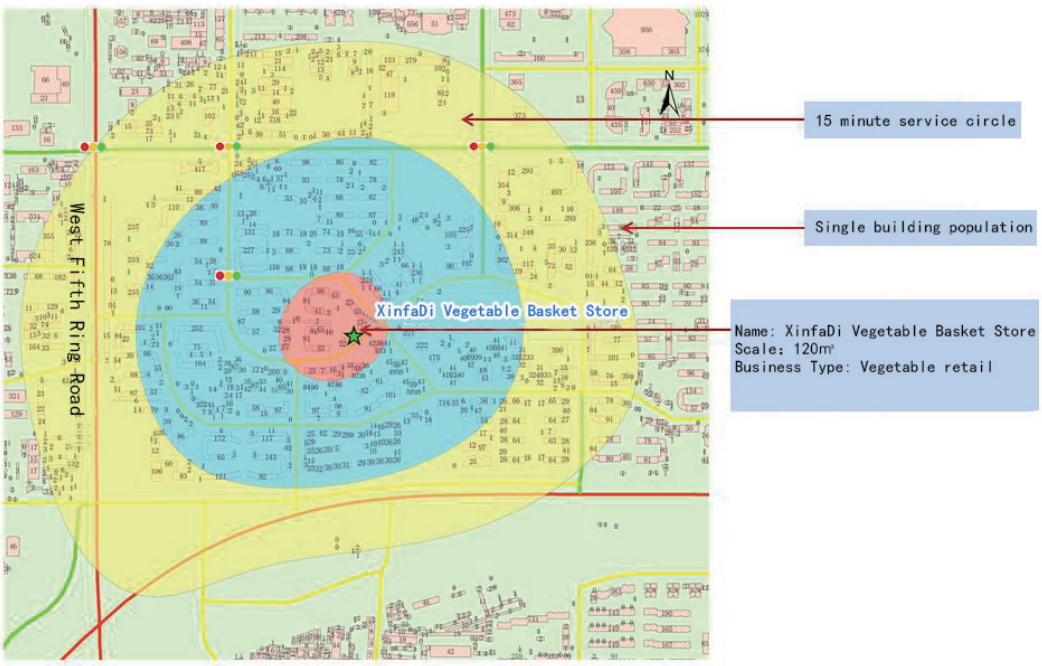

Fig. 4. (Color online) Schematic diagram of the range of a 15-min service circle.

Table 1
Configuration requirements for actual service capacity of community service facilities.

No.	Type of community service facility	Configuration standard	Policy basis
1	Vegetable market	Construction area of 50 m^2/1000 people to be served	Supporting indicators of Refs. 22 and 23
2	Breakfast spots	At least one service outlet for 3000 people to be served	Guidance on the Implementation of Beijing's Neighbourhood Commercial Ecological Allocation Index [Beijing Business Regulations (2018) No. 31][23]
3	Small commercial service (supermarket, convenience store)	Construction area of 10–20 m^2/1000 people to be served	Ref. 23
4	Recycling station	Construction area of 5 m^2/1000 people to be served	Supporting indicators of Ref. 22
5	Other commercial service facilities	Other commercial service facilities for supporting residence: hypermarket, convenience store, breakfast (catering), beauty salon, domestic service point, laundry, convenient maintenance, pharmacy, end delivery point - construction area of 535–625 m^2/ 1000 people to be served	Ref. 23
6	Community health service center	Construction area of 60 m^2/1000 people to be served	Supporting indicators of Ref. 22
7	Community health service station	Construction area of 24 m^2/1000 people to be served	Supporting indicators of Ref. 22
8	Community cultural facility	Construction area of 100 m^2/1000 people to be served	Supporting indicators of Ref. 22
9	Outdoor sports field	Construction area of 250–300 m^2/1000 people to be served	Supporting indicators of Ref. 22
10	Indoor sports facility	Construction area of 100 m^2/1000 people to be served	Supporting indicators of Ref. 22
11	Kindergarten	Construction area of 100 m^2/1000 people to be served	Supporting indicators of Ref. 22
12	Community management service facility	Construction area of 50 m^2/1000 people to be served	Supporting indicators of Ref. 22

Vegetable Basket Store. Assume that the maximum actual population served by the facility is PA, then add up the resident population of each point (ordered by walking distance from smallest to largest) in the building set T, and stop adding up when the cumulative value of the population exceeds PA. The set Tsub, formed by the buildings accumulated, is the building set included in the maximum service capacity of Xinfa Di Vegetable Basket Store. The range circle of the maximum actual service capacity of the facility is generated and saved, as shown in Fig. 6. A convex hull operation is performed on the building set Tsub, and the circumscribed polygon obtained is the range circle of the maximum actual service capacity of the Xinfa Di Vegetable Basket Store. Repeat steps (5) to (7) for each community service facility and add up the actual range of service capacities of all facilities.

