COMPUTER AIDED LAND USE - TRANSPORT ANALYSIS SYSTEM (CALUTAS) FOR EVALUATION OF INFRASTRUCTURE PLANNING

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1. INTRODUCTION

Infrastructure improvements greatly influence the region. It is essential to analyse spatial interactions in detail for evaluation of such effects as those on transport conditions, environmental changes and economic impacts. There have been many land use - transport models developed for such analyses (1). However, they are not always applicable in a detailed description of actual land use changes on the one hand, not operational in practical planning because of insufficient functions in processing vast amounts of data and in providing various results of the analysis as a result of alternative policies on the other.

This study is an attempt to improve the reliability and operationality of infrastructure planning practice. We have tried to develop an integrated land use - transport model, which is equipped with a man-machine interactive system and database management system, that describes land use changes by considering detailed land conditions. The analysis system provides information which are essential for the evaluation of infrastructure planning, with understandable presentation using computer graphics. Examples of such functions are forecasting changes in transport conditions, land price and land use pattern. In order to illustrate this system, future changes in land use and transport in the Tokyo metropolitan area due to the proposed Tokyo Bay Bridge have been analyzed. This paper will concentrate on the total analysis system and not on the detail on land use - transport models which was already presented in a previous paper (2).

2. BASIC CONCEPT OF THE COMPUTER AIDED LAND USE - TRANSPORT ANALYSIS SYSTEM

2-1. SYSTEM CONFIGURATION

The system consists of two major parts as shown in Figure 1. The first part is an integrated land use - transport model system which adequately describes the locational behavior of land uses and consequently forecasts future land use patterns. The second one is an analysis management system which can handle the whole analysis in an efficient way using the model system.

The land use - transport model has a hierarchical structure as shown in Figure 1 which first allocates land use demand into city size zones and then into 1km^2 grids. The allocation model for the zone level has a Lowry type structure, but each sub-model for industrial, business and residential location is based on some assumptions of its own locational behavior. The allocation model for the grid level describes competition among land uses under constraints of zoning regulations according to the principle of maximization of locational surplus. Transport conditions are determined by estimating trips generated from new locations. Location of land uses and transport conditions interact with each other in the model.

The integrated land use - transport model is comparatively complex. Additionally, the analysis using the integrated model requires a large amount of data such as land conditions within each 1 km^2 grid. Consequently, in order to analyse and evaluate impacts of alternative plans of infrastructure planning using the integrated model, the analysis system should be operational in practice. This will improve the reliability of analyses by repeated trials.

The computer aided analysis system developed in this study contains a database system which manages vast amount of spatial data for land use - transport analysis as well as an interactive operation system using computer graphics and a hierarchical menu for program execution.

2-2. FUNCTION AND STRUCTURE OF THE LAND USE-TRANSPORT MODEL

The land use-transport model (see Figure 1) forecasts future location of population, industrial and business activities, and consequently land use patterns and tranportation environments inside a metropolitan area.

As input data, total future population and industrial products by sector are assumed to be given by the socio-economic master plan of the metropolitan area. Transportation improvement projects as well as land use policies such as zoning regulations, both of which are exogenously given as alternatives, will affect the spatial allocation of population and products in the region and generate new and varying land use patterns.

Disaggregating the Tokyo metropolitan area is conducted in two stages (see Figure 1). In the first stage, the Tokyo metropolitan area is divided into 69 zones which correspond to established administrative zones and outstanding physical characteristics of the region. In the second stage, the Tokyo metropolitan area is divided into about 20,000 areas called grids, each of which is $1km^2$ in size.

In the model, land uses are classified in the following four types according to their locational characteristics:

(a) priority location type (e.g., large-scale basic industries)
(b) optional location type (e.g., business areas, housing)
(c) subsequent location type (e.g., neighbourgood stores, school)
(d) passive location type (e.g., agricultural areas, forests)

This land use classification is related to the Standard Classification of Industrial Sectors as shown in Table 1. The location and amount of type (a) use is determined a priori on the basis of an existing development plan of a given area. Type (b) use has wide locational options. Type (c) are land uses which are determined in proportion to the amount of land alloted to type (a) and (b) use. In contrast to these urban land uses, type (d) is largely agricultural land use which is considered to be the source of supply of new sites for urban land use.

