Study on Optimal Spatial Configuration of Indemnificatory Community Public Service Facility Based on Modified MOGA

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ABSTRACT

Due to the diversity of its objectives, the optimal spatial configuration process of public service facilities in indemnificatory communities is a multi-objective decision issue. As for the study on optimization for spatial configuration of indemnificatory community public service facility, it is important to find an objective, reasonable and effective method that can address multi-objective decision-making challenges. The method is also the foundation for achieving the effect of indemnification and building a harmonious society. Based on the overall objectives of “resource efficiency” and “maximum benefits”, this paper builds the modified Multi-objective Genetic Algorithm (MOGA) model for optimizing spatial configuration of indemnificatory community public service facility, conducts an empirical simulation based on the case of the New Jiangqiao City in Jiading District of Shanghai, with the purpose of introducing the optimal spatial configuration solution for public service facilities. Compared with the ordinary GA-based results, the optimal spatial configuration of public service facilities based on modified MOGA is more reasonable and compact. The model improves the configuration theory for public service facilities in indemnificatory communities, which is of substantial theoretical and practical significance for creating more scientific and reasonable configuration of public service facilities in indemnificatory communities.

Keywords: indemnificatory community; public service facility; Multi-objective Genetic Algorithm (MOGA), spatial configuration optimization

1. AIMS AND BACKGROUND

Public service facility configuration is essentially a complicated multi-objective non-linear dynamic optimization decision-making issue. On the one hand, the configuration process must take into account the effects of various factors such as the location, accessibility and fairness of the public facilities as well as the interaction and interconnection with one another. On the other hand, during the multi-objective optimization for the configuration of public service facilities, the sub-objectives to be optimized simultaneously usually conflict with one another. The key to solving the optimization problem of spatial configuration of public service facilities lies in finding an objective and quantified balance solution (i.e. the Pareto optimal set) under the effects of multiple factors and during the multi-objective optimization.

Current researches on the public service facility configuration mainly focus on the subjects of location, accessibility and fairness of facilities. For example, the study on location of public service facilities focuses mainly on their location optimization. Alcada-Almeida et al., (2009) designed a Gaussian diffusion model for optimal configuration of multi-objective spatial location by using mixed integer and multi-objective planning. Teixeira and Antunes(2008) introduced a discrete rating configuration model for public service facility location and validated the effectiveness of the model through a school network planning case. Jing and Jin (2007) proposed that the community planning should start from the city’s
perspective and aim for interaction with the city and constructed the community design principle of interaction with the city. The study on accessibility of public service facility usually takes the medical, educational, cultural and sport facilities as well as parks and greenbelts as objects. Langford et al., (2008) took Cardiff of South Wales as study object and analyzed the effect of alternating population distribution on the accessibility to public service facilities through the two-step floating catchment area (2SFCA) method. Macintyre et al., (2008) pointed out that the spatial accessibility of public service facility, which is an important indicator of the city residents' life quality, concerns the social fairness and justice of the city public resources allocation. Tanimura et al., (2011) gave a quantitative analysis on the spatial accessibility of children's hospitals in Oita, Japan, and used the Monte Carlo simulation to come up with accessibility indicators, Tanimura et al., (2011) applied these indicators in public health facility planning and policy-making, making it possible to measure the fairness of spatial accessibility. Song et al., (2010) gave a definition to the spatial accessibility of public service facilities and attached more importance to the spatial elements affecting facility deployment. In terms of researches on fairness of public service facility, Cha and HoSeop (2009) examined the fairness issues in city traffic facilities. Ogryczak (2009) used the mean-equity model during the site selection decision-making and offered optimization solutions to the facility unfairness and minimum distance. Arif Wismad et al., (2014) built the space preference model (SPM) and applied it in their study of the transportation infrastructure in Indonesia, offering a new method for the spatial fairness on site selection. Wu et al., (2011) started out from the supply scale, supply characteristics and supply sequence, and carried out supply optimization throughout the whole process of population intake, on the basis of the supply and demand equilibrium theory, thus achieving the effectiveness and fairness of public service facility supply configuration in indemnificatory community.

