Transport, Land-Use and the Environment

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CHAPTER 13

AN ANALYSIS SYSTEM FOR INTEGRATED POLICY MEASURES REGARDING LAND-USE, TRANSPORT AND THE ENVIRONMENT IN A METROPOLIS

Kazuaki Miyamoto and Rungsun Udomsri

1. Introduction

Growing concern about environment is strongly urging planners and policy makers of a metropolis to more explicitly care the impacts of policy alternatives on various aspects of environment. Since most aspects of urban environment can be regarded as externalities of land-use and transport, it is indispensable to forecast and evaluate changes in environment which seem to occur when proposed policy measures related to land-use and transport, to say nothing of environment, are implemented. In addition, the policy measures should be an integrated set of instruments regarding land-use, transport and environment, because more effectiveness can be expected by integrating such policy measures. In other words, integrated planning and implementation regarding land-use and transport as well as environment is most necessary for metropolises, particular in developing countries where dramatic changes in urban structure are occurring (Miyamoto and Udomsri, 1994).

To make the integration possible, it is requisite to formulate an institutional set-up which is really functional. However, without effective tools for analysis, it is impossible for related agencies to discuss policies and their implementing measures sufficiently, because options are so various and complex in their

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interactions. An analysis system covering land-use, transport and the environment is expected to provide the related agencies of a metropolis with a forum in which they can discuss policies and their implementing measures substantially.

Many kinds of land-use models and transport models as well as their integrated models have been developed to forecast their changes for various purposes, and some of them can be applicable to forecast as far as environmental changes. However, most of them have little compatibility with other models. It means that each model development aims to build its own simulation model only, and not to utilise existing program modules. In other words, there have been few ideas of standardisation in simulation programs of land-use, transport and environment models. Since existing program modules have various ways of input and output of data, they cannot be used as standard parts which constitute a large simulation system.

When we prepare an analysis system for integrated planning and implementation, the system should consist of modules of land-use, transport and the environment. It would take a long time and much cost if we try to develop all the simulation models only by ourselves. Therefore, establishment of a standard for other modules is as important as providing existing stock of program modules with interface, to connect them organically to the simulation system. For this purpose, we should set up a general framework for an analysis system that allows easy incorporation and replacement of modules of land-use, transport, environment and, moreover, any sector of a metropolis.

The objective of the present study is to develop a pilot system to evaluate integrated sets of policy measures related to land-use, transport and the environment in a metropolis, which will contribute to establish a forum of related governmental agencies for their integrated planning and implementation and to make it actually effective and substantial.

In the following part of this paper, we discuss some of the basic concepts for the development of the analysis system. In the latter part, we propose an integrated model of land-use, transport and the environment for the analysis system by improving a land-use model based on Random Utility/Rent-Bidding ANalysis (RURBAN) (Miyamoto *et al*, 1992).

2. Requirements for the Analysis Tool

2.1 Outline of the System of Land-Use, Transport and Environment

Before building an analysis system, it is necessary to identify the issues regarding land-use, transport and the environment in a metropolis. In this study, the system related to land-use, transport and the environment is grasped as shown in Figure 1. In this figure, land-use as well as transport are composed of two elements; markets and governmental agencies. It is assumed that environment is an externality of both land-use and transport and that it does not constitute a market by itself. Environment can be regarded as nothing but a situation of environmental qualities most of which land-use and transport determine. Therefore, the treatment of environment in the system is different from those of transport and land-use. However, in a wider sense, it can be said that land-use, transport and the environment constitute a market, in spite of that there are a variety of externalities in it. The metropolitan market has interactions with national, internationally regional and as far as global economies and environment. Particularly for the case of environment, pollutants as well as land cover changes in the microscopic level, such as emissions from vehicles and deforestation, affects the global environment.

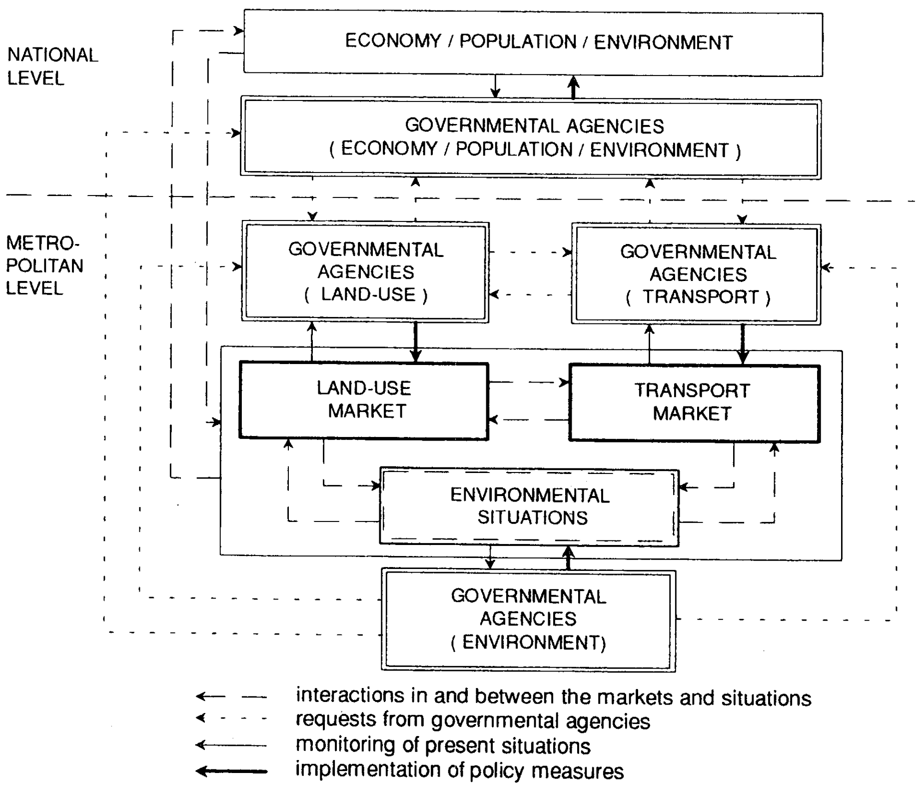


Fig. 1. Configuration of the System of Governmental Agencies, Land-Use and Transport Markets, and Environmental Situations in the Metropolis
Source: Miyamoto and Udomsri, 1994