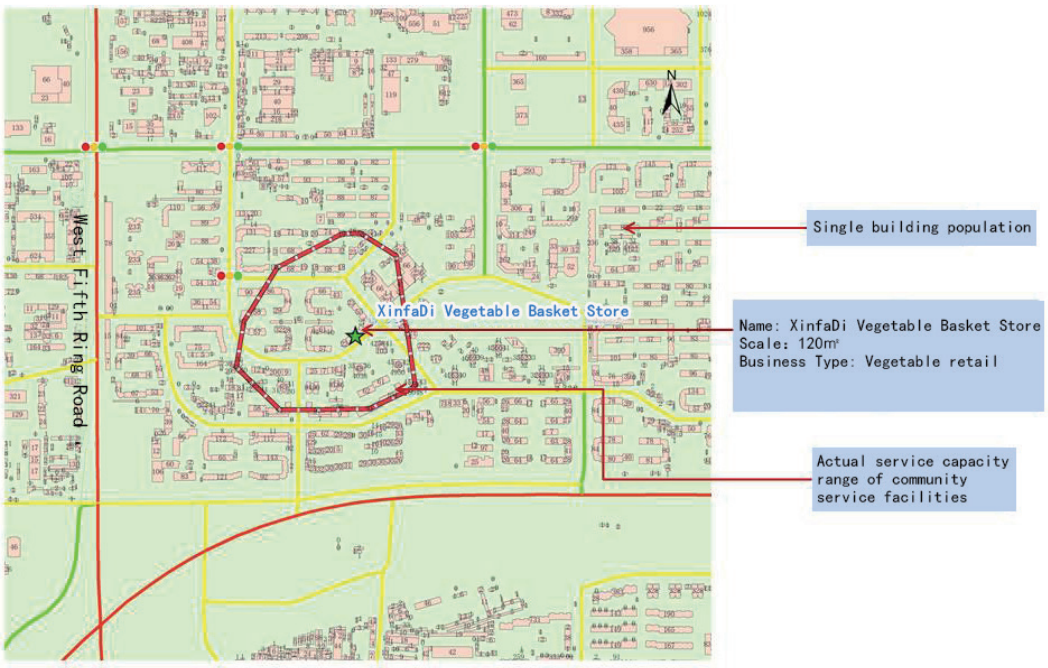

Fig. 5. (Color online) Schematic diagram of actual service capacity range of community service facilities in Fig. 4.

