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Spatial Matching and Policy-Planning Evaluation of Urban Elderly Care Facilities Based on Multi-Agent Simulation: Evidence from Shanghai, China

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Abstract: China is about to enter the stage of deep aging, and the number of disabled elderly is growing continuously. Although the government continues to increase its investment in elderly care institutions and facilities, there is still an unreasonable and unbalanced structure of resource allocation, and the configuration of elderly care institutions and facilities is not well coupled with the geographical layout of the population. Taking Shanghai, China, as an example, based on the multi-agent simulation method, this paper forecasts the supply and demand of elderly care institutions, and evaluates the rationality of relevant policy planning by comprehensively analyzing the behavior of the elderly, the behavior of elderly care institutions, and the interaction between the actors and the environment. The study concludes that: (1) With the increase of aging in Shanghai, the disability rate and chronic diseases will reach 18.7% and 42.0%, respectively, before the arrival of the peak of the elderly population in 2030, and 32.2% of the elderly will be willing to receive nursing services in elderly care institutions, which may make it difficult for the incremental reform of institutional beds in the existing policy planning to meet the actual needs. (2) The index of the number of beds for 100 people in the spatial configuration of elderly care institutions continued to increase, but the actual utilization rate of beds continued to decline, which was only 61.3% in 2030. (3) From the regional perspective, there is an obvious imbalance. The research shows that, with the increase in the disability rate of the elderly and the high incidence of chronic diseases, increasing the supply of facilities for elderly care institutions is an inevitable choice to meet the differentiated needs of the elderly. The demographic characteristics, psychology, economic costs, and spatial distribution of the elderly have a comprehensive impact on the decision-making of institutional elderly care. Institutional facility planning needs to combine urban development strategies, comprehensively consider economic costs, population characteristics and spatial distribution, and achieve a reasonable layout of different types of elderly care institutions. In summary, this paper provides a reference for the scientific layout of urban elderly care institutions through multi-agent simulation, and provides empirical support for how to achieve a good configuration of “population–facilities” in space.

Keywords: elderly care services; multi-agent simulation; spatial matching

1. Introduction

Regionality and dynamics are the two most significant spatiotemporal characteristics of China’s aging population [1]. Due to the limitations of data and technology, related research has focused on the regional characteristics of population aging for a long time. In recent years, with the progress and popularization of technology, it has become possible to describe the dynamics of population aging; in light of China’s economic and social transformation in particular, it is necessary to explore how to determine the dynamic laws of population aging through data and spatial-analysis technology [2]. In this context, the spatial organization and planning of elderly care resources has become an important...
issue. Sociology, geography, demography, and other disciplines have expounded the spatial distribution, spatial-element composition, and characteristics of elderly populations and elderly care services from different perspectives [3–5], which emphasize the physical and social attributes of space. These studies have shifted from traditional analyses based on the study of the geographical spatial patterns of resource allocation to the study of “people”, “land”, and the complex relationships within the “social environment” [6,7].

With the establishment of the people’s livelihood orientation in China, the government’s public expenditure on elderly care services has continued to increase; in particular, with the rapid development of community home-based elderly care service, relevant policies and plans have been extensively introduced, thereby continuing the effort to break down the institutional barriers of “the distance to a bowl of soup” and “the last meter”. For example, the National Plan for the Development of the Aged Cause and the Elderly Care Service System during the “Fourteenth Five Year Plan” requires that, by 2025, the rate of nursing beds in China’s elderly care institutions will reach 55%, the total number of elderly care beds will reach 9 million, and a balanced, reasonable, high-quality, and efficient elderly care supply-network system will be built to cover urban and rural areas, benefiting the whole population [8]. However, there are often unreasonable and unbalanced resource-allocation structures. The allocation of elderly care resources has not matched the geographical layout of the population. The vacancy rate of beds in elderly care institutions is high, and the spatial difference between central urban areas and suburban areas is large [9,10]. At the same time, the equalization of public services does not only involve fair and equitable access, but also the product of the interaction between population changes and the spatial allocation of resources [11]. It is of great significance to reasonably plan and lay out elderly care resources, optimize the spatial layout of elderly care services, and match people with institutions.

At present, the spatial allocation of elderly care resources mainly focuses on three aspects. The first is the fairness of the spatial distribution of old-age-service resources, which emphasizes that public services for the elderly should be given to each elderly group fairly and equitably. That makes geographical location (where to care for the elderly) the primary issue of equalization [12–14], so as to bring into discussion the differences between regions in willingness to provide care, the methods of care for the elderly, and the supply of and demand for elderly care services [9,15]. The second is the efficiency of the spatial allocation of elderly-service resources. Based on the consideration of elderly care facilities as physical spaces, the focus is on the distribution characteristics of elderly care facilities and their coupling relationship with the population [16,17], the accessibility of elderly care facilities, and the spatial coordination and continuity of service facilities [18–20]. Among these, spatial accessibility is widely used as an effective method to measure access to services and their geographic differences [21,22]. A further focus is on the use-efficiency of beds in elderly care institutions, which involves attention to the differentiated needs of the elderly and their dynamic change characteristics, and the simulation, prediction, and discussion of the scale, type, and spatial planning of elderly care facilities [23–25]. The third is the discussion of the relationship between the older population, the environment, and behavior. Based on the possible impact of geographical environment and spatial factors on the elderly, many studies have discussed the relationship between longevity, health, and the environment (including the natural geographical environment and human social-environmental factors), and then evaluated the livable environment [26–28]. Some scholars have also focused on the daily behavior, mobility, and migration of the elderly in space, and discussed the interaction between individuals and the environment at the micro level [29].

