Development and Application of a Hierarchical Land-use Model

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Abstract

This paper aims to propose a Hierarchical Land-use Model (HILUM), and to present its application to a regional transport network planning. HILUM is composed of two subsidiary models; the Activity Location Model and the Land-use Model. The total activities in a metropolitan area are allocated in a hierarchical manner using these two models. The basic concept of each subsidiary model has already been presented by the authors.1),2),3) In this paper, we exemplify the application of HILUM to a regional transport network planning in the Osaka Metropolitan Area, as well as the structure of the model.

1. Introduction

The creation of a sound urban environment must be based on a rational and systematic land-use plan. When public and private projects are planned, it is often necessary to estimate beforehand the impact of these projects on the land-use pattern.

Various urban models for this purpose have been developed in North American and European countries since the 1960s. The history of urban modelling and the various features of existing urban models have been reviewed in several books.4),5),6)

In this paper, a Hierarchical Land-use Model (HILUM) is proposed and its validity is examined by applying it to the Osaka Metropolitan Area. This model aims to investigate the major impact on land-use pattern in a metropolitan area under various projects. We applied HILUM to analyse the impact on land-use patterns resulting from a regional transport network construction in the Osaka Metropolitan Area. The operationality of the model for transport planning is exemplified through this application.

2. The Basic Structure of HILUM

HILUM is composed of two subsidiary models; the Activity Location Model and the Land-use Model. The total activity in an urban area is allocated stepwise, first to each large zone using the Activity Location Model, and then to each small zone within a large zone using the Land-use Model. The large zone contains several administrative districts, and the small zone is composed of about ten 500-meter square grids. The basic structure of HILUM is shown in Figure 1.

The Activity Location Model is a linear-regression location model which was typically described by Hill's EMPIRIC model.[7] It also considers the economic base mechanism by using the Lowry-type linkage among land-use activities.[8],[9] Various kinds of employment and population in each large zone are estimated with linear functions of employment, population, employment change, and various kinds

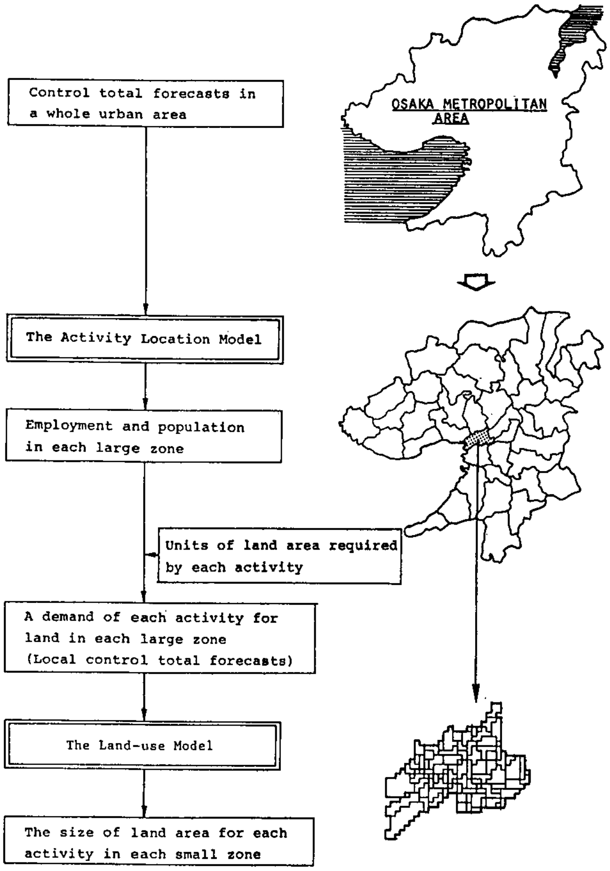


Fig. 1. The Basic Structure of HILUM

of accessibility indices.

The Land-use Model determines the land-use pattern in each small zone, using the control total forecasts of various activity levels obtained from the Activity Location Model. It simulates the locational competition among land-use activities under some hypothetical relationships between the bid price and the land price. This model requires the demand for land as major input data. Therefore, employment and population estimates are converted into the demand for land with the unit of land area required by each land-use activity.

The theory of urban land use based on the idea of bid price was first presented by Alonso.10) His theory was expanded by many researchers,11),12) and led to the establishment of New Urban Economics. Empirical studies on bid price have also been carried out,13) and there have been several trials to introduce the concept of bid price to operational land-use models.14),15) However, most of the operational models have not been very successful because of the large data requirements and the computational problems. Moreover, the research was confined to the modelling of housing markets and did not intend to develop a general land-use model. The Land-use Model presented in this paper attempts to build a general land-use model based on the concept of bid price. A micro simulation technique using the Monte Carlo method is applied to simulate the bidding competition among land-use activities and to determine the land-use pattern in each zone.

3. The Structure of the Activity Location Model

3.1 The Model Structure and Submodels

The Activity Location Model is a linear urban model, which estimates the location of various activities using a linear equation system.

In the Activity Location Model, activities are classified into three sectors; manufacturing employment, service employment, and population. The employment of manufacturing and service sectors is further disaggregated in the model. Table 1 shows the industries which are estimated in the Activity Location Model. The disaggregation of population is not considered in the model.

Figure 2 shows the structure of the Activity Location Model. The model is composed of three submodels, corresponding to the above sectoral classification. First, the employment of manufacturing industries is estimated for each zone by the Manufacturing Location Submodel. Second, the Residential Location Submodel and the Service Location Submodel are applied in an iterative manner in order to consider the economic base mechanism between these two sectors. This iterative

Table 1 The Classification of Activities in the Activity Location Model

Coarse classification	Industry
Manufacturing	(1) Timber and Furniture (2) Pulp and Paper (3) Leather Products and Rubber Products (4) Chemical Products (5) Petroleum and Coal Products (6) Ceramics (7) Food Products (8) Textiles and Clothes (9) Metals and Nonferrous Metals (10) General Machinery (11) Others
Service	(1) Construction (2) Wholesale (3) Local Service (4) Finance, Insurance and Real Estate (5) Transport and Communications (6) Electricity, Gas and Water Services
Residence	Population

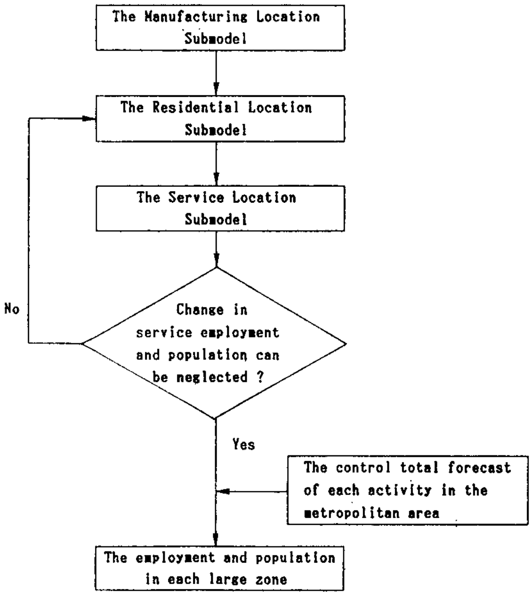


Fig. 2. The Structure of the Activity Location Model

procedure stops when the changes in service employment and population become small. The control total forecast of each activity in the metropolitan area, which is given exogenously, is allocated to each zone in proportion to the estimated employment and population, and the final activity distributions in the metropolitan area are determined.

3.2 The Manufacturing Location Submodel

The Manufacturing Location Submodel estimates the outdoor service employment of manufacturing industries and the indoor service employment in each zone. As for the outdoor services, the industries 7 to 11 in Table 1 are endogenously estimated in this submodel. The employment of other manufacturing industries (i.e. 1 to 6 in Table 1) is given exogenously for each zone.