The governmental agency in charge of the market is monitoring its situation through surveys and studies. Based on the studies, it makes a plan and selects policy measures for the implementation of the plan under its responsibility. If the interactions between the agencies are well coordinated, they would be able to work efficiently as if they constitute a single planning and implementing organisation. But this is not the case in most metropolises. In addition, even in the case of agencies in charge of the same market, either land-use or transport, it is seldom the case that they are well coordinated, to say nothing of the case of coordination between land-use and transport agencies. Therefore, there are such variety of problems that the most effective policy measures are out of options because they are under other the responsibility of another agency and that implemented measures don't work effectively because they contradict each other.

2.2 Integrated Sets of Policy Measures and Analysis Tools

Based on the above-mentioned system identification, one of the most important issues is how to adopt appropriate measures or instruments that facilitate the implementation of plans. Only with appropriate implementation measures, the plan can be translated into reality. Usually, each of them is regarded as a specific measure for either land-use, transport or environment, although it can also be a measure, sometimes a very effective one, for the rest through the interactions. In addition, a set of policy measures in integrated planning would be a combination of these policy measure elements which will be prescriptive for the metropolis. The concept of the integrated policy measures of this study is same as that of the integrated strategies approach (May, 1991) and/or management approach in transport planning except in that the approach of this study covers as far as land-use and the environment explicitly. The selection of policy measure elements should be made by taking the interaction into consideration. Some examples of policy measure elements are listed in Table 1.

Table 1. Examples of Implementation Measure Elements of Land-Use, Transport and Environmental Policies in Developing Metropolises

[Regulation]
(1) Bus priority / exclusive lanes
(2) Unleaded gasoline
(3) Land-Use zoning
(4) Building control
[Taxation / Pricing]
(1) Vehicle import / purchase taxes
(2) Fuel taxes
(3) Land-Use taxes
(4) Development charges
[Investment]
(1) Provision of road network
(2) Provision of Mass Rapid Transit
(3) Land development / readjustment
(4) Housing Development
[Operation]
(1) Mass transit operation
(2) Area traffic control
(3) Flexible working hours
(4) Open hours of shops
[Education]
(1) Car pooling
(2) Ride sharing
(3) Promotion by mass media

Source: Miyamoto and Udomsri, 1994

2.3 Analysis Tools

It is well known that the interaction between land-use and transport should be taken into consideration in the planning process. Integrated land-use and transport models which deal with both land-use and transport as well as the interaction between them have been developed as described in Webster *et al* (1988). However, there have not been many cases which employed such integrated land-use and transport models in actual planning even in developed countries. An integrated model should be built in accordance with the objectives of its application. The model should ideally represent the universe of land-use and transport as briefly as possible, so far as it satisfies the requirements given by the objectives. Bigger models are not necessarily better models.

In addition, provision of an analysis model with understandable presentation tools using computer graphics, will promote coordination among governmental agencies in the stages of both planning and implementation. With the analysis tool, they can discuss on the integrated land-use and transport and compare possible options of policy measures with each other. It can be expected that this kind of technical development is to bring about a better institutional set-up. In addition, a user-friendly analysis system can make it possible for both planners and implementers to analyse long-range or action plans flexibly even in uncertain future framework of a developing metropolis.

Since it takes long time and huge cost to build an analysis system which covers land-use, transport and the environment, it is not feasible for each local government of a metropolis to originally develop it by itself. Therefore, it is worthwhile for researchers to establish an methodology to provide metropolises with a standard system which has enough flexibility to install existing stocks and future developments of land-use, transport and environment models as well as computer system functions.

3. Basic Concepts of Analysis System Building

3.1 Background of System Building

The authors have been developing a land-use/transport analysis model named RURBAN (Random Utility/Rent-bidding ANalysis) by which land-use in a metropolis can be simulated by considering small units of land. In addition, a personal computer support system is also being developed to analyse policy alternatives with the model (Miyamoto *et al*, 1992). The system is fully user-friendly and actually operational. The system employs graphics as much as possible both for input of policy alternatives and output presentation. Almost all operations are done by using mouse through conversation with the system. Although the present study is an advanced version in the course of RURBAN development, it employs new concepts for system building as well as model development.

3.2 Basic Concepts for System Development

We intend to provide a general framework for an integrated land-use, transport and the environment analysis system which is feasible to be built even in developing countries. The principles for the system development can be summarised as follows;

- to make a prototype of system that can be easily introduced almost everywhere
- to make the system able to deal with an integrated policy measures
- to make the system user-friendly
- to make the system flexible for existing stock of models
- not to stick to our own model but to provide it as one of alternative models

3.3 System Structure

The conceptual framework of the system is represented in Figure 2. The system is designed under the condition that it is built in the environment of Microsoft Windows 3.1. Graphical User Interface (GUI) and Dynamic Data Exchange (DDE) are the functions of Windows 3.1. The reasons why Windows 3.1 is selected for the system development are as follows; (1) application programs can be shared with a standard input/output interface, (2) it is one of the most popular operation systems, (3) it can be operated under personal computers which are available at any places, (4) the system has high possibility for further development.