Recently, the issue of elderly care facilities has been extended from the analysis of the geographical pattern of resource allocation to the complex relationship of “people”, “places”, and “social environment”. It is necessary to investigate the spatial configuration of elderly care facilities and scientifically measure their spatial configuration, and not just consider the number of new beds and facilities. It is also necessary to take into account the
actual utilization rate of beds in elderly care institutions, as well as the spatial accessibility and availability of population distribution. As far as the method is concerned, the theoretical framework and technology of spatial analysis are gradually being applied to the analysis of aging or elderly care services. Most of the methods are based on the GIS spatial-analysis method and the service-radius method, the two-step floating catchment area (2SFCA) method, the Gini coefficient, and the Theil index [30–32], but it is difficult to consider the comprehensive effects between multiple actors. Because multi-agent simulation analysis can deal with very different “individual” models, from simple entities (usually referred to as “reactive” agents) to more complex entities (“cognitive” agents), it comprehensively considers the interaction between the government, enterprises, and individuals, as well as between multiple agents and the environment. Therefore, taking Shanghai as an example, this paper focuses on the spatial allocation of elderly care resources, adopting a multi-agent micro-simulation model method to analyze and evaluate the spatial matching degree of population facilities and the spatial allocation efficiency of elderly care services, in order to seek to achieve a good matching of “population–facilities” on the basis of accurately simulating multi-agent decision-making behavior, so as to continuously improve the science of the spatial allocation of elderly care services.

2. Overview of Research Area

Shanghai is not only the earliest city to have become an aging city in China, but also the most economically developed city. Located in the Yangtze River Delta, its geographical area only accounts for 0.06% of China’s total territory, but it contributes 3.6% of China’s GDP. There are 16 districts in Shanghai, including 7 districts in the central urban area, namely Yangpu, Hongkou, Jing’an, Putuo, Changning, Xuhui and Huangpu District, and 9 districts in the suburbs, namely Songjiang, Qingpu, Jinshan, Fengxian, Minhang, Baoshan, Jiading, Chongming district and Pudong New Area (see Figure 1). According to the data of the seventh national population census in 2020, 23.4% of the permanent residents in Shanghai are 60 years old and over, and 16.3% are 65 years old and over. Compared with the sixth national population census in 2010, the proportion of the population aged 60 and above increased by 8.3 percentage points, and the proportion of the population aged 65 and above increased by 6.2 percentage points. The degree of aging continues to intensify and has entered the stage of deep aging.

Figure 1. Location of the study area (1, 2, 3, 4, 5, 6, and 7 represent Yangpu, Hongkou, Jing’an, Putuo, Changning, Xuhui, and Huangpu districts, respectively).
Among the four first-tier cities, Beijing, Shanghai, Guangzhou, and Shenzhen, Shanghai has the highest aging population and the largest number of elderly people (see Figure 2).

![Figure 2. Comparison of aging in China's four first-tier cities in 2020 (age 65+). Source: data of the Seventh China Population Census.](image)

Relevant data show that, in the next 20 years, the number of elderly people in Shanghai will grow rapidly, as will the degree of population aging [33]. In terms of spatial distribution, the level of aging in the central urban area is higher than that in the suburbs. Changning, Hongkou, and Xuhui District are the most serious cases among the 16 districts. At the same time, the aging degree in the suburbs has increased (see Figure 3).

![Figure 3. Geographical-distribution map of population density of the elderly in Shanghai (2020). Source: Shanghai permanent-population data from 2020.](image)

In terms of the facilities in elderly care institutions, there were 730 elderly care institutions and 158,600 beds in Shanghai in 2021. In total, 352 of them, with 66,700 beds, were provided by private institutions [34]. From the perspective of geographical location, the
elderly care institutions are mainly distributed in the central urban area, while there are relatively few elderly care institutions in the outer urban areas and suburbs.

It can be seen from the above that Shanghai’s elderly population, elderly care facilities, and beds are seriously differentiated in geographical space (see Figure 4), and there is still much room for improvement in the spatial configuration between population and facilities. In fact, the decisions as to the spatial layout of elderly care institutions are always based on the interaction between the needs of the elderly population, actors’ behavior, the environment, and other factors.

Figure 4. Geographical distribution of Shanghai elderly-service institutions (2019).

3. Materials and Methods

3.1. Data Sources

Two main types of data were used in this study. One was data from elderly care institutions in Shanghai in 2019 (number, beds, geographical location, charging). The data showed that there were 718 elderly care institutions and 151,600 elderly care beds in 16 districts in the city. Most nursing homes in Shanghai charged about CNY 5000, which corresponded to the average pension of CNY 4080 in 2019. The longitude and latitude data were drawn from the Shanghai elderly-care-information platform (https://shyl.mzj.sh.gov.cn/map, accessed on 10 December 2021) built by Shanghai Civil Affairs Bureau, Baidu coordinate pickup system (http://api.map.baidu.com/lbsapi/get-point/index.html, accessed on 1 December 2021), and obtained by vectorization through ArcGIS 10.4. The second was population data, including the seventh population census and data on the permanent elderly population in each street of Shanghai’s 16 districts (some data were converted from the aging rate). Based on the above data, this paper studies the spatial allocation of elderly care institutions in 16 districts of Shanghai from the street scale.