The accessibility measure (1) is used to estimate the employment of each manufacturing industry in each zone. This index represents the convenience of trade with other manufacturing industries.

$$\begin{aligned} ACS(k)_i^t = & \sum_j \{(\sum_l r_{kl}^{t-1} \cdot \rho_l^{t-1} \cdot E_{lj}) \cdot \exp(-\alpha T_{ij}^{c,t})\} \\ & + \sum_j \{(\sum_l r_{lk}^{t-1} \cdot \rho_l^{t-1} \cdot E_{lj}) \cdot \exp(-\alpha T_{ij}^{c,t})\} \end{aligned} \qquad (1)$$

where,

k, l: manufacturing industries
i, j: zones
t–1, t: time points
E_{lj}: the amount of employment in manufacturing industry l in zone j
(employment at time t for exogenous industries and
employment at t–1 for endogenous industries)
r_{kl}^{t-1}: the number of units of inputs from industry k to industry l
r_{lk}^{t-1}: the number of units of inputs from industry l to industry k
ρ_l^{t-1}: a productivity ratio (output/employee) for industry l
$T_{ij}^{c,t}$: the travel time between zones i and j by car
α: a distance exponent

An estimation function for each industry is formulated using (1) as an explanatory variable. It estimates the employment of a manufacturing industry in each zone at one point in time. Equation (2) shows the general form of the estimation function.

$$E(k)_i^t = \iota_k ACS(k)_i^t + \kappa_k \tag{2}$$

where,

$E(k)_i^t$: employment of manufacturing industry k at time t
ι_k, κ_k: empirically estimated parameters

The amount of indoor service employment of manufacturing industries in each zone is estimated in proportion to the number of outdoor service employment in each zone.

3.3 The Service Location Submodel

The Service Location Submodel estimates the location of various kinds of service employment during a time period τ (i.e. from time t-1 to time t). The following assumptions on service demands are made to formulate the equations in the Service Location Submodel.

(1) Services are mainly demanded by four groups; the total employment, the total service employment (except the service employment being estimated) and the population. In addition to these four groups, the local service industries are assumed to be served by the wholesale industries.

(2) The extent of services is classified into local services and regional services. Local services are provided only within the zone where service industries are located, whereas regional services are provided beyond the zone.

Table 2 shows the explanatory variables, which are defined on the basis of these two assumptions. It is also assumed that service demand arises from both the total activities at time t–1, and the additional activities that locate during the time period τ (i.e. from time t–1 to time t). The demand for regional services is defined by the

Table 2 The Explanatory Variables in the Service Location Submodel

Activity	Local service		Regional service	
Total employment	TE_i^{t-1}	$\varDelta TE_i^\tau$	$ACS(TE)_i^{t-1}$	$\varDelta ACS(TE)_i^\tau$
Total manufacturing employment	EM_i^{t-1}	$\varDelta EM_i^\tau$	$ACS(EM)_i^{t-1}$	$\varDelta ACS(EM)_i^\tau$
Service employment (except the service activity being estimated)	ES_i^{t-1}	$\varDelta ES_i^\tau$	$ACS(ES)_i^{t-1}$	$\varDelta ACS(ES)_i^\tau$
Population	P_i^{t-1}	$\varDelta P_i^\tau$	$ACS(P)_i^{t-1}$	$\varDelta ACS(P)_i^\tau$
Local service employment	ELS_i^{t-1}	$\varDelta ELS_i^\tau$	$ACS(ELS)_i^{t-1}$	$\varDelta ACS(ELS)_i^\tau$

(note) The index $\varDelta$ represents the change in each variable during a time period τ (i.e. from time $t-1$ to time t).

following accessibility measure.

$$ACS(A)_i = \sum_j A_j \cdot \exp(-\alpha \cdot T^c_{ij}) \tag{3}$$

where,

$ACS(A)_i$: an activity which needs to be served
A_j: the total amount of activity A in zone j
T^c_{ij}: travel time between zone i and j by car
α: a distance exponent

The general form of estimation functions in this submodel is shown in (4).

$$\begin{aligned} \Delta E(k)^\tau_i &= \sum_r \varepsilon_{rk} \cdot A_{ri}^{kt-1} + \sum_r \xi_{rk} \cdot \Delta A_{ri}^{k\tau} \\ &+ \sum_r \eta_{rk} \cdot ACS(A^k_r)^t_i + \sum_r \theta_{rk} \cdot \Delta ACS(A^k_r)^\tau_i \end{aligned} \tag{4}$$

where,

k: service industry
i: zone
t–1, t: time points
Δ: change in activity level during the time period τ (i.e. from t–1 to t)
$E(k)_i$: employment of service industry k in zone i
A^k_{ri}: the amount of activity r served by the service industry k
$\varepsilon_{rk}, \xi_{rk}, \eta_{rk}, \theta_{rk}$: empirically estimated parameters

3.4 The Residential Location Submodel

The Residential Location Submodel estimates the change of resident population during the time period τ (i.e. from time t–1 to time t) in each zone.

The resident population in zone i at time t is defined by the following equation:

$$P^t_i = P^{t-1}_i + (B^\tau_i - D^\tau_i) + (I^\tau_i - O^\tau_i) \tag{5}$$

where,

P^{t-1}_i, P^t_i: the resident population in zone i at time t–1 and time t
B^τ_i: the number of births in zone i during a time period τ
D^τ_i: the number of deaths in zone i during a time period τ
I^τ_i: the number of immigrations in zone i during a time period τ
O^τ_i: the number of migrations in zone i during a time period τ

The term $(B^\tau_i - D^\tau_i)$ in Equation (5) represents the natural change of population, and the term $(I_i^\tau - O_i^\tau)$ means the social change of population.

A natural change of population is assumed to occur in proportion to the amount of resident population in zone i.

$$B_i^\tau - D_i^\tau = \delta \cdot P_i^{t-1} \tag{6}$$

The social change of population results from the economic behavior of the residents in each zone, and is assumed to be estimated by factors, such as the availability of job opportunities, housing conditions, environmental conditions, and so on. Thus, the following function is formulated.

$$I_i^\tau - O_i^\tau = \sum_h \varepsilon_h \cdot F_{hi} \tag{7}$$

where,

F_{hi}: factors which influence the social change of population in zone i
ε_h: a regression coefficient

The change of population in zone i during a time period τ is estimated by Equation (8) derived from Equations (5) to (7).

$$\Delta P_i^\tau = P_i^t - P_i^{t-1} = \delta \cdot P_i^{t-1} + \sum_h \varepsilon_h \cdot F_{hi} \tag{8}$$

4. The Structure of the Land-use Model

4.1 The Model Structure and Submodels

The employment and population levels estimated in the Activity Location Model are converted into a demand for land based on the units of land area required by each activity. This demand is a control total forecast of each activity for each large zone, which is allocated to small zones using the Land-use Model.

In the Land-use Model, the behaviors of the demand and supply sides in a land market are modelled using the concept of a bid price. The future land-use pattern is estimated by simulating a bidding competition among activities in each lot. The Land-use Model estimates the land-use patterns for four kinds of land-use activities; manufacturing, commerce, residence and agriculture. The model is composed of four submodels as shown in Figure 3.

The Bid-price Submodel estimates an average bid price for lots in each small zone, using a hypothetical relationship between the bid price and the land price. The Land-use Trend Submodel simulates the bidding competition among activities for each lot using the idea of bid price. Its output is the number of lots which can

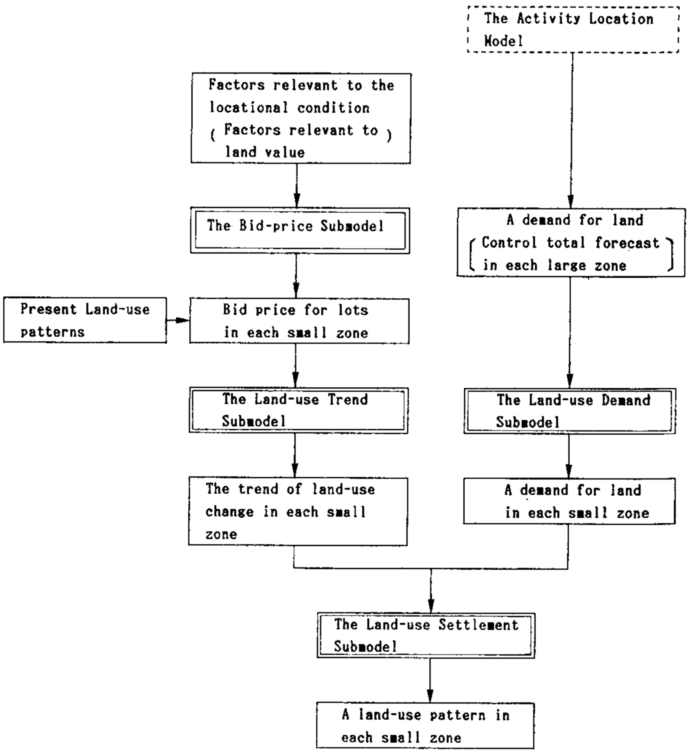


Fig. 3. The Structure of the Land-use Model

be supplied to each activity. The Land-use Demand Submodel allocates the total demand to each lot in each small zone according to the attractiveness and suitability of land for activities. The supply and demand obtained in the above submodels are adjusted to equilibrium by the Land-use Settlement Submodel, and the final land-use pattern in each small zone is determined.

