

COMPARISON OF SPATIAL COMPACTNESS EVALUATION METHODS FOR SIMPLE GENETIC ALGORITHM BASED LAND USE PLANNING OPTIMIZATION PROBLEM

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ABSTRACT:

As one of the most important objectives for land use planning towards sustainability, the compactness could not only decrease threat to species survivability and the energy consumption, but also improve the accessibility of city and the social equity towards sustainability et al. Although there have existed several methods to evaluate compactness, the spatial autocorrelation methods have not been applied in raster based land use planning optimization problem, which is one kind of spatial optimization problem and of great complexity and generally operated by heuristic methods, such as Genetic Algorithm (GA), Simulated Annealing (SA) et al. Besides, there has not been comprehensive comparison of these methods including linear, non-linear, or spatial statics methods during the optimization process. In this research, most of these methods related are reviewed, furthermore, three of these representative methods including the non-linear neighbour method, shape index and Moran's I have been compared based on simple GA on hypothesis data. The non-linear neighbour method with the simplest principle yields the best effect and efficiency. On the other hand, Moran's I method shows another angle to evaluate the compactness although the result is not very good. Furthermore, the mono Moran's I and comprehensive Moran's I also have been compared, compared to the worse result of mono Moran's I, the comprehensive Moran's I did better while it is also worse than the neighbour methods. The effect clearly shows us one possible combination of compactness and other objectives, such as compatibility, so as to improve the efficiency of the whole land use planning optimization process.

1. INTRODUCTION

1.1 Background

Compact land use is desired in various planning domains, such as forest management and reserve design et al. Promoting compactness/controlling fragmentation thus has been a common and important goal of land use planning towards sustainability, which is a hot topic nowadays.

On the contrary to compactness, urban sprawl is a widespread problem affecting much of the urban development that has occurred in the past fifty years. Environmentally, there are two main concerns related to urban sprawl: the extent it is consuming the landscape, and the air pollution that such a high level of automobile reliance is causing (Williams, 1999; Guiliano and Narayan, 2003). This also leads to the destruction of natural habitat for many species, which as a result have become endangered. Besides, sprawl is also the consumption of land resource with so much highly inefficient form, which is harmful to the provision of services and infrastructure by local governments. Furthermore, it also causes the need of more transportation facilities with much worse air pollution and energy consumption.

As for the social aspect, while the societal effects of urban sprawl are very difficult to measure accurately, there are also obvious evidences of its unsustainability. Reduced social equity, negative health impact, a loss of community, segregation, polarisation and an inability to adapt to changing lifestyles and family structures are just some of the ways in which urban sprawl is said to adversely affect social sustainability (Gillham,

2002; Kelly-Schwartz et al., 2004). Furthermore, social equity is negatively impacted in many detailed ways below: limiting transport options of the poor due to the high costs of car ownership and poor public transport; increasing the likelihood of poor people living in less desirable neighbourhoods; increasing fear and anxiety generated by high traffic volumes; greater exposure to air pollution and resulting poor health; and losing 'a sense of community' as most people travel beyond the local neighbourhood to conduct their daily activities (Hillman, 1996).

As talked above, the negative environmental, economic and social effects of land use sprawl are widespread, diverse and clearly at odds with the concept of sustainability. The concept of compactness attempts to provide a more sustainable alternative style of land use sprawl. It should be one of the important objectives to plan a sustainable city.

Although there may be consensus that the compact land use is clearly distinct from urban sprawl, and is very essential to pursue the final objective of sustainability. There still remain many questions surrounding exactly how to evaluate the compactness of the land use during the land use planning optimization process, which not only require the effect of compactness but also the efficiency to evaluate amounts of land use planning scenarios as one kind of complicated spatial optimization problem. In this research, the methods used to evaluate the compactness will be reviewed and systematically compared during the land use planning optimization process based on simple GA, which might be very meaningful to supply the raster based land use planning optimization possibility to

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evaluate the compactness more effective and efficient. Besides, as one kind of spatial optimization, the research will also be spread to other similar applications inside spatial optimization problem.

