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GIS-Based Microsimulation System for Evaluating Urban Space Usage

GIS を用いた都市空間利用のためのマイクロシミュレーションシステム

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1. Introduction

In order to simulate changes in urban landuse and to forecast the influences of new measures on the block level, there is a need to develop a micro landuse system that can represent the changes of individual buildings including usage, area, height, floor area ratio, etc. Miyamoto et al.[3] developed a model of detailed physical landuse patterns to represent the changes in building types and use by block. This model does not consider the possibility of lots merging. Another system has been suggested to simulate space use in downtown planning[2]. Although this system has a graphical interface that shows the simulation result, the urban patterns that it can handle are limited to chess-board-like patterns. In this research, a landuse forecasting model is implemented on a PC using object-oriented GIS concepts. It is assumed that the total quantities of urban activities in a zone are known. Then, these quantities are allocated to lots according to the probability of change of the landuse and based on the attributes of these lots. The possibility of merging adjacent lots is also considered.

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2.MIcro LandUse Simulation System (MILUSS)

The flow of the MIcro LandUse Simulation System (MILUSS) developed in this research is as follows: (1) Input lots and buildings' GIS data, and total floor areas to be allocated for each landuse. (2) Create lot' s neighborhood information. (3) Perform lot merging based on the probability of merging and using Monte Carlo simulation, then update lots' data. (4) Calculate the utility and the probability of each landuse for all lots. (5) Sort lots according to each landuse probability. (6) Allocate the total demand for floor area of each activity (building type) to the lots in order using Monte Carlo simulation. (7) In case that a change in a lot's landuse occurred that involves a change in the structure on the lot, a new *Building* object is created, and the floor areas to be allocated are updated. (8) The allocation process is complete when all the demands for all activities are allocated, or when all the available lots in the zone are allocated. In the later case, the information about the remaining demand that could not be allocated is fed-back to the macro model. (9) After the end of the allocation process, GIS data of lots and buildings are saved. (10) The simulation results are displayed in 2D and 3D.

The software is developed using Visual Basic, and the GIS functions are implemented using MapObjects[1]. The object-oriented model of MapObjects allows the state and behavior of an object to be modeled as attributes and methods, respectively, which greatly facilitates the reuse and extension of objects. In addition, a special function has been developed in the GIS simulation software that creates the basic shapes of buildings by extrusion, and uses other attributes, such as the type of the roof, to add more details to the 3D buildings' model parametrically using VRML.

3. Micro landuse forecasting model

A micro landuse forecasting model for building type selection is developed in this research. The urban activities located at the zone-level can be used as control total for the lot-level allocation. For instance, an existing micro-analytical residential mobility model is available for the forecasting of housing locations according to traffic analysis zones. Also, a business location model is being developed using input-output tables to establish the relationships among the economic activities and population in the urban area.

After forecasting the total quantities of activities in the zone of interest, these activities are mapped to floor-area and allocated probabilistically according to lots' attributes within the zone. The type of the landuse in the lot depends on the profitability potential of development. The developer profit is the expected revenue minus the costs of the building. This utility can be formulated as in Eq.(1)

$$U_{il} = a_l X_l - C_i \quad (1)$$

where U_{il} is the utility of building type i at a lot l, X_l is the array representing land conditions of the lot, and C_i is the total costs of the building. The land conditions of a lot include its area, the relationship with its surrounding lots and roads, landuse regulations, land price, etc. If the age of buildings is considered, then the demolition of an old building can be an opportunity for a change in the landuse or an increase in the number of floors.

Using the logit model, the probability that a lot l will be used for building type i is given by Eq.(2)

$$P_{il} = \frac{\exp U_{il}}{\sum_j \exp U_{jl}} \quad (2)$$

4. Case Study

(1) Study area

The study area is at a sub-center about 10 min. from the CBD of Nagoya City. It is a commercial and mixed-use area of about 50 ha including 1173 lots. Although this area has several main roads and a subway station connecting it to the CBD, and has undergone several land readjustment projects, it still contains a large number of small old detached houses and shops side-by-side with new high-rise buildings.

