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An interactive simulation model of urban ecosystem and its implementation*

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Abstract — An interactive simulation model is established based on the methodology of "sensitivity model" (SM) during the cooperative research process between the founders of SM and the authors. And the conceptual framework of SM is developed into the interactively qualitative and quantitative simulation model presented in this paper, which makes it possible to break down a complex urban ecosystem into simple and visual quantitative or qualitative relationships between the factors. By studying the dynamic responses of the system to the changes of the inputs and parameters of the model, future trends in urban development can be predicted and strategies formulated. The whole process is realized on micro-computer in the course of man-computer interaction. Its potential use is shown in a case of Tianjin City.

Keywords: ecological simulation model; urban ecosystem; system analysis.

INTRODUCTION

The interactive simulation model of urban ecosystem (ISMUE) is established based on the methodology of "sensitivity model" (Vester, 1980). The main characteristics of the sensitivity model (SM) are to try to apply the principle of ecological cybernetics to the simulation and practical regulation of an urban ecosystem, and to give satisfactory strategies for the sustainable development of the city according to the varied situations, but not to find an optimal solution to the urban ecosystem regulation. Because of the characteristics it is very useful for the regulation of complex urban ecosystem. But actually SM is only a conceptual framework, most of its procedures are implemented literally or qualitatively. Its main procedures are the determination of system boundary, selection of variables (or factors of the system), interaction patterns of the selected variables, key feedback loops analyses, simulation of dynamic features of selected system and cybernetic interpretation of the simulation results and so on. Of these, only the simulation stage is quantitatively implemented on computer, and most of other procedures are finished with the aid of experts consultation through sending out questionnaires to the experts with different backgrounds or talks with them.

In ISMUE, we try to implement these procedures on a large capacity micro-computer through the strong connection and flexible communication of the model with data base, graphic

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base, knowledge base and management interface under the Decision Support System for Urban Ecosystem Regulation (Yang, 1990). The data base is full of social, economic, natural and environmental data of the city, based on which the past and current situations of the urban ecosystem are analyzed and the problems found out. The graphic base can show different graphs of the factors, their relations and feedback loops, it gives us more visual impression on the change trends of the factors and dynamic features of the system. And the knowledge base is fed with the related principles, and knowledge and experiences of experts with different backgrounds, only with the intelligent support of the knowledge base can the computerization be realized.

And the whole process of ISMUE is an intelligence-aided decision support process with the flexible man-computer dialogue.

As for simulation methods, in SM, system dynamics (SD) method (Forrester, 1968) was taken as the main tool of simulation and policy test. It is well known that SD can be easily used to solve the non-linear and delay problems. Therefore, it is convenient to simulate the complex urban ecosystem by use of SD. But SD does have its shortcomings. In SD, the rate (decision) variables are considered to be independent, e. g., any rate variables can not be directly determined by the other rate variables. Thus, SD method is limited to one-dimension decision process. It is difficult to deal with the decision problems in n-dimension space like the complex urban ecosystem properly since the decision variables or factors are interrelated. In view of that weakness, SD is not taken as the main tool of simulation in ISMUE, but some advantages of SD, such as using flow diagrams to describe the interaction patterns of the variables of the complex system, are draw on. In ISMUE, the technique of combination of many mathematical methods is used, the suitable method is selected to determine the dual relationship of factors according to the feature of each problem and factor. The dual relationship is the qualitative and quantitative relationship between two related factors. After the dual relationships are determined, the dynamic feature of the whole system or each subsystem is simulated by means of Pulse Model (Roberts, 1976). Pulse Model is somewhat similar to SD model in form, but different to SD model it pays more emphases on the interrelations of the factors, and it is also easily connected with other methods through the transmission of parameters. SD method can also be one of these methods after we made some appropriate improvements on it. Because DYNAMO language used in SD method is in fact a kind of continuous system simulation language described by difference equation, we can easily translate this specific simulation language into other advanced computer languages based on the principles of SD, then it will overcome its shortcomings through the flexible combination with other methods.

An urban ecosystem, because of its non-visual, non-linear and complex characteristics, some dual relations of factors within it can not be simulated accurately by mathematical models. Thus, in ISMUE, the technique of artificial intelligence is introduced to determine these dual relations.

IMPLEMENTATION

System description

System description is intended to describe the whole urban ecosystem and each subsystem, including the determination of the boundary and factors of the system, interaction patterns of the factors, key feedback loops and factors.

The boundary of an urban ecosystem is vague, that can be determined according to the natural, social and economic characteristics of the city and requirements of our study. As mentioned above, the data and maps of the urban natural, economic, social and environmental conditions are fed into data base and graphic base respectively. Thus, the decision-makers and computer operators can determine the system boundary and its constituent factors through analyzing the data and maps with the aid of expert knowledge and their own experiences, they can also modify and append the existing data files based on their determination.

