A LAND USE-NETWORK DESIGN MODEL TO GENERATE ALTERNATIVE SKETCH MAPS FOR URBAN PLANNING

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Abstract: The sketch map for urban planning in this paper represents the rough layout of a physical plan, which usually contains two elements, land uses and transport network. This paper develops a land use-network design model to assist urban planners in generating the sketch maps. The model can produce a set of alternatives approximating the Pareto optimum, on which the tasks of evaluation and detailed design are based. In this paper, problem definitions and a conceptual framework are first introduced. Then, the model using multiobjective programming is developed with a numerical example, and a case study is conducted with a comparison analysis for demonstration purpose.

1. INTRODUCTION

In the development of a physical plan, creating layout is an important task. The layout is presented on a development map, which will provide the rules for urban development and will serve as a guideline for the general public.

The layout task usually begins with the generation of alternatives, among which a favorable sketch will be chosen and modified to achieve a detailed and clear development map. The process of generating alternatives has long been viewed as a "black box" inside which planners are subjective and alternatives are few, so the development map is always biased and inappropriate. Consequently, an efficient and systematic process by which the real optimum layout can be obtained become essential.

The content of a physical plan consists of two elements, land use and transport network, which should be jointly considered. However, most of the studies regarding layout problem merely concentrate on one or the other, under the fixed condition of the other. For example, Brotchie *et al* (1980), Gordon and MacReynolds (1974), Bammi *et al* (1976), Bammi and Bammi (1979), Barber (1976), Brotchie (1978), Ridgley and Giambelluca (1992), and Dokmeci (1993) conducted studies of the land use design problem under a given transportation system; while Mackinnon and Hodgson (1970), Leblanc (1975), Poorzahedy and Turnquist (1982), Maganti and Wong (1984), Janson and Husaini (1987), and Xiong and Schneider (1995) examined the network design problem under a given land use distribution. Although some studies, Lundqvist (1973), Los (1978), and Los (1979), attempted simultaneously to deal with the optimum layout of both the land use and the network, those studies are for the purpose of combining rather than integrating these two elements. This study therefore developed an integrated land use - network design model, using multiobjective programming solved by genetic algorithm to generate alternative sketch maps. This developed model can generate approximating nondominated solutions for two planning objectives, environment harmony and development efficiency, and it is tested by a numerical example and is considered to be feasible in operation. Besides, the characteristics of the parameters used in genetic algorithm show that the larger the generation size or population size, the closer the obtained alternatives to the Pareto optimum. The case study of Tanhai, a new town in Taiwan, is provided for demonstration purpose. The result of the case study indicates that the sketches generated by the developed model are better in achieving Pareto optimum than those using the conventional hand-drawing method.

This paper continues with the problem definition and the conceptual framework in the second section; the model is formulated in the third section; the developed model is tested by a numerical example in the fourth section; the case study is illustrated for demonstration purpose in the fifth section. Finally, the conclusions and recommendations are presented.

2. CONCEPTUAL FRAMEWORK

The layout of a physical plan consists of two entities: objects and space. The relationship between objects and space is that *objects* indicating different types of land uses and transport links are located in *space*, which is equally divided into cells accommodating these *objects*. The size of each type of planned land use is given and measured by the number of cells. The capacity (measured by the number of cells) of planned area equals the sum of the scales of the planned land uses, as shown in Figure 1. Transport links are considered regardless of their patterns and service levels inside the planned area. The results of land use feasibility analysis are treated as given conditions, and the physical constraints of constructing the links are known. This study is to seek alternative sketch maps in which objects are optimally arranged, as the examples show in Figure 1.

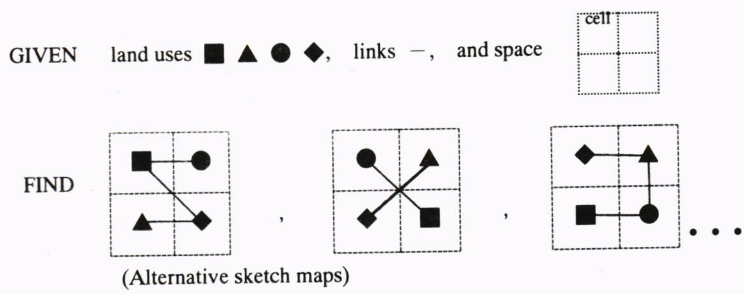

Figure 1. Problem Definition

Two major desires of people in their living circumstances are a *comfortable life* and *convenient activity*. However, these two desires sometimes appear in conflict. For example, people living near an open-air market can enjoy the convenience of shopping, but might experience persistent noise; while those who live far away from such a market can enjoy amenity, but might find shopping somewhat inconvenient. In this study, two objectives signifying comfortable life (measured by environment harmony) and convenient activity (measured by development efficiency), and which appear to be in conflict, are proposed, as shown in Figure 2. Since the purpose of this research is looking for the nondominated solutions, which are used to be the alternatives, the compromise between two objective functions is not necessary to be considered here.