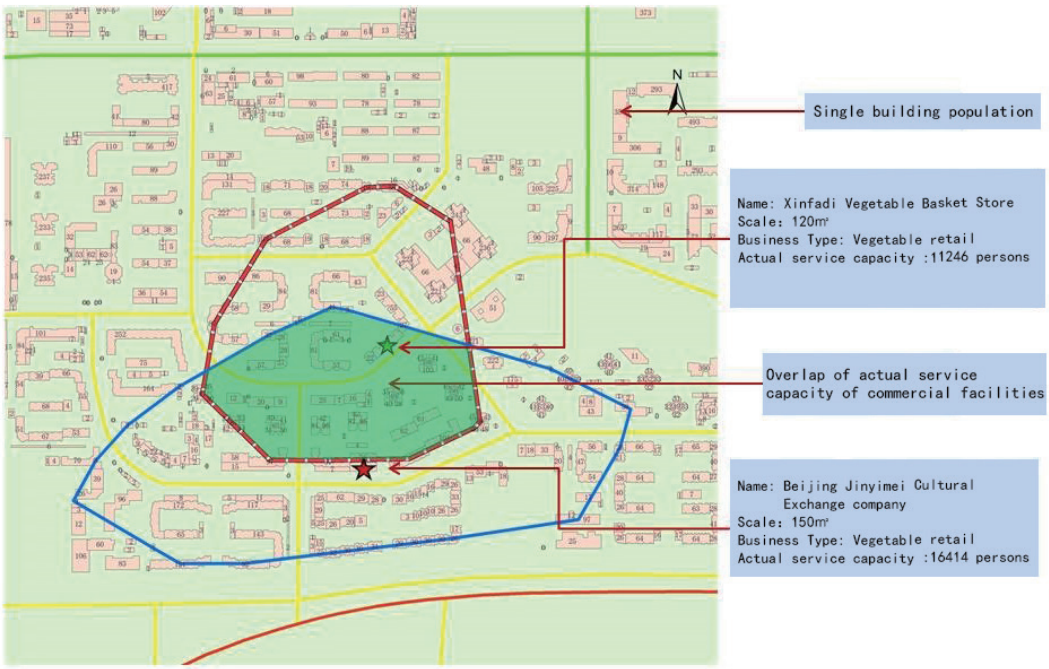

Fig. 6. (Color online) Diagram of overlapping scope of actual service capacity of two or more facilities of the same type. Permanent population is calculated only once.

3.3 Calculate the service gap between the actual service capacity and the 15-min service circle

(8) Overlay the spatial distribution map of the actual service capacity of point A and the 15-min service circle, as shown in Fig. 7. Analyze the service gap between them, and calculate and draw the range of the service gap for point A.

This case provides a 15-min community service circle range model, an actual service capacity range model, and a service gap model between the actual service capacity and the 15-min service circle. These models can accurately assess the need for the gaps in community service facilities and provide practical suggestions for constructing a community service circle to improve the service capacity of the community service circle.

Taking Figs. 8 and 9 as examples and combining the 15-min service circle and the actual service capacity along with the spatial distribution of the resident population in the street, we found that the spatial distribution of the breakfast spots in the street was uneven. Therefore, the service capacity is insufficient, and the residents' needs cannot be met. Adding two breakfast spots in communities not covered by the service capacity (the community on the West Street of Stadium and first community on Jingyang East Street) is necessary.

Taking Figs. 10 and 11 as examples and combining the 15-min service circle and the actual service capacity along with the spatial distribution of the resident population in the street, we found that the spatial distribution of the spots of supermarkets/convenience stores in the street is balanced, but their service capacity was slightly insufficient. However, the number of

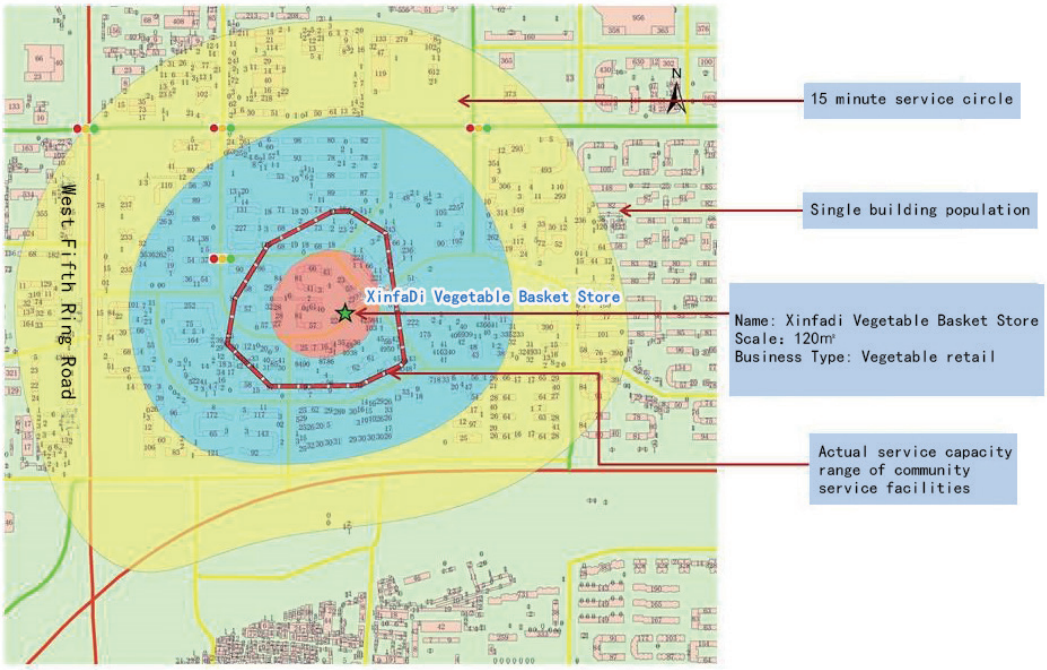

Fig. 7. (Color online) Schematic diagram of service gap between the actual service capacity of community service facilities in Fig. 5 and the 15-min service circle in Fig. 4.