The Genetic Algorithms (GA), first introduced by Professor Holland from Michigan University in 1962, is a parallel random search optimized global algorithm that works by simulating the natural generic mechanism and biological evolution. It features high search efficiency, versatility, fast convergence rate and prematurity prevention, and has been used extensively for solving multi-objective optimal configuration issues (Wu and Lu, 2012; Zhang and Yan, 2012; Luo and Chen, 2012; Li et al., 2012).

From the perspective of simulating organism’s dynamic adaptability to the environment as well as the relationship of competition and synergy between organisms, this paper sets the multiple objectives and multiple restrictions, which totally aim at “resource efficiency” and “maximum benefits”, builds the optimal spatial configuration model for indemnificatory community public service facility based on the modified Multi-objective Genetic Algorithm (MOGA). The study takes the New Jiangqiao City of Jiading District in Shanghai as an empirical research example.

2. EXPERIMENTAL

2.1 Construction of modified MOGA-based model

Setting of Model Objective Function and Restrictions

The optimization issue on spatial configuration of public service facility affects all subjects, including residents, real estate development enterprises and the government. As for the real estate development enterprises and the government, the optimal configuration decision objective is to obtain the maximum benefits while investing the minimum resources. The benefits include but are not limited to the satisfaction of residents and the population served by the public service facility. By reference to the researches of relevant scholars (Wismadi et al., 2014; Han and Yu, 2012; Wang et al., 2012; Liu and Li, 2010; Han et al., 2014), this paper sets resource efficiency and maximum benefits as the overall objectives of the model, and sets the relevant sub-objectives and restrictions based on the
overall objectives, as follows:

Objectives of resource efficiency:

\[
\text{Min } \sum_{i=1}^{n} \sum_{j=1}^{m} \sum_{k=1}^{k} P_{ijk} X_{ijk}
\]  

(1)

\[
\text{Min } \sum_{i=1}^{n} \sum_{j=1}^{m} \sum_{k=1}^{k} d_{ijk} X_{ijk}
\]  

(2)

Objectives of maximum benefits:

\[
\text{Max } \sum_{i=1}^{n} \sum_{j=1}^{m} \sum_{k=1}^{k} Suit_{ijk} X_{ijk} + \sum_{i=1}^{n} \sum_{j=1}^{m} \sum_{k=1}^{k} \omega_{ijk} X_{ijk}
\]

\[
+ \sum_{i=1}^{n} \sum_{j=1}^{m} \sum_{k=1}^{k} \sum_{i=1}^{n} \sum_{j=1}^{m} \max\{\text{dense}(c) \times D_{\text{area}} \times \exp[-r \times \text{dis}_s(c)]\} X_{ijk}
\]

(3)

Restrictions on objectives:

\[
\sum_{i=1}^{n} \sum_{j=1}^{m} X_{ijk} = X_k
\]  

(4)

\[
\sum_{i=1}^{n} \sum_{j=1}^{m} X_{ijk} D_{\text{area}} = D_{n \times m}
\]  

(5)

\[
H_{i,j',j} \geq 2
\]  

(6)

In the above formula, the area to be configured is segmented into grid units of n rows and m columns, and k represents the type of the public service facility in units (i, j) and (i', j') respectively. In accordance with the Standards for Public Service Facilities of Urban Residential Areas and Communities in Shanghai (DGJ08-55-2006, J10768-2006), the public service facility in units shall have only 6 types, i.e. cultural, sport, educational, medical, commercial, and financial facility. Unit(i', j) is the neighboring grid of unit (i, j). X is the total space of k types of public service facility; \(P_{ijk}\) represents the expenses for deploying k types of public service facility in unit (i, j); \(d_{ijk}\) represents the distance between the k types of public service facility deployed in unit (i, j) and the nearest similar types of public service facility. \(Suit_{ijk}\) is the suitability of deploying k types of public service facility in unit (i, j). The suitability weights of various types of public service facility are calculated through the Analytic Hierarchy Process (AHP). \(W_{ijk}\) represents the satisfaction level of residents when k types of public service facility are deployed in unit (i, j), which is measured by the residents’ selection frequency for each type of public service facility and expressed as a percentage. \(X_{ijk}\) and \(X_{i'j'k}\) are binary variables whose value is 1 in the event that the units (i, j) and (i', j') are configured with the same type of public service facility; otherwise, their value is 0. \(\text{dis}_s(c)\) represents the Euclidean distance from grid c to p configuration sites. \(\text{dense}(c)\) represents the current population density in grid c; \(D_{\text{area}}\) is the area taken up by the current type of public service facility on the grid; \(\exp[-r \times \text{dis}_s(c)]\) is the attraction level of p configuration sites for the current population on grid c, wherein r is the attraction factor, which has inverse relation with the attraction of the configuration sites for the population on the neighboring grid. Therefore, bigger value the r takes means smaller attraction. \(C_{\text{dense}}\) is the objective function coefficient. \(D_{n \times m}\) is the total area of the grid units of row n and column m. \(L_{i,j',j}\) is a binary variable whose value is 1 in the event that the units (i, j) and (i', j')
are adjoining units; otherwise its value is 0. $H_{ij,i'j'}$ represents the number of units having the same type of public service facility as the to-be-configured unit $(i, j)$.