The objective of environment harmony is to maximize the value of harmony index (defined in the latter section) of the cell whose value is the lowest among all cells, while that of development efficiency is to maximize the benefit/cost ratio of public investment. Associated with these two objectives, four constraints are considered: first, all land use objects ought to be assigned to the planned area; second, a cell can only accommodate one land use object; third, at least one transport path is provided for any two different cells in the planned area; fourth, every object must avoid being assigned to unsuitable locations.

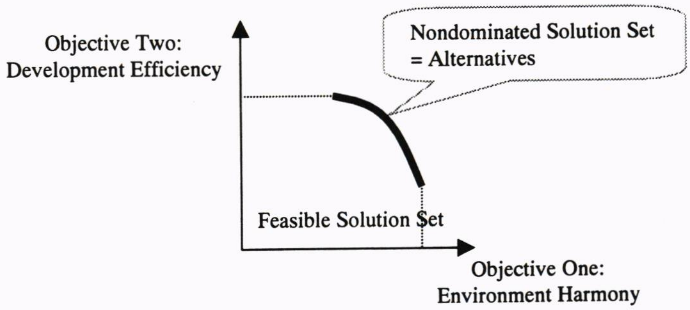

Figure 2. Model Objectives

3. MODEL FORMULATION

The Sketch Layout Model (SLM), which contains two objectives and four constraints, is formulated in this section.

3.1 Definitions

Decision variables. Space is equally divided into cells, which are encoded by horizontal axis and vertical axis, as shown in Figure 3. Two decision variables are defined: ${}^kX_{ij}$ and $Y_{ij,i'j'}$. The ${}^kX_{ij}$ stands for the land use k being (=1) or not being (=0) assigned to cell ij. The $Y_{ij,i'j'}$ stands for the link being (=1) or not being (=0) located between cell ij and cell i´j´, which are in the Von Neumann Neighborhood. All decision variables$\in\{0,1\}$, $k\in[1,K]$, $i\in[1,I]$, and $j\in[1,J]$.

Distance. Two kinds of distance between two cells are defined in this study. One is the *flying distance* $d_{ij,i'j'} = \|[(i-i')^2+(j-j')^2]^{1/2}\|$, where $\|\blacksquare\|$ means the round integer of $\blacksquare$. The flying distance is measured by the length of straight line between two cells and is used to describe the feelings about the environment as defined later. Another distance is the *path distance* $D_{ij,i'j'}$, which means the shortest path distance between two cells given the layout of links. The path distance is used to measure the accessibility between two cells as defined later and in the unit of the number of links. The comparison between two types of distance is shown in Figure 4.

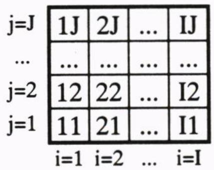

Figure 3. Cells and Coding Rule

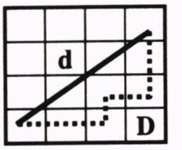

Figure 4. Meaning of Distance

Combination. Cell-object combination, termed as ij-k, is defined as the situation in which land use k is assigned to the cell ij.

Parameters. The ${}^{d}h_{kk'}$ means the harmony feeling of land use k on land use k′ which is d cells away. It is dependent on two elements, the characteristics of land uses and flying distances between two cells, because the more similar the characteristics of land uses and the shorter the flying distance between two cells, the more harmonious the environment and vice versa. Since the *harmony*, *similarity* and *neighborhood* are all vague linguistic variables, in this study the fuzzy relations are used to quantify them. The ${}^{d}h_{kk'}$ can be generated from the fuzzy intersection between similarity of land uses and neighborhood of cells, and the range of value $\in [0,1]$. The higher the value, the more harmonious the feeling. The $r_{kk'}$ is used to measure the relationship between two types of land use. For instance, the residential area might have a high relationship with the industry area because workers living in the residential area commute to the industry area, and the products produced in the industry area are transported to the residential area for consumption. In this study, the value of $r_{kk'}$ is measured by the trip investigation between two types of land use. The range of value $\in [0,1]$. The higher the value, the higher the relevance it has.The $a_{ij,i'j'}$, is used to describe the travel accessibility between two cells given the layout of transport links. In this study, $a_{ij,i'j'}$ is measured by $(D_{ij,i'j'})^{-1/\alpha}$, $\alpha > 0$. The value is ranged in [0,1], and the shorter the path distance, the higher the value (and the accessibility).The ${}^{k}X$ means the given size of land use k, which must be assigned to the space.