4.2 The Bid-price Submodel

When an activity group demands land, it appraises the attractiveness of the land and determines a bid price as a measure of willingness to pay. In this submodel, an existing activity which occupies a lot is regarded as a land supplier. When the bid price of the demand side exceeds the asking price of the supply side, the negotiation between supply and demand sides occurs, and the negotiated price is the land price for the lot.

As the bid price of activity k for lot l in small zone r, B^k_{rl} is assumed to be normally distributed around the average bid price for lots in each small zone B^k_r.

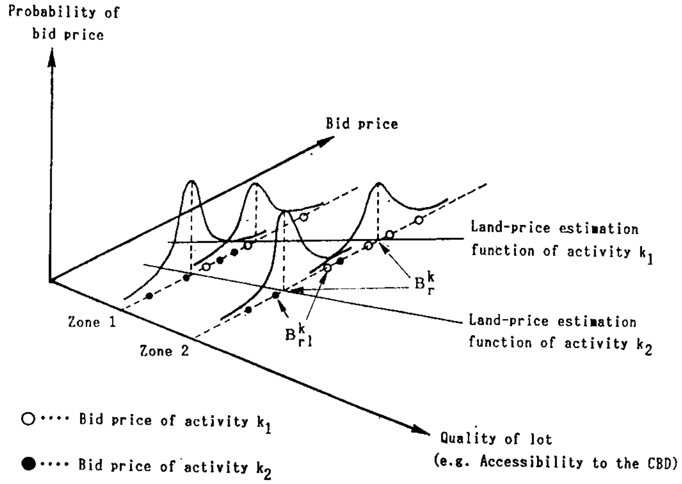


Fig. 4. The Relationship between the Bid Price and the Land Price

That is,

$$B^k_{rl} = B^k_r + \delta^k_{rl} \tag{9}$$

where,

δ^k_{rl}: a stochastic component of the bid price

It is assumed that an average bid price B^k_r is equal to an average land price for lots in each small zone, which is estimated using an average land-price estimation function. Figure 4 illustrates the relationship between the bid price and the land-price estimation function for two activities. This stochastic approach enables coping with the uncertainty of locational preference of each activity and the insufficient information about locational attractiveness. The land-price estimation function is formulated as a linear equation. Its independent variables includes various factors relevant to the land price. The stochastic component δ^k_{rl} is assumed to be a normal stochastic variable with variance σ^2_k. That is,

$$\Phi(x) = \frac{1}{\sqrt{2\pi\cdot\sigma_k}} \exp\left(-\frac{x^2}{2\cdot\sigma_k}\right) \tag{10}$$

Therefore, B^k_{rl} has a normal distribution $N(B^k_r, \sigma^2_k)$. The variance σ^2_k is obtained as the variance of the residual in the calibration of the land-value estimation function. B^k_{rl} is estimated by applying the Monte Carlo method, which generates many random numbers following the normal distribution $N(B^k_r, \sigma^2_k)$.

The asking price of an existing activity is generally higher than that of a new activity because of the demolition and relocation costs and an intentional rise in trading costs of the existing activity. In this model, this dominance of existing activities is considered as a locational priority value B^k. Therefore, as the bid price of activity k, B^k_{rl} is defined as follows;

$$B^k_{rl} = B^k_r + B^k + \delta^k_{vl}\,, \qquad \text{for existing activities} \tag{11}$$

$$B^k_{rl} = B^k_r + \delta^k_{rl}\,, \qquad \text{for new activities} \tag{12}$$

4.3 The Land-use Trend Submodel

The land in each small zone is divided into many small lots. These lots represent hypothetical units which are treated among land-use activities. The area of a lot is assumed to be 10^4 km^2 in this application.

The Land-use Trend Submodel simulates the bidding competition among activities using a bid price of each activity for a lot. It is assumed that a lot is supplied to the activity which shows the highest bid price. The bid prices for a lot are compared among activities, and the locational priority rank of each activity in each lot is determined. The outputs from this simulation is the number of lots supplied for each activity.

Figure 5 shows the simulation procedure in this submodel. First, a bid price of each activity for a lot is estimated using the normal distribution $N(B^k_r, \sigma^2_k)$.

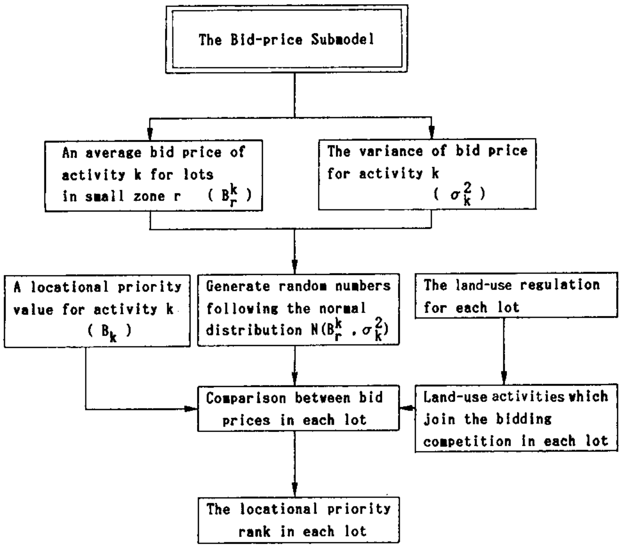


Fig. 5. The Simulation Procedure in the Land-use Trend Submodel

Second, the land-use activities which join the bidding competition for a lot are determined by reference to the land-use regulation for the lot. Then the bid prices for the lot are compared among activities, and the locational priority rank of each activity is determined. This rank shows the priority of location in each lot among activities in the prediction time.

4.4 The Land-use Demand Submodel

In this submodel, the demand of each activity for lots is estimated in each large zone. Each activity compares the locational attractiveness among lots, and demands the lot where maximum utility or profit is obtainable.

A bid price of an activity for each lot is used for the index of locational attractiveness. The locational attractiveness rank is determined by comparing bid prices of an activity among lots. This rank is combined with the locational priority rank obtained in the Land-use Trend Submodel. They are summarized in a locational rank table, which is shown in Table 3. This table arranges the lots in a large zone in order of bid prices. The higher rank in this table represents the higher locational attractiveness.

The total land-use demand (i.e. the control total forecast for each large zone) of each activity, which is obtained in the Activity Location Model, is allocated according to the locational rank in this table.

4.5 The Land-use Settlement Submodel

The control total forecast of each activity is allocated to each lot using the Land-use Demand Submodel. However, the total land-use supply, which is estimated in the above three submodels, is generally not consistent with the control total forecast for each large zone.

The following adjustment procedures are applied to determine the final land-use pattern in each large zone.

Table 3 An Example of the Locational Rank Table

Locational rank	Land-use activity	Lot No.	Locational priority rank	Bid price (yen/m^2)
1	Commerce	952	1	4520
2	Commerce	1021	1	3610
:	:	:	:	:
989	Residence	3	2	1850
:	:	:	:	:
:	Residence	2	3	1820

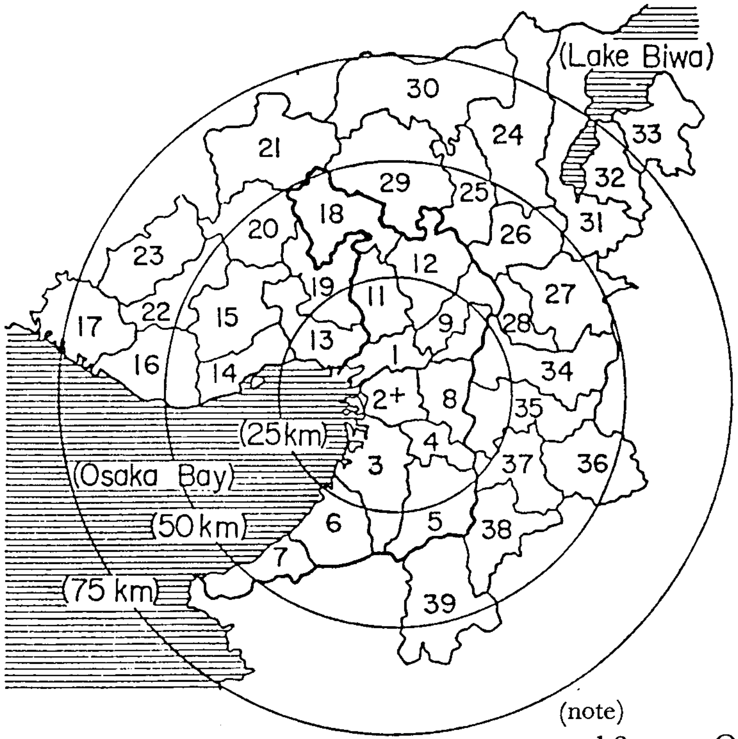
(1) If the control total forecast exceeds the land-use supply, the unused lots are allocated to the excess control total in proportion to the bid price of each activity.