Objectives (1) and (2) are for resource efficiency. Objective (1) minimizes the spatial distance between the to-be-configured area and the already configured area, in order to achieve the purpose of effective use of land resources to form the high-density, intensive land utilization. Objective (2) minimizes the total configuration expenses of public service facility types and reduces the configuration cost. Objective (3) is for maximum benefits, wherein $\sum_{i=1}^{n} \sum_{j=1}^{m} \sum_{k=1}^{k} \text{Suit}_{ijk} X_{ijk}$ represents the coordination level or suitability of the configured public service facilities, $\sum_{i=1}^{n} \sum_{j=1}^{m} \sum_{k=1}^{k} \omega_{ijk} X_{ijk}$ represents the satisfaction level of the residents after the configuration of the public service facilities; $\sum_{i=1}^{n} \sum_{j=1}^{m} \sum_{k=1}^{k} C_{dense} \frac{\text{max}\{\text{dense}(c) \times D_{area} \times \exp[-r \times \text{dis} (c)]\}}{X_{ijk}}$ represents the service capacity of the public service facilities. Objective (3) aims at the maximum benefits through the maximization of the above three parts. Restriction (4) ensures that the area of each type of public service facility must fit in with the maximum configuration area for the public service facilities. Restriction (5) ensures that the grids to be configured must fit in with the total land area. Restriction (6) ensures that there are at least two neighboring units that are configured with the same type of public service facility as the to-be-configured unit $(i, j)$.

2.2 Model algorithm

In line with reference as follows, this paper designs the Multi-objective Genetic Algorithm (MOGA) for optimizing the spatial configuration of indemnificatory community public service facility. In this genetic algorithm, each entity has its adaptability and coordination capability; all entities are distributed in the grid units of n rows and m columns in the area to be configured, with each entity taking up one grid. All neighboring entities improve their own adaptability via mutual selection, crossover and mutation and filter. They evolve themselves, keeping those with high adaptability and eliminating those with low adaptability, so that the new species inherits the traits of and also exceeds the father generation. Through the repeated iteration, the grid occupied by the original entity will change the spatial configuration status of public service facilities as the optimal entity located in the grid changes, thereby reaching the optimal spatial configuration of public service facilities.

In this study, the optimization resolution to spatial configuration of indemnificatory community public service facility is to find the optimal species of entities with the maximum benefits using minimal resources. Each entity in the species has its perception and impact on the environment. The complexity, adaptability and coordination of the entities need to be realized through certain structures, plans and behavior.

2.3 Selection operators

Selection operators are the operators selected from the primary species into the new species with a certain probability. The probability of an entity being selected relates to its adaptability; bigger adaptability will result in bigger probability of the entity being selected, and vice versa. Genetic Algorithm essentially follows Darwin’s theory of evolution by natural selection, ensuring that the new species both carries all the information of the father generation and is better than that generation. This paper uses the roulette for selection operators. If N represents the scale of the species and $f_{fit}(x_i)$ represents the adaptability of entity $x_i$, the probability of each entity being selected is as follows:
The roulette selection strategy ensures that the entity with greater adaptability has a better chance of being selected, in order to pass the good genes on to the next generation, thus reaching the optimal solution through the fast convergence of genetic algorithms.