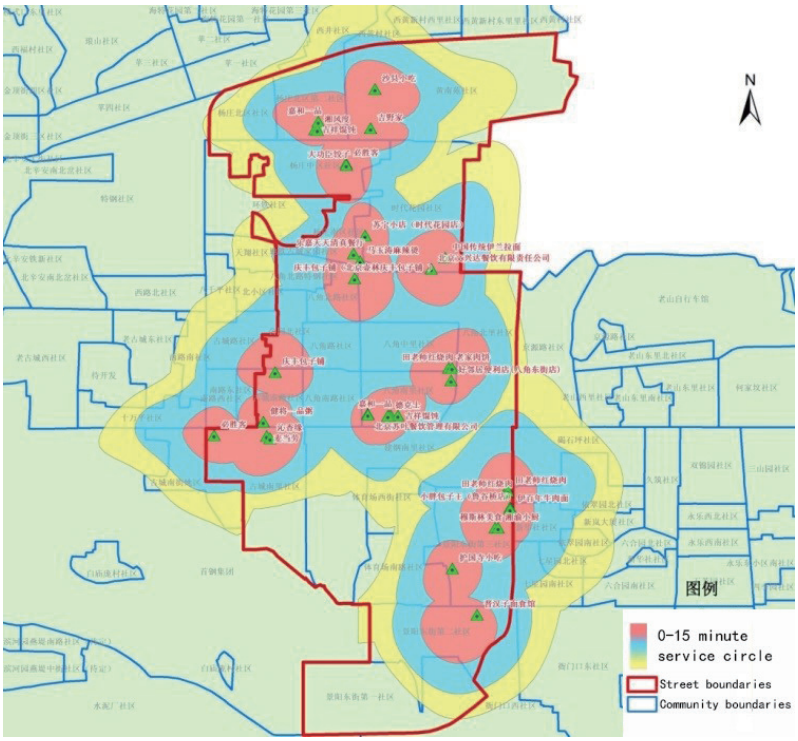

Fig. 8. (Color online) 15-min service circle of breakfast spots.

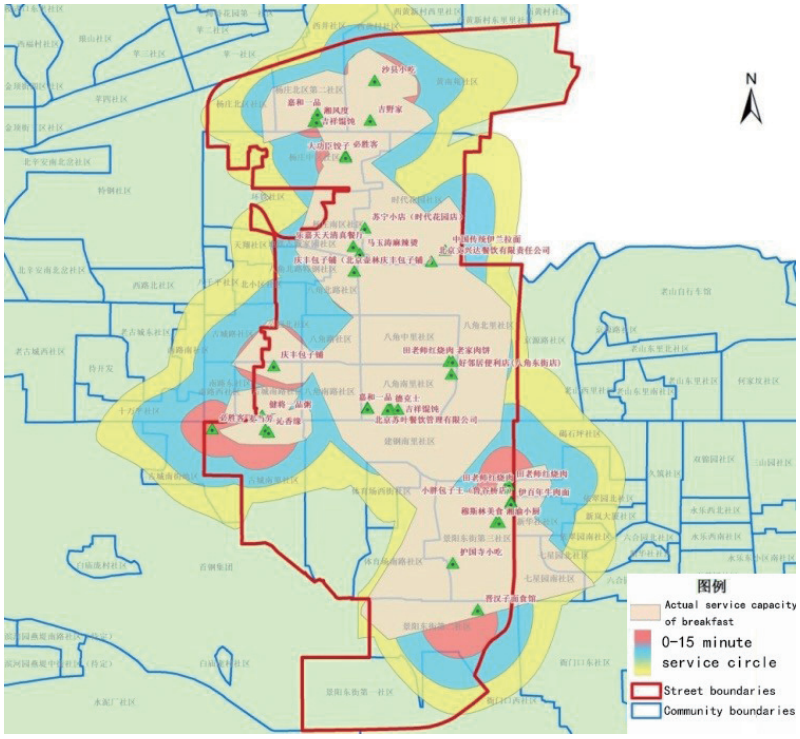

Fig. 9. (Color online) Service capacity gap of breakfast spots.