3.2. Research Methods

3.2.1. Agent-Based-Simulation-Analysis Method

Since the 1960s, scholars have begun to use model-simulation methods to study urban problems, such as Wilson’s model and Wegener’s Dortmund model. Since then, under the initiative of Michael Batty and Ye Jia’an, artificial-intelligence theories, such as cellular automata and multi-agent decision-making theory, have made great
breakthroughs in the research of urban and regional development simulation [35, 36]. As one of the two basic methods, agent-based simulation (ABS) has developed rapidly. It studies the macro laws of entire systems by simulating and observing the micro behaviors of large numbers of individuals. On the basis of grasping micro-individual-behavior laws, it integrates people’s behaviors on a detailed spatial scale, so as to dynamically simulate and predict urban and regional development, which can better solve the integration problem of macro-scale decision-making processes and micro-scale analysis processes [37].

In a multi-agent system, each agent has its own attributes and behavior rules, and communicates, cooperates, and even competes with others according to these rules [38]. It is a system under the joint action of multiple agents, and it is composed of a group of simultaneous computer processes. The goal is to discuss how these independent agent processes are coordinated. Coordination is the core problem of multi-agent systems. Among them, the agent is one of the most important concepts in multi-agent systems [39]. From the perspective of artificial intelligence, the agent is a kind of software body that can continuously complete autonomous and goal-oriented behavior in a heterogeneous collaborative environment. It has its own knowledge structure, behavioral logic, and expected goals. Generally, the framework of multi-agent simulation includes the following five parts: agents, environment, rules and parameters, interface, and platform [40]. These are used to solve practical problems according to the general laws of simulation. Of course, we also need to note the deficiencies of the model tools, and corresponding investigation and empirical analysis are needed to support the model’s rules of action. It is necessary to fully draw on and refer to existing research.

In the spatial configuration of elderly care services, the elderly, care institutions, policy makers, and other actors are mainly involved. Since this paper mainly discusses the matching between population and institutional facilities, in the model design, we opened the “black box” of policy formulation, but only investigated the behavior of the elderly and care institutions. At the same time, the environmental factors that affect the behavior of the elderly and care institutions mainly take into account the family, living environment, and policy environment of the elderly.

3.2.2. Multi-Agent Micro-Simulation Model for Facility Configuration of Elderly Care Institutions

The planning of elderly care facilities should comprehensively consider the satisfaction of the needs of the elderly, the rational allocation of urban space and element resources, and the interaction between the government, enterprises, and individuals, as well as micro-interest actors and the environment. The following describes the model composition of multi-agent simulation.

1. Actor behavior of the elderly

The needs of the elderly may change according to their health status, living style, income, and other attributes, but also according to their life-cycle stage. Elderly people with strong self-care abilities are mainly connected with community services, but with the decline in their self-care ability, they become more connected with hospitals, families, nursing homes, day-care centers, and hospices [41]. Although most elderly people will choose home-based elderly care services in their care arrangement, some elderly people still choose care institutions based on their own needs and preferences, and their choice of institutional care is often affected by the combined impact of living style, economic status, health level, and other factors [42]. It can be concluded that this decision-making process can include three independent modules.

(1) Life-cycle module. Mainly based on gender, age-specific population and mortality, fertility and life expectancy, the overall structure of the population and the development trend of aging are predicted. Generally, parameters such as survival probability and mortality rate of age can be calculated according to the population of each age group and their average life expectancy. Fertility rate can be obtained according to $F_x = g(x)/TFR$, where
where \( g(x) \) is the distribution of fertility frequency of women of current reproductive age and \( TFR \) is the total fertility rate. In this way, the basic judgment of the population structure can be obtained from these basic parameters.

(2) Selection module of the elderly care mode. Instead of adopting the practice of dividing the four types of old-age-care methods into living alone, care by children, community home, and institutional care in some studies, based on Shanghai “9073” policy framework (meaning that 90% of people are cared for at home, 7% in the community, and 3% in institutions), in this module, the elderly care modes are divided into three types: self-care, community care, and institutional care. In this paper, the elderly care mode is taken as the decision variable, which is affected by the economic attributes of the main body and environmental variables. The decision-tree model of health and disability is obtained through data mining.

(3) Selection of elderly care institutions. The preference of the elderly who prefer institutional care is affected by the nature of ownership, location, service standards, and fees of elderly care institutions. Different institutions can have different preference indices (i.e., the proportion of the number of people selected). Generally speaking, the preference index is not very high for institutions with higher fees in suburban areas, and public care institutions with more accessible fees are better supported. In 2020, the average pension for the elderly in Shanghai will be CNY 4779. At the same time, due to the high home-ownership rate, they can also obtain rent and investment income [43]. The average monthly income of most elderly people actually exceeds CNY 5000. The elderly in Shanghai have the ability to purchase elderly care services on the market, and their income level is generally sufficient to meet the minimum charge for living in elderly care homes. However, the cost for the elderly in Shanghai to purchase institutional elderly care services is generally more than 50% of their average monthly income. They are highly sensitive to the price of institutional elderly care charges. If the price is high, they may not choose to purchase institutional elderly care services. Therefore, we can judge the likelihood of an elderly person living in an institution according to the main characteristics of the elderly person and the institutional conditions. Suppose that the elderly care institution with the greatest overall effectiveness is selected, and the institution can also provide him with corresponding beds, it is possible to form a judgment as to whether the accommodation needs can be met.