3.4 Functions of the System Parts

Graphical user interface

Since land-use and transport as well as environment are all essentially spatial matters, it is indispensable to fully make use of advantages of graphical user interface. Graphical User Interface is now readily available in some Geographical Information System (GIS) and also easily developed originally under Windows system. Even without such tools, original GUI can be relatively easily provided (Miyamoto *et al*, 1992).

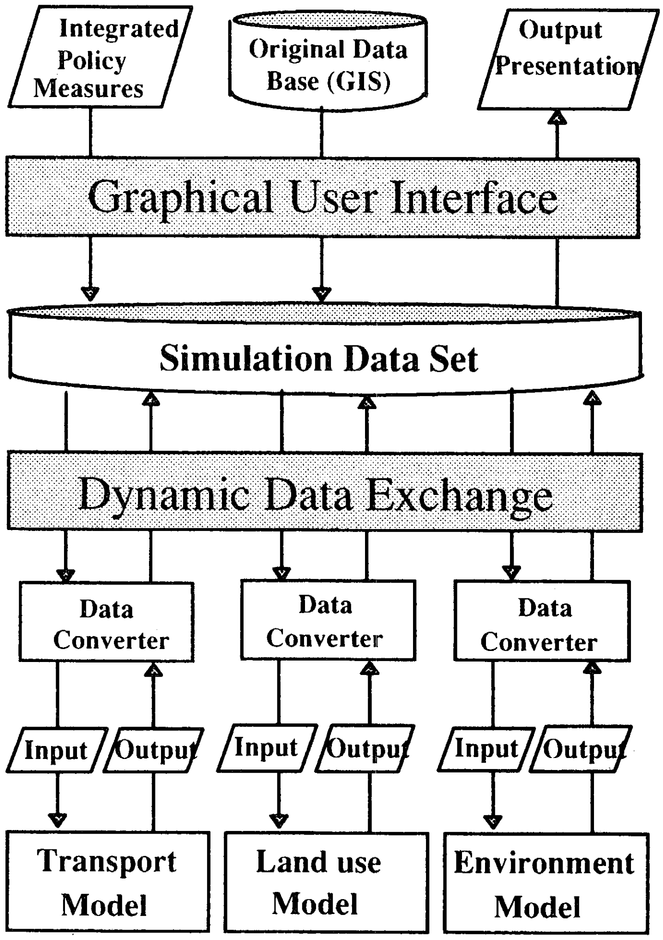


Fig. 2. The Conceptual Framework of the Analysis System

Integrated policy measures

Various policy measures should be integratedly analysed in the system. The input method should be also user friendly with GUI.

Original data base

Original data base can take any form; from established GIS data base to a file of existing data. The form can be selected by taking into consideration the availability of both hardware and software.

Output presentation

The same as input of policy alternatives, output presentation should be also user-friendly with the help of GUI.

Simulation data set

This is one of the most important part of the system. The simulation data set means "a model of the metropolis for simulation". The data set represents a simulation world of the metropolis. It contains all data which are necessary for land-use, transport and the environment at a level of analysis unit. Each model will make "the interactions through the simulation metropolis". The data of land-use, transport, and the environment by year are always updated through Dynamic Data Exchange function.

Dynamic data exchange function

This is one of the functions which the Windows system originally provided. DDE always update land-use, transport and the environment data when they are changed by models.

Data converter

Data converter has a function to connect simulation data set and application models. Existing program modules have their own input and output data layouts. In the case of the land-use model, data converter gets land-use data and explanatory variables for land-use changes, and process them to the input data layout of the model. After a calculation, the model outputs land-use changes, and the changed land-use data are transferred to the converter. Then, the changed data is again transferred to simulation data set.

Models

Existing program modules can be incorporated in the system without any modification. The system is completely independent from the application models. Therefore, any available model can be added to the system. In addition, plural number of models which simulate the same subject, for example some different land-use models, can exist in the system. The selection of the models for simulation is made by the simulation definition batch file.

Simulation batch file

Simulation batch file is an executive file to control whole simulation. It defines simulation periods and steps, selection of modules, sequence of module execution, judgement of simulation end. The operator can define in the file how land-use and transport are interacted in the simulation. Time lags and leads are also defined in the statement of the file.

4. Brief Explanation of the RURBAN Model

4.1 Assumptions and Basic Concepts

In this part, a land-use model based on Random Utility/Rent-Bidding ANalysis (RURBAN) (Miyamoto *et al*, 1992) is built is briefly explained.

This study discusses land-use and transport in a limited metropolitan area, which is hereafter called the "study area". The study area is assumed to be a closed city, which means that the demand for location is given from outside the model. To deal with the land market simply and conveniently, every zone in the study area is assumed to be owned by its own imaginary landowner and that every locator pays the rent to the landowner.

To segment the demand side in the land market, locators, which are travellers in the case of transport modelling, are classified according to their characteristics into a limited number of locator groups. These groups represent discrete options in the random rent-bidding analysis. The supply side of the land market is segmented by aggregating individual sites into zones based on locational conditions. The zones are regarded as discrete options in the analysis of location choice with random utility.