Data of lots and buildings in the study area and the changes in the landuse are usually available at the city hall for official use only and are difficult to obtain. Fortunately, 1:2500 scale maps including the shape of lots and buildings are available for major Japanese cities[4)]. These maps are updated annually in a book form, and recently in digital form, with tables of the number of floors and names of households, shops, and companies occupying most buildings. Attributes of lots and buildings were attached to these maps for the years of 1991 and 1997. Digital data are available for 1997 only. The attributes include the areas of the lots and the buildings, the number of floors of buildings, whether the building faces a main road or is on a corner or not, and the usage of a building classified as housing, commercial, office, parking, vacant land, and other uses. Landuse regulations were also added to each lot including the allowable usage, maximum height, and maximum floor-area and building-coverage ratios. In addition, land prices of 1991 at several points in the area were added. The lots where changes in the landuse occurred, including merging of lots, between 1991 and 1997 were also extracted for comparison.

Fig.1 shows the zoning regulations, the lots' distribution, and the present buildings' distribution of the study area. The two numbers on each zone in Fig. 3(a) are the percentages of the floor-area ratio and the building-coverage ratio. Fig. 2 shows the land areas percentage of each landuse type. Fig. 3 shoes the land areas with respect to the used percentage of the maximum floor-area ratio. It is clear from Figs. 2 and 3 that a large part of the floor areas of the housing use is in low-rise buildings, and that the used percentage of the maximum floor-area ratio is generally small.

(2) Parameters estimation

Tables 1 and 2 show the estimated parameters of the binary lot merging and multinomial landuse logit models, respectively, based on land conditions of lots. The results are generally acceptable.

Table 1. Parameters of the Lot Merging Model

Variable	Parameter	*t* value
Area (m^2)	-0.0016	-6.87
On-main-road dummy	0.79	2.90
Number of observations = 320		
Likelihood ratio (ρ^2) = 0.21		
Hit ratio = 65.63		

(3) Evaluating measures for landuse control

Several scenarios are suggested for controlling and improving the urban landscape by imposing physical constraints on building heights and building-coverage ratio or by introducing a tax reduction on property ownership. The aims and conditions of each scenario are as follows:

(1) Scenario A: Imposing a minimum and maximum heights on the buildings

(2) Scenario B: Imposing a new regulation for encouraging the merging of small lots into bigger ones with a large façade on the road by a property tax reduction. The aim of this regulation is to accelerate the replacement of old small detached houses and pencil-like buildings by larger buildings with a large façade on the road.

(3) Scenario C: Imposing a new regulation that aims to decrease the building-coverage ratio. The aim of this regulation is to increase the open space between buildings.

The present and resulting landscapes in the case of scenario C are assessed visually as shown in Fig.4.

5. Summary and future work

A microsimulation model for forecasting the changes in landuse on the lot level is developed and implemented using a programmable GIS library on a PC. This model assumes that the choice of a specific landuse, for example high-rise commercial use, is based on the expected improvement in the utility value of a lot. The utility is assumed as a function of the area of the lot, its location with respect to a main road, the floor-area ratio, and land price. The prototype simulation system is innovative in that it allows for the dynamic manipulation of the topology of the polygons representing lots and buildings. The system is implemented using an object-oriented GIS approach and used to simulate the changes in the landscape under several scenarios. This research is a part of the Future City Research Project at Nagoya Industrial Science Research Institute (project leader: Yoshitugu Hayashi).

References:

1) Environmental Science Research Institute (1997a). Building Applications with MapObjects: GIS and Mapping Components, USA.