2. Actor behavior of elderly care institutions

For measuring the capacity of elderly care institutions, beds are the most direct indicator. In fact, the government provides one-off construction subsidies for elderly care institutions, and daily operation subsidies are given according to the number of beds. For elderly care institutions, the scale, service level, location, and pricing may affect their operating costs and benefits, but, ultimately, all institutions rely on the utilization rates of their beds. Maximizing the utilization rate of beds has become the key to institutional profits. According to the data from China’s seventh census, the utilization rate of beds in China’s elderly care institutions is only 43.2%, which causes the serious loss of many elderly care institutions [44]. Therefore, increasing the utilization rate of beds has become an important approach to maximizing the benefits of elderly care institutions. Of course, regardless of whether the elderly care institutions accept the elderly, when there are enough beds, they should also consider the degree of self-care requirements for the elderly, that is, whether the elderly care institutions are able to accept the elderly with a higher level of professional care.

The reception status can be determined according to the number of effective beds: acceptable (if the ratio of occupied to available beds is <80%) or tight (the ratio of occupied to available beds is ≥80%); the number of beds is considered tight and full if the number of occupied beds is equal to the number of valid beds. In the acceptable state, whether the elderly can pay the fees of the elderly care institution becomes an important factor affecting the acceptance of the institution. In a first-tier city such as Shanghai, even though the
elderly have high pensions and rich property incomes, most elderly people do not want to burden their children; therefore the cost of living in elderly care institutions is mainly met by disposable income. In fact, the elderly do not use all their pension to pay for the expenses of elderly care institutions. They may also consider helping their children financially, or leave a sum of money for themselves for financial security in old age. Therefore, it may not be appropriate to simply compare elderly people’s income with the charges in elderly care institutions. The support of children is not considered here. If the fee for the elderly care institution is less than 50% of the disposable income of the elderly, it can be accepted, otherwise it is not acceptable. It should be noted that the charging data of some elderly care institutions are difficult to obtain, in which case the average price in the relevant statistical chronology or the minimum fee provided by the institution is used. In the case of a shortage of beds, policy practice emphasizes that elderly care institutions give priority to accepting disabled and semi-disabled elderly people. Therefore, in addition to the charging situation, the degree of disability of the elderly, that is, elderly care institutions needing to give priority to the acceptance of disabled people, should also be considered in the model discrimination.

3. Inter-actor and actor–environment interaction

Since the interactions between the elderly, care institutions, and the environment occur through the interaction of functions and parameters between simulation modules, it is necessary to describe the relationship between modules [7]. The interaction between the above modules in the lifecycles of the elderly, care mode, and facility selection, the supply module of elderly care institutions, and the interaction between actors and environmental factors constitute the relationship roadmap of multi-agent simulation (see Figure 5). Among these factors, the importance of environmental factors in the selection of elderly care methods and facilities, which mainly include family environment, living environment, and policy environment, should be specially considered. The family environment refers to the family population and family structure, and the living environment refers to housing, public transport, public services and other environments of residents, while the policy environment refers to the government’s relevant planning on elderly care facilities.

![Figure 5. Multi-agent decision-making model of urban elderly care service institutions.](image)

4. Results

Based on the multi-agent simulation analysis method, this paper first simulates the supply of and demand for elderly care services in Shanghai, and then presents a rationality evaluation of the current spatial distribution of elderly care institutions.
4.1. Simulation of Supply of and Demand for Facilities in Shanghai Elderly Care Institutions

First, as the initial condition of the model, Shanghai Data from the Seventh Population Census were used as the benchmark, that is, the data of 24.87 million people. Among them, the population aged 60 and above was 5.81 million, accounting for 23.4%, and the population aged 65 and above was 4.05 million, accounting for 16.3%. Since the spatial inversion of individual samples was relatively mature, the spatial distribution of population samples was simulated using GIS inversion of population-density surface based on the macro census data, in order to achieve the spatial positioning of individual samples; that is to say, the spatial distribution of the elderly population in Shanghai was inverted. On this basis, combined with the environmental space layer, the environmental variables of individual samples were identified and the ABS simulation was used. This idea of taking environmental variables as the main attribute of resident agents is also the mainstream method of urban-system ABS under the scarcity of data [45].

Based on the individual data-acquisition method in line with the Chinese context, structural inversion was carried out on the information about age, gender, education, income, family structure, and other information from Shanghai Seventh Census data (part of the data came from district statistics). In spite of this, it is also important to note that agent decision-making exerts an impact on the achievement of living space, depending on its own attributes. Therefore, some scholars have noticed that the inversion of attributes should be reflected in ABS [46]. The main principle of the model is to calculate normal distribution parameters and correlation coefficients according to statistical data, and then carry out inversion according to two-dimensional normal distribution.

In the process of attribute inversion, the FID attribute of the geometry corresponding to each sample can be given. Each geometry uses a random method to generate the point elements of the number of individual samples included in it, as the spatial object corresponding to the individual samples, and then inverts the points. The obtained individual samples are in a one-to-one correspondence with spatial objects. The process of the derivation of its mathematical formula is not elaborated here, and the emphasis is on using this method to realize the inversion of its own attributes. This paper uses the information (including number, beds, and geographical location) and other attribute data of various elderly care institutions in 2019 provided by the Shanghai Municipal Civil Affairs Bureau (note: the real-time data of elderly care institutions at the end of 2019 can be considered synchronous with the population data at the time point of the 2020 census), establishes a simulation program based on the NetLogo platform, and inputs the contents of the above modules into the model. The simulation model outputs the scale and population structure of the disabled elderly population from 2020 to 2030, as well as the demand for institutional elderly care beds and other relevant data.