(2) If the land-use supply exceeds the control total forecast, the excess land-use supply is left as unused lots.

5. Calibration of the Model for the Osaka Metropolitan Area

5.1 The Study Area and the Data Base

HILUM was calibrated for the Osaka Metropolitan Area, and its reliability was examined. The model was calibrated from data used for 1968 and 1973. Then, the employment, population and land-use patterns for 1978 were estimated for each zone. The reliability of the model was examined by comparing these estimated values with their real values in 1978.



(note)
zone 1,2 : Osaka
zone 14,15,16: Kobe
zone 24,25,26: Kyoto

Fig. 6. The Study Area and Zoning System in the Activity Location Model

The study area and zoning system in the Activity Location Model are shown in Figure 6. This area is called the Osaka Metropolitan Area, which is the second largest urban region in Japan. The population was about 15.5 million in 1978 and its area is 8078 km^2. There are 174 administrative districts, which were aggregated into 39 large zones referring to a previous zoning study by the Japan Housing Corporation.[16] The data on various kinds of employment and population were processed from the formal statistics published by the Japanese Government.

The Land-use Model was applied to the Osaka Prefectural Area, as shown in

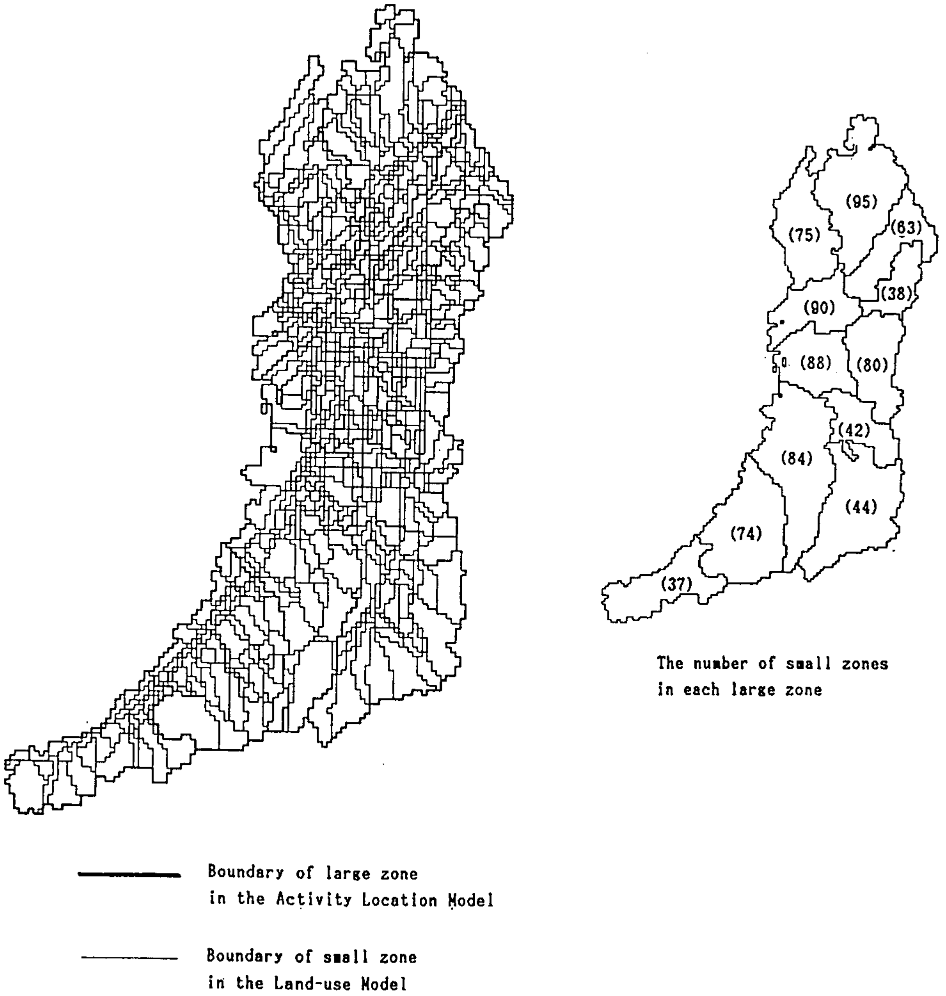


Fig. 7. The Study Area and Zoning System in the Land-use Model

Figure 7. This area had a population of about 8.2 million in 1978 and its area is 1861 km^2. This central part of the Osaka Metropolitan Area contains 13 large zones of the Activity Location Model and was further divided into 841 small zones for the Land-use Model. This small zone nearly corresponds to a residential zone and is composed of about ten 500-meter square grids. Various kinds of data in each small zone were processed from the 500-meter square grid data which was available from the Osaka Prefectural Government. The data for land value in 1975, which was published by the National Land Agency, were also used in this model.

5.2 Calibration and Validation of the Activity Location Model

5.2.1 Calibration of the Manufacturing Location Submodel

The estimation functions for endogenous manufacturing industries were calibrated from data used for 1973. Equations (13) to (17) show the results of the calibration. The calibration results are good, as indicated by their coefficients of determination and the t-statistics.

(Food Products)
$$E(EMF)_i^t = 0.242 \cdot ACS(EMF)_i^t - 537.8 \qquad (13)$$
$$(t = 9.6) \qquad (\bar{R}^2 = 0.715)$$

(Textile and Clothes)
$$E(EMT)_i^t = 0.265 \cdot ACS(EMT)_i^t - 2272.5 \qquad (14)$$
$$(9.1) \qquad (\bar{R}^2 = 0.692)$$

(Metals and Nonferrous Metals)
$$E(EMM)_i^t = 0.049 \cdot ACS(EMM)_i^t - 1352.5 \qquad (15)$$
$$(11.9) \qquad (\bar{R}^2 = 0.794)$$

(General Machinery)
$$E(EMG)_i^t = 0.348 \cdot ACS(EMG)_i^t - 3136.1 \qquad (16)$$
$$(13.4) \qquad (\bar{R}^2 = 0.831)$$

(Others)
$$E(EMP)_i^t = 0.283 \cdot ACS(EMP)_i^t - 2365.9 \qquad (17)$$
$$(12.4) \qquad (\bar{R}^2 = 0.808)$$

The estimation function for indoor service employment of manufacturing industries was calibrated, using the level of total outdoor service employment in each zone as an explanatory variable. The result of the calibration is shown in Equation (18).

$$EMI_i^t = 0.129 \cdot EMO_i^t + 0.313 \cdot DA_i \cdot ACS(EMO)_i^t - 1067.8 \qquad (18)$$
$$(t = 16.5) \qquad (6.2) \qquad (\bar{R}^2 = 0.973)$$

where,

EMI_i^t: total employment of indoor service of manufacturing industries in zone i at time t

EMO_i^t: total employment of outdoor service of manufacturing industries in zone i at time t

$ACS(EMO)_i^t$: accessibility index for outdoor service of manufacturing industries at time t

DA_i: a dummy variable (1 for zones in Osaka City, 0 for other zones)

5.2.2 Calibration of the Service Location Submodel

The estimation function for each service employment was calibrated using the explanatory variables in Table 2. Equations (19) to (24) are the results of the calibration for this submodel. The explanatory variables of each equation were determined by reference to various conditions, such as the coefficient of determination R^2, sign conditions of parameters and t-satistics for independent variables.

