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Optimization of Rural Residential Area Location with the Farming Radius Constraint

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Abstract

With an example of Xinfu District in Xinzhou, Shanxi Province, this article studies the change law of the farming radius and the farming inner radius in this area based on the data of the rural residential area, traffic network, cultivation block, and so on, and applies the set covering location problem (SCLP model) under the maximum farming radius to filter the minimum and best village location system as the planning target from the existing rural residential area location systems in Xifu District. The optimized results can be the foundation of the efficiency of land use and the construction of rural basic public service.

Keywords: SCLP; rural residential area; farming radius; location-allocation.

1. Introduction

The least facility problem is the Set Covering Location Problem (SCLP) [1,2], attributing to set covering problem [1-3] of location-allocation basic problems, which was put forward by Berge [4]. Fulkerson, Ryser [5] and Edmonds [6] gave the equation, and Church, Toregas [2,7,8]discussed in detail the SCLP model and its applicability. SCLP is used widely in areas such as land and resources administration, urban and rural planning, national defense and military, public service facility layout, etc.

2. Theory of location distribution

2.1. Location distribution on a plane

Choose p（$1\leq p\leq K$ ）as the number of the facility. Each demand-point is supplied by one of the facility. This problem is a NP problem, which is expressed by mathematical model: the objective function of the two variables (the only variables are the two coordinates of the new facility) is:

$$\text{Min } z=\sum_{i\in I} d_i w_i=\sum_{i\in I} w_i\sqrt{(a_i-x)^2+(b_i-y)^2} \tag{1}$$

where customers are located at (a_i, b_i), the facility is to be sited at （x, y）, w_i is the known demand (or weight) of customer i; And I is the set of customers. The first-order conditions are first written in the form

$$\text{Min } x=\frac{\sum_{i\in I}\frac{w_i a_i}{\sqrt{(a_i-x)w_i^2+(b_i-y)^2}}}{\sum_{i\in I}\frac{w_i}{\sqrt{(a_i-x)w_i^2+(b_i-y)^2}}} \tag{2}$$

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In contrast, when the objective of the minimum weighted squared distances is differentiated with respect to the x and y coordinates of the facility, the resulting equations are separable and a simple closed-form solution exists, in which

$$\text{Min } \bar{x} = \frac{\sum_i w_i a_i}{\sum_i w_i} \quad \text{and} \quad \bar{y} = \frac{\sum_i w_i a_i}{\sum_i w_i} \tag{3}$$

where J is a set of facility locations, where the point (xj, yj) is the location of the jth facility for all $j \in J$ .Defining uij as the proportion of customer i's demand that is served by the jth facility, the multifacility location problem can then be written as

$$\text{Min } z = \sum_{i \in I} \sum_{i \in I} w_i d_{ij} u_{ij}$$

$$\text{s.t.} \quad \sum_{j \in J} u_{ij} = 1 \quad \forall i \in I , \quad u_{ij} \in \left| \forall i \in I, j \in J , \quad x_i, y_j \right| \forall j \in J \tag{4}$$

where the variables xj and yj, $j \in J$ appear only implicitly in the formulation in the guise of the distances dij.

2.2. Location distribution on network

ReVelle and Swain were the first to formulate the p-median as a zeroone programming problem. A variant of their original formulation is [9].

$$\text{Min } \; z = \sum_{i \in I} \sum_{i \in I} w_i d_{ij} u_{ij}$$

s.t.

$$\sum_{j \in J} x_{ij} = 1 \quad \forall i \in I , \quad x_{ij} \le y_{ij} \quad \forall i \in I , \quad j \in J ,$$

$$\sum_{j \in J} y_j = p , \tag{5}$$

$$x_{ij} = 0 \vee 1 \quad \forall i \in I , \quad j \in J , \quad y_i = 0 \vee 1 \quad \forall j \in J$$

where the locational variables y_j are one, if a facility is located at node *j* and zero otherwise. The allocation variables x_{ij} denote the proportion of the demand of the customer at node *I* that is assigned to a facility at node *j*. Finally, *p* denotes the number of facilities that are to be located; the remaining parameters are as defined above.