Sets. The ${}^{k}C$ means the set of cells which are not suitable for accommodating land use k, and the ${}^{A}C$ means the set of cell pairs (i.e., two different cells) in which the link can not be located. Both sets are given conditions.

3.2 The Model

Objective one. The first objective is to maximize the harmony feeling of the combination, which is the lowest among those of all combinations in the layout. The harmony feeling for a specific combination ij-k can be represented by the sum of harmony feeling of it on every other combination, and is calculated by $\sum_{i'j'k'}({}^{k'}X_{i'j'} \cdot {}^{d}h_{kk'})$, $d = d_{ij,i'j'}$. The first objective therefore can be formulated as follows:

$$\text{Maximize} \quad \text{minimum}\{10^{Z(1-{}^kX_{ij})}[\textstyle\sum_{i'j'k'}({}^{k'}X_{i'j'}\,{}^{d}h_{kk'})],\ \forall\ i, j, k\}. \qquad (1)$$

The "Z" is an infinitely large given number, and the function of $10^{Z(1-{}^kX_{ij})}$ is the correctness of the land use k being assigned to cell ij. In the event that land use k is not correctly assigned to cell ij, the ${}^kX_{ij}$ will become zero and Z, which acts as penalty, will lead the value of this objective to an infinitely large number for which the minimum will not be feasible for this ij-k combination.

Objective two. The second objective is to maximize the benefit/cost ratio. The number of assigned links, $\sum_{(ij,i'j')} Y_{ij,i'j'}$, can be used to indicate the relative level of public investment cost, given the assumptions of: (1) the fixed size and fixed development cost for each type of land use, and (2) the fixed development costs for each link. The agglomerate benefit is used to measure the benefit of a layout. For any combination pair (i.e., any two different combinations), a smaller difference between relevance and accessibility, formulated as $|(\sum_{k,k'} {}^kX_{ij}\,{}^{k'}X_{i'j'} r_{kk'}) - a_{ij,i'j'}|$, will lead to a higher agglomerate benefit, formulated as $[1-|(\sum_{k,k'} {}^kX_{ij}\,{}^{k'}X_{i'j'} r_{kk'}) - a_{ij,i'j'}|]$. The sum of agglomerate benefits generated by all of the combination pairs indicates the total benefit generated from a layout. The second objective therefore can be formulated as follows:

$$\text{Maximize} \quad \{\textstyle\sum_{(ij,i'j')}[\,1-|(\sum_{k,k'} {}^kX_{ij}\,{}^{k'}X_{i'j'} r_{kk'}) - a_{ij,i'j'}|\,]\}/\sum_{(ij,i'j')} Y_{ij,i'j'}\,. \qquad (2)$$

Constraints. The first constraint, indicating that all of the land use objects ought to be assigned to the planned area, is formulated according to the concept that the sum of ${}^kX_{ij}$ for each cell ij will equal the planned size of land use k, ${}^kX$, as in the following formula:

$$\textstyle\sum_{ij} {}^kX_{ij} = {}^kX,\ \forall k. \qquad (3)$$

The second constraint, indicating that a cell can only accommodate one land use object, is formulated according to the concept that the sum of ${}^kX_{ij}$ for each k will equal 1, as in the following formula:

$$\textstyle\sum_{k} {}^kX_{ij} = 1,\ \forall ij. \qquad (4)$$

The third constraint, indicating that at least one path should exist between two cells, is formulated according to the concept that the path distance between any two cells will not equal infinity, as in the following formula:

$$D_{ij,i'j'} \neq \infty,\ \forall (ij,i'j'). \qquad (5)$$

The last constraint indicates that the unsuitable locations for each object must be excluded, as in the following formula:

$${}^kX_{ij} = 0,\ \forall\, i,j \in {}^kC;\ Y_{ij,i'j'} = 0,\ \forall (ij,i'j') \in {}^AC. \qquad (6)$$

4. A NUMERICAL EXAMPLE

In this section, the developed model is tested and discussed by a numerical example.