In this study, the land market is grasped from two viewpoints of locators and sites. If a locator chooses a certain site, it implies that the site must give the locator the highest utility compared with alternative sites. On the other hand, it also indicates that the locator must bid the highest rent among alternative locators at the site. At the level of aggregated locator groups and zones, the market can also be similarly explained, although probabilistic consideration should be introduced to represent the coexistence of a number of locators of various groups in a zone which consists of a number of sites. Locators belonging to a group are distributed in zones in proportion to the probability of each zone to give the group the highest utility. The area share by locator group in a zone is also proportional to the probabilities that the locator group bid the highest rent at the zone. These probabilities are obtained by logit models in RURBAN. The introduction of probabilistic terms in RURBAN follows the assumptions which most applications of the logit model employ (Ben-Akiva and Lerman, 1986). At this level of modelling, "the rents in all zones" and "the levels of utility of all locator groups" are indispensable in the former and the latter explanations, respectively.

In this study, it is assumed the existence of a state of general equilibrium of land market within the study area. The state of general equilibrium can be obtained through either equilibrium rents of all zones or equilibrium levels of utility of all locator groups, since the determination of the former brings about the settlement of the latter and vice-versa as is explained in 4.5. This general equilibrium is defined in this study as the case that the demand for location of a locator group in a zone is equal to the land supply of the zone to the locator group for all pairs of locator group and zone within the study area. The land used by a locator group in a zone is called demand, and land offered by a zone for a locator group is called supply. They represent not only newly generated or flow values but include the total distribution of locators or stock values. Therefore, such areas where housing units are built but nobody is living are regarded not as residential areas but as vacant or non-used areas in this model.

The model deals with only actual use of land.

4.2 Demand for Land Derived from Random Utility Analysis

The amount of location of a locator group in a particular zone depends on the corresponding utility in that zone which is represented by a "representative" indirect utility. The indirect utility, which is the maximum utility the locator can attain in that zone, is assumed to be distributed randomly around a represented utility by following the assumption of the logit model. All locators belonging to a group are assumed to locate themselves in the study area with an equal level of utility. The same level of utility is obtained as a probabilistic expectation of the maximum utility, which is given by so-called logsum function, for all zones. The demand function of a locator group for a zone is then defined as a probabilistic expectation of the demanded area which is given by the number of locators of the group allocated to the zone multiplied by the amount of land used by a locator of the group in the zone. The former is given by the logit model and the latter is endogenously obtained by an equation based on the Alonso model (Alonso, 1964).

4.3 Supply of Land Derived from Random Rent-Bidding Analysis

In the RURBAN, the total area of available land in the study area is exogenously given to the model. It means that the supply of land is rigid. In addition, the supply of either floors or buildings is not explicitly considered. The supply of land of a zone to a locator group in the RURBAN is determined according to its bid-rent compared with other groups' bid-rents as follows. At each site in the study area, the existing locator is bidding the highest rent which becomes the actual rent. This means that the imaginary landowner supplies the site for the maximum bidder at the maximum bid-rent. However there are a number of sites in each zone, and their characteristics are not necessarily the same within the whole zone. Therefore, it is assumed that the land in each zone is supplied to locator groups according to their "representative" bid-rents at the zone. The supply function of a zone for a locator group is given as an expectation obtained from the probability that the locator group is the highest rent-bidder in the zone. The probability is given by the random rent-bidding analysis (Ellickson, 1981).

4.4 Structural Equations of RURBAN

The followings are the structural equations of RURBAN. They are derived under the condition that the demand and the supply explained in the previous parts are equal (Miyamoto and Kitazume, 1989).

$$\mu U_{IS} = \mu\alpha_I X_{IS} - \omega B_{IS}^* \tag{1}$$

$$q_{IS} = \theta_I \exp(-B_S^*) \tag{2}$$

$$L_{IS} = \frac{A_S}{q_{IS}} \tag{3}$$

$$\omega B_{IS} = \mu\alpha_I X_{IS} - \mu U_I^* \tag{4}$$

$$U_I^* = \frac{1}{\mu}\ln\sum_S \exp(\mu U_{IS} + \ln L_{IS} + \ln w_{IS}) \tag{5}$$

$$B_S^* = \frac{1}{\omega}\ln\sum_I \exp(\omega B_{IS} + \ln N_I + \ln w_{IS}) \tag{6}$$

where,

I : the locator group
S : the zone
U_{IS} : the systematic part of random utility of locator group I in zone S
B_{IS} : the systematic part of random bid-rent of locator group I in zone S
q_{IS} : the amount of land used by a unit of locator group I in zone S
X_{IS} : location conditions (except rent): (X_{IS1} ,..., X_{ISk} ,...)
α_I : parameters for locator group I: (α_{I1} ,..., α_{Ik} , ...)^{t}
L_{IS} : the number of available sites for the use of locator group I in zone S
U_I^* : the level of utility of locator group I
B_S^* : the representative rent of zone S
μ : a positive scale parameter of indirect utility function in location choice
ω : a positive scale parameter of bid-rent function
N_I : the number of individual locators belonging to locator group I
A_s : available area of zone S
w_{IS} : the measure of heterogeneity of individual locators in locator group I and individual sites in zone S
θ_I : a parameter of locator group I

Equation (1) represents an indirect utility of a locator group I in a zone S. Equation (2) gives the amount of land used by a unit of the group in the zone which is inversely proportional to representative rent of the zone. This function implicitly represents multistoried uses of land in a high land price area. Equation (3) shows the number of available sites for the use of the group at the zone. The number of optional sites in the zone affects the probability of the group to choose the zone. Equation (4) represent bid-rent of the group at the zone. This equation is a kind of dual equation of equation (1). Equation (5) gives the level of utility of the group in the whole area. It is a logsum function of all utilities of the group in the study area. Finally, equation (6) represents the representative rent in the zone which is also a logsum function. The latter two functions give key values which determines the general equilibrium of the land market as explained before.

