MODELING OF PARKS AND OPEN-SPACE ALLOCATION FOR A LARGE SCALE NEW TOWN DEVELOPMENT

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abstract: This paper, first, proposed a basic allocation concept of parks and open-space in a new town. The second, a mathematical model, which maximizes land suitability and utility of residents dealing with accessibility for parks, has developed. The Hopfield type of neural network algorithm has employed because of its effective approximation in order to solve this nonlinear problem regarded as a N.P.-complete optimization problem. Validity of the model is confirmed by the results of numerical examples for a simplified linear city.

1. INTRODUCTION

The Urban Park Act in Japan stipulates the basic allocation method of various types of parks in a new town, which are constructed for everyday usage. A basic concept of allocation pattern in the Act known as the Christaller's central place theory is referred to which is based on the popular essence of the neighborhood unit. Most parks in a new town have been allocated according to the Act since 1956.

The central place theory states that each park has its own spatially closed hinterland having its size, service radius and characteristics as given by Table-1. The allocation planning based on the theory is rational, since many previous studies (e.g. Shimomura, *et al.*, 1995) states that the main reason for visiting parks of everyday usage is accessibility from home. In addition to it, the theory is effective as a preventive function against disasters for Japan, a prone earthquake country.

Table-1 The Main Parks for Residents

Park Type	Standard Size	Service Radius	Spatial Hinterland (one neighborhood unit = 100ha)
Block Park	0.25 ha	250 m	one quarter unit
Neighborhood Park	2.00 ha	500 m	one unit
District Park	4.00 ha	1000 m	four unit

The Act however produced monotonous landscape here and there in Japanese new towns because of their uniformity and homogeneity. The central place theory considers little on the allocation of parks from the viewpoint of the land attributes. Here, the land attribute for parks means the characteristic of existing natural green spaces, slope of land, cultural properties, and so on. It might be the most important to preserve those precious characteristics of land and/or beautiful natural green spaces, since these areas are more suitable and attractive as an open space for playground as well as better landscape view.

In order to take the land attributes into account, this paper proposed a new allocation concept of open space, such as park. Further, it developed a mathematical model which maximized land attributes for each land use and utility of residents dealing with accessibility for parks, which is known as the conventional central place theory. It is quite obvious that a mathematical model can not include all necessary factors for open space allocation. The model in this paper however, will be used for providing some reasonable alternatives with very clear evaluative criterion for new town planners.

2. MODEL FORMULATION AS AN OPTIMIZATION PROBLEM

2.1 Basic Structure of Open Space Allocation Model

A new concept of the model is to maximize land suitability score in order to take account of the attributes of land use. This paper tries to develop a numerical model to realize the planning of this concept, then, suggests a two step model on which parks and open-space (hereafter, simply called parks) should take precedence over other land use. The first step, land use only for housing and park will be allocated, and second step other land use such as public, commercial and industrial facilities may be located in the residential land use. A prototype model of the first step is proposed under the above concept of allocation planning. The urban space in this paper deals with a limited length of linear city of unit width.

2.2 Introduction of the Hopfield Type Neural Network Model

The two dimensional allocation of land use is a very complicated nonlinear problem in nature. If this nonlinear problem is regarded as a combinatorial optimization problem, the conventional optimization algorithms cannot solve this problem since it is N.P.-complete. This paper introduces the Hopfield neural network model algorithm (Hopfield, 1982 and 1984) as one of the effective approximation, since the model can accurately solve them within practical calculation times (Tank, *et al.*, 1985). Although this method cannot find the global optimum but find instead many local optimum solutions, the solutions seem to be more desirable if other factors for the land use planning is taken into account.

Maximization of land suitability score based on the appropriate analysis is introduced as an objective function. The developing area is divided into many zones to estimate land suitability score. There are some studies of land suitability analysis made in the past. The land suitability score is supposed to be given exogenously. Shimizu, *et al.* (1990) formulated an allocation problem of land use as a combinatorial optimization problem. The model of Shimizu has been revised and formulated as Equation (1): Land use s will be allocated on each zone i for maximizing the sum of land suitability as much as possible.

$$max. \quad f(X) = \sum_{i}^{N} \sum_{s}^{s1,s2} (V_{is} X_{is}) \tag{1}$$

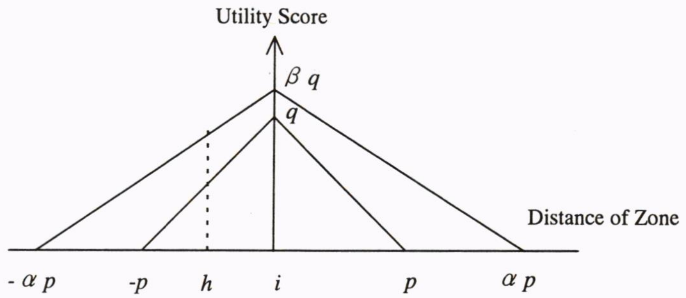
Where $s1$ is residential land use, $s2$ is parks land use, and V_{is} are land suitability score of land use s of zone i. X_{is} are, only if land use of zone i is s, then 1, otherwise 0.