(Construction)
$$\begin{array}{llll} \Delta E(ECM)_i^\tau = & 0.0043\cdot(TE_i^{t-1}+P_i^{t-1}) & +0.0694\cdot\Delta ES_i^\tau & \\ & (t=2.6) & (1.4) & (19) \\ & -269.17 & (\bar{R}^2=0.766) & \end{array}$$

(Wholesale)
$$\begin{array}{llll} \Delta E(EWM)_i^\tau = & 0.0199\cdot ACS(ELS)_i^{t-1} & +0.0588\cdot\Delta ACS(ELS)_i^\tau & \\ & (2.1) & (1.5) & (20) \\ & -571.75 & (\bar{R}^2=0.653) & \end{array}$$

(Local Service)
$$\begin{array}{llll} \Delta E(ELS)_i^\tau = & 0.018\cdot(TE_i^{t-1}+P_i^{t-1}) & +0.047\cdot(\Delta TE_i^\tau+\Delta P_i^\tau) & \\ & (4.1) & (2.1) & (21) \\ & -977.00 & (\bar{R}^2=0.881) & \end{array}$$

(Finance, Insurance and Real Estate)
$$\begin{array}{llll} \Delta E(EFM)_i^\tau = & 0.0123\cdot TE_i^{t-1} & +0.0368\cdot\Delta ES_i^\tau & \\ & (4.4) & (1.2) & (22) \\ & -156.93 & (\bar{R}^2=0.830) & \end{array}$$

(Transport and Communication)
$$\begin{array}{llll} \Delta E(ETM)_i^\tau = & 0.0271\cdot\Delta P_i^\tau & +0.0602\cdot\Delta ACS(EM)_i^\tau & \\ & (5.6) & (1.4) & (23) \\ & -585.47 & (\bar{R}^2=0.666) & \end{array}$$

(Electricity, Gas and Water Services)
$$\begin{array}{llll} \Delta E(ERM)_i^\tau = & 0.224*10^{-3}\cdot(TE_i^{t-1}+P_i^{t-1}) & & \\ & (2.6) & +0.0017\cdot(\Delta TE_i^\tau+\Delta P_i^\tau) & \\ & & (1.8) & (24) \\ & +2.07 & (\bar{R}^2=0.211) & \end{array}$$

5.2.3 Calibration of the Residential Location Submodel

The population in each zone is estimated using Equation (8). The change of accessibility for commuters and the activity density variable were introduced in Equation (8) to explain the social change in the population. The accessibility for commuters was defined by the following index:

$$ACS(TE)_i = \sum_j TE_j \cdot \exp(-\alpha \cdot T^R_{ij}) \tag{25}$$

where,

$ACS(TE)_i$: the accessibility for commuters in zone i

TE_j: the number of total employment in zone j

T^R_{ij}: travel time between zone i and j by railway

α: a distance exponent

The activity density variable was introduced to reflect the decline of population in zones of large cities. It is defined by the product of population P^{t-1}_i and total employment of each zone TE^{t-1}_i.

The result of the calibration is shown in Equation (26).

$$\begin{aligned} \Delta P^\tau_i = {} & 0.029 \cdot P^{t-1}_i + 1.45 \cdot \Delta ACS(TE)^\tau_i - 0.209 \cdot 10^{-6} \cdot (P^{t-1}_i \cdot TE^{t-1}_i) \\ & (t = 0.7) \qquad (3.9) \qquad\qquad (7.4) \\ & -11089.1 \qquad\qquad\qquad (\bar{R}^2 = 0.686) \end{aligned} \tag{26}$$

where,

P^{t-1}_i: the number of population in zone i at time t-1

TE^{t-1}_i: the number of total employment in zone i at time t-1

$\Delta ACS(TE)^\tau_i$: change in accessibility for commuters in zone i during a time period τ

5.2.4 Validation of the Activity Location Model

The Activity Location Model was applied to predict the location of each activity in 1978. The reliability of the model was examined by comparing the estimated values with the real values. The quality of the predictions was measured with the correlation coefficients. Table 4 shows the correlation coefficient for each activity.

The correlation coefficients of activity levels in 1978 were high. These results show that the model has good ability to predict future activity patterns. This table also shows the correlation coefficients between the estimated and the real values of the change in activity from 1973 to 1978. Most of the correlation coefficients are fairly good. These results certify the sufficient reliability of the model. However, the correlation coefficients for food products, electricity, and gas and water service

Table 4 The Results of Validation for the Activity Location Model

Industry			Correlation coefficient	
			Activity in 1978	Change in activity from 1973 to 1978
Manufacturing	(7)	Food Products	0.954	0.186
	(8)	Textiles and Clothes	0.969	0.855
	(9)	Metals and Nonferrous Metals	0.975	0.904
	(10)	General Machinery	0.970	0.751
	(11)	Others	0.975	0.475
		Indoor Services	0.892	0.416
Service	(1)	Construction	0.998	0.937
	(2)	Wholesale	0.999	0.748
	(3)	Local Service	0.999	0.939
	(4)	Finance, Insurance and Real Estate	0.999	0.599
	(5)	Transport and Communications	0.997	0.555
	(6)	Electricity, Gas and Water Services	0.984	0.439
Residence		Population	0.994	0.750

are not so good. Additional refinements of equations for these industries will be necessary to improve the model.

5.3 Calibration and Validation of the Land-use Model

5.3.1 Calibration of the Land-price Estimation Function

The land-price estimation functions were calibrated from land-price data used for 1975. The data were collected at 1811 points in the Osaka Prefectural Area, and were classified into manufacturing, service and residential use areas. A land-price estimation function was calibrated for each activity by applying a multiple regression analysis. Table 5 shows the results of the calibration. The accessibility indices in Table 5 are defined by the following equation.

$$ACS_i = \sum_j A_j \cdot \exp\left(-\alpha \cdot T^m_{ij}\right) \tag{27}$$

where,

ACS_i: the level of accessibility in zone i
A_j: the activity level in zone i
T^m_{ij}: travel time between zones i and j by transport mode m
α: a distance exponent

The definition of each accessibility index is shown in Table 6. The distance

Table 5 The Land-price Estimation Function for Each Land-use Activity

	Explanatory variable	Unit	Parameter	
Manufacturing	(1) Accessibility to manufacturing activity	—	0.221×10^{-2}	$\bar{R}^2=0.596$ Standard error $=205.6$
	(2) Distance to the nearest highway inter-change	km	-0.0119	
	(3) Employment of secondary industries	person	0.340×10^{-2}	
	(4) Average number of floors in each small zone	—	82.11	
Commerce	(1) Accessibility to service activity	—	0.0293	$\bar{R}^2=0.377$ Standard error $=1529.5$
	(2) Distance to the nearest railway station	km	-203.7	
	(3) Employment of tertiary industries	person	0.0263	
	(4) Average number of floors in each small zone	—	460.6	
Residence	(1) Accessibility to work places	—	0.0417	$\bar{R}^2=0.645$ Standard error $=178.0$
	(2) Distance to the nearest railway station	km	-43.03	
	(3) Percent of drainage provision	%	1.931	
	(4) Average number of floors in each small zone	—	76.46	

Table 6 The Definition of Each Accessibility Index

Activity	Accessibility Index	Transport mode (m)	Activity level (Aj)
Manufacturing	Accessibility to manufacturing activity	Car	Employment in Manufacturing
Commerce	Accessibility to commercial activity	Car	Employment in commerce
Residence	Accessibility to workplace	Railway	Population

exponent of each accessibility index was estimated using the transportation survey data in the Osaka Prefectural Area. The estimated values for parameter α are 0.0534 for manufacturing, 0.0574 for commerce and 0.0557 for residence.

The standard error of each function corresponds to σ_k^2 in Equation (10). As agriculture is not expected to bid a price for a lot occupied by other land-use activities, its land-price estimation function is not formulated. The average number of floors in each small zone is introduced to reflect the effect of high rise buildings on the land price in each zone. This variable is excluded from the land-price estimation function in calculating the average land-price in each small zone.

5.3.2 Estimation of the Locational Priority Value and the Locational Restriction Based on the Land-use Regulation System

The locational priority value, which represents the locational priority of existing activities against new activities, was determined by minimizing the difference between the estimated and the real land area of each activity for the overall study area. The estimated values are shown in Table 7.

The location of each land-use activity is strictly regulated in urban areas in Japan. The location of each land-use activity was restricted as shown in Table 8, considering the present land-use regulation system in Japan.

