【土木計画学研究・講演集 No.16(1) 1993年12月】

Basic Concepts of an Analysis System for Integrated Policy Measures of Land use, Transport and Environment in a Metropolis

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ABSTRACT: This paper presents a new approach in the development of an analysis system for integrated land use, transport and environment planning. The analysis system is designed with stressing operational simplicity as well as conceptual simplicity. The basic concepts of system development regarding analysis system building, integration of land use and transport models, and aggregation and disaggregation method of units for analysis are discussed.

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 environment. Since urban environment can be regarded as an externality of land use and transport, it is indispensable to forecast and evaluate the 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 a metropolis, particular in a developing metropolis where dramatic changes in urban structure are occurring.[1)]

To make the integration possible, it is indispensable to provide better institutional set up. However, without effective tools for analysis, it is impossible for related governmental agencies to discuss policies and their implementing measures efficiently, because options are so various and complex in their interaction. An analysis system covering land use, transport and 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.

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Many kinds of land use, transport and their integrated models have been developed to forecast future changes in land use and transport 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 utilize existing models. In other words, there have been no idea of standardization in land use, transport and environment modeling.

When we prepare an analysis system for integrated planning and implementation, the system should consist of modules of land use, transport and environment. It would take a long time and much cost if we try to develop only by ourselves all the simulation models of land use, transport and environment. Therefore, we should change the conventional approach to aim original development of models to new approach to utilize existing stock of models. For the purpose, we should set up a general framework for an analysis system which allows the system to easily incorporate and replace models of land use, transport, environment and, moreover, any sector of a metropolis.

The objective of the study is to develop a pilot system to evaluate an integrated policy measure related to land use, transport and environment in a metropolis which will contribute to a forum of related governmental agencies for their integrated planning and implementation.

In the present paper, we discuss some of the basic concepts for the development of the analysis system; (1) a concept of analysis system building, (2) a concept of integration of land use and transport models and (3) a concept of aggregation and disaggregation method of units for analysis. The second concept is, of course, important in terms of theoretical consistency between land use and transport analyses, while the third concept is indispensable in integrating different type of models in an analysis system.

2. BASIC CONCEPTS

2.1 Background of the Study

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 analyze policy alternatives with the model.[2] 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 thorough 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.

2.2 Basic Concepts for System Development

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

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

With the principles, the system is being developed.

3. ANALYSIS SYSTEM BUILDING

3.1 System Structure

The conceptual framework of the system is represented in Figure 1. The system is designed under the condition that it is built under Microsoft Windows 3.1 environment. 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, (2) it is one of the most popular operation system, (3) it can be operated under personal computers which are available at any places, (4) the system has high possibility for further development.

3.2 Functions of the System Parts

(1) 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. [2]

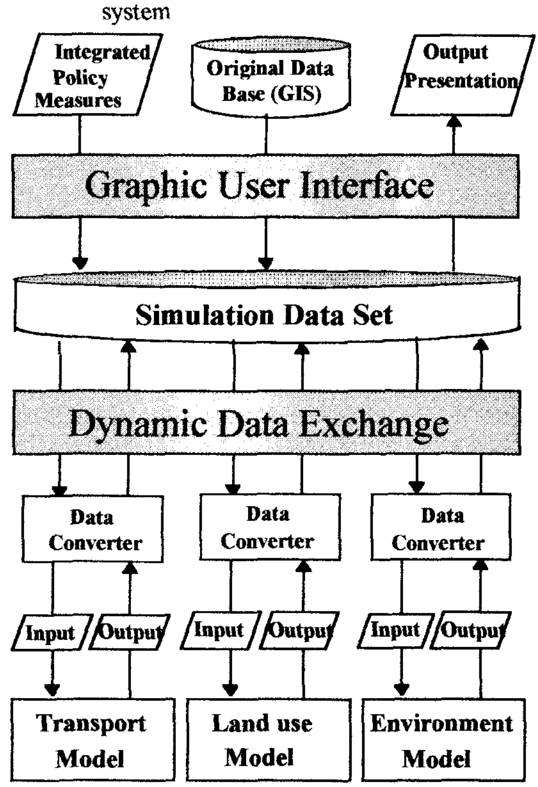
(2) Integrated Policy Measures

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

(3) Original Data Base

Original data base can take any form; from

Figure 1 The conceptual framework of an analysis system



established GIS database to a file of existing data. The form can be selected by taking into consideration the availability of both hardware and software.