Locations of optional type uses are described by the following three models according to different patterns of locational behavior, that is 1) indusrial location model, 2) business location model and 3) residential location model.

Using these models, the level of activity within each of the 69 zones is estimated, and then, if necessary, more detail information within the $1 km^2$ grid can be obtained by the 4) local land use model. Transport environment such as amount of trip distribution and traffic volume is forecast by the 5) transport model. These conditions will influence the location of activities in the next period.

3 LAND USE - TRANSPORT MODEL

3-1 TRANSPORT MODEL

Transport model provides interzonal travel times and costs of rail and road networks. This sub-model includes a series of travel demand models and network models.

The inputs of the sub-model are information regarding rail and road networks, existing trip distribution by trip purpose and the newly generated trip distribution which is obtained as outputs of location models. The network models of railways and roads can reduce computing time of assignment substantially by means of aggregation of the actual networks into virtual ones(3). The transport model makes it easy to analyze impacts due to many alternative plans of networks.

3-2 INDUSTRIAL LOCATION MODEL

The industrial location model allocates manufacturing industries of each sector according to their locational preferences. As a manufacturing industry is assumed to have comprehensive criteria for evaluating locational factors in each site, we try to derive an indicator, called a locational preference indicator, which quantifies the criteria.

There might be a difference between the scores of locational preference indicators in a site where a firm locates and that in another site where the firm does not locate. The scores are estimated by discriminant analysis of the located site and non-located site using questionnaire survey data.

According to the scores of locational preference, locational demand of industry is allocated in industrial zones inside the area.

3-3 Business location model

Business activities consist of different sectors such as retail, financing, and governmental, and every sector has different characteristics concerning locational behavior. However, these activities locate themselves depending on the locations of other activities. In addition to these characteristics, they have different patterns of service needs that can be classified as neighborhood service type and wide-area service type. The location of activities of the latter type depends upon the economic distances to the service areas and upon the competitive power of other locations.

Considering the locational characteristics of business sectors, the following type of equation is introduced to estimate the scale of business activities in every zone. The scale of each activity can be represented by the size of employment. The following equation is an example for the retail sector.

$$R_i = 0.0381 P_i + 0.0478 \, P_j S(r_{ji})$$

(multiple correlation coefficient=0.9994)

R_i: employment of retail sector in zone i

P_i, P_j: populations in zone i and zone j

$S(r_{ji})$: share of zone j among all surrounding zones of zone i with regard to shopping by inhabitants of zone i

Similar equations for all business sectors have been empirically estimated for the Tokyo metropolitan area with reasonable accuracy.

The forecast of business activities can be found from the distribution of population and the employment of manufacturing industries. These projections are generated from the residential location model, the industrial location model and the distribution of existing business activities. Thus, the amount of located activities of every sector is estimated by successive calculation of the derived equations.

3-4 RESIDENTIAL LOCATION MODEL

The residential location model allocates households based on the level of their own locational surpluses. This locational surplus is defined as the difference between the present value of locational utility during the useful life of land, which differs according to work places of householders, and the present land prices.

The present value of locational utility and land price is derived from land price function. Table 1 shows an estimated land price function which expresses the relationship between land price and level of locational factors using sample data for more than 3,000 land plots in the Tokyo metropolitan area.

In estimation of the function, land price is assumed to represent the value of locational utility for a householder whose commuting condition is an average among the locators in a grid of $1km^2$. With this assumption, land price function provides not only the land price but also the value of locational utility for a certain householder by using his own commuting condition.

The locational demand is calculated by the work place and housing type using a discrete choice model, considering new and relocational demands. The demand is allocated according to the diversity of locational surplus due to the variety of attributes of households and that of locational factors within zones.