In the same way they can also select some factors for simulation and determine the interaction patterns, positive and negative feedback loops between these factors by man-computer dialogue with the aid of expert knowledge.

Establishment of dual relationship between factors

Two factors whose relationship to be determined are inputted into the computer at first, then the sample data about the factors are got from the data base, and the scattered points or curve of the relationship between the two factors are drawn on the computer. The user can select a suitable method to describe the relationship of the two factors according to the feature and shape of the curve. As for dual relations difficult to be determined by the mathematical methods, they can be determined with the aid of expert knowledge.

General methods for the determination of dual relations are:

* linear fitting
* nonlinear fitting
* exponential fitting
* logistic curve fitting

The user can also select other methods or give his own formulas to determine dual relationships until he gets satisfactory results.

Simulation of the dynamic feature of the system

Simulation of the dynamic feature of the system is to determine the sensitivity of the system to the changes of the outside conditions, and the impacts of the changes of some factors or relations in the system on the other factors or the whole system, and to search for the corresponding eco-strategies. The features of dynamic changes of the system are always reflected by the changes of the key factors. The change of each factor at some time can be regarded as a pulse it gets at that time, the pulse comes from either the outside (called outside pulse) or the inner (called inner pulse) of the system. Thus, for factor Vj, the pulse it obtains from time t to $(t+1)$ is

$$Vj\ (t+1) - Vj\ (t) = P'j\ (t+1) + \sum_{i=1}^{n} Wi\ j \times Pi\ (t)\ , \qquad (1)$$

where, $Vj\ (t+1)$, $Vj\ (t)$ are values of Vj at the time $(t+1)$ and t respectively; $P'j\ (t+1)$ is the outside pulse it gets at that time interval; $Pi\ (t)$ is the change of Vi at

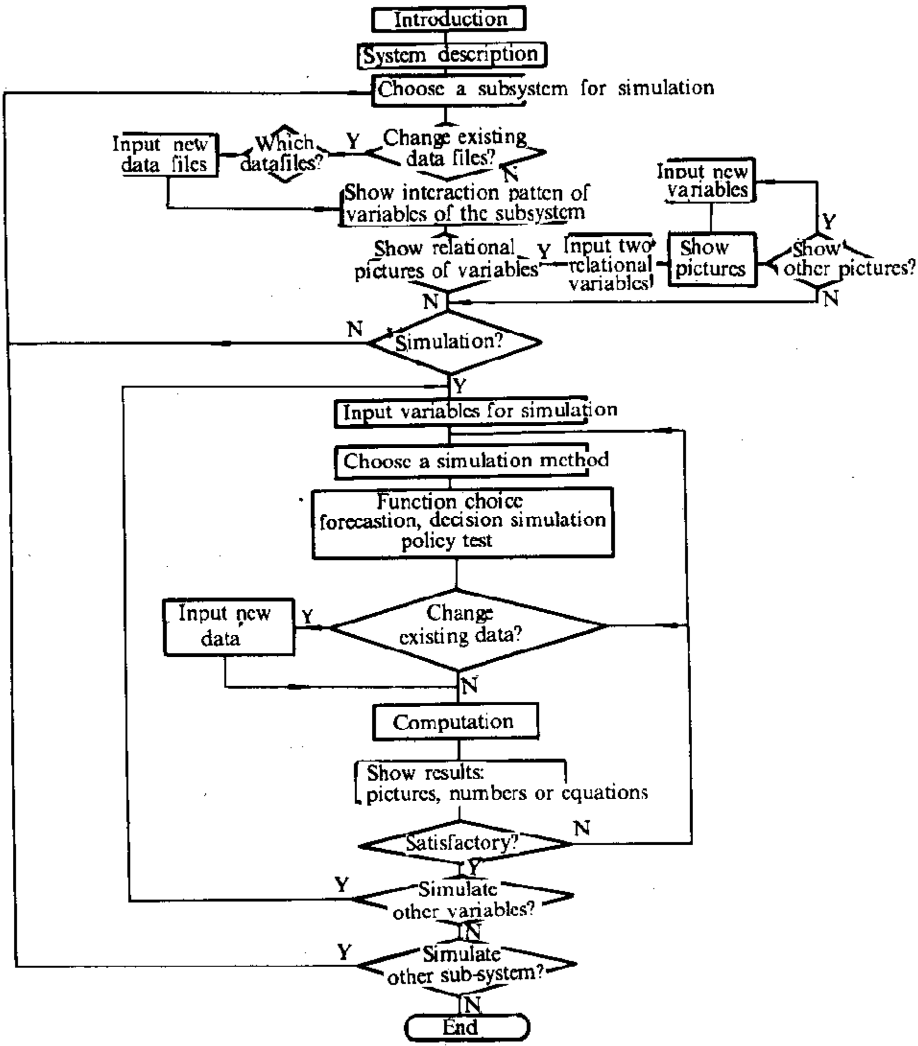

Fig. 1 Simulation procedure

the time t; Wji is effect weight of Vi on Vj, it reflects thc quantitative relations between the two factors. It can be changed over time. The methods for the determination of dual relations are to determine Wij.