(4) Output Presentation

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

(5) 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 environment at a level of analysis unit. Each model will make "the interactions through the simulation metropolis". The data of land use, transport, and environment by year are always updated through Dynamic Data Exchange function.

(6) Dynamic Data Exchange Function

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

(7) Data Converter

Data converter has a function to connect simulation data set and application models. Application models have their own input and output data layouts. In the case of 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.

(8) Models

Application models 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 and plural number of models which can exist in the system. The selection of the models for simulation is done by the simulation definition batch file.

(9) 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, judgment of simulation end. The operator can decide how land use and transport are interacts in the simulation in the file. Time lag and leads are also defined in the statement of the file.

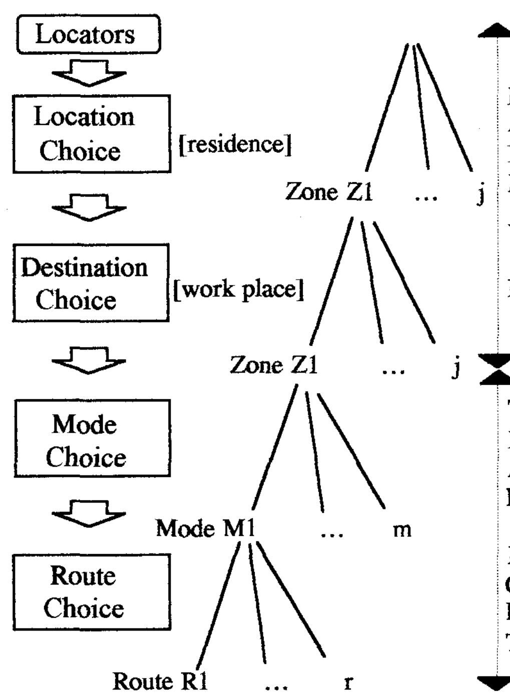
4. INTEGRATION OF LAND USE AND TRANSPORT MODELS

4.1 The Approach

The main parts of analysis system are land use and transport models. In this study, RURBAN model has been improved [2)] 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 by not only directly integrating land use and transport but also separating them under the proposed analysis system framework as discussed in section 3.

The RURBAN employs aggregate logit model structure. The improvement is being done along with the same structure. There are several important implications of the decision to use a form of the RURBAN model, which should be mentioned here. Firstly, the model is able to fully and consistently integrate transport choices within location choices. Therefore, land use and transport are modelled within a single model framework. Secondly, the

Figure 2 Integration of land use and transport analysis [an example of residential group]



model has mechanism to represent price's market equilibrium between demand and supply. Thirdly, the theory underpinning RURBAN model is random utility discrete-choice model. It also integrates the concept of bid-rent analysis with the maximum random utility model. Changes in land use and transport are represented by "choice" as shown in Figure 2.

The choice in location and trips are viewed as outcome of a probabilistic choice process. The process simply describes 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. Figure 2 shows how this process can be described in a hierarchical concept. In the case of residential location, destination choice is "choice of working place". The hierarchical structure represents that "a site which is convenient for commuting" means to be closed to large working places. The structure covers both location and transport behaviors of aggregated locators and travelers.

4.2 Theoretical Basis

We adopt the probabilistic choice approach based on *discrete-choice random-utility* models to describe the behavior of urban locators and travelers. The models assume that locator group's evaluation of available alternatives and their attributes can be conceptually described by utility function. Therefore, the probability of a locator group locating in a zone or using a particular mode/route of transport is calculated as a function of utility, which is related to the price of given options.