2.3 Formulation of Constraints

1) Condition of the Central Place Theory

There are many previous studies that analyzed the relation between usage of park and residential behavior. Major outcomes of these studies can be summarized as follows; first, the closer the park, the more residents visit. Secondly, the visiting distance between a place of resident and a park, so called service radius, depends on the size of park. These conclusions based on their field survey express that the central place theory is adequate to be employed. However, this paper tries to introduce the central place theory as a constraint and formulate it as a function by introducing a utility concept.

A basic concept of utility function means accessibility. If the size of a park is larger, the utility value increases. This function could be formulated as shown in Figure-1. This continuous function will be converted into discrete value taking shape like a step function. The horizontal axis shows the distance between housing zone and parks. The vertical axis gives a level of aggregated utility score that is received by the residents in a zone. If zone *i* is allocated to parks land use by the model, this zone gives a utility score to a residential zone *h* within the service radius.



h : a residential zone within the service radius of zone i of parks land use
p : the service radius
q : the maximum utility score
α, β: incremental value of p, q.

Figure-1 General Concept of the Central Place Theory

In order to take a size of parks into account, both the maximum utility score and the service radius have increased in accordance with the size of parks. Thus, a small inside triangle in Figure-1 denotes the utility function with single unit of parks and a larger outside triangle means the utility function with two units of parks. Two functions are formulated in Equation (2).

$$u_{ih}^{jt} = -\beta q / \alpha p \left| i - h \right| + \beta q \qquad (2)$$

Where zone j means an adjacent zone i, t means land use of zone j, and this function is subject to, when land use of zone j is $s1$, $(\alpha, \beta) = (1.0, 1.0)$; and also when zone j is $s2$, (α, β) = (over 1.0, over 1.0). In addition, another condition is required since any parks zones cannot get utility score. When $-\alpha$ p < h < α p and $X_{h \cdot s2} = 1$, then $u_{is}^{jt} = 0$. If zone h is outside from the service radius of parks zone i, Equation (2) obtains minus value. Therefore, when h < - α p, α p < h, then $u_{is}^{jt} = 0$.

If the size of the adjoined parks zones is getting larger, the value of α and β should be increase more by proportion to the size. This paper, however, assumes that α, β keep constant value of two zone size because of simplification.

It is necessary to discuss whether utility score that produced from more than two parks can be accumulated or the maximum utility among the parks in question should represent those utilities. Since all parks here assumed to produce the same kind of utility, most of residents will expect to use one of them. Under this discussion, a zone must get the maximum utility among parks in concern. Equation (2) is revised as Equation (3) based on this concept.

$$U_{ih}^{jt} = u_{ih}^{jt} - \max_{i=1,i-1} u_{ih}^{jt} \tag{3}$$

This function means that parks land use should be allocated to maximize the utility score which all residential zones can get. Equation (4) is the final form for the utility of residents by parks as objective function.

$$max. \quad g(X) = \sum_{i,j}^{N} \sum_{h}^{N} \sum_{s,t}^{s1,s2} (V_{is} U_{ih}^{jt} \delta_{s \cdot s2} X_{is} X_{jt}) \tag{4}$$

Where δ is Kronecker delta. Since the land suitability score V_{is} suppose to represents the quality of parks, the utility score should multiply by V_{is}. The value of V_{is} means a weighting factor considered to be an attracting potential of each park in nature.

2) Predetermined Allocation of Land Use in the Study Area

Land use allocation such as housing and park in the study area must be predetermined by other conditions. If total area of each land use supposed to be given by a master plan exogenously, this constraint might be formulated by Equation (5).

$$1 - (\sum_{i}^{N} a_i X_{is}) / A_s = 0 \tag{5}$$

This condition subjects to for all s. Where a_i is the unit sizes of each zone i, and A_s is the given area of land use s.