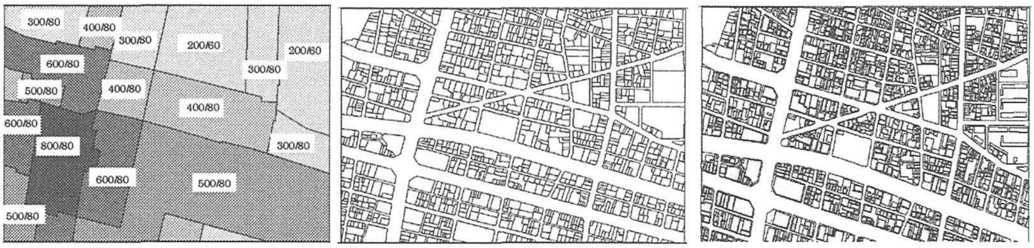
2) Kaneda, T. (1998). A System Design of Space Use Simulator for Downtown Planning, Proceedings of the Annual Meeting of Japan Architects Association (in Japanese).

3) Miyamoto, K. et al. (1998). A model of Detailed Physical Landuse Patterns for Environmental Considerations, Paper submitted to the 8th World Conference on Transport Research, Antwerp, Belgium.

4) Zenrin Zmap-Town (1997). Technical Reference (in Japanese).

Table 2. Results of Parameters Estimation of the Landuse Model

Variable	Parameter value			*t* value
	Low rise Residential	High rise Residential	Commercial	
Area (m^2)	-	0.001		1.23
Floor-area ratio regulation (%)	-	0.004		4.71
On-main-road dummy	-	1.28		3.58
Land price (10,000 Yen)	-0.002		-	-3.49
On-corner dummy	-	-	0.64	2.20
Commercial block dummy	-	-	0.94	2.67
High-rise housing constant	-	-3.19	-	-8.23
Commercial constant	-	-	-2.27	-6.99
Number of observations = 867				
Likelihood ratio (ρ^2) = 0.33				
Hit ratio = 66.44				



(a) Zoning Regulations (b) Lots' Distribution (c) Buildings' Distribution

Fig. 1 Area of the Case Study

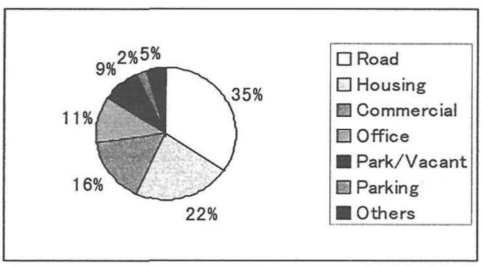


Fig. 2 Land Areas Percentage of Each Landuse Type

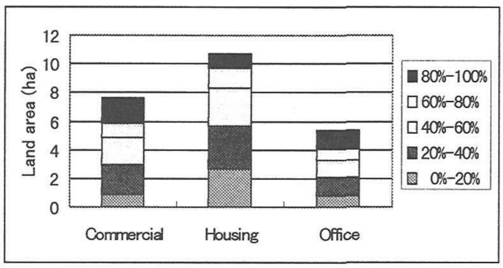
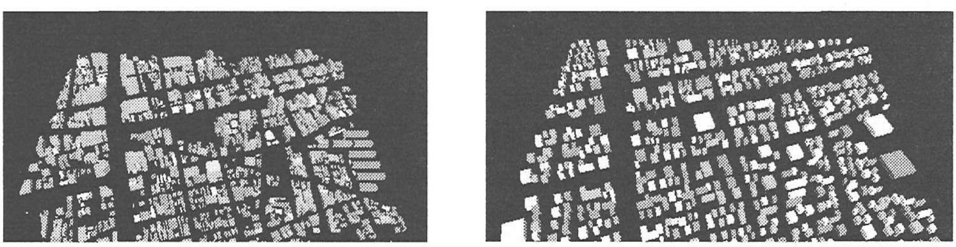


Fig.3 Used Percentage of Max. Floor-area Ratio



(a) Present Landscape **(b) Landscape in the Case of Scenario C**

Fig.4 3D Representation of the Present Landuse and Simulation Result