4.1.1. The Number and Disability Rate of the Elderly Population

Judging from the age group of the elderly population in Shanghai and the “9073” elderly care pattern in Shanghai, the number of disabled elderly in Shanghai will be 657,000 in 2020 (see Figure 6), and the disability rate of the elderly in Shanghai will continue to increase in the next decade, reaching 703,000 in 2030 (see Figure 7). By contrast, the seventh census data in 2020 show that there are 5,815,500 elderly people aged 60 and above in Shanghai, including 380,000 elderly people who have high medical needs but can take care of themselves, and 180,000 elderly people who cannot take care of themselves. Without considering the immigrant population, the number of elderly people over 80 years old in Shanghai will continue to increase, accounting for 18.7% of the total number of elderly people by 2030, which is generally consistent with the relevant forecast. At the same time, the health attributes of the elderly in Shanghai will further deteriorate. The rate of elderly people with chronic diseases will reach 42.0% of the total elderly population, and the number of people who find it difficult to take care of themselves will further increase.
4.1.2. Demand for Beds in Elderly Care Institutions

Generally speaking, the demand for elderly care institutions will continue to increase with age. According to the forecast, in 2030, 32.2% of the elderly in Shanghai expect to receive old-age care in institutions, and 37.0% of the elderly will choose to care for themselves, which will cause greater pressure on the beds in institutional facilities, especially in suburban districts, where resources are scarce. This also means that the elderly’s demand for institutional beds will continue to increase, increasing to 237,000 beds by 2030 (exceeding the relevant forecast of 178,000 beds by 2030 (see Figure 8). In the newly issued “Fourteenth Five Year Plan” for the Development of Elderly Care Services in Shanghai and the special plan for elderly care service facilities, it is required to “take the number of elderly people registered in 2020 as the base, increase 10% of the planning space as the reservation, and control the land use at the bottom line according to 178,000 pieces” [47]. According to this standard, the actual supply of beds will reach 178,000 in 2025, but the current actual demand is 207,000, which has exceeded the planned supply in five years.
4.2. Rationality Evaluation of Space Allocation of Elderly Care Institutions

4.2.1. Evaluation Index of Spatial Allocation Rationality of Elderly Care Institutions

The space allocation based on elderly service facilities should focus on the dual goals of efficiency and fairness. The former focuses on the meeting of differentiated needs and making full use of beds \([48,49]\), while the latter focuses on the coupling of population and facility space. Both should meet the goal requirements of accessibility and availability, so that every elderly person can enjoy equal services \([50,51]\).

In Shanghai, there are great differences in the layouts of elderly care institutions in urban and suburban areas. Due to the scarcity of land, the central urban area is more comprehensive and integrated in the construction of facilities, while the suburban area is relatively poor in this regard. Although there are many new beds in the suburbs, the actual utilization efficiency of these beds is not very high, which means that the layout of elderly care facilities should not only consider the absolute number of elderly people, but also consider beds and their actual utilization, and seek to improve the configuration efficiency while pursuing new beds. At the same time, the accessibility of facilities should also be considered in the layout of facilities—that is, whether it is convenient for the elderly to find suitable care-service facilities, which can be paid for by the elderly and their families. Therefore, when considering the space configuration of facilities for elderly care institutions, accessibility and compliance with the elderly’s ability to pay are important aspects of their measurement. This paper adopts three evaluation indicators, namely, bed-vacancy rate, bed number, and spatial matching degree, proposed by Yan (2015). The spatial matching degree mainly reflects the matching between the elderly population and elderly care institutions, namely

\[
M_i = \left( \frac{P_i}{\sum P_i} \right) - \left( \frac{C_i}{\sum C_i} \right)
\]

where \(M_i\) is the spatial matching degree between the elderly population in the space unit \(i\) and the elderly care institutions, \(P_i\) is the number of elderly people in the space unit, \(C_i\) is the number of elderly care facilities in the space unit, \(\sum P_i\) is the sum of the total elderly population, and \(\sum C_i\) is the sum of all elderly care facilities. \(M_i\) close to 0 indicates a good match between the elderly population and facilities, and \(M_i > 0\) or \(M_i < 0\) indicate that institutional facilities are under- or over-provisioned, respectively. Regarding the spatial uncertainty of the choice behavior of the elderly, this paper is based on the tendency of the elderly to opt for adjacent facilities, and does not discuss the selectivity of spatial units in depth.
4.2.2. Rationality of Spatial Allocation of Elderly Care Institutions in Shanghai

We assume that the number of elderly care institutions will increase by 4%. Therefore, we assume that the total number of elderly care beds will reach 196,000 in 2030, with 3.3 beds per 100 people. However, the utilization rate of beds will not increase with the increase in elderly care institutions and beds; in fact, it will decline to some extent (see Figure 9). With the continuous growth of the aging population in Shanghai, and with the increase in the disabled population, the number of elderly people willing to stay in elderly care institutions will continue to increase. However, on one hand, the development of embedded elderly care services in Shanghai communities enables the elderly to receive relevant services in comprehensive elderly care centers closer to home; and on the other hand, due to economic conditions, consumption habits, institutional layout, fees and other factors, the supply of and demand for institutional elderly care do not match. In this regard, we forecast the number of beds and the utilization rate of beds based on such factors as the spatial distribution of the elderly population, demand status, preference for care code, health status, and the supply of elderly care institutions. Although this forecast was adjusted based on the population-peak data in the 13th Five Year Plan, it still takes some inspiration from the data on the utilization rate of beds.