2.4 Crossover operators

Crossover operators refer to the production of a new superior entity through the exchange and integration of the chromosomes of two entities that are selected from all species. Crossover operation ensures that the excellent genetic segment of the father generation is carried on to the next generation, producing an even better next generation. Using the unified crossover operators introduced by Syswerda (Shen, 2013), a random mask is generated, which is used for the exchange of relative genes between the father generations. Two chromosomes were randomly selected from the species, and one or multiple chromosome positions were randomly chosen for crossover interchange. This resulted in the information of the two father chromosomes being passed on to the next generation, thereby producing two new generation chromosomes.

2.5 Mutation operators

Mutation operators refer to the production of new superior entities via chromosome gene mutation in the species. Each gene type in the chromosome has the probability of mutation, of which the value is in [0, 1]. In line with reference (Shen, 2014), a father chromosome that needs to undergo mutation operation is randomly selected, the new generation post-mutation chromosomes are obtained using the “deterrence move”, and an optimal entity among the father chromosomes and the filial chromosomes are selected as the result. The operation is repeated until the number of mutation operation times reaches the pre-set value.

2.6 Adaptive genetic algorithm parameters

In genetic algorithm, crossover probability ($P_c$) and mutation probability ($P_m$) are the keys affecting the algorithm performance, and have direct impact on the convergence and efficiency of the algorithm. If $P_c$ is too large, the genetic model of the optimal entity cannot carry on; if $P_c$ is too small, the algorithm search process would be too slow, causing premature convergence. If $P_m$ is too large, the algorithm becomes a pure random search; and if $P_m$ is too small, it would be hard to produce a new entity structure (Yan et al., 2007). Therefore, this paper uses the adaptive method to determine the value of $P_c$ and $P_m$, that is, the crossover probability and mutation probability are determined through the comparison of the adaptability of individual entity and the overall performance of the species. The detailed calculation method refers to the research (You et al., 2003).

2.7 Determination of adaptability function

In the optimal spatial configuration model for the indemnificatory community public service facility, this paper compares the adaptability value of entities to measure their quality. Adaptability value is obtained through the objective function and the restrictions via the comprehensive adaptability function, as shown in formula (11). All the entities in the species are sequenced based on their quality in the different objective functions, and the total adaptability value is calculated using the adaptability value calculation method based on the sequencing result.

$$Z(i) \ (i = 1, 2, \ldots, n)$$ represents the objective function, in which $n$ is the number of objects. For
each objective $i$, all the entities would, based on their quality to the function value of the objective, lead to a solvable sequence $x_i$. After sequencing each objective, the overall performance of individual entities for each of the objective functions is derived. The adaptability value is calculated based on the sequence of the entities:

$$ F_i(X_j) = \begin{cases} (N - Y_i(X_j))^2 Y_i(X_j) > 1; & i = 1, 2, \ldots, n \\ kN^2Y_i(X_j) = 1; & \end{cases} $$(8)

$$ F(X_j) = \sum_{i}^{n} F_i(X_j) \quad j = 1, 2, \ldots, n $$(9)

Wherein, $n$ is the total of objective functions; $N$ is the total of individual entities; $X_j$ is the $j$th entity in the species; $Y_i$ is the sequence number of the entity based on its performance for objective $i$ among all entities; $F_i(X_j)$ is the adaptability of $X_j$ to objective $i$;

$$ \sum_{i}^{n} F_i(X_j) $$

is the comprehensive adaptability of $X_j$ to all objectives; $k$ is a constant in $(1,2)$ which is used for increasing the adaptability of individual entities at the time of optimal function value. Functions (8) and (9) suggest that entities with better overall performance can have greater adaptability and obtain more opportunities for participating in the evolution (Chen et al., 2006).