4.1 Meta-heuristic Algorithm

Solving SLM is an elaborate task because it contains the complexity of 0-1 integer, multi-objective, and nonlinear programming, particularly, when the systems comprise a broad area and a large number of physical items (i.e., land uses and transport links). The genetic algorithms (GAs) can effectively deal with the nonlinear and local optimum programming models using their powerful parallel search capability. Some studies (Palmer and Kershenbaum, 1995; Al-sultan *et al*, 1996; Chakroborty *et al*, 1995; Pereira, 1996; Tzeng *et al*, 1997; Tzeng *et al*, 1996; etc.) have concluded that GAs are better than current heuristic algorithms in terms of solving efficiency. In this study, the Cumulative Genetic Algorithm (CGA) (Xiong and Schneider, 1995) is modified to be a meta-heuristic algorithm to generate approximating nondominated solutions for SLM.

4.2 Data Input

An example indicates that nine cells are in a space, as shown in Figure 5. The objects, which include seven types of land uses and one type of link, are assigned as shown in Table 1. Each type of land use can potentially be located in any cell, while the link can be located between two neighboring cells which are in the Von Neumann Neighborhood. Figure 6 displays two kinds of input data, the harmony feeling (${}^{d}h_{kk'}$) and the relevance degree ($r_{kk'}$). For example, ${}^{2}h_{56}$ indicates that the harmony degree between school (k=5) and market (k′=6) which are 2 cells away is 0.3, while r_{56} indicates that their relevance degree (school and market) is 0.1. These data can be obtained through investigation. The higher the value, the more harmonious the feeling (or the higher the relevance it has) between two types of land use.

j=3	13	23	33
j=2	12	22	32
j=1	11	21	31
	i=1	i=2	i=3

Figure 5. Assumed Space of the Numerical Example

Table 1. Assumed Objects of the Numerical Example

k	Object	Number	k	Object	Number
1	Residential area	3	5	School	1
2	Commercial area	1	6	Market	1
3	Industry area	1	7	Wastewater plant	1
4	Park	1	-	Road	-

k \ k′	1	2	3	4	5	6	7
1	1	.4	.4	.9	.9	.6	.1
2	.4	1	.2	.4	.5	.5	.5
3	.4	.2	1	.5	.4	.7	.8
4	.9	.4	.5	1	.8	.4	.3
5	.9	.5	.4	.8	1	.5	.1
6	.4	.5	.7	.4	.5	1	.5
7	.1	.5	.8	.3	.1	.5	1

${}^1h_{kk'}$

k \ k′	1	2	3	4	5	6	7
1	.5	.3	.3	.4	.4	.3	.1
2	.2	.5	.1	.2	.1	.1	.3
3	.1	.1	.5	.1	.1	.2	.1
4	.2	.2	.3	.5	.2	.2	.2
5	.2	.2	.3	.3	.5	.3	.1
6	.1	.3	.2	.1	.1	.5	.2
7	.1	.1	0	.1	0	0	.5

${}^2h_{kk'}$

k \ k′	1	2	3	4	5	6	7
1	0	.1	.3	0	0	.2	.1
2	0	0	0	0	0	0	.1
3	0	0	0	0	0	0	0
4	0	0	.1	0	0	0	.1
5	0	0	0	0	0	0	0
6	0	.1	0	0	0	0	0
7	0	0	0	0	0	0	0

${}^3h_{kk'}$

k \ k′	1	2	3	4	5	6	7
1	.4	.4	1	.3	.4	.3	.2
2	.4	.2	.15	.05	.05	.1	.1
3	1	.15	.5	.05	0	.05	.3
4	.3	.05	.05	0	.3	.4	.1
5	.4	.05	0	.3	.3	.1	.05
6	.3	.1	.05	.4	.1	0	.25
7	.2	.1	.3	.1	.05	.25	.05

$r_{kk'}$

Figure 6. Assumed Parameters of the Numerical Example

4.3 Tests

Sixteen tests, under the sixteen conditions from the combination of four given values: 5, 20, 50 or 100 for generation size and population size with a fixed mutation rate of 0.01, are undertaken. The numbers of solutions obtained and average time used per solution are listed in Table 2. This table reveals that the bigger the generation size or population size, the longer the average length of time of calculations, and that the number of solutions obtained does not necessarily increase by generation/population size.