Figure 9. The number of beds and their utilization rate in Shanghai’s elderly care institutions from 2020 to 2030.

Based on the Shanghai “9073” framework, the layout planning of Shanghai’s elderly care institutions and the prediction of the elderly population, the spatial-matching degree of the two was analyzed at the street level. The blank part indicates that the supply-and-demand balance is good, the light-green part indicates that the supply is slightly greater than the demand, and the dark-green part indicates that the supply is greater than the demand. The pink part indicates that the demand is slightly greater than the supply, and the red part indicates that the demand is greater than the supply (see Figure 10). From the figure, we can also see that some streets and towns have insufficient supply, to varying degrees. It can be said that, in terms of the number of elderly care institutions in the spatial unit, the core area does not have the expected supply-and-demand mismatch, but it is more difficult for the supply in the peripheral area and the suburban area to meet the demand. In other words, due to the uneven development of elderly care services, it is difficult to meet the needs of elderly people in suburbs.
Of course, from the perspective of beds, most of the core and fringe areas in Shanghai have not yet reached the standard of 40 beds/1000 people, and there is a great shortage of beds in the streets and towns near the urban areas of Jing’an and Pudong New Area (except for some vacant beds in Changning). By contrast, it is obvious that there are vacant beds in the suburbs of Jinshan, Qingpu, and Fengxian district. Of course, there are also some streets and towns where supply exceeds demand in the area between the suburbs and the outer suburbs.

This is in line with the actual situation; that is, as the population center of Shanghai moves outward \[3,52\], the aging degree of the central urban area is relatively high, resulting in a dislocation of population and institutional facilities. However, in fact, the regional development of the central urban area cannot provide appropriate institutional facilities and beds, as this would affect the region’s economic development.

Based on the above analysis, it is easy to understand why the elderly care institutions have been growing rapidly in the suburbs and why the suburbs reached the “3%” standard before the urban areas, while the number of beds in the central urban areas has been growing slowly.

5. Discussion

5.1. Institutional Care Needs and Spatial Matching of Elderly Care Institutions

Based on the multi-agent simulation model, this paper comprehensively considers the interaction between the government, enterprises, and individuals, as well as between these and the environment, and evaluates the rationality of the policy planning of elderly care institutions in order to meet the needs of the elderly and achieve a reasonable allocation of urban space and factor resources.

(1) Demand for institutional beds. According to our research, by 2030, 32.2% of the elderly in Shanghai will be willing to receive care services in elderly care institutions, which will continue to increase the demand for beds, leading to the fact that elderly care institutions in many regions cannot meet the actual demand for beds. Based on this serious fact, Shanghai has successively issued a number of elderly care service policy plans, which require further balancing the spatial layout of elderly care facilities in central urban areas and suburban areas in the next five years. From the actual situation at the end of 2020, the number of elderly people with household registration in Shanghai will reach a peak of 5.93 million in 2030. According to the rate of 3% beds, nearly 178,000 beds will be
converted; that is, 19,000 beds will be added on the existing basis. According to our research, the demand for institutional elderly care is still higher than the supply, and 237,000 beds will be needed by 2030, much higher than the estimated 178,000 beds. Some people may think that the demand for institutional beds may not be so high due to the development of community embedded elderly care services. However, as a provider of long-term care and professional services, institutions have their unique advantages over community embedded elderly care services, and with the constant changes in the concept of the elderly and the continuous optimization of institutional services, there is still a wide range of market demand. With the improvement of the elderly’s economic security level and their pursuit of high-quality life, especially when many elderly people in Shanghai live alone in empty homes (many of their children live abroad), they are more likely to choose institutional care rather than day care or short-term community care. Therefore, further increasing the supply of facilities for elderly care institutions is an inevitable choice to encourage high-quality development of elderly care services and meet the differentiated needs of the elderly.

(2) The spatial disproportionality of the bed in elderly care institutions. In Shanghai, the spatial composition of the elderly registered population is different from the distribution structure of the overall population. The aging is serious in the central urban area, but relatively low in the suburbs. In contrast, due to the relatively rich land resources in the suburbs, more institutional facilities can be built. In the central urban area, more attention is paid to the comprehensive and integrated construction of elderly care institutions and facilities. Therefore, on the one hand, we can see the phenomenon of the elderly population and institutions’ beds in the central urban area dropping away from the suburbs. On the other hand, we should also note that the number of beds, rather than the number of institutions and facilities, can better reflect this spatial difference. As for the shortage of beds in the central urban area, it cannot be simply considered that the problem can be solved by adding more beds. The standard of bed planning in the central urban area is lower than that in the suburb, but it is difficult to improve rapidly due to the scarcity of land, and the incremental reform of institutional beds in the central urban area is relatively limited [53]. In many cases, it can only be achieved by tapping internal potential and expanding institutional facilities. In fact, according to the field survey of Putuo District and Changning District, many government officials are skeptical of the increase of institutional facilities, and believe that the allocation of elderly care institutions and beds cannot be increased at the expense of economic strength. In this regard, we must achieve the increase of elderly care beds through the overall layout of urban development space. For example, the construction of the “five new cities” (suburbs) in Shanghai’s new round of urban planning can guide the elderly population to migrate to the suburbs, so as to reduce the pressure on beds in the central urban area, and also help change the imbalance in space of institutional beds.