As shown in land price function, the commuting time, the distance to the nearest station, the availability of gas and sewerage, and the level of land readjustment can be considered as alternatives of infrastructure planning.

3-5 LOCAL LAND USE MODEL

The local land use model describes changes of the land use pattern in the 1 km^2 grid by considering the competition among land uses while the wide-area location sub-model describes the distribution of activities among zones in a metropolitan area. Modeling of competition determines priority based on the concept of "locational surplus." This concept is similar to the residential location model except that land use zoning regulations in a grid are considered and that industrial and business uses are regarded as "would-be land users" as well as residential users. The competitiveness of different land uses in a grid is determined by the value of locational surplus.

The extent of industry, residence and business located in a zone is exogenously given to the local land use model as a control total which has been estimated by the wide-area location sub-models. Applicability of the sub-model was tested in a suburban area of the Tokyo metropolitan area and has proven reliable (4).

4. MANAGEMENT SYSTEM FOR COMPUTER AIDED LAND USE - TRANSPORT ANALYSIS

4-1 FUNCTIONS REQUIRED FOR THE ANALYSIS MANAGEMENT SYSTEM

The following functions are required for the system:

(a) A highly productive database management system for data entry, retrieval and editing,
(b) Easy input of various alternative plans,
(c) Immediate monitoring of intermediate results during the analysis,
(d) Understandable presentation of outputs and
(e) Simple operations of model analysis.

In order to satisfy these requirements, the system contains a database system, a program management system and a graphic system.

4-2 DATABASE SYSTEM

4-2-1 FRAMEWORK

In order to meet both requirements of compatibility of data for different programs and efficiency in data processing, this system has two types of random access databases, that are entitled, master database and project database. The master database stores original data and will be used commonly for various analyses. The project database, which plays the same role as the existing data files, is specified for individual application programs and stores processed data of the master database in special forms suitable to them.

4-2-2 MODELING OF DATA FOR LAND USE - TRANSPORT ANALYSIS

The main components of data for land use - transport analysis are summarized as follows:

(a) Spatial data describing land conditions (e.g., terrain, road and rail networks and existing zoning regulations);
(b) Alternative plans (e.g., future economic framework, infrastructure improvement and alteration of zoning regulations);
(c) Exogenous parameters (e.g., product per unit area and number of workers per household).

Data requested for land use - transport analysis consists mainly of spatial ones because this type of analysis places great emphasis upon locational considerations. This is one of the distinguishing traits of land use - transport analysis in comparison with socio-economic planning which has more of a macro-focus. The major characteristic of spatial data is that it consists of data which describes the location (geometrical) and the characteristics (attributes). It is convenient to describe these two types of data separately because attribute data is frequently retrieved or added as additional information while geometrical data is usually fixed and rarely retrieved. For example, information on road links is of the latter type while traffic volume is of the former type.

The ability to develop alternatives which may consist of many options of plans and exogenous parameters in interactive systems results in easier applications in practice and of sensitivity analysis in testing the stability of the model.

There are three types of database models, namely, the tree type model, the network type model and the table type model. The third type model is usually called the "relational database model"(5). The relational database model, which most satisfactorily meets the above requirements, is applied in this system.

4-3 PROGRAM MANAGEMENT USING A HIERARCHICAL MENU OPERATION

In the analysis of alternatives using this computer aided system, planners make alternative plans, obtain forecasts of future changes and evaluate them using the computer in every stage in the following manner:

(1) Call the required information, such as the results of forecasts from the project database, and observe the output in forms of maps, figures or tables,

(2) Select an optional menu of programs for a new analysis or a sensitivity analysis with different parameters, judged by the observation of the earlier outputs, and

(3) Input the selected alternative plan or modified parameters for the selected analysis program.

The program management method adopted in this system has a hierarchical menu structure of various programs (Figure 3) and it enables easy interactive communication between the analyst and the computer. Without this method, it is too difficult to effectively operate such a vast program system.