Table 7 The Locational Priority Value B^k

Land-use activity	Locational priority value (100 yen/m^2)
Manufacturing	500
Commerce	600
Residence	600
Agriculture	400

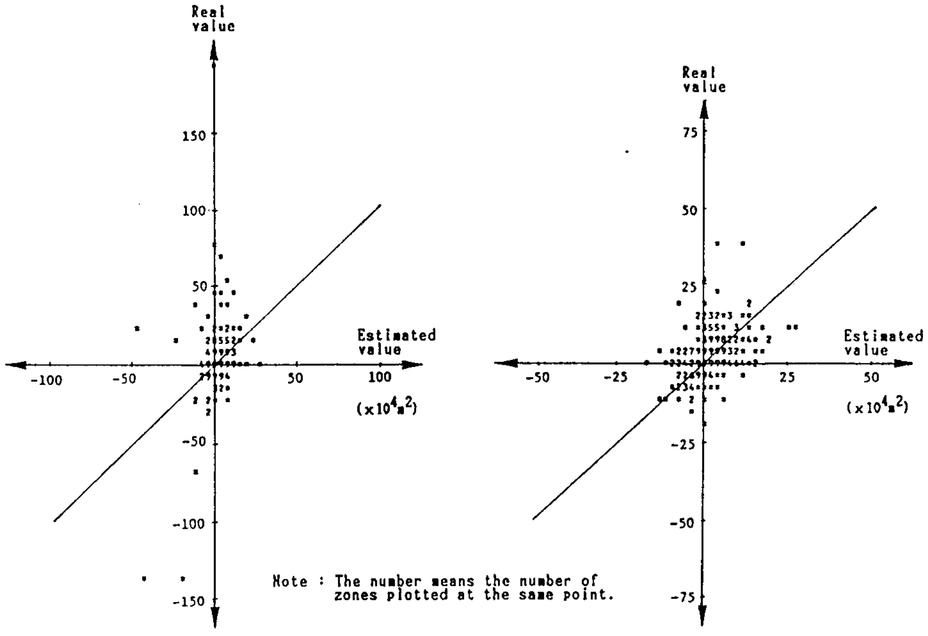
Table 8 Locational Restrictions According to the Land-use Regulation System

Land-use area	Land-use Activity			
	Manufacturing	Commerce	Residence	Agriculture
(1) Class 1 residential area	×	×	○	×
(2) Class 2 residential area	×	○	○	×
(3) Residential area	○	○	○	×
(4) Neighbourhood commercial area	○	○	○	×
(5) Commercial area	○	○	○	×
(6) Semi-industrial area	○	○	○	×
(7) Industrial area	○	○	○	×
(8) Exclusive industrial area	×	○	○	○
(9) Urbanization control area	○	○	○	×

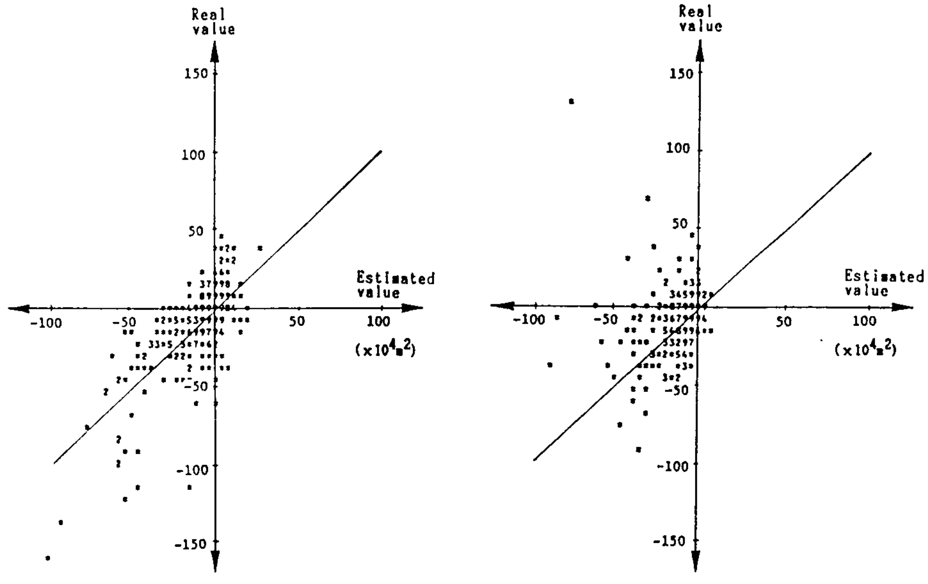
(Note) ○...Not restricted, ×...Restricted

Table 9 The Results of Validation for the Land-use Model

Land-use activity	Correlation coefficient	
	Land-use in 1978	Land-use change from 1973 to 1978
Manufacturing	0.930	0.299
Commerce	0.881	0.388
Residence	0.972	0.741
Agriculture	0.975	0.318



(1) Manufacturing (2) Commerce



(3) Residence (4) Agriculture

Fig. 8. The Estimated and the Real Values for the Change in Land Area

5.3.3 Validation of the Land-use Model

The Land-use Model was applied to the Osaka Prefectural Area, and its reliability was examined by comparing the 1978 estimated land area with the real land area in each small zone.

Table 9 shows the correlation coefficients between the estimated and the real values of land areas for 841 small zones in the Osaka Prefectural Area. The correlation coefficients for 1978 were high. These results show that the model has a good ability to predict future land-use patterns. Table 9 also shows the correlation coefficients between the estimated and the real values of the change in land areas from 1973 to 1978. The scattergrams between these two values of each zone are shown in Figure 8. The correlation coefficient for residence is fairly good, whereas those for other activities are low. However, as for agriculture, if we exclude a few zones which show irregular increases in Figure 8, the correlation coefficient is 0.448,

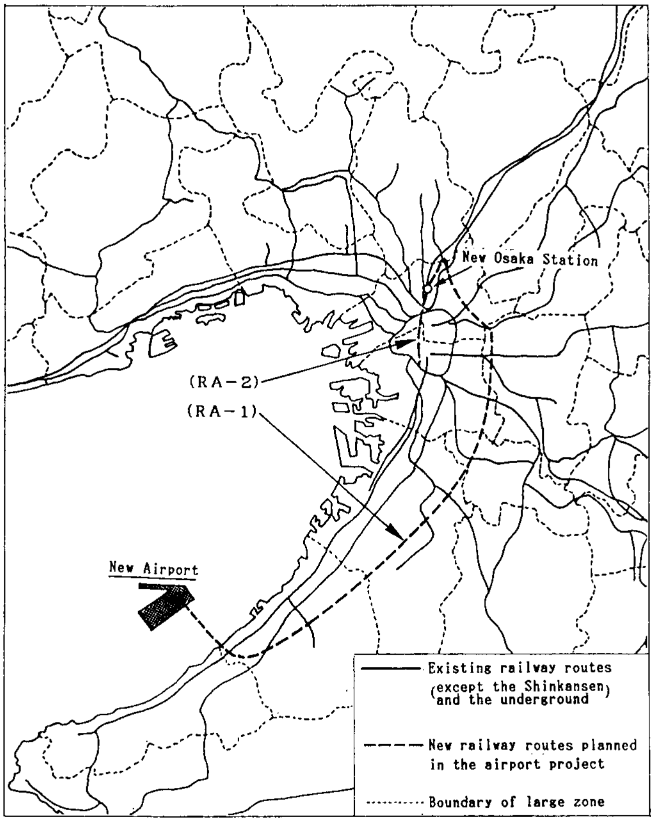


Fig. 9. New Railway Routes Planned in the Airport Project

which is a sufficient value. As for manufacturing and commerce, although the correlation coefficients are low, the tendencies of the change in land areas are predicted fairly well in Figure 8.

6. Application of HILUM to Regional Transport Network Planning

6.1 Alternative Plans of Transport Network

A new international airport is now being planned for the south of Osaka City. This project contains the construction of a transport network and will lead to a large change of the land-use pattern in the Osaka Metropolitan Area. HILUM was applied to predict the land-use changes under alternative transport network plans. The major effects on land-use pattern in the metropolitan area were clarified through the application.