(3) The utilization rate and structure of beds. It is not enough to only focus on the number of beds, but also the utilization rate of beds must be considered. The study found that although the number of beds for 100 people in Shanghai has increased rapidly, the utilization rate of beds has continued to decline, only 52% in 2030. On the one hand, this utilization rate may be due to the development of community embedded elderly care services such as community day institutions and long-term care centers, which may replace the elderly care institutions; on the other hand, the vacancy rate of beds may also increase due to the increase of elderly care facilities in the suburbs. This means that it is more critical to improve the space allocation efficiency of beds. We should not only seek the coordinated development of different types of institutions in the region, but also pay attention to the structural problems of beds. That is, we should increase nursing beds in consideration of the continuous increase in disabled elderly people. In fact, Shanghai emphasizes the development of community embedded institutions and the construction of nursing beds for cognitive impairment in the central urban area. That is due to the saturation of institutional beds in the central urban area and hoping to meet the care needs of the elderly
through small community elderly care institutions. The study found that the supply and demand of beds in the central urban area is not as serious as expected, which proves that community embedded elderly care greatly alleviates the elderly’s demand for beds in elderly care institutions.

(4) Elderly care behavior. The decision-making of the elderly is affected by psychological, economic affordability and children’s living distance. For example, the Shanghai Civil Affairs Bureau once conducted an experiment. An elderly woman with moderate Alzheimer’s disease wanted to find an elderly care institution with a charge of about CNY 3500–4000. Most eligible elderly care institutions are located in the suburbs, and two eligible institutions are located in urban areas, but they are very crowded. In fact, the elderly person is unlikely to choose the suburb for caring. The decision for old-age care is further reflected in the vacancy rate of beds in central urban areas and suburbs. This requires that the spatial planning of elderly care institutions must comprehensively consider the elderly care decision-making factors of the elderly and their families, further improve the matching degree of population and facilities, and achieve a reasonable spatial layout of elderly care institutions. According to our research, in 2030, the number of elderly people in Shanghai willing to receive care services in elderly care institutions will account for 32.2%, which will make the demand for beds in elderly care institutions continue to grow, leading to the inability of elderly care institutions in many regions to meet the actual demand for beds. Based on this severe fact, Shanghai has successively issued many policy plans for elderly care services, which require further balancing of the spatial layout of elderly care facilities in central urban areas and suburbs in the next five years. The layout of elderly care facilities must be constantly strengthened and optimized in combination with the construction of “five new cities” (suburban satellite towns).

5.2. Suggestions

Based on these policy responses and empirical-analysis results, this paper puts forward corresponding development strategies and suggestions on the spatial matching of elderly care institutions’ facilities.

(1) Further increase the supply of facilities for elderly care institutions according to the spatial distribution and demand characteristics of the elderly population. Geographic location, population structure, care-mode selection, charging and service quality affect the decision making of elderly care institutions, while the elderly in central urban areas, and near and distant suburbs differ in their willingness to choose care institutions. Therefore, the incremental supply of facilities for elderly care institutions should be scientifically planned according to the preferences and demand characteristics of the elderly in the region. A reasonable matching of elderly care resources should be achieved based on population, geographical spatial pattern, and environmental factors in order to ensure that the elderly can obtain affordable institutional elderly care services in specific regions. At present, on the one hand, the demand for institutional elderly care in some areas is not well met due to the shortage of beds in public and private elderly care institutions. On the other hand, there is a lack of inclusive private elderly care institutions. The number of beds in these institutions and the cost of care deter ordinary elderly people from considering them, which further aggravates the waiting times in public elderly care institutions. In this regard, it is necessary to further increase the distribution of inclusive elderly care institutions, or add inclusive beds in private elderly care institutions to better meet the needs of ordinary elderly people. This kind of inclusive elderly care institution has been proved to be able to provide high-quality care in a low-cost way in many developed countries [54]. Of course, special consideration should be given to the unbalanced distribution of institutional facilities in Shanghai in the circle structure.

(2) Guide the elderly population to go to the suburbs and care for the elderly in other places, and reduce the pressure on institutional beds caused by aging in central urban areas.
Even if we build beds for 2.5% of the elderly, it is difficult to increase the number of beds in urban areas due to the shortage of land, which will make institutional beds face greater pressure before the arrival of the peak of the elderly population in Shanghai in 2030. The greater pressure is bound to structurally require more elderly people to turn to the suburbs or other places for old-age care. With regard to the current distribution of elderly care institutions between the central urban area and the suburbs, it is difficult to build institutional facilities based on the elderly care needs close to elderly households in central urban areas with high population densities. In addition to continuing to support the development of community-embedded elderly care services, we should also actively guide the elderly across regions and other places, which can not only reduce the rising aging level of the population in central urban areas, but also solve the contradiction between economic development and service security. This would also give full play to the economic advantages of the elderly and help them to enjoy better institutional elderly care services at relatively cheap prices. In 2020, the average pension of the elderly in Shanghai will reach CNY 4779. In addition to property income, this would ensure that the elderly have a considerable ability to pay to stay in institutions in the suburbs and surrounding areas, as well as avoiding queuing in central urban areas. Of course, due to the psychological attitude of the elderly to relocation, they are not willing to leave familiar places. However, the population center of Shanghai is generally moving outward, and five new cities are under construction; these cities could perform functions transferred from the central urban area of Shanghai in terms of social services, providing the conditions for the migration of the elderly population and the development of institutional elderly care. In the current Yangtze River Delta integration strategy, it is necessary to better carry out remote elderly care (including cross-district elderly care), actively guide the elderly population and families to give play to Shanghai’s higher income advantages, and make full use of the cheaper elderly care facilities in the suburbs and around Shanghai to form a life arrangement after retirement. The development of anti-urbanization and migration after retirement in many developed countries can provide us with relevant inspiration, and we can guide them to migrate to the suburbs and other cities through relevant policies.