3) Land Use Trade-off Condition

A zone must basically be allocated to only one land use. This condition subjects to for all i.

$$1 - \sum_{s}^{s1,s2} X_{is} = 0 \tag{6}$$

4) Reduction to the Hopfield Model

The Hopfield model locally minimizes an energy function defined by Equation (7). In order to minimize the energy function, after neurons change their inner states according to Equation (8), the output value is renovated by Equation (9) called Sigmoid function.

$$E(X) = -(1/2) \sum_{i,i'}^{N} \sum_{s,s'}^{s1,s2} T_{isi's'} X_{is} X_{i's'} - \sum_{i}^{N} \sum_{s}^{s1,s2} I_{is} X_{is} \tag{7}$$

$$H_{is} = \sum_{i',s'} T_{isi's'} X_{i's'} + I_{is} \tag{8}$$

$$X_{is} = (1/2)\{1 + \tanh(H_{is}/\theta)\} \tag{9}$$

Where $T_{isi's'}$ are elements of an interconnection matrix representing the strengths of connections and I_{is} are input biases. H_{is} are neuron's inner states and θ is a sensitivity parameter. Equation (9) is applied to a technique of Sharpening by which the energy function can escape from local minimum by decreasing the value of θ gradually from the initial unit steps. The model also adopts asynchronous transition mode with random delays in order to escape wandering around the state space near the local minimum of the energy function (Takeda, *et al.*, 1986).

Since Hopfield's energy function has a quadratic form with respect to X_{is}, it is necessary to define a quadratic function corresponded to minimizing objective functions. An energy function that satisfies such requirements is given by

$$E'(X) = -w_1 \sum_{i}^{N} \sum_{s}^{s1,s2} (V_{is} X_{is}) - w_2 \sum_{i}^{N} \sum_{h}^{N} \sum_{s}^{s1,s2} (V_{is} U_{ih}^{jt} \delta_{s \cdot s2} X_{is} X_{jt})$$

$$+ w_3 \sum_{s} \{1 - (\sum_{i} a_i X_{is}) / A_s\}^2 + w_4 \sum_{i} (1 - \sum_{s} X_{is})^2 \quad (10)$$

Where, w_1, w_2, w_3 and w_4 are positive weighting parameters. By expanding to correspond to coefficients of both the quadratic Equation (7) and Equation (10), the interconnection strengths T_{isjt} and the biases I_{is} can be determined by Equation (11). When Equation (10) is expanded, it is necessary to escape from self-feedback terms.

$$E(X) = E'(X)$$

$$= -(1/2) \sum_{i,i'}^{N} \sum_{s,s'}^{s1,s2} \{w_2 V_{is} \delta_{s \cdot s2} \delta_{j \cdot i'} \delta_{t \cdot s'} \sum_{h}^{N} U_{ih}^{jt} - 2 w_3 (a_i a_j / A_s^2) \delta_{st} (1 - \delta_{ij}) - 2 w_5 \delta_{ij} (1 - \delta_{st})\} X_{is} X_{i's'}$$

$$- \sum_{i}^{N} \sum_{s}^{s1,s2} [w_1 V_{is} - w_3 \{(a_i^2 / A_s^2) - 2(a_i / A_s)\} + w_4] X_{is} \quad (11)$$

3. NUMERICAL EXAMPLES

Some numerical examples are carried out using various sets of parameters to examine the performance of the model.

3.1 Exogenous Conditions

The linear city with one hundred zones is supposed to be enough size to simulate various cases and to test various parameters. Since the linear city cannot escape from the influence of a boundary condition, 25 dummy zones are set at both ends of city as for the outside of the planning area for evaluation. A set of land suitability score is given exogenously as shown in Figure-2.

.5	.9	.8	.7	.7	.8	.8	.3	.6	.3	.5	.7	.8	.9	.5	.6	.4	.6	.5	.2	.3	.5	.4	.1	.6	.8	.7	.3	.7	.5	.6	.5	.6	.8	.5
.4	.6	.1	.4	.3	.4	.6	.7	.5	.4	.3	.6	.1	.3	.4	.8	.8	.7	.5	.6	.8	.7	.9	.4	.8	.5	.5	.3	.1	.4	.5	.6	.4	.2	.3
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35

The upper row is residents' point, the middle is parks point and the lowest is zone number.

Figure-2 The Condition of Land Suitability Score of Each Zone (A Part)

Unit zone size was set to be 0.25ha (= 50m x 50m) which is the minimum size of block park in the Urban Park Act. (call back to Table-1) Service radius p of a park with single zone is assumed to be 5 zones distance (= 250m). Regarding the two unit park which considered to be Neighborhood Park of the Act, an multiple constant α is assumed to be 2.0, then service radius of αp was 500m accordingly.

The maximum utility score q is set to be 2.0 which is given a priori but come from the balance of output value. According as the increase of the size of park, the maximum level of utility should increase. However, as well known, marginal utility of a park must be diminished with respect to the size of it. Constant value of β is assumed to increase at the rate of 20%, i.e. β =1.2.

The proportion of allocated area of park was basically set to be 30% of whole study area. However, it is not necessary strictly to satisfy this constraint. An inequality constraint between the range of 25% and 35% is introduced instead.