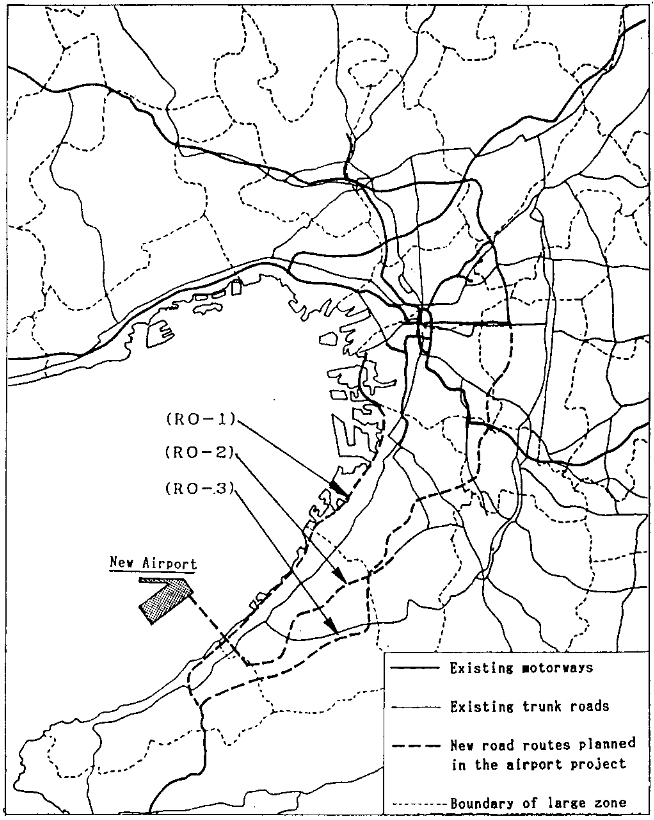


Fig. 10. New Road Routes Planned in the Airport Project

Table 10 The Alternative Plans of Transport Network

Alternative plan	New routes planned in the airport project				
	Railway		Road		
	RA-1	RA-2	RO-1	RO-2	RO-3
A (No construction)					
B (Railways)	○	○			
C (Roads)			○	○	○
D (Railways and roads)	○	○	○	○	○

The new airport will be located 50 km south of Osaka City. The constructions of new railways and roads have been proposed to connect the airport with major cities and terminals in the metropolitan area. Figures 9 and 10 show the railways and the roads which are planned in the airport project. The alternative network plans are formulated by combining these routes.

Table 10 shows the alternative plans formulated in this application. Alternative plan A does not contain any construction of a transport network. The predictions under this plan are used as a standard case in comparing the results among other alternative plans. Plans B and C are composed of either railway constructions or road constructions. Alternative plan D contains both railway and road constructions.

6.2 Assumptions for the Application of HILUM

HILUM was applied to the impact study under the following assumptions.

(1) The aim of this study was confined to examining the impact of each alternative plan on land-use patterns through the change in travel time among zones. Other effects were not considered in this application.

(2) The prediction period was assumed to be from 1973 to 1993. As the HILUM predicts the land-use pattern at five year intervals, the model was run four times in a recursive manner in order to predict the land-use in 1993. The control total forecast of each activity was given exogenously by assuming that the employment and population would increase by the same rates during the period from 1968 to 1973.

(3) The construction of each alternative plan was assumed to be completed during the first five years of the prediction period (i.e. the period from 1973 to 1978).

(4) The aggregation procedures were carried out for activities and zones in comparing the prediction results.

First, the employment was aggregated into three sectors; employment in retail

Table 11 The Classification of Activities into Three Sectors

Three sectors	Classification of activities in the Activity Location Model
Non-Service (EMNS)	(1) Timber and Furniture
	(2) Pulp and Paper
	(3) Leather Products and Rubber Products
	(4) Chemical Products
	(5) Petroleum and Coal Products
	(6) Ceramics
	(7) Food Products
	(8) Textiles and Clothes
	(9) Metals and Nonferrous Metals
	(10) General Machinery
	(11) Others
	(12) Construction
Non Retail Service (EMNR)	(1) Wholesale
	(2) Finance, Insurance and Real Estate
	(3) Transport and Communications
	(4) Electricity, Gas and Water Services
Retail Service (EMRT)	Local Service
Population (POP)	

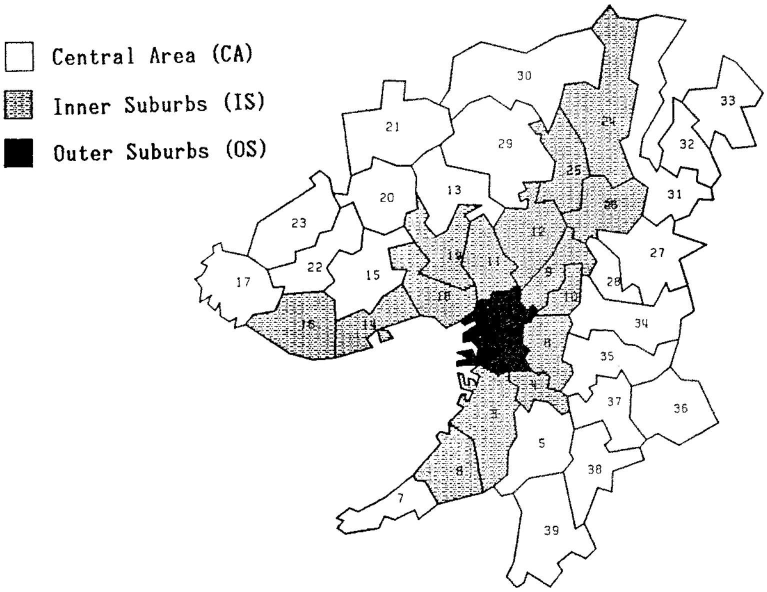
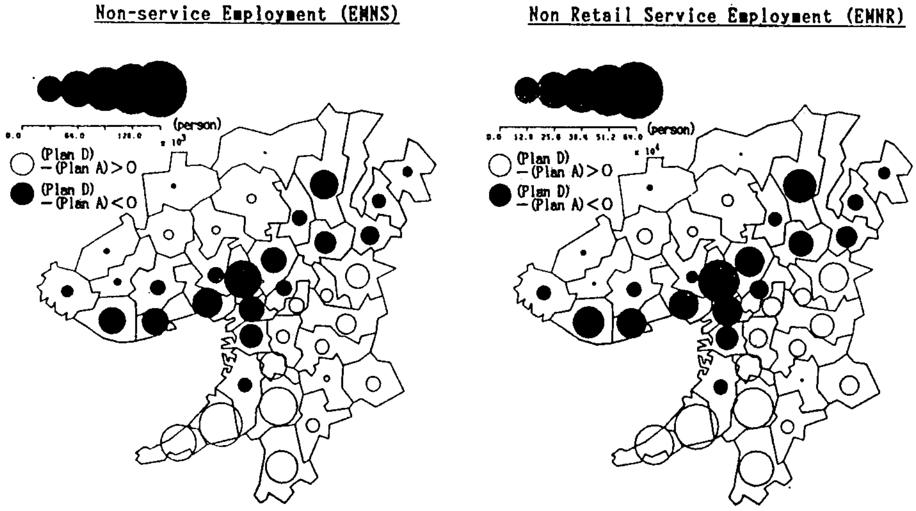


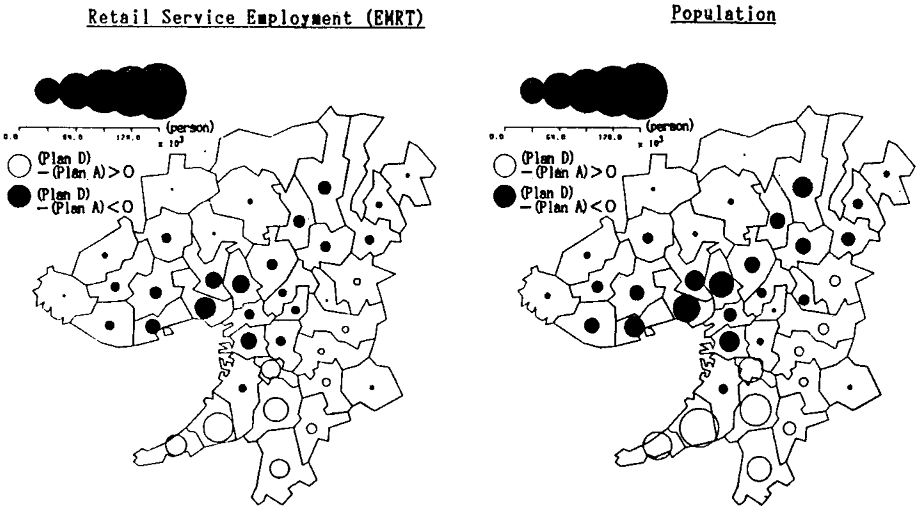
Fig. 11. The Classification of Large Zones into Three Areas

service industries (EMRT), employment in non-retail service industries (EMNR) and employment in non-service industries (EMNS). Table 11 shows the comparison among these three sectors and industries in the Activity Location Model.