1.2 Review of Existing Measures

Though the objective of encouraging land compactness is apparent, there exists no common accepted the best measures of spatial compactness. Herein, for different land use types, there has been several kinds of measures listed below or similar ones on “compactness” for raster based spatial problem:

- 1) Non-linear integer program-neighbour method;
- 2) Linear Integer program-neighbour method;
- 3) Linear Integer Program using Buffer cells;
- 4) Linear IP using “Aggregated Blocks”/Minimization of the number of clusters per land use types;
- 5) Minimization of Shape Index (Aerts 2002; Stewart 2004);
- 6) Spatial Autocorrelation (Wardoyo and Jordan 1996; Kurttila et al. 2002).

The first one is the most direct explanation to compactness of land use, which only takes advantage of the neighbours of each cell to evaluate the compactness by sum. The second one is equivalent linear reformulation of the first model, at the expense of including additional integer variables. The third one (Wright, Reville, and Cohon 1983; Williams and Reville 1998), was described as a problem where one selects parcels and each reserve (one land use type) consists of core cells, and surrounding buffer zone. Compactness is indirectly obtained through minimizing the number of buffer cells around the core areas. The fourth idea is to aggregate individual cells to blocks and develop a model that minimize the number of blocks that contain only one land use type in the final allocation result. In other words, the target is to minimizing the number of clusters according to each land use type. The fifth one is to compute the shape index of each cluster, which sounds very complex but effective to represent the compactness. The last method is from the perspective of spatial statistic, by taking advantage of Moran’s I, Geary’s C et al.

Most utilization of compactness as the objective are included or deviated from the six models talked above. Aerts, Stewart, and Janssen (2003; 2004; 2007) have combined the fourth model and the sixth model with the definition of maximization of the large cluster of each land use type to pursue the target of compactness of each scenario and the effect is good within the small research area. Aerts and Erwin have compared the anterior four models in 2002, according to the result on the testing area (8*8 grid). From the comparison of the four models by them, we can clearly know that the efficiency and the effect of the first measure is the best. It is the fastest way to get the global optimum while it is not a linear method. Although the spatial autocorrelation methods have been used to evaluate the characteristic of compactness, there has not been the comparison of the spatial autocorrelation with the other methods on the effect and efficiency to pursue the compactness of land use planning during the optimization process.

In this research, one new application of Moran’s I index to evaluate the compactness will be tested to compare with the methods non-linear neighbour method with the best efficiency and the shape index method with the best explanation of compactness.

2. METHODS

2.1 Non-linear Neighbour Method

The first measure can be described in terms of recording for each cell, the number of neighbouring cells which have the same land use. In this sense, the “neighbouring” cells to (i, j) are the (i-1, j), (i+1, j), (i, j-1), (i, j+1), (i-1, j-1), (i+1, j+1), (i-1, j+1), (i+1, j-1) (ignoring cells outside the region). At this definition, it can be shown as follows:

Minimize:

$$-\sum_{k=1}^K \sum_{i=1}^N \sum_{j=1}^M A_{ijk} x_{ijk} \tag{1}$$

Where

$$A_{ijk} = x_{i-1jk} + x_{i+1jk} + x_{ij-1k} + x_{ij+1k} + x_{i-1j-1k} + x_{i+1j+1k} + x_{i-1j+1k} + x_{i+1j-1k} \\ \forall k = 1, \dots, K, i = 1, \dots, N, j = 1, \dots, M \tag{2}$$

Herein we understood a neighbourhood of eight cells (top, down, left, right, left-top, right-down, right-top, left-down), but alternatively there are some other smaller or larger neighbourhood can be defined, such as four neighbours etc. It can be clearly seen that minimization process can give birth to solutions in which neighbouring cells have the same land use type.

2.2 Shape Index Method

The shape index method can be calculated using the following equations:

$$Shape_{total} = \sum_{k=1}^K \sum_{c=1}^C \frac{P_{kc}}{\sqrt{R_{kc}}} \tag{3}$$

Where P_{kc} stands for the perimeter of one cluster c for land use type k. And R_{kc} represents the area of each cluster c for land use k. The values for the perimeters of cluster A, B, C and D are 20, 20, 18, and 14. The values for cluster A, B, C and D are 16, 13, 12, and 7, so the value for this shape index is 21.04.