4.5 Structure of RURBAN

Figure 3 shows the general structure of the RURBAN model. The RURBAN model has two partial equilibrium parts; location choice of locator groups based on utility analysis which is represented in the upper part of the figure, and locator choice of zones based on rent-bidding analysis which is represented in the lower part of the figure. The given values in the upper partial equilibrium are the rents at all zones and in the latter are the levels of utility of all locator groups. The levels of utility are obtained from the utility analysis and the rents are derived from the rent-bidding analysis. The equilibrium levels of utility and the equilibrium rents are obtained as converged values after iteration between two partial equilibrium parts. In the convergence, the area of locator I in zone S obtained by random utility analysis, which is represented as Φ_{IS}^{U} in the figure, should become equal to the area Φ_{IS}^{b} obtained by random rent-bidding analysis for all pairs of I and S. Then, they can be regarded as those in the state of general equilibrium.

In order to obtain both of them, the land market should be modelled with two partial equilibrium aspects. In addition, when either of the general equilibrium values of levels of utility or rents are obtained, the other values naturally become those that are in the state of the general equilibrium.

As Figure 3 shows, the structure of RURBAN consists of two kinds of single constraint entropy models. In the end, that is in the state of general equilibrium, RURBAN becomes a doubly constrained entropy model.

So far as the authors know, such idea as that both random utility and random rent-bidding are simultaneously considered in the land-use model was firstly proposed in a former version of RURBAN in Miyamoto and Yagi (1987), although there was inappropriate interpretation regarding the joint probability between utility and rent-bidding analyses. In addition, recently have applied a few models such as Hayashi *et al* (1989) and Martinez (1992) which employ very similar scheme to that of RURBAN with different ways of formulation. The most particular difference of RURBAN from these two models is that the amount of area used by a unit of locator in each zone is endogenously obtained in the RURBAN.

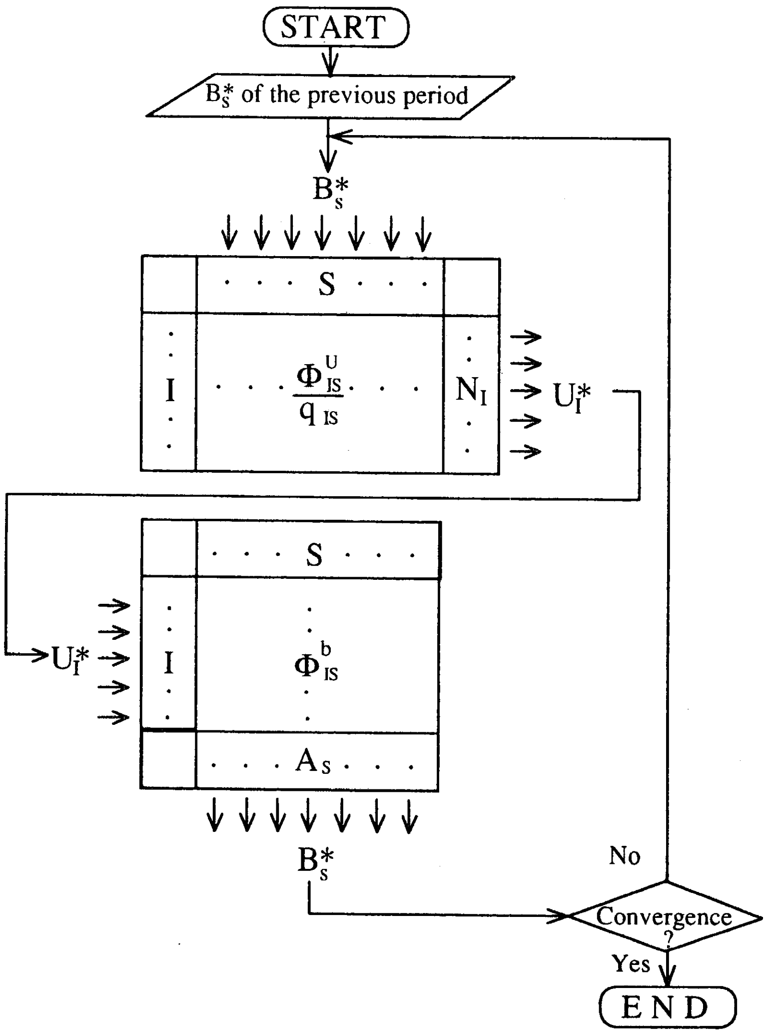


Fig. 3. The Partial Equilibrium in Location Choice of Locator Groups, the Partial Equilibrium in Location Choice at Zones and the General Equilibrium of the Land-Use Market in RURBAN

5. An Integrated Model of Land-Use and Transport with Environment

5.1 The Approach

The main part of the analysis system is an integrated land-use and transport model. In this study, RURBAN model has been improved to represent transport more explicitly. In this improvement, it is intended to keep consistency between land-use and transport. The improved model can be operated not only by directly integrating land-use and transport but also by separating them under the proposed analysis system framework as discussed in section 3. Figure 4 shows the structure of the integrated land-use, transport and environment model. It corresponds to the system configuration of land-use, transport and the environment in a metropolis shown in Figure 1.