5 EVALUATION OF EFFECTS OF ALTERNATIVE INFRASTRUCTURE IMPROVEMENTS -------- THE CASE OF THE TOKYO BAY BRIDGE PROJECT

An application of land use - transport analysis system was conducted for the forecast of land use changes in the Tokyo metropolitan area from 1975 to 1990 as a part of an assessment of the Bay Bridge which is planned to cross the Tokyo Bay. Figure 4 shows the estimated effects of the Bay Bridge on residential lecation and land price.

Direct effects of infrastructure improvement, such as shortening of travel time and cost (Photo 3), is calculated by the Transport Model as a result of improvement of rail- and road- networks (Photo 1 and 2). Using this type of information on change of land conditions, land price (Photo 4) and the present value of locational utility (Photo 5) (consequently that of locational surplus for a householder who, for example, is commuting to Yokohama) are estimated by the land price function.

The level of locational surplus for a householder determine the degree of intensity of residential location from his work place and consequently the located amount together with the volume of housing demand.

The future population (Photo 6) calculated from located amount of houses will induce business and commercial locations. The employees of the business and commercial sector generate an additional housing demand together with relocation demand. Such interaction will continue until an equilibrium occurs like the Lowry model.

Finally, the future land price (Photo 7) is estimated by land price function; thus, the economic effect can be estimated in terms of capital gain from an increase of land price by 1km^2 grid.

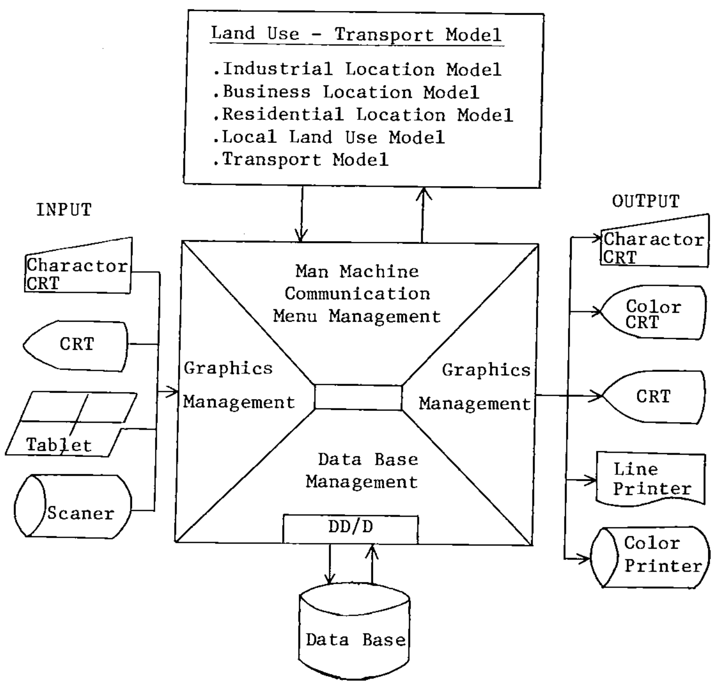

Figure. 1 Configuration of the Computer Aided Land Use-Transport Analysis System

Using the information of future land use patterns from the model simulation, economic impacts inside the area such as changes in the values of land, levels of employment , industrial products, traffic generation, as well as environmental impacts, will be estimated for the evaluation of the project, comparing both cases with and without the bridge.

6 CONCLUDING REMARKS

The model developed in this study is aiming at a precise land use - transport analysis, and therefore, the computer aided system is constructed using a large - scale computer hardware system.

Recently, some attempts have been undertaken to use micro - computers in transport analysis. We are trying to simplify the model system as well as the algorithms to be suitable for calculation using micro - computers.

This system has been applied not only to the Tokyo Bay Bridge project, but also to the impact studies of other projects, such as the construction or improvement of commuter rail lines in several metropolitan areas in Japan. Currently, the model is being improved as a result of accumulated experiences from these studies.