For some special situation, such as the single cell as a cluster in an optimal result, through the minimization of the Shape total, the function can prove both the shape of each cluster and the number of the clusters. Of course, the complexity is also obvious.

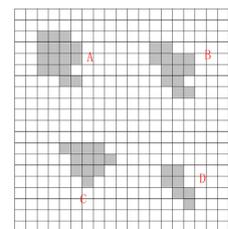


Figure 1 Shape Index of the Four Clusters

2.3 Moran's I Method

Moran's I is a measure of spatial autocorrelation developed by Patrick A.P. Moran. Like autocorrelation, spatial autocorrelation means that adjacent attribute for the same phenomenon that is correlated. Spatial autocorrelation is about proximity in (two-dimensional) space. Spatial autocorrelation is more complex than autocorrelation because the correlation is two-dimensional and bi-directional.

Moran's I is defined as

$$I = \frac{n}{\sum_{i=1}^n \sum_{j=1}^n W_{ij}} \times \frac{\sum_{i=1}^n \sum_{j=1}^n W_{ij} (x_i - \bar{x})(x_j - \bar{x})}{\sum_{i=1}^n (x_i - \bar{x})^2} \quad (4)$$

Where n is the number of spatial units indexed by i and j. x is the variable of interest; \bar{x} is the mean of x; and W_{ij} and W_{ji} are matrices of spatial weights.

The expected value of Moran's I is

$$E(I) = \frac{-1}{N-1} \quad (5)$$

Its variance equals

$$Var(I) = \frac{\{n[(n^2 - 3n + 3)S_1 - nS_2 + 3S_0]\} - \{k[(n^2 - n)S_1 - 2nS_2 + 6S_0^2]\}}{(n-1)(n-2)(n-3)S_0^2} - E(I)^2 \quad (6)$$

Where

$$S_0 = \sum_{i=1}^n \sum_{j=1}^n W_{ij} \quad (7)$$

$$S_1 = \sum_{i=1}^n \sum_{j=1}^n (W_{ij} + W_{ji})^2 / 2 \quad (8)$$

$$S_3 = \sum_{i=1}^n (W_{i.} + W_{.i})^2 \quad (9)$$

($W_{i.}$ and $W_{.i}$ mean i row and i column of the related matrix)

$$k = \frac{\left[\sum_{i=1}^n (x_i - \bar{x}) / n \right]^4}{\left[\sum_{j=1}^n (x_j - \bar{x})^2 / n \right]^2} \quad (10)$$

According to the steps talked above, the Moran's I will be between -1 and 1, if the index is greater than 1, it means that the correlation is positive; if less than 0, it means negative, and the more, the larger of the correlation, and vice versa. And if the value is near to 0, it represents random distribution.

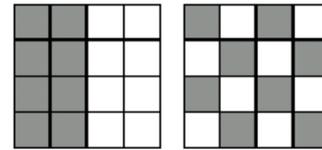


Figure 2 The Representations of Positive and Negative Correlation for value of 1 and -1

3. COMPARISON ON HYPOTHESIS DATA

In the previous section, three good methods encouraging compactness are presented. In this section we will evaluate and compare these models on their effect and the efficiency for use. The comparison will be operated on 20 by 20 grid with 5 assumed land use types and PC with an Intel Xeon CPU @2.33GHZ processor, 3GB RAM base on simple GA. The performance of the methods used can be evaluated by two criteria. Criterion 1 evaluates the computation time against the achieved degree of compactness. Thereafter, the characteristics of the compactness created by these methods should also be considered as the criterion 2.

3.1 Comparison of Efficiency

Table 1 Comparison of the CPU time based on Three Models (the unit is second, and Model-1, Model-2, and Model-3 are separately related to non-linear neighbour method, shape index method and Moran's I method)