The quality of the obtained solutions are measured by the following index:

$$DI_i = \left(\sum_{j=1}^{n_i} \frac{\delta_{ij}}{N}\right) \div n_i \times 100\%; \quad (7)$$

where DI_i means the dominated index for test i, n_i means the number of solutions obtained for test i, δ_{ij} means the dominated frequency of j^{th} obtained solution in test i by the obtained solutions from all tests, and N means the total number of obtained solutions from all tests.

The values of DI range from 0 to 100 and the lower the DI, the closer the obtained solutions are to nondominated solutions. The values of DI for the sixteen tests, as shown in Figure 7, conclude that the bigger the given generation size or population size, the better the obtained solutions are.

Table 2. *Number / average seconds of calculation* for obtained solutions

Generation\Population	5	20	50	100
5	3/2	3/8	2/30	2/57
20	4/6	3/29	5/43	2/214
50	4/14	4/51	3/179	4/273
100	5/20	3/148	3/336	4/558

P.S. IBM/PC486-33 computer and Turbo Pascal 6.0 program language are used.

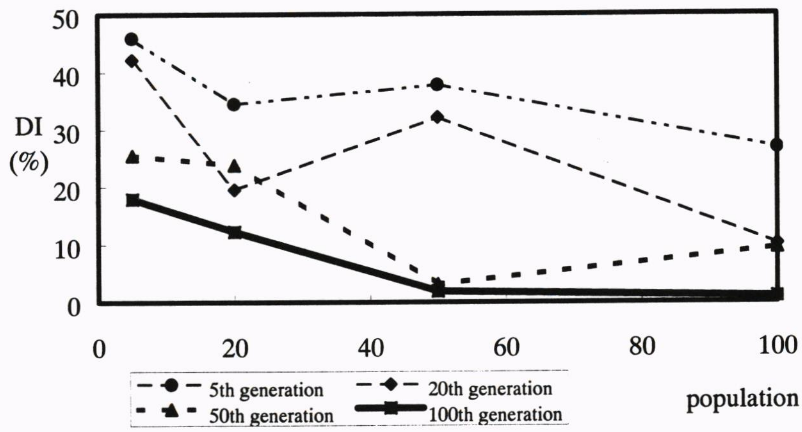

Figure 7. Comparison of DI by Population Size and Generation Size

5. CASE STUDY

Tanhai, a new town whose shape of planned area is shown in Figure 8, is located in the north of Taipei metropolis with a land scale of about 1,700 hectares. The new town, was created to provide the functions of residence, industry, and recreation, with a capacity of 0.3 million residents to mitigate the pressure of over-development of Taipei metropolis. The master plan was officially published in January 1991, and is still being revised.

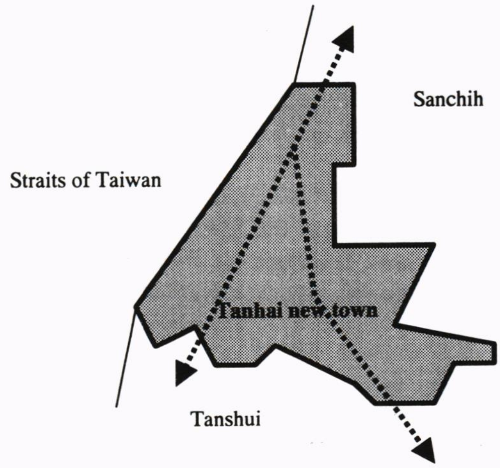

Figure 8. Planned Area of Tanhai

5.1 Data input

The space is divided into forty cells of about a hundred hectares each, as shown in Figure 9. Three conditions are given for this space: (1) among the forty cells of input space, seventeen cells (shaded area) fall within the planned area in which a college and a golf course have been located at cell 37 and cell 43, respectively, and the cells 25 and 26 are restricted to recreational use; (2) twenty-three dummy cells, the cells outside the planned area into which no object will be assigned, are set for the convenience of computer programming; (3) fourteen links (representing roads) exist and twelve potential links can be considered in the planned area. Thirteen units of land use object belongs to seven types of land use as shown in Table 3 are given to be assigned to the planned area.

The harmony degree between two types of land use under a given flying distance (from 1 to 3 cells), ${}^{d}h_{kk'}$, and the relevance degree between two types of land use, $r_{kk'}$, are listed in Figure 10. The higher the value, the more harmonious the feeling (or the higher the relevance it has) between two types of land use. The population size, generation size, and mutation rate used in the CGA are fixed as 100, 50, and 0.01, respectively, according to the conclusion reached earlier that the higher the given generation size or population size, the better the solutions obtained.