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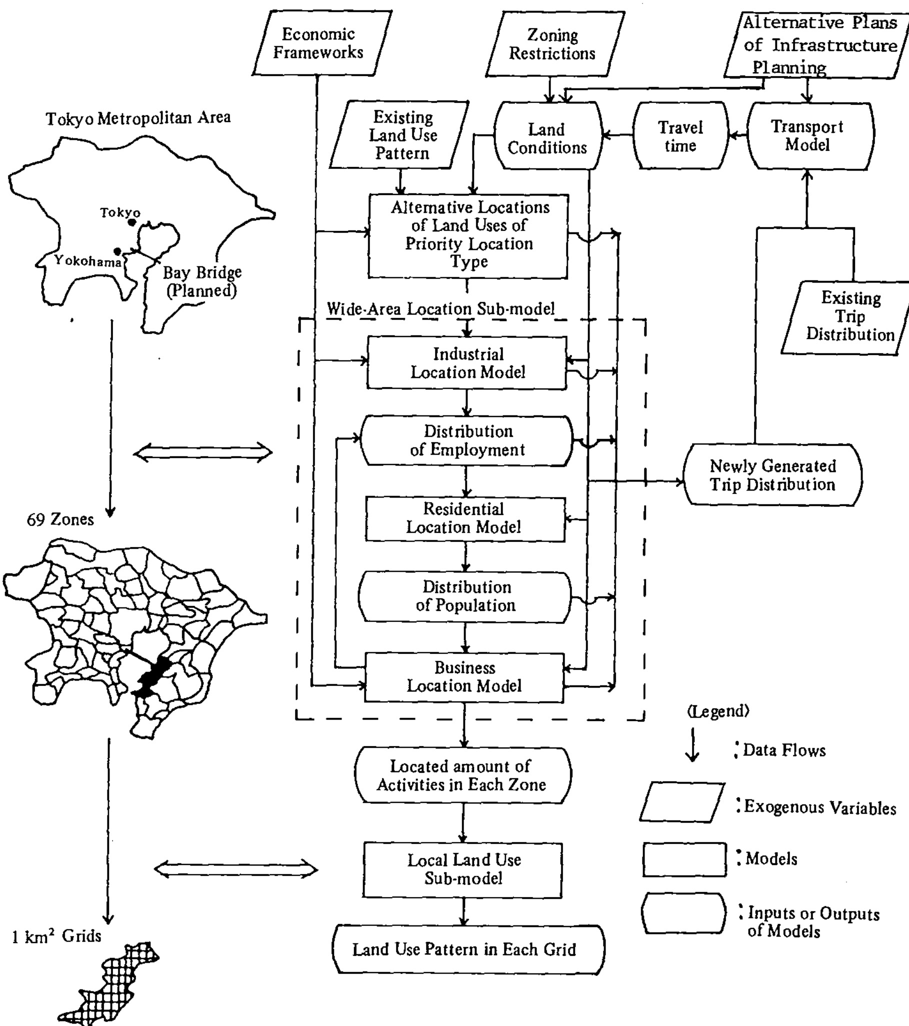
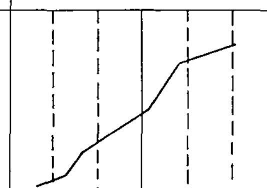
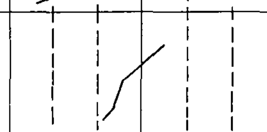
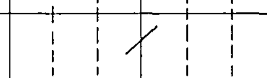
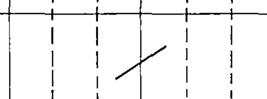
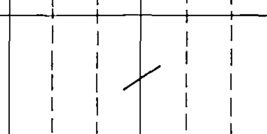
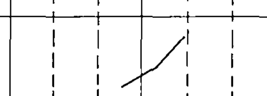
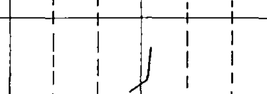