The multiple choice probabilities are expressed by the multinomial logit model. It is derived from random utility models and has the form:

$$P_n(i) = \frac{\exp(\mu V_{in})}{\sum_j \exp(\mu V_{jn})} \quad \text{.........................(1)}$$

where $P_n(i)$ is the probability of decision maker n choosing alternative i and V_{in} be the utility of an alternative and μ is the logit constant.

Since the choice in locations and trips are viewed as a sequential process, which is strictly hierarchical representation, the *nested logit model* appears likely to be the most appropriate model to describe the choice in decision chain. The estimations of the nested logit model perform at the lowest levels of models first, and condition on this estimation, estimations are made subsequently at the higher levels of the model. The aggregated utilities (S_l) calculated at each level is given by

$$S_l = \frac{1}{\mu} \ln \sum_j \exp(\mu V_{jn}) \quad \text{........................... (2)}$$

This expression is commonly known as *"logsum function"*. Operationally, this formulation has also the advantage of representing a simplified method of aggregation and disaggregation of analysis unit, as will be seen in the next section.

4.3 Analytical Framework

An urban system is represented by two markets: the market for land and market for transport. As a result, land use and transport markets determine the situation of urban environment. In analytical term, each market can be described in term of utility level; locational utility for land market and travel utility for transport. The utility function is calculated as a function of price market, e.g. land prices for land use and travel cost for transport. In order to achieve theoretical consistency in the analysis, all elements in representation of land use and transport should be treated as choice situations correspond to nested logit model.

The land use model estimates the location of activities (or urban locators) in different zones in which the study area has been divided, and equilibrates the market price. The utility function of urban locators is expressed as a function of land prices or bid-rent. The locational utility includes the level of accessibility which indicates transport condition of a zone. The activity's allocation process results in location of activities or land use distribution of a zone. The distributions of activities are then transformed into trips (or travelers) generated from zones. In other words, the demand of transport is given by the flows of locators between each pair of origin-destination zone.

The transport model, in turn, allocates these demand to transport network and therefore modes, as a function of calculated travel utility represented by transport costs. The travel utility is first calculated at route level for assignment, then aggregated for all routes for modal split, and aggregated for all modes to have the cost of travel between destination zones. Transport costs, which is one of the components of utility function in the activity allocation model, will be fed back to the land use model.

Given the price, the utility of both location and travel can be estimated. The equilibrium of the system is achieved by adjusting the price of land and transport. Equilibrium will be obtained through the iteration procedure defined by a simulation framework.

4.4 Model Formulation

Our attempt to improve the RURBAN model for this study is to integrate it with suitable transport model for representing transport choices up to route level. This section describes how land use and transport interaction are formulated in RURBAN structure.

The following are notations.

n, m, r, l superscripts represent activities group, mode, route, respectively.

i, j subscripts represent origin and destination zones

β logit constant

(1) Land use calculations

The RURBAN model performs the calculation of location of activities (or locator group) in a metropolis. The random utility of a locator group in a zone represents the demand for land of the group in the zone, and the random rent-bidding of a locator group in a zone determine the supply of land to the group in the zone.

The interaction between land use and transport is taken into consideration in RURBAN structure by representing transport components in utility function in activity's allocation process. The locational utility (U_i) of locator group includes the following elements: locational condition (X_i) of a zone, equivalent land prices or bid-rent (B_i) and commuting condition represented by accessibility level (A_i).

$$U_i = \Phi\left[X_i, B_i, A_i\right] \quad \text{.....................} (3)$$

The locational condition is expressed as a linear function of explanatory variables regarding land use conditions, but excluding land prices and travel costs. The land use conditions, for example, can include variables related to land use regulations, socio-economic factors, public utility provision, environmental condition and so on. The parameters of explanatory variables are obtained by logit estimation. The accessibility is expressed as a function of attractiveness of the destination zones and the generalized travel costs (C_{ij}^{n}) to the destination, which is calculated by transport model, as follows;

$$A_i = \frac{1}{\beta_j} \ln \sum_j \exp\left(\alpha_1 Y_j + \alpha_2 C_{ij}^{n}\right) \quad \text{........} (4)$$

where Y_j is attractiveness of destination zone j and α is parameter.