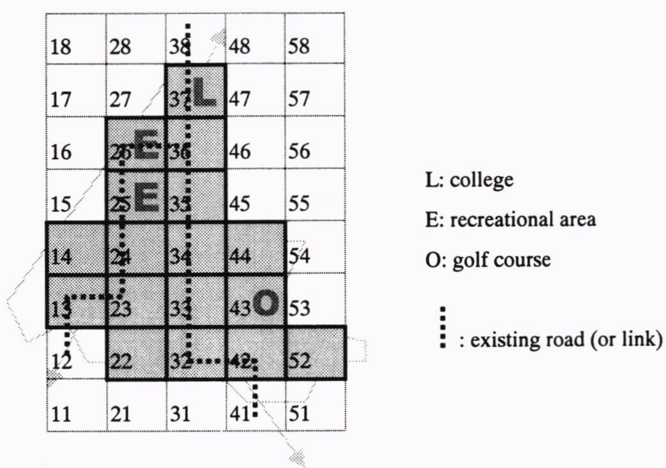

Figure 9. Space Input in the Case Study

Table 3. Objects Input in the Case Study

k	Object	Number		
		Existing	Waiting to being located	Total
1	Residential area (R)	0	7	7
2	Commercial area (C)	0	1	1
3	Industry area (I)	0	1	1
4	Stadium (S)	0	1	1
5	Park (P)	0	1	1
6	Wastewater plant (W)	0	1	1
7	Garbage plant (G)	0	1	1
8	Recreational area (E)	2	0	2
9	Golf course (O)	1	0	1
10	College (L)	1	0	1
-	Dummy zone	23	0	23
	Land use total	27	13	40
-	Link	14	12*	26**

* Potential links.

**Including potential links.

$^1h_{kk'}$

k \ k′	1	2	3	4	5	6	7	8	9	10
1	1	.4	.4	.9	.9	.1	.1	.4	.9	.9
2	.4	1	.2	.5	.4	.5	.5	1	.4	.5
3	.4	.2	1	.4	.5	.8	.8	.2	.5	.4
4	.9	.5	.4	1	.8	.1	.1	.5	.8	1
5	.9	.4	.5	.8	1	.3	.3	.4	1	.8
6	.1	.5	.8	.1	.3	1	1	.5	.3	.1
7	.1	.5	.8	.1	.3	1	1	.5	.3	.1
8	.4	1	.2	.5	.4	.5	.5	1	.4	.5
9	.9	.4	.5	.8	1	.3	.3	.4	1	.8
10	.9	.5	.4	1	.8	.1	.1	.5	.8	1

$^2h_{kk'}$

k \ k′	1	2	3	4	5	6	7	8	9	10
1	.5	.3	.3	.4	.4	.1	.1	.3	.4	.4
2	.2	.5	.1	.1	.2	.3	.3	.5	.2	.1
3	.1	.1	.5	.1	.1	.1	.1	.1	.1	.1
4	.2	.2	.3	.5	.3	.1	.1	.2	.3	.5
5	.2	.2	.3	.2	.5	.2	.2	.2	.5	.2
6	.1	.1	0	0	.1	.5	.5	.1	.1	0
7	.1	.1	0	0	.1	.5	.5	.1	.1	0
8	.2	.5	.1	1	.2	.3	.3	.5	.2	.1
9	.2	.2	.3	.2	.5	.2	.2	.2	.5	.2
10	.2	.2	.3	.5	.3	.1	.1	.2	.3	.5

$^3h_{kk'}$

k \ k′	1	2	3	4	5	6	7	8	9	10
1	0	.1	.3	0	0	.1	.1	.1	0	0
2	0	0	0	0	0	.1	.1	0	0	0
3	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0
5	0	0	.1	0	0	.1	.1	0	0	0
6	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	0	0
8	0	0	0	0	0	.1	.1	0	0	0
9	0	0	.1	0	0	.1	.1	0	0	0
10	0	0	0	0	0	0	0	0	0	0

$r_{kk'}$

k \ k′	1	2	3	4	5	6	7	8	9	10
1	.4	.4	1	.4	.3	.2	.2	.4	.3	.4
2	.4	.2	.15	.05	.05	.1	.1	.2	.05	.05
3	1	.15	.5	0	.05	.3	.3	.15	.05	0
4	.4	.05	0	.3	.3	.05	.05	.05	.3	.3
5	.3	.05	.05	.3	0	.1	.1	.05	0	.3
6	.2	.1	.3	.05	.1	.05	.05	.1	.1	.05
7	.2	.1	.3	.05	.1	.05	.05	.1	.1	.05
8	.4	.2	.15	.05	.05	.1	.1	.2	.05	.05
9	.3	.05	.05	.3	0	.05	.05	.05	.3	.3
10	.4	.05	0	.3	.3	.05	.05	.05	.3	.3