Figure 2 Structure of the Integrated Land Use-Transport Model

Table 1 Land Price Function in Residential Areas

Factor	Indicator (Z_i)	Category	Number of Samples	Category Score (α_{ij})	Difference (1000's yen) −20 −10 0 10 20	Partial Correlation Coefficient
Transport Service	Z_1: Travel Time to Work Places by Train	(minutes) 20 – 50 50 – 60 60 – 70 70 – 80 80 – 90 90 – 120 120 – 160 160 –	 86 83 122 94 73 80 66 14	 48175 35314 34668 30182 22397 16744 12491 4436		0.090
	Z_2: Distance to Nearest Station	(meters) 0 – 500 500 – 1200 1200 – 2200 2200 – 5000 5000 –	 57 215 220 102 24	 15344 9571 7185 5229 0		0.268
Natural Environment	Z_3: Terrain Feature	Hills Alluvial Plain	339 279	3113 0		0.140
Availalility of Public Utility	Z_4: Level of Gas and Sewerage Availability	One or Both Utilities None	285 333	8236 0		0.317
	Z_5: Percentage of Land Readjust-ment Area in 1 km^2 grid	(%) 25 – 100 0 – 25	 203 415	 3930 0		0.157
Maturity of Residence	Z_6: Percentage of DID Area within 1 km^{2}Grid	(%) 75 – 100 25 – 75 0 – 25	 126 105 387	 10728 6592 0		0.332
Comfortability	Z_7: Plot Size	(m^2) 300 – 180 – 300 0 – 180	 129 290 199	 2076 1703 0		0.078

Multiple Correlation Coefficient R = 0.844

$$\text{LAND PRICE: } P(Z_1, \cdots, Z_7) = \sum_{i=1}^{7} \sum_{j=1}^{n_i} \alpha_{ij} \cdot \delta(ij), \quad \text{where } \delta(ij) = \begin{cases} 1 & (Z_i \in \text{category } j) \\ 0 & (Z_i \notin \text{category } j) \end{cases}$$