(3) Considering the different characteristics and needs of the elderly, we should integrate economic costs, demographic characteristics, and spatial distribution to achieve a reasonable distribution of different types of elderly care institutions.

According to the Shanghai Survey, if it is assumed that these elderly people do not live near other areas, each institution in Jing’an District and Huangpu District in the central city will receive 982 and 909 elderly people respectively. In fact, the number of beds in elderly care institutions is far from reaching this scale, which means that most elderly people will be taken care of in their families and communities. At the same time, there are differences in the scale of elderly care institutions in Shanghai center’s central urban area and suburban areas. Relatively speaking, due to the shortage of land resources, the scale of institutions in the central urban area is small. For example, there are 125 institutions in Pudong New Area and 45 institutions in Putuo, Hongkou and Xuhui District, but few institutions have more than 500 beds; many are small, with 50 to 100 beds, while most beds in Pudong are more than 500, located in the suburbs. It can be said that the development of small elderly care institutions (including various community institutions and facilities) is more in line with the actual needs. Based on this, Shanghai has vigorously developed community embedded elderly care services. Although there are not many beds in these small day care centers embedded in the community, the construction of a 15 min elderly care circle has led to intensive construction. Therefore, it is necessary to consider the differential development of beds in different types of institutions and facilities while emphasizing the increase in the number of beds. Considering the economic cost and the actual situation of land resources, it is not appropriate to develop retirement institutions on a large scale. We should focus on the development of small community elderly care institutions, embed elderly care homes and day-care-center beds, and meet the differentiated and diversified needs of the elderly. Just as the development of “de-
institutionalization” and “community care” emerged in the 1960s and 1970s, it is considered that it has more advantages of humanization and low cost [57]. In a first-line city like Shanghai, it is also difficult to provide the land needed by elderly care institutions. Therefore, it is considered necessary to develop small community elderly care institutions and embed beds in elderly care homes and day care centers. It can not only relieve the pressure of institutional beds, but also meet the needs of the elderly for nearby elderly care.

(4) Considering the needs of the disabled elderly, the proportion of nursing-type and cognitive-impairment-care beds should be added into the spatial planning of elderly care institutions.

Although the bed-setting structure is not directly related to the spatial layout of the facilities of the elderly care institutions, it may affect the choice of elderly care mode; that is, disabled or elderly people are more likely to choose institutions with nursing-type and cognitive-impairment beds. Many elderly care institutions have set up special-care areas for cognitive impairment to provide professional institutional care services. By the end of 2019, a total of 2679 nursing beds for cognitive impairment had been renovated in Shanghai. By 2022, Shanghai aims to complete the transformation of 8000 standardized nursing beds for cognitive impairment. It can be said that the addition of nursing beds and cognitive-impairment-care beds is a development trend, but how to reasonably match the needs of the elderly population in space requires good planning. This planning should be undertaken with a consideration of the disability rate of the elderly population, the selection of pension methods, the utilization rate of beds, and other indicators. The bed assessment should not be the only requirement, rather, it should be combined with the size of the institution, the geographical location, and the demand characteristics of the elderly to transform the availability of beds.

6. Conclusions

In this study, based on previous research results and the data for Shanghai, the spatial matching of elderly care resources was evaluated through a multi-agent-simulation analysis, and some thoughts and suggestions on policy optimization were put forward. The results should alter the predictions of current policy planning, highlighting that, with the arrival of the aging society, the elderly in first-tier cities may create higher demand for institutional care. At the same time, the characteristics of the urban circle structure should also be considered. There is a large difference in the spatial matching between the supply of and the demand for elderly care services in central urban areas and suburban areas.

Therefore, on one hand, we should correctly examine the relationships between institutions, communities, and home-based elderly care services in the “9073” policy framework. In order to encourage the integrated development of homes, communities, and institutions in the new development stage, we must further consider the professional supporting role of elderly care institutions and provide more choices for the professional service needs of the elderly. On the other hand, we should correctly treat the use of the indicator of beds per 1000 people. As an important indicator in local political-performance assessment, the utilization rate of beds in some regions has not increased with the increase in government public-service expenditure, which has led to a large amount of resource waste and inefficient behaviors. Therefore, the indicators of bed-utilization rate and the matching degree of institutional facilities are equally important. We should vigorously improve the efficiency of bed utilization to continuously improve the resource-allocation efficiency of elderly care services.

In addition, the method adopted in this paper may have some deficiencies. As a new technology in urban research, multi-agent-simulation technology has been widely used in education, science and technology, and other fields. Considering that the resource allocation of elderly care services is affected by a variety of actors and environments, its ideas on micro and macro integration can help with the spatial distribution and policy planning of elderly care services. However, due to the spatial uncertainty of elderly care choices (such as some elderly people choosing institutions across districts or preferring
institutions close to their children’s residence), the determination of their spatial units and decision-making behavior is complex, which may also create a gap between supply-and-demand simulation results and the real situation.

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