In order to maintain the diversity of the species to the greatest extent, avoid genetic deviation, and achieve the purpose of exploring multiple areas simultaneously, this paper introduces the “niche” technology based on the sharing mechanism to reduce the replication of similar entities. The estimated niche radius is as follows ($\sigma_{\text{share}}$) (Zhang et al., 2011).

$$ N\sigma_{\text{share}}^{n-1} = \frac{\prod_{i=1}^{n}(F_i(X_j) + \sigma_{\text{share}}) - \prod_{i=1}^{n} F_i(X_j)}{\sigma_{\text{share}}} $$

(10)

After sharing, the comprehensive adaptability function $Fit(X_j)$ of entity $X_j$ is as follows:

$$ Fits(X_j) = \frac{\text{Fit}(X_j)}{\Sigma_{k=1}^{N}s(X_j, X_k)} $$

(11)

Wherein, $\text{Fit}(X_j)$ is the comprehensive adaptability function of $X_j$ after sharing to all objectives; $X_k$ is the $k$th agent of the species; $s(X_j, X_k)$ is the agent sharing coefficient.

$$ s(X_j, X_k) = \begin{cases} 1 - \frac{d}{\sigma_{\text{share}}}, & d \leq \sigma_{\text{share}} \\ 0, & d > \sigma_{\text{share}} \end{cases} $$

(12)

Wherein, $d$ is the sharing search radius,

$$ d = \sqrt{\sum_{i=1}^{n} [F_i(X_j) - F_i(X_k)]^2} $$

(13)

### 2.8 Project overview
The New Jiangqiao City of Jiading District in Shanghai is one of the six large indemnificatory communities planned and constructed in Shanghai in 2009. It is a large indemnificatory community project with a complete set of public service facilities, including educational, cultural and commercial facilities, etc. The project has a land area of 500,000 m² and a total construction area of about 670,000 m². The land utilization plan is illustrated in Figure 1.

![Figure 1. Land utilization plan of New Jiangqiao City](image)

### 2.9 Determination of parameters

The adaptability weights of public service facilities are calculated through the AHP method. This paper evaluates the adaptability of the public service facilities in New Jiangqiao City by building the judgment matrix. The adaptability weights of public service facilities are shown in Table 1:

**Table 1** Adaptability weights of public service facilities in New Jiangqiao City

<table>
<thead>
<tr>
<th>Evaluation Type</th>
<th>Cultural</th>
<th>Sport</th>
<th>Educational</th>
<th>Medical</th>
<th>Commercial</th>
<th>Financial</th>
</tr>
</thead>
<tbody>
<tr>
<td>Adaptability Weight</td>
<td>0.04</td>
<td>0.03</td>
<td>0.12</td>
<td>0.41</td>
<td>0.17</td>
<td>0.23</td>
</tr>
</tbody>
</table>

This paper uses survey to determine the residents’ satisfaction level about the public service facilities of the New Jiangqiao City by distributing 500 questionnaires, out of which 462 are recovered and 0 invalid, with a recovery rate of 92.4%. Based on the selection times of the types of public service facilities, the study finds out the satisfaction level of residents about the essential facilities in their life, which is shown in Table 2:

**Table 2** Satisfaction level of residents about essential facilities

<table>
<thead>
<tr>
<th>Evaluation Type</th>
<th>Cultural</th>
<th>Sport</th>
<th>Educational</th>
<th>Medical</th>
<th>Commercial</th>
<th>Financial</th>
</tr>
</thead>
<tbody>
<tr>
<td>Adaptability Weight</td>
<td>0.08</td>
<td>0.13</td>
<td>0.17</td>
<td>0.22</td>
<td>0.19</td>
<td>0.20</td>
</tr>
</tbody>
</table>

The relative configuration expenses of the public service facilities are listed in Table 3. (Note: The configuration expenses herein are not the actual configuration expenses, but the relative construction expenses under government control.)

**Table 3** Relative configuration expenses of public service facilities (10,000 yuan/unit)

<table>
<thead>
<tr>
<th>Evaluation Type</th>
<th>Cultural</th>
<th>Sport</th>
<th>Educational</th>
<th>Medical</th>
<th>Commercial</th>
<th>Financial</th>
</tr>
</thead>
<tbody>
<tr>
<td>B₁</td>
<td>-</td>
<td>0.09</td>
<td>0.09</td>
<td>0.09</td>
<td>0.09</td>
<td>0.09</td>
</tr>
<tr>
<td>B₂</td>
<td>0.19</td>
<td>-</td>
<td>0.19</td>
<td>0.19</td>
<td>0.19</td>
<td>0.19</td>
</tr>
</tbody>
</table>
### 3. RESULTS AND DISCUSSION