(2) Transport Calculations

The transport model involves the calculation of travel costs which is represented by the utility of travelers. The purpose of transport calculation is to estimate the cost of travel along the route (C_{ij}^{nmr}), the composite cost by mode (C_{ij}^{nm}) and composite generalized transport cost (C_{ij}^{n}). The link cost is first calculated and then aggregated into routes, modes and zones. The proper way to do this is by applying equation (2).

$$C_{ij}^{nm} = \sum_k x_{ijk}^{nm} + \frac{1}{\beta_{mr}} \ln \sum_r \exp\left(\beta_{mr} C_{ij}^{nmr}\right) \text{..} (5a)$$

$$C_{ij}^{n} = \frac{1}{\beta_m} \ln \sum_m \exp\left(\beta_m C_{ij}^{nm}\right) \quad \text{............ ......} (5b)$$

where x_{ijk}^{nm} represents mode specific variables.

The number of trips assigned to each route is compared with the capacity of the route, and adjust travel times accordingly. This process performs iterative until the convergence is reached.

5. AGGREGATION/DISAGGREGATION METHOD OF UNITS FOR ANALYSIS

An analysis system for integrated policy measures is dealing with the evaluation of impacts of a variety of policy measures. Some of policy measures have some metropolitan wide impacts while others have some area-specific ones. In this sense, the analysis system should have some flexible functions by which units for analysis can be changeable. This section presents an aggregation/disaggregation method of units for land use and transport analyses, in other words area and network data conversion.

5.1 Representation of Unit

The units of analysis comprise of locator groups and land zones in the case of land use, and travel groups and transport network in the case of transport. In geographical representation, it is common to represent land use and land attributes by dividing the study area into series of grid cell. Each cell can become an analysis zone. Each zone's centroid is connected by two or four transport links to produce fairly regular grid network. The zones and network units can be coded into different levels of detail, e.g. fine, medium and coarse ones. The higher levels of aggregated units are developed by combining units in a lower level into a suitable size.

In analytical term, these units are represented by utility level; locational utility for land use and travel utility (cost) for transport. Therefore, it is possible to draw hierarchical relationship between different levels of analysis units. Figure 3 illustrates geographical and analytical representation of land use and transport units.

5.2 Methodology

The aggregation and disaggregation process are performed in hierarchical basis. In aggregation process, the utility at a lower level is first calculated and then aggregated to a higher level by applying logsum function. Disaggregation is a reverse process of aggregation to translate variables on a higher level of unit to a smaller unit. This simplified disaggregation process requires some additional information to estimate utility at a lower level. If land use data at the lower level is added, explanatory variables for location at the level can be estimated. If one of key explanatory variables are given at the level, land use distribution is obtained by using the logit model. It is necessary to find out what variables are most effective for this process. Figure 4 describes the sequence process of aggregation and disaggregation.

6. CONCLUDING REMARKS

This papers briefly describes the basic concept of the analysis system which we are now developing. The pilot system is expected to be built by the time of the presentation of this paper.

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Figure 3 Representation of land use and transport units

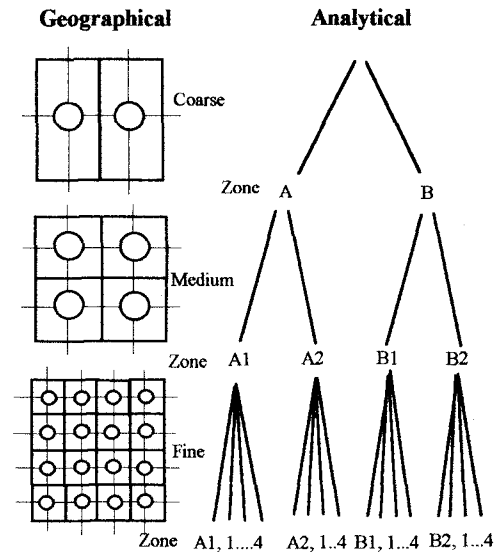

Figure 4 Aggregation and Disaggregation procedure