For the urban ecosystem, the outside effects (pulses) on the system can be realized by the changes of the inner factors (inner pulses), so $P'j\ (t+1)$ can bc regarded as zero.

If the base values and beginning pulse are known, the values of the factors at the time t can be forecasted according to the following formula:

$$\bar{V}\ (t) = \bar{V}\ (0) + \bar{P}\ (0) \times \sum_{s=0}^{t} \bar{W}^{s}, \qquad (2)$$

where, $\bar{V}\ (t) = [V1\ (t),\ V2\ (t), \cdots\cdots Vj\ (t), \cdots\cdots, Vm\ (t)]$;

$\bar{P}\ (0) = [P1\ (0),\ P2\ (0), \cdots\cdots Pj\ (0), \cdots\cdots, Pm\ (0)]$;

$\bar{W} = \{ Wij \},\ i, j = 1, 2, \cdots\cdots m$;

$\bar{P}\ (t) = [P1(t),\ P2(t), \cdots\cdots Pj\ (t), \cdots\cdots Pm\ (t)]$;

m — number of sampling factors.

If the base value and goal value of the factors are known, the beggining pulse can also be computed according to the above formula, that is the original strategies should be taken to reach the goal through certain time span. And then the strategies at each time fo. reaching the goal can be obtained according to the following formula:

$$\bar{P}\ (t) = \bar{P}\ (0) \times \bar{W}^{t}. \qquad (3)$$

Policy tests can be done by modifying the goal values, beginning values, effect weights and so on through man-computer dialogue.

Simulation procedure

The entire procedure of simulation is shown in Fig. 1.

APPLICATION — A CASE STUDY

The simulation model has been adopted to simulate the reconstruction and development of

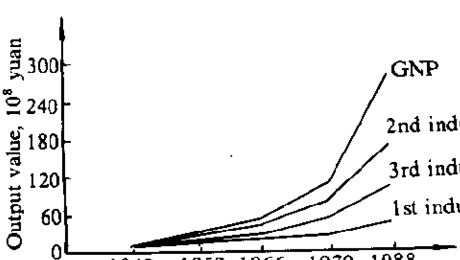

Fig. 2 Growth of GNP in Tianjin City

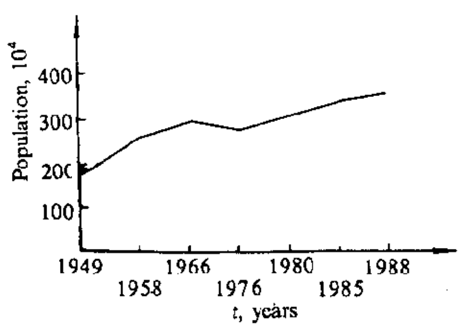

Fig. 3 Population growth of Tianjin City

Tianjin central area, the results are well accepted.

The reconstruction and development of Tianjin central area concerns with many social, economic, natural and environmental factors. All these factors and their change trends are listed on the screen of the micro-computer, for example, Fig. 2 to Fig. 5 show the evolution and development tendencies of economy, population and land use, respectively. We choose the main factors by man-computer interaction with the aid of expert knowledge. Through an overall analyses of those factors, we selected eleven main factors for simulation. The chosen factors and the interaction pattern between them are shown in Fig. 6.