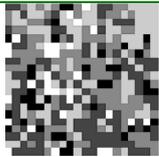
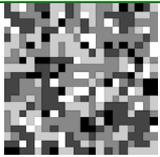
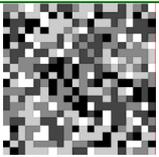
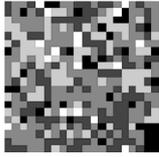
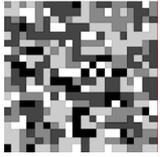
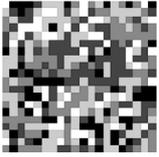
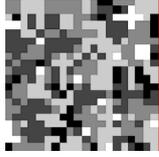
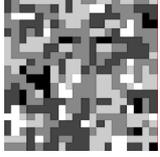
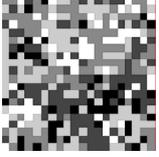
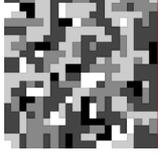
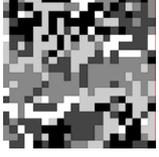
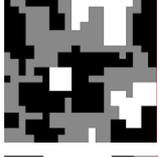
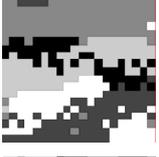
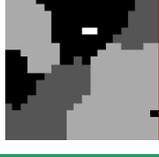
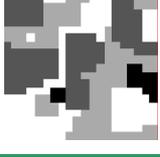
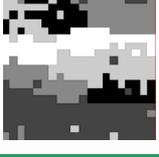
Iteration Number	Model-1	Model-2	Model-3
100	8.39	33.34	279.17
200	10.32	45.62	387.67
500	19.46	75.64	755.04
1000	35.17	127.16	1402.36
5000	156.83	442.9	5877.64
10000	316.13	780.47	12930.07
50000	1526.12	3367.32	56595.42

From the Table 1 above, it is evident that the Model-1 (non-linear neighbour method) is the fastest model to achieve the compactness than the other two models: shape index and Moran's I. On the contrary, the Moran's I method is the worst with the much more time spending than the neighbour model.

3.2 Comparison of Effect

From the comparison of the effect in the Table 2, the effect of the each model is good enough to operate the optimization process. The effect of the non-linear neighbour model is smoother than the other two models, which is more suitable to reflect the reality of the real change of the land use. For the other two models, shape index and Moran's I, the effect are also good enough to satisfy the need of optimization, however, the time spending are too much for the process of optimization if the research area is larger.

Table 2 Comparison of the Effect based on the Three Models

Iteration	Model-1	Model-2	Model-3
100			
200			
500			
1000			
5000			
10000			
50000			

3.3 Comparison of Mono-Moran's I and Comprehensive Moran's I

While from the Table 3 below, when considering the comprehensive Moran's I, which is considering the five land use types at one time, not only the compactness but also the correlation among different land use types can be reflected from the effect, the result is evidently better than the Mono Moran's I using less than 1/4 time. It means that, we can take use of this model to achieve two or more objectives (such as the compatibility et al) at one time to promote the efficiency and effect, of course, the weighting of the compactness and the compatibility might be the problem.

Table 3 Comparison of efficiency and effect of Mono and Comprehensive Moran's I Index (Mono Moran's I means only considering one land use on one time; Comprehensive Moran's I means considering five land use types together, and the unit is second)

	Mono Moran's I	Comprehensive Moran's I
Time Spending	56595.42	10791.35
Result		

4. CONCLUSION

Compactness is one of the most important objectives for land use planning, which could decrease threat to species survivability, decrease the energy consumption, improve the accessibility of city and the social equity towards sustainability et al. However, during the land use planning optimization process, which is generally very complicated and solved by heuristic methods, it lacks of efficient quantified evaluation methods to pursue the compactness of the land use as one important objective. Although there have existed several methods to evaluate compactness, there have not been application of autocorrelation methods on spatial optimization problem, which not only require the effect but also the efficiency, besides, the comprehensive comparison of these methods is also meaningful to the development of quantification evaluation of compactness on land use planning optimization. In this research, all the methods to quantified evaluation of compactness are reviewed, furthermore, three of these representative methods including the neighbour method, shape index and Moran's I have been compared using the same simple GA environment on hypothesis data. Obviously that the neighbours method with the simplest principle yields the best effect and efficiency; Moran's I method brings its potential to evaluate the compactness although the result is not very good. Besides, the mono Moran's I and comprehensive Moran's I also have been compared, compared to the worse result of mono Moran's I, the comprehensive Moran's I does better while it is also worse than the neighbour methods. The result also suggests one possible combination of compactness and other objectives, such as compatibility, which might improve the effect and efficiency of the whole optimization process.

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