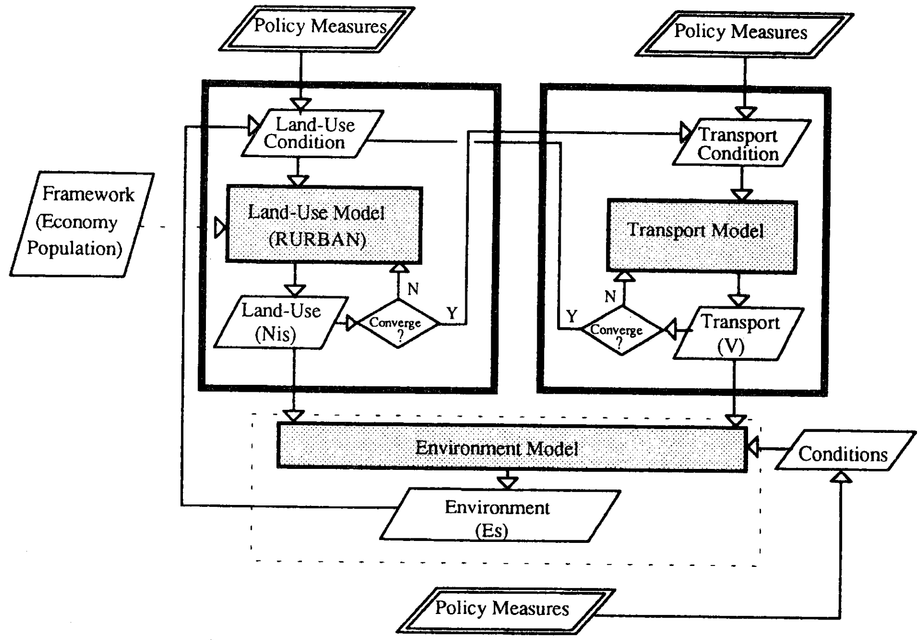


Fig. 4. The Structure of An Integrated Land-Use, Transport and Environment Model

The RURBAN employs aggregate logit model structure as described before. The improvement is being done along with the same structure. The reasons why we decided to improve the RURBAN for developing an integrated model of land-use, transport and the environment are explained as follows. Firstly, the model is able to fully and consistently integrate transport choice steps within the location choice. Therefore, land-use and transport are modelled within a single model framework. Secondly, the model has mechanisms to represent market equilibrium both in land-use and transport markets. Thirdly, the logit model or the nested logit model, which is the theoretical background of the RURBAN, can consistently deal with the cases in which units for analysis are either aggregated or disaggregated.

The choices in location and trip are viewed as outcome of a probabilistic choice process. The process is simply described by four levels of choice hierarchy in decision-making chain starting from location choice and destination choice in land-use level, to mode choice and route choice in transport level. The basic concept has been also employed in Martinez (1992) and others. Figure 5 and Figure 6 show how this process can be described in the hierarchical concept. In the case of residential location, destination choices mean "choices of working place, school and shopping places". The hierarchical structure represents that "a site which is convenient for commuting" means that it is close to large working places. It is also explained that the site has better accessibility to large working places compared with other sites. The structure covers both behaviour of aggregated locators and travellers.

5.2 Choice Tree and Location Utility

Figure 5 shows the location conditions or explanatory variables for the utility function of a locator group *I* in a zone *S*. For explanation, let *I* denote the residential locator group. There are four categories in location conditions. The first category covers "accessibilities" which represents, for example, work, school and shopping trip conditions which are expressed by trip purpose *p*. They are represented by both the attractiveness of available destinations and transport conditions, which are also explained by the nested tree structure shown in Figure 6. The second category consists of the characteristics of the zone itself which are foot-tight conditions. The third category includes all aspects of the environment which are determined by land-use and traffic of the neighbouring zones. The forth category indicates the price of the land which is named "the representative rent" of the zone in the RURBAN.

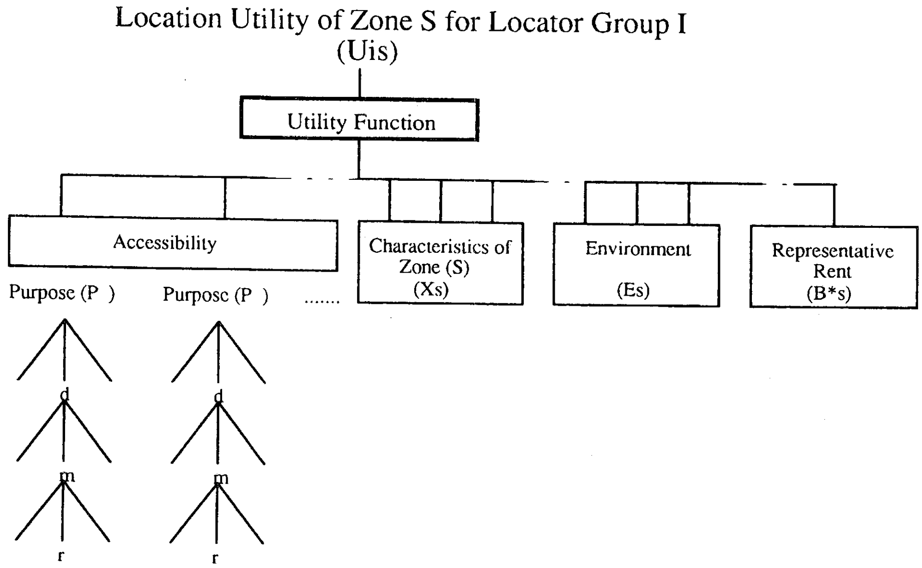


Fig. 5. Location Utility and Factors (Explanatory Variables)