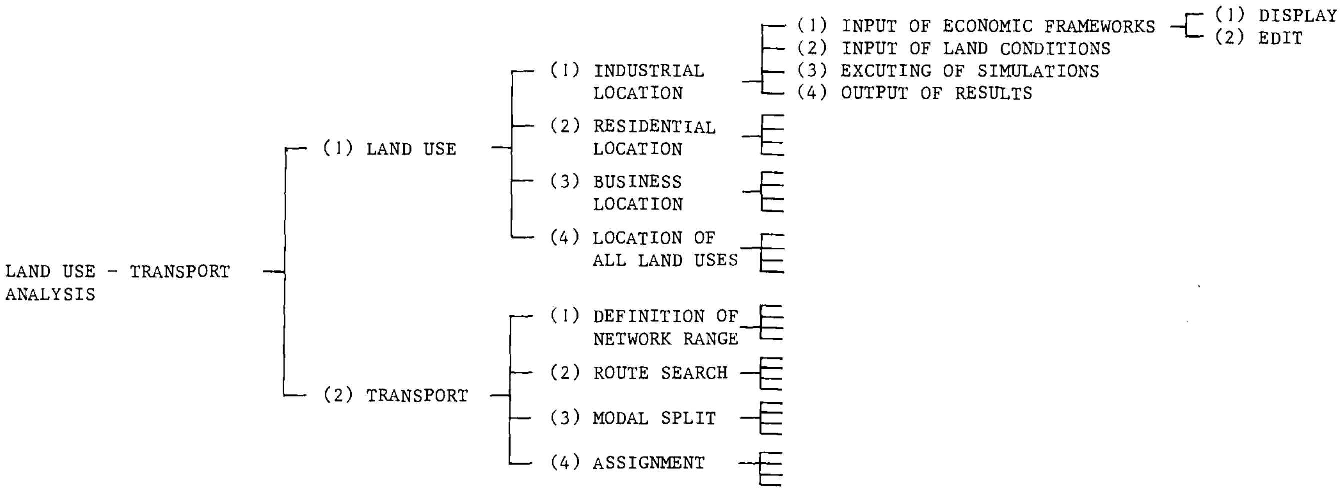


Figure 3 Menu Structure for Analysis of Land Use - Transport plan

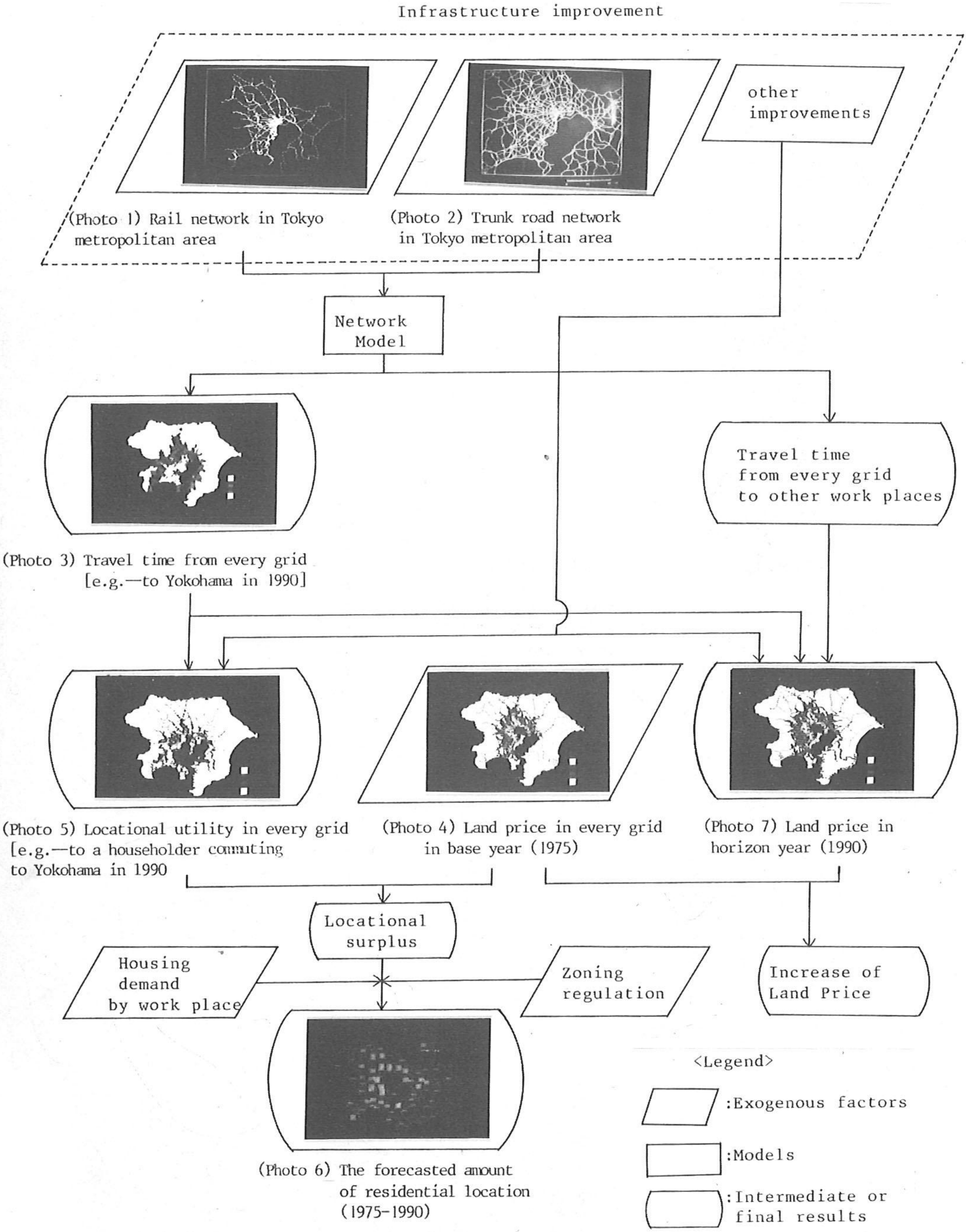


Figure 4. Estimation Process of Effects of Infrastructure Improvement