3. Optimized model of rural residential location under the maximum farming radius

To formalize, denote again I as the set of demand nodes and let J symbolize all candidate sites at which facilities may be located. The model that allows locations only at the vertices of a network is referred to as the vertex-center problem and it can be formulated as follows:

$$\text{Min} \quad z$$

$$\text{s.t.} \quad \sum_{j \in J} y_{ij} = 1 \quad \forall i \in I,$$

$$y_{ij} - x_j \le 0 \quad \forall i \in I , \quad \forall j \in J , \quad \sum_{j \in J} y_{ij} = p , \quad z - \sum_{j \in J} d_{ij} y_{ij} \ge 0 \quad \forall j \in J , \tag{6}$$

$$x_j \in \{0,1\} \quad \forall j \in J \;, \quad y_{ij} \in \{0,1\} \quad \forall i \in I \;, \quad \forall j \in J \;.$$

From the above definition, we infer the SCLP under the maximum service radius [9-11]. That is, on the premise of the given traffic network and that the all studied farming cultivation blocks are within the maximum farming radius, to solve the minimum rural residential location and its distribution. The equation is as follow:

$$p = \min \sum_{j \in J} x_j \tag{7}$$

Constraints:

$\sum_{j \in N_i} x_j \geq 1$, $i \in I$ (there is at least one rural residential point in the maximum farming radius);

$x_j = (0,1)$, $j \in J$ (when the rural residential is located on j , it is 1. If not, it is 0);

N_i is the farming block; is the maximum farming radius; the total number of the rural residential points within is

$$N_i = (j \in J \mid d_{ji} \leq d_{\max}) \qquad i \in I \tag{8}$$

Among them: p is the number of the chosen rural residential points: i is the encode of the farming blocks ($i \in I$, i = 1,2, …, m); j is the encode of the candidate rural residential points ($j \in J$, j = 1,2,…,n); d_{ji} is the shorted route distance from the rural residential point j to the farthest point of the farming block i ; $d_{\max}$ is the maximum of the farming radius.

4. Data and analysis

4.1 Analysis on the maximum of the farming radius

The farming radius is the spatial distance from the rural residential point to the farming block. There is rural residential radius in the rural residential point, which is the radius of a circle which center is the center of gravity of the rural residential point and which area is equal to the area of the rural residential point. In this article, the farming radius in SCLP model is the sum of the distance from the edge of the rural residential point to the farming block and the inner radius of the rural residential point.

Using Path Distance Model, the study first calculate the Path distance from the farming block in the study area to the nearest rural residential point (fig 1), and then figure out the rural residential radius in the study area (fig 2) according to the areas of each rural residential point. The result is that the maximum farming radius from the edge of the rural residential point to the farming block is 2647m, and the maximum rural residential radius is 650.88m. With the sampling, the maximum farming radius is finally determined to 3500m.