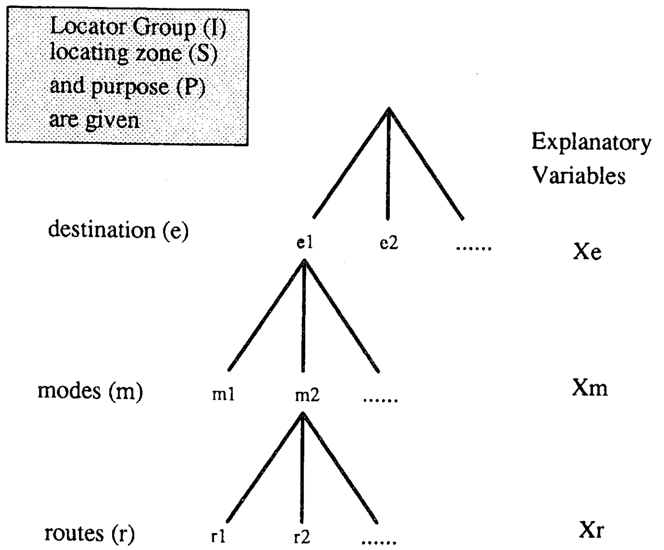


Fig. 6. Accessibility of Zone S for Purpose P and of Locator group I

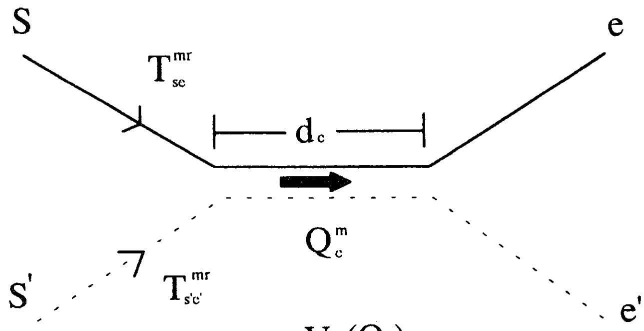
The choice tree structure of transport shown in Figure 6 consists of a destination, mode and route choice hierarchy. In the case of commercial location, the top choice level is not destination but origin choice, because the accessibility means the size of the population in the hinterland which are discounted by the transport condition. However, for the convenience of explanation, the word of destination is used in the choice of accessibility, because reverse-direction trip can substitute for it.

In the level of mode choice, it also includes type of vehicles as well as other type of communications, for example telecommunications. It is indispensable to classify the type of vehicles, for example passenger cars or heavy trucks, for the evaluation of environmental changes caused by the mixed traffic.

Regarding route choice, each route consists of some links as shown in Figure 7. In addition, each link is generally shared by some routes. In order to obtain the traffic volume on a link, it is necessary to sum up trips of all routes which have the link as a part. The general service level of the link is obtained by its service function which contains its conditions such as capacity and length. Moreover, the service level is determined by the composition of different vehicle type in the total traffic volume. The service level will also determine the efficiency of energy consumption as well as pollutant emission which are estimated by the environment model.

5.3 Utility Function and Rent-Bidding Function

Also in this improvement of the RURBAN, the basic concept of the model consists of both random utility of the locator group in location choice and random rent-bidding in locator choice of the zone. The top level of behaviour is location choice. The bid-rent function can be derived from the utility function since they have dual relation between each other. The structure of locator choice is shown in Figure 8.



$$v_c = V_c\,(Q_c)$$

$$Q_c = (\,Q^{'}_c\,, \ldots\ldots, Q^m_c, \ldots\,)$$

$$Q^m_c = \sum_S \sum_e \sum_{r(c\in r)} T^{mr}_{Se}$$

Fig. 7. Accessibility (Q_C) and Service level (v_C)

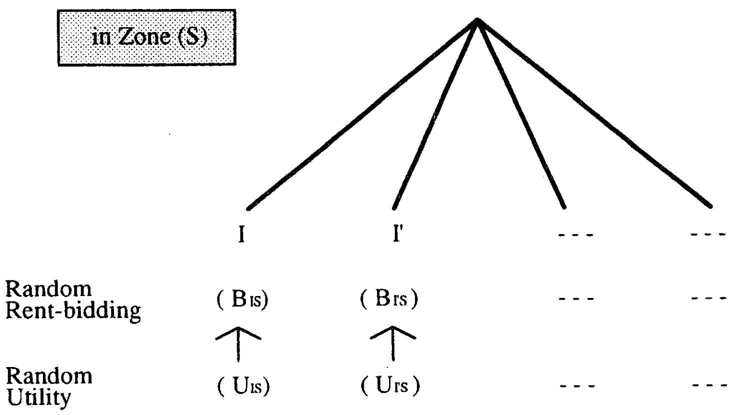


Fig. 8. Locators Choice in Zone S

5.4 Formulation

Based on the above-mentioned explanation, the following equations are derived to represent land-use, transport and the environment. Denotations are as follows,