Figure 10. Input Parameters of the Case Study

5.2 Outputs and Comparisons

Four alternative sketch maps shown in figure 11 are generated by SLM, and the performance of planning objectives for these alternatives are displayed in figure 13. It is found that alternative 1 attains the most harmonious environment, while alternative 4, the most efficient development. The differences of efficiency objective among alternatives are rather small, but the differences of harmony objective among alternatives are somewhat large. The harmony feeling of alternative 1 is twice as good as that of alternative 4.

The performances of planning objectives for the official sketch map, which is displayed in figure 12, are also displayed in figure 13. For the objective of environment harmony, the performance of official sketch is as bad as that of alternative 4, which has the worst environment harmony. For the objective of development efficiency, the performance of official sketch only attains the half level of the performance of alternative 1, which is the most inefficient layout among four alternatives. It is obvious from the diagram that any single alternative solution is performing better than the official one, because both objectives' value for every alternative are not less than those for official sketch.

6. CONCLUSIONS

Allocating the physical items in the planned area is generally a tough task for which a systematic and objective tool is needed for planners to complete the sketch layout. This study therefore develops a Sketch Layout Model (SLM), using multiobjective programming, to generate alternative sketch maps. This model can generate nondominated solutions for two planning objectives, environment harmony and development efficiency, under the consideration of four constraints: (1) all of the planned land uses must be assigned exhaustively; (2) each cell can not be over-capacity; (3) the paths must exist between any two cells; and, (4) every object must be examined for location suitability.

The model is tested by a numerical example and is considered to be feasible. In addition, the characteristics of the parameters used in the algorithm show that the larger the generation size or population size, the longer the average length of time of calculations, and the closer the obtained alternatives to the Pareto optimum are. In order to approach the Pareto optimum, the study thus suggests that the population size or the generation size should be set as large as possible, under the constraints of computer capacity. Finally, a case study demonstrates the use of SLM. The results indicate that the sketch layouts generated by SLM are better than the conventional hand-drawing method, in terms of achieving Pareto optimum. The parameters (${}^{d}h_{kk'}$ and $r_{kk'}$) used in SLM can be obtained through investigation, of which the detailed approaches were described in Lin(1999).

There are four points indicating the superiority of SLM. First, SLM can find alternatives approximating to the Pareto optimum, whereas the conventional hand-drawing method can hardly reach the optimum. Second, SLM is a visibly systematical approach, whereas the conventional method is generally considered as a "black box". Third, since the input data of SLM are obtained from the public, the layouts can reflect the preference of the multitude rather than the planners' attitude. Finally, SLM can reduce the work burden of planners through the assistance of computer technologies.

However, there are some restrictions for the wide application of SLM. First, it is used for new development projects, e.g. new community or new town, rather than for urban regeneration and review projects. Second, since the service area of any facility is not considered in SLM, the planned facilities can only confine to regional facilities (neighborhood facilities are not feasible). Third, SLM only considers the "distance" for describing the spatial relationships between cells, ignoring another important factor: the direction. Consequently, it is not suitable for land use objects which are greatly affected by the direction factor, such as incinerator. It is expected that these restrictions are only technical and it is a matter of time to address and eliminate them in further research.