Spatial configuration optimization results of public service facilities in New Jiangqiao City

Before applying the model, the average population density is calculated in accordance with the demographic census data of the New Jiangqiao City and the vector space data of the borders of the region to be configured. The population data and the data of the to-be-configured region is then converted into grid data, which results in 40x50 grid units in the to-be-configured region. According to investigation, the primary grid data on the spatial configuration of public service facilities are 153 cultural units, 196 sport units, 489 educational units, 738 medical units, 352 commercial units and 72 financial units. On the basis of the objective function and restrictions and in accordance with the Standards for Public Service Facilities of Urban Residential Areas and Communities in Shanghai (DGJ08-55-2006, J10768-2006), the primary spatial configuration plan is optimized through modified MOGA. With regard to the grid units after optimization, there are 116 cultural units, 252 sport units, 514 educational units, 768 medical units, 286 commercial units and 64 financial units respectively.

For the purpose of making a quantitative analysis on the rationality of the spatial configuration results for public service facilities before and after the modified MOGA-based optimization, this study combines the multi-objective functions and restrictions, and uses spatial layout indicators such as the Mean Patch Fractal Dimension (MPFD), Mean Euclidean Nearest-neighbor Distance (MNN) and Aggregation Index (AI), in order to evaluate the overall spatial compactness of the patch configuration of a certain type of public service facility. The calculation formula for MPFD, MNN and AI are given in reference below. The results are shown in Table 4.

**Table 4** Evaluation result of spatial configuration of public service facilities before and after optimization

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Pre-Optimization</th>
<th>Post-Optimization</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Cultural Sport</td>
<td>Educational Medical Commercial Financial</td>
</tr>
<tr>
<td>MPFD</td>
<td>1.1 1.2 1.43 1.5 1.268 1.1 16</td>
<td>1.0 1.1 1.35 1.466 1.17 1.0 5 12</td>
</tr>
<tr>
<td>MNN</td>
<td>143.67 7.4 29 5.6 8 164.5 1</td>
<td>138.34 3.2 8 164.76 172.58 145 21 0.5 3 9</td>
</tr>
<tr>
<td>AI</td>
<td>69.9 58.4 49.2 46.9 55.72 76.15</td>
<td>74.25 62.72 54.1 51.18 61.0 3 48</td>
</tr>
</tbody>
</table>

A comparison of Table 4 shows that the MPFD and MNN values for all types of public service facilities after optimization are lower than those before optimization, while the AI after optimization is higher than that before optimization. This suggests that the patch adjacency, continuity, aggregation and compactness of the spatial layout of public service facilities has been greatly improved by the modified MOGA-based optimization, which demonstrates that the modified MOGA-based spatial configuration optimization model of public service facilities in indemnificatory communities can produces a more reasonable spatial
configuration.

4. CONCLUSIONS

(1) This paper defines the multiple objectives and restrictions for “resource efficiency” and “maximum benefits”, combines the practical challenges in spatial configuration optimization of public service facilities in indemnificatory communities, and builds the modified MOGA-based model for spatial configuration optimization of public service facilities in indemnificatory communities. Research results suggest that the configuration results AFTER the optimization saw greater improvements in terms of patch adjacency, continuity, aggregation and compactness than those BEFORE the optimization. This ensures better configuration of public service facilities in the indemnificatory community and maximum possible satisfaction level of residents on the premise of meeting the government’s requirements.

(2) Despite the fact that this paper has taken into consideration the multiple objectives of “resource efficiency” and “maximum benefits” during the spatial configuration optimization of public service facilities, there are a large number of subjective factors during the quantifying process for such parameters as adaptability weights and residents’ satisfaction of public service facilities. Therefore, more often than not, it is necessary to configure more numbers of, and more complicated, objectives and restrictions during the spatial configuration optimization of public service facilities. The future researches will focus on improving the quantification of parameters and building a more comprehensive multi-objective and restriction evaluation system.

5. ACKNOWLEDGEMENTS

Supported by the National Natural Science Foundation of China (No.71403173) and the Ministry of Education Fund (NO.13YJC630183).

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