Initial values of some system parameters for Hopfield model are required to set in advance. In order to reflect the land suitability into a land use planning, the initial value of a neuron is set to be its original score through all simulation cases. If state of a neuron were

$X_{is} \geq 0.90$, it assumed to be converged to the value of 1.0. If that were $X_{is} \leq 0.20$, it also assumed to be the value of 0.0. The value of sensitivity parameter θ in Equation (9), which control a number of iteration steps, is set a priori to be 10.0.

3.2 The Results of Simulation Tests

As well known, a result of neural network simulation is deeply depended on a combination of weighting parameters (Takeda, *et al.*, 1986). A planner can reflect his own idea such as keeping a constraint strictly or following a land suitability more by changing the balance of weighting parameters. Some cases of parameters' set are examined here to know the sensitivity of the weighting parameters in Equation (10).

Three cases of parameter's set were simulated as demonstrated in Table-2. Since the model adopted asynchronous transition mode, in each case fifty pattern types were examined by selecting arbitrarily the neurons numbering. If all constrains are satisfied in every pattern type, the converge percent is 100%.

The relation between w_3 and w_4 of constraints were examined by Case 1, while the values of w_1 and w_2 of objective terms is 1.0 and be kept constant. Since the trade-off condition of land use is strictly satisfied, when w_4 is greater than or equal 20.0, the value of w_4 was fixed at 20.0. This also applies to the other two cases. Iterative simulation tests were carried out by increasing a value of w_3 step by step until a land use allocation constraint is satisfied. When w_3 reached a value of 30.0, the proportion value of park area satisfied their constraint is at 33%. Figure-3 shows the final result of simulation case 1.

Case 2 further continue to simulate until a land use allocation of park is 30%. When w_3 = 150.0, the constraint was strictly satisfied. Figure-4 shows the result of case 2. The result of the case 2 seems to be better than case 1 in all aspects, however, the rate of convergence declined significantly. It must be a big obstacle when the number of zones will increase.

The case 3 examined the relation between w_1 and w_2 of objective terms. If w_1 exceeds a boundary value, the trade off condition of single land use should be violated. When the value of w_1 has increased until 20.0 and w_4 stay constant at the value of 20.0, the solution has reached the extreme result which completely followed the given land suitability score. In this case, the condition of the proportion of park area is not satisfied. This extreme result is shown as Figure-5.

Table-2 The Results of Example

	w1	w2	w3	w4	Residents Score	Park Score	Utility Score	Park Area %	Converge %
Case 1	1.0	1.0	30.0	20.0	60.10	32.50	113.59	32%	30%
Case 2	1.0	1.0	150.0	20.0	62.60	29.10	114.51	30%	5%
Case 3	20.0	1.0	30.0	20.0	54.40	40.40	100.97	42%	0%

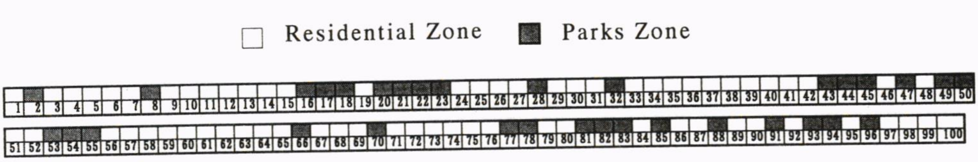


Figure-3 The Allocation Result of Case 1

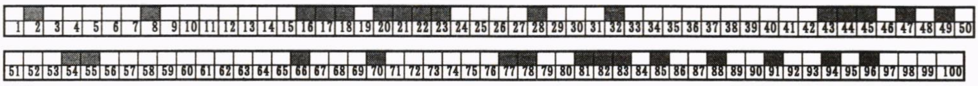


Figure-4 The Allocation Result of Case 2

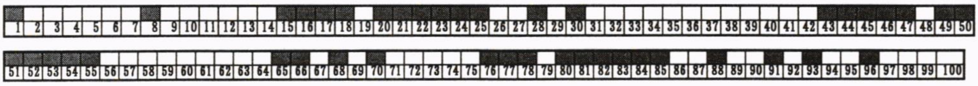


Figure-5 The Allocation Result of Case 3

4. CONCLUSION

Major findings of this paper are as follows:

(1) The paper proposed a new allocation concept of parks and open-space in a new town. The concept takes account of the land attribute in addition to utility of residents, which is considered in the conventional central place theory. For this purpose, a two steps model was proposed, and it give a priority to parks and open-space than other land use.

(2) A mathematical model based on the Hopfield type of neural network was formulated. The model maximize a land suitability and residents' utility by parks.

(3) Through numerical examples applied to a simplified linear city, the model was proved to be useful to generate various kinds of land use pattern alternatives that can reflect an idea of a planner.

The model proposed here is a prototype, however, it is easy to expand and/or to revise in the following aspects. The revised model with the following points can be applied to the real world.

(1) Expansion to a general two-dimensional urban space instead of linear city.

(2) To introduce realistic value of the maximum utility score q based on a field survey.

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