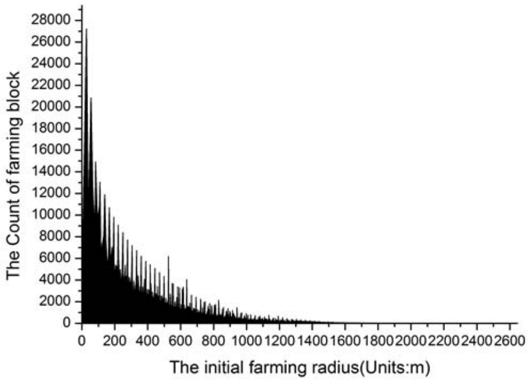

Fig. 1 The distribution of initial farming radius in Xinfu District

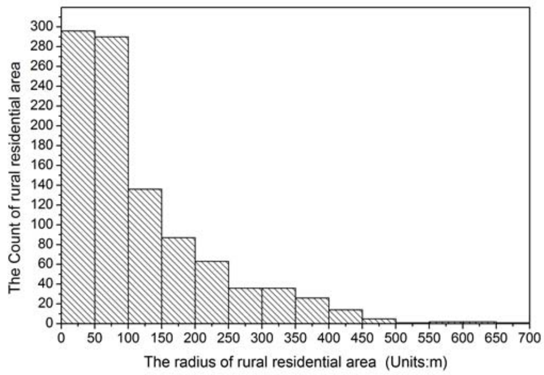

Fig. 2 The distribution of rural residential area radius in Xinfu District

4.2 Analysis on optimization of rural residential location

In the model, the centers of gravity of the patches of the 8140 rural residential points sized 100×100m2 serve as service facility level. The centers of gravity of the patches of the 79157 pieces of farming blocks sized 100×100m2 serve as demands level. Impedance conversion is Linear, impedance is length (m), the way direction is Facilities to Demand, U-turn is allowed, and the output pattern type is straight line. To optimize the rural residential location in Xinfu District by SCLP model under maximum farming radius, the existing 995 rural residential points in Xinfu District can be optimized to 370 central villages ensuring the maximum farming distance is within 3500m (Fig 3). The network distance from any farming block sized 100×100m2 to the nearest central village is under 3500m (Fig 4). According to the best plan to divide the 71563 pieces of farming blocks to the central villages, the least number is 1, the largest number is 969, the average number is 193, the middle number is 93, and the standard number is 216.

5. Discussion and conclusions

5.1 Discussion

Apply Surfer 10 software to make the distribution of central rural residential farming block number in XinFu District (fig 5). In the figure, it is clear that the central villages in Xinding Basin in East Xinfu District are given more farming blocks, while the central villages in western mountain areas are given less farming blocks, among which, the North Taiping Village has 968 pieces of farming blocks, and the Shiti Village and South Gao Village in Qicun Town, Yaokuan Village in Yangpo Township, Wen Village in Wencun Township, Xiashagou Village in Houhebao Township, Liujiazhuang Village in Xinjian Road Subdistrict Office, Longfengpo Village in Lancun Township, Xinbao Village and Xiangyang Village in Douluo Town, Zhuangmo Village in Zhuangmo Town have only 1 piece of farming block respectively. Apply Surfer 10 software to make the total farming radius of central rural residential farming block in XinFu District (fig 6) by nearest natural neighbor. In the figure, it is noted that the total farming distance of the rural central villages surrounding the central city in Xinding Basin is the longest. The total farming distance of the central villages located in the plain areas such as outer central city, southwest hilly and mountainous areas, river valley and floodplain, with relatively centered farming blocks is shorter. The total farming distance of the central villages in hills and low mountainous areas is shorter than the former. The total farming distance of the central villages in the north, west and south mountainous areas is the shortest.