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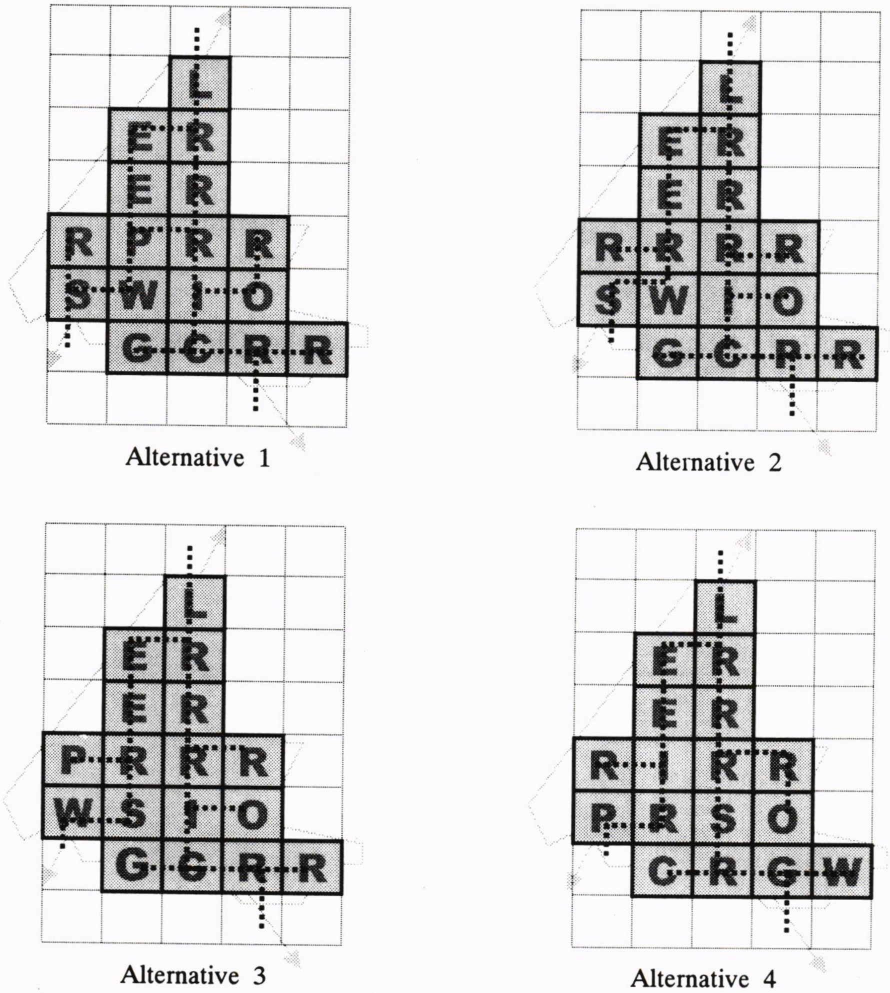

R: residential area	P: park	O: golf course
C: commercial area	W: wastewater plant	L: college
I: industry area	G: garbage plant	
S: stadium	E: recreational area	······· : link

Figure 11. Alternatives Generated for the Case Study

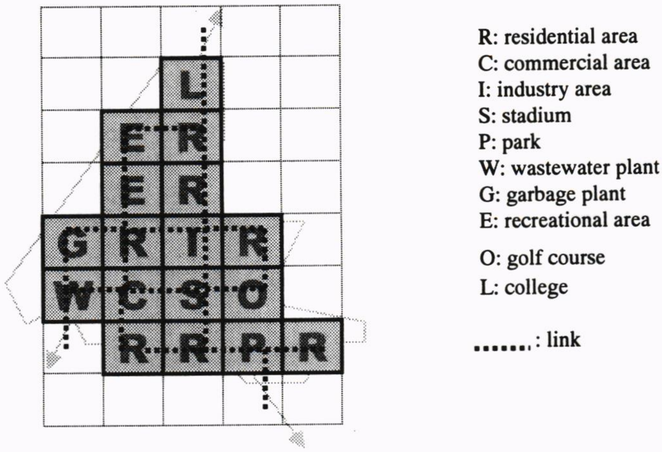

Figure 12. The Official Sketch Layout

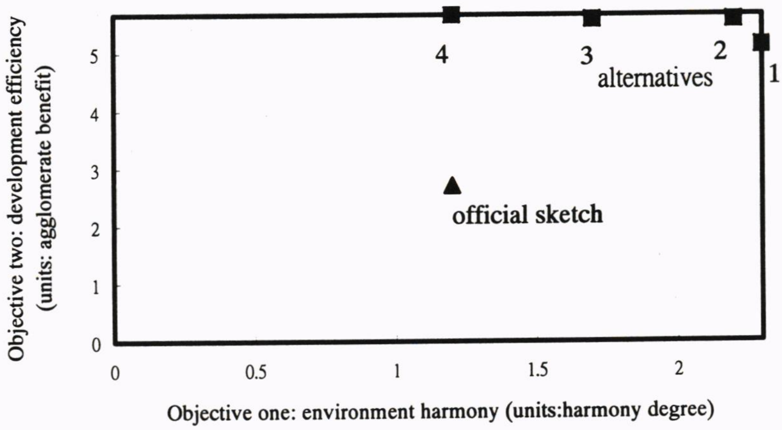

Figure 13. Performances of Four Alternatives and Those of Official Sketch

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