I : the locator group
S : the zone
c : link
r : route
m : mode (including type of vehicle)
e : destination
p : (trip/communication) purpose
U_c, U_r, U_m, U_e, U_s : utilities for link, route, mode, destination and locating zone
$\mu_r, \mu_m, \mu_e, \mu_s$: positive scale parameters of route, mode, destination and locating zone choice
$\alpha_m, \alpha_e, \alpha_s$: parameters for mode, destination and zone choice
X_m, X_e, X_s : explanatory variables for mode, destination and zone choice
$C(\ )$: cost function
v_c : service level of link c
d_c : condition of link c
${}^p_I g_S$: trip production of locator group I for purpose p from zone S
${}^p_I \pi$: trip production rate of locator I for purpose p
n_{IS} : number of location of locator group I in zone S
${}^p_I t^{mr}_{Se}$: assigned trips locator group I for purpose p for route r
T^{mr}_{Se} : total assigned trips for route r
$V(\ )$: service level function
Q^m_c : traffic volume of mode m in link c
E_S : environmental indicators (vector) in zone S
$E(\ )$: estimation function of environmental indicators.
$v = [v_c]$
$n = [n_{IS}]$
$Q = [Q^m_c]$
$Q_c = [Q^m_{(c)}]$

Regarding the choice tree, it is understandable to trace from the bottom to the top. The utility of route r can be expressed by the summation of the utility of each link c which constitutes the route as shown equation (7). The utility function of the link c can be represented by the cost function of service level and link condition as equation (8).

$$U_r = \sum_c U_c \tag{7}$$

$$U_c = C(v_c, d_c) \tag{8}$$

The choice probability of route r is expressed by equation (9), under the condition that locator I, locating zone S, purpose of trip and destination p/e, and mode m are given.

$$\text{Prob}\,(\text{I,S,p / e,m} \mid \text{r}) = \frac{\exp(\mu_r U_r)}{\sum_{r'} \exp(\mu_r U_{r'})} \tag{9}$$

Following the choice tree, the choice probability and utility of mode choice are expressed as equation (10) and (11). The utility of mode m contains a logsum function of utilities of routes which belong to it.

$$\text{Prob}\,(\text{I,S,p / e} \mid \text{m}) = \frac{\exp(\mu_m U_m)}{\sum_{m'} \exp(\mu_m U_{m'})} \tag{10}$$

$$U_m = \alpha_m x_m + \frac{1}{\mu_r} \ln \sum_r \exp \mu_r U_r \tag{11}$$

In the level of destination choice, it depends on the trip or communication purpose p. Same as the previous derivation, equations (12) and (13) are derived.

$$\text{Prob}\,(\text{I,S} \mid \text{p / e}) = \frac{\exp(\mu_e U_e)}{\sum_{e'} \exp(\mu_e U_{e'})} \tag{12}$$

$$U_e = \alpha_e x_e + \frac{1}{\mu_m} \ln \sum_m \exp \mu_m U_m \tag{13}$$

In the top level of choice behaviour, the choice probability of locating zone S by locator group I is expressed by equation (14) which is same as the original RURBAN. In this improved version, however, the original utility function (1) is substituted by the following equation (15). In this case, logsum functions which represent the "accessibility" are summed up over purposes.

$$\text{Prob (I|S)} = \frac{\exp(\mu U_{IS} + \ln L_{IS} + \ln w_{IS})}{\sum_{S'} \exp(\mu U_{IS'} + \ln L_{IS'} + \ln w_{IS'})} \tag{14}$$

$$U_{IS} = \alpha_I x_{IS} + \sum_p \frac{1}{\mu_e^p} \ln \sum_e \exp \mu_e^p U_e^p - \omega B_S^* \tag{15}$$

As for the calculation of travel demand, trip production is calculated by equation (16). Then trips assigned to route r is calculated by equation (17). By summing up the trip production over purposes and locator groups, assigned traffic volume for route r is obtained by equation (18).

$$ {}_I^p g_S = {}_I^p \pi \, n_{IS} \tag{16}$$

$$ {}_I^p \mathrm{t}_{Se}^{mr} = {}_I^p g_S \ \text{Prob (I,S,p / e,m,|r)} \tag{17}$$

$$T_{Se}^{mr} = \sum_I \sum_p {}_I^p \mathrm{t}_{Se}^{mr} \tag{18}$$

The service level of each link is determined by the total traffic volume in it which is obtained by equation (19) (see Figure 7). The service level of link c is determined by the function of equation (20).

$$Q_c^m = \sum_S \sum_e \sum_{r(c \in r)} T_{Se}^{mr} \tag{19}$$

$$v_c = V(Q_c, d_c) \tag{20}$$

In the final stage, the environmental indicators are estimated by the environmental model function of (21).

$$\mathrm{E}_s = \mathrm{E(v,Q,n)} \tag{21}$$

5.5 The Structure of the Integrated Model

Once again see Figure 4 which shows the whole structure of the integrated model. The land-use distribution (n_{IS}) is not only output of the model but also input as the attractiveness of destination. In the land-use model (RURBAN), iteration is needed to get to a convergence. Also in the transport model, transport service level (v_c) is both input and output of the model. Some iteration are necessary before reaching to a convergence. In addition, as a whole model system of the integrated land-use, transport and environment model, iteration processes of a larger circle are necessary for a convergence of the total system.

The iteration of the whole system should start from the equilibrium situation, that is the point of convergence, of the previous period.

6. Concluding Remarks

This paper briefly describes the basic concepts of the analysis system which we are now developing. Since the conceptual system building goes first, we may be facing several issues which we have to resolve in the development of the pilot system. In addition, regarding the development of the integrated model, some devices will come to be indispensable to adjust the theoretical model with actual situations of land-use, transport and the environment. Data availability may urge the development to add some assumptions and special treatment of parameter estimation.

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