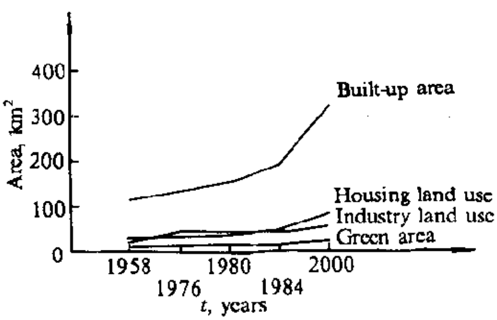

Fig. 4 Land use over time

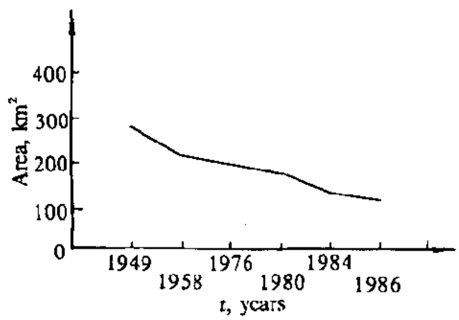

Fig. 5 Reduction trend of available land

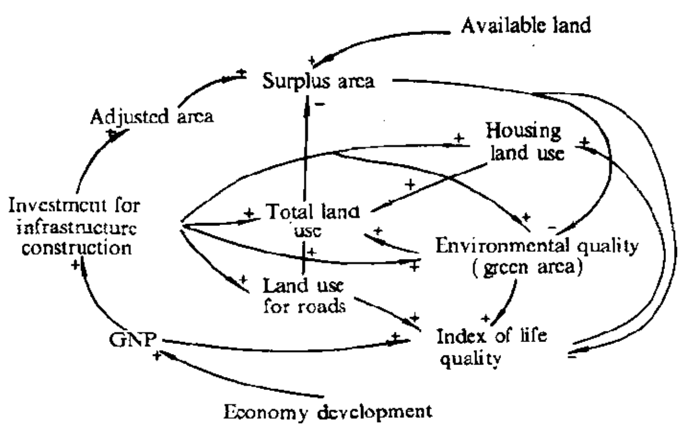

Fig. 6 Interaction pattern

By regressing the statistical data of these factors, the dual relationships are established. The dynamic feature is simulated under the following conditions : (1) Adjusting housing price; (2) Increasing investment on new infrastructure construction; (3) Increasing investment on industry land use adjustment; (4) Meeting the demand of residents for housing to increase the living quality; (5) Increasing green area to improve environmental quality; (6) Changing the speed of economic development.

Through the simulation, we get three general strategies for the reconstruction and development of Tianjin central area: (1) The housing price within the first and second ring road should be increased to control the immigration of outside people, and simultaneously the investment on the infrastructure construction between the second and out-ring road increased to attract more people in the central area to move in. It is suitable to set land price according to Fig. 7; (2) More attention should be put on the adjustment of land use, particularly industry land use in the central area should be reduced by moving factories to the out-ring or suburban areas. Otherwise, the land area within the existing boundary can not meet the demand of residents for housing and other land use after five years; (3) According to the location and environmental impacts of the factories in the urban area, the taxes or fees (Fig. 8) should be charged and used for the environmental protection and afforestation to increase the environmental quality and green area in the center.

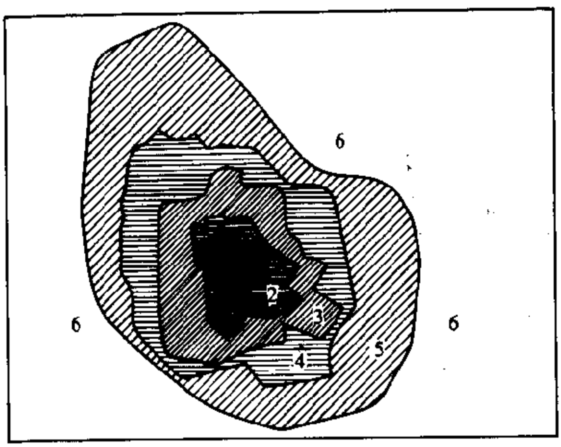

Fig. 7 Classification of land price in Tianjin City

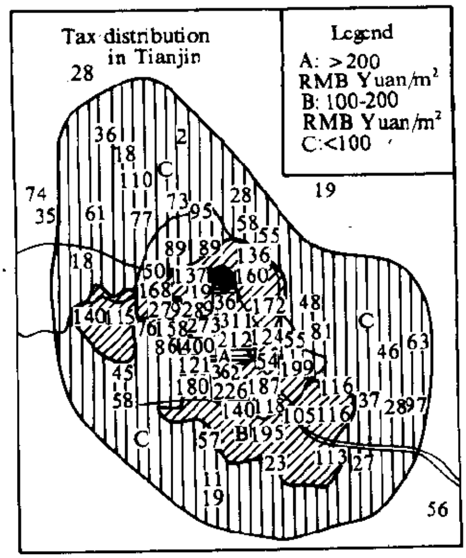

Fig. 8 Tax distribution in Tianjin City

DISCUSSION

The simulation model is a part of flexible modeling support system under the Decision Support System for Urban Ecosystem Regulation (DSSUER) whose framework has been well constructed. The simulation process can not be realized without the strong and flexible connection of the model with data base, knowledge base and management interface. Our further research activity will focus on the development of methodology for intelligent communication of mathematical models with data base and knowledge base, and the development of flexible and intelligent user-friendly management environment.

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