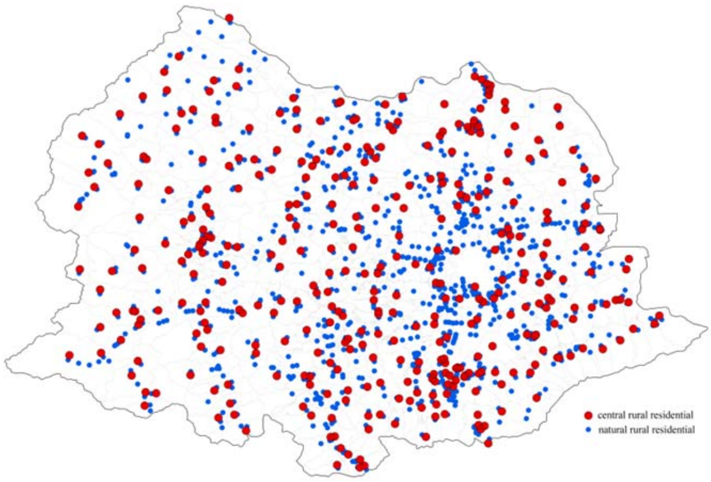

Fig.3 The distribution of central rural residential in XinFu District

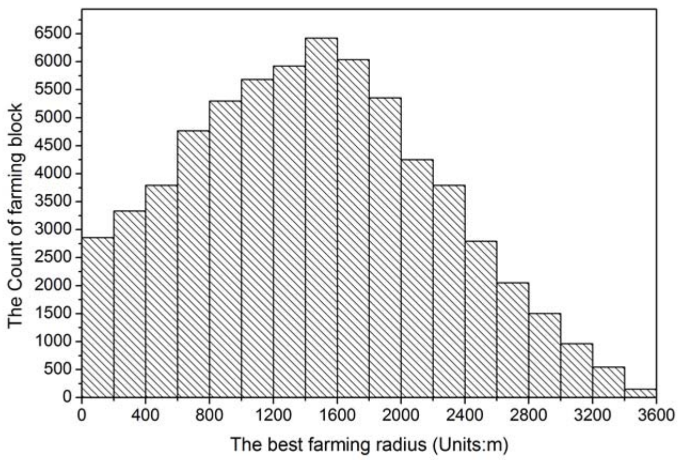

Fig.4 The best farming radius distribution of farming block in XinFu District

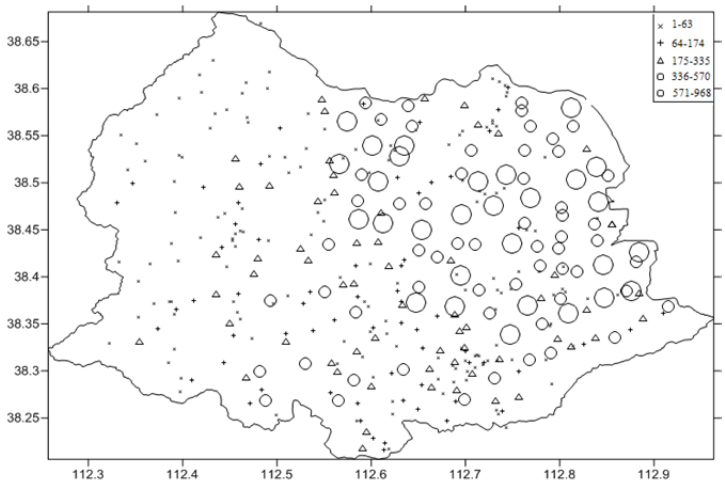

Fig.5 The distribution of central rural residential farming block number in XinFu District

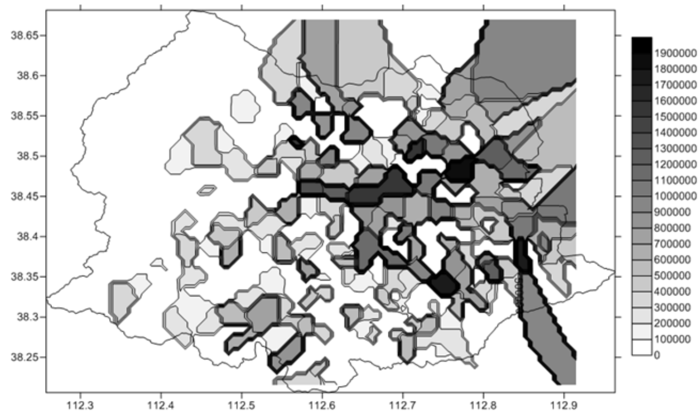

Fig.6 The total farming radius of central rural residential farming block in XinFu District

5.2 Conclusions

Applying SCLP model under the maximum service radius, we can calculate accurately in the study area the minimum rural residential location under the fixed farming radius, to optimize the existing rural residential location efficiently. According to SCLP model under the maximum farming radius, we can provide accurately the future optimizing direction and location of the rural residential location, and the scientific basis for identifying rural construction location, improving use efficiency of rural constructional land, and is beneficial to the intensive economy land use capability. Practically, considering the secondary and ternary industry location and historical and cultural situation, identifying redundant rural residential points, combining land reclamation and efficiency land use, we can move the peasants in the redundant rural residential points to the pointed central villages, and change the left land to the farming land step by step, to release the construction land potential and optimize the construction land location.

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