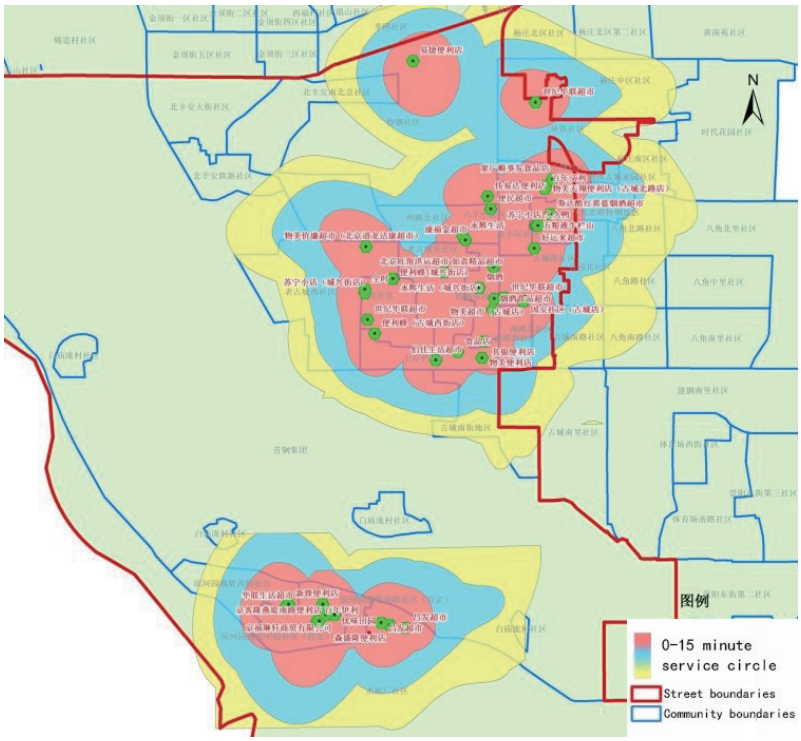

Fig. 10. (Color online) 15-min service circle of supermarket/convenience store spots.

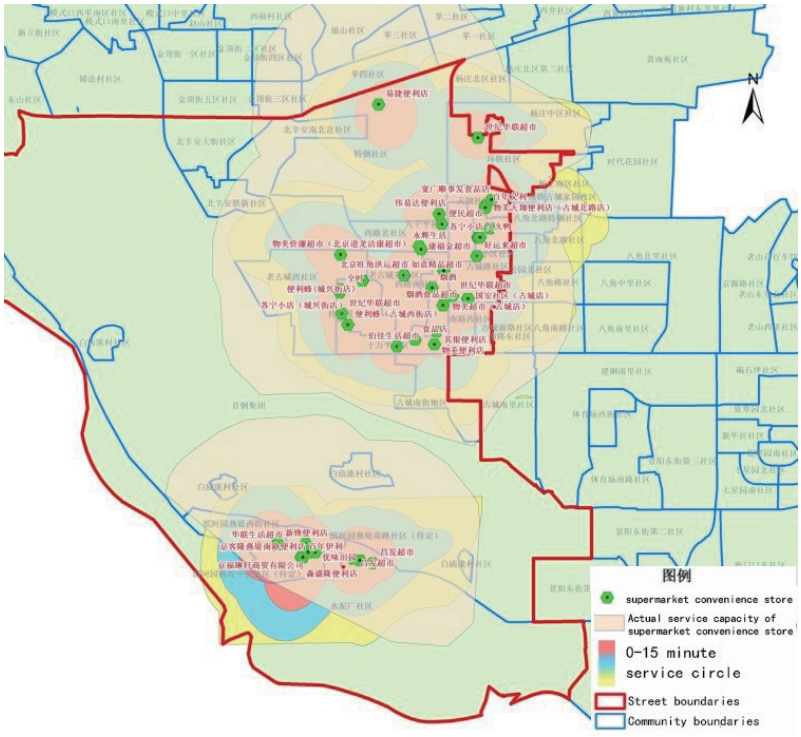

Fig. 11. (Color online) Service capacity gap of supermarket/convenience store spots.

supermarkets/convenience stores spots met the requirements. Therefore, we recommend keeping the number of spots the same. The spatial layout of the spots of supermarkets/convenience stores or the business format of other commercial facilities can be adjusted to meet the demand for a reasonable spatial layout and sufficient service capacity.

5. Conclusions

This technical method could efficiently calculate the service gap between the actual service capacity of different types of community service facilities and the 15-min service circle while also taking into account the spatial distribution density of the population, the walking time based on the network of roads, and the scale and actual service capacity of different types of facilities. The service gaps of community public service facilities were accurately assessed. In addition, this method identified not only the blind spots of traditional calculation methods, with more comprehensive considerations of the influencing factors and higher calculation accuracies than other methods but also deficiencies and shortcomings in community services, thereby consolidating the foundation for further adjusting and optimizing the function settings of community service facilities and enhancing the service capacity of community public facilities. This report illustrates a preferred means of implementation of this kind of study, but several improvements can still be made in this technical field.

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