Second, the 39 zones in the metropolitan area were classified into three areas;


Non-service Employment (EMNS)

Non Retail Service Employment (EMNR)


Retail Service Employment (EMRT)

Population

Fig. 12. Comparison of Prediction Results between Alternative Plan D and A

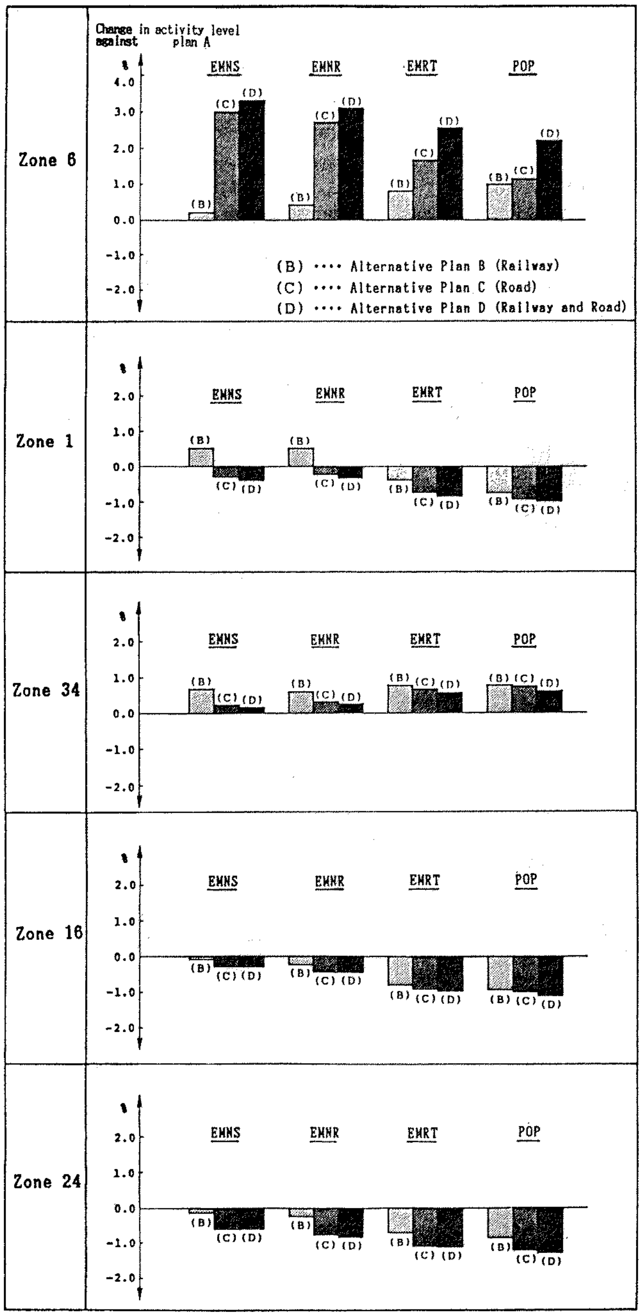


Fig. 13. Comparisons of Prediction Results among Alternative Plans in the Selected Five Zones

the central area of the city (CA), the inner suburbs (IS) and the outer suburbs (OS). The Cluster Analysis was applied by using the data on employment and population in 1978. Figure 11 shows the result of the classification.

6.3 Predictions by the Activity Location Model

The Activity Location Model was applied to the prediction of employment and population in each zone under each alternative plan. The prediction results under alternative plans B, C and D were compared with those of plan A. Figure 12 shows the comparisons of employment and population between alternative plans A and D. As similar results were obtained under alternative plans B and C, they were omitted in this paper.

Figure 12 shows the increases of employment and population in the east and the west zones in the metropolitan area, whereas the employment and population in zones of large cities and their surrounding areas have generally decreased. These results reflect the relative decline of travel convenience in large cities against zones in the suburbs.

Figure 13 shows comparisons of employment and population of the five zones

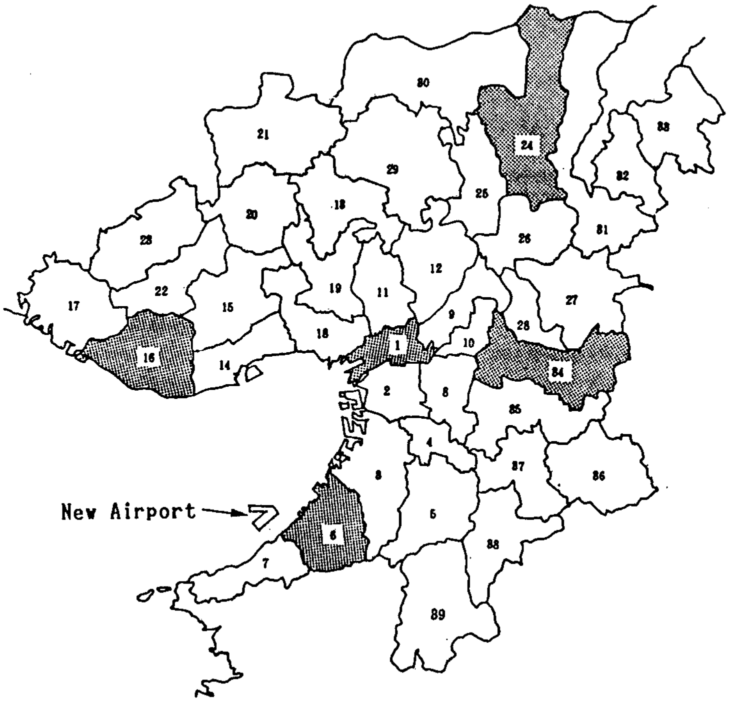


Fig. 14. The Locations of Five Zones in Figure 13

in Figure 14. The following index is used to examine the difference of predictions between alternative plans p and A.

$$\left(\frac{X_i^p}{X_{ct}}-\frac{X_i^A}{X_{ct}}\right)\times 100\ (\%) \tag{28}$$

where,

i: zone

X_i^p: predicted employment (or population) under plan p

X_{ct}: total employment (or population) in the study area

The employment and population in zone 6, where the new airport is closely located, show large increases. However, the changes of employment and population in other zones are small.

6.4 Predictions by the Land-use Model

The employment and population predicted by the Activity Location Model were converted into the control total forecasts of land-use activities in the Land-use Model. The land-use pattern in each small zone was estimated by the Land-use Model using these control total forecasts.

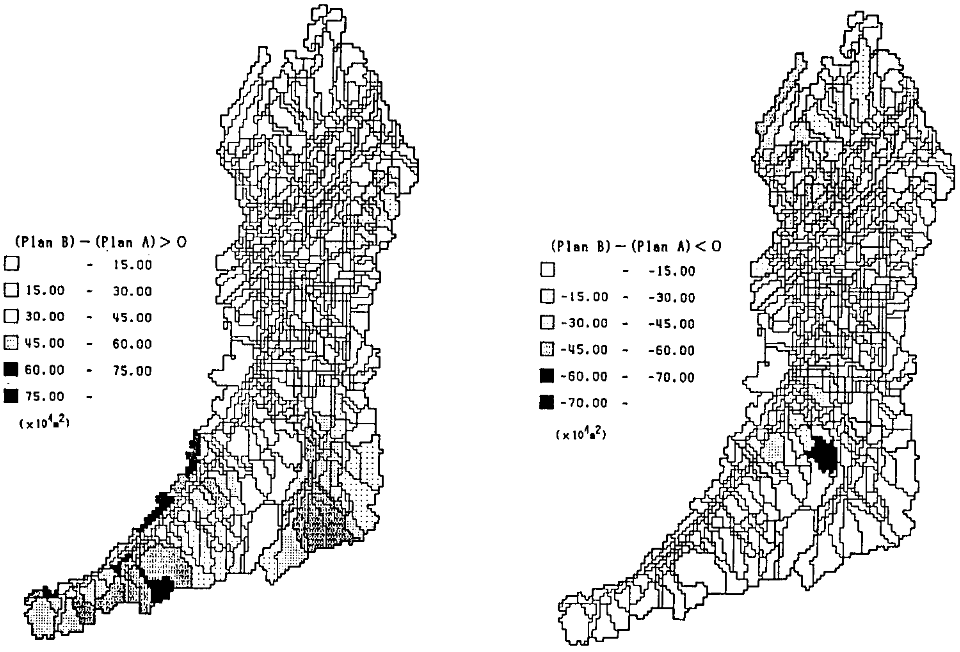


Fig. 15. The Comparison of Residential Land Area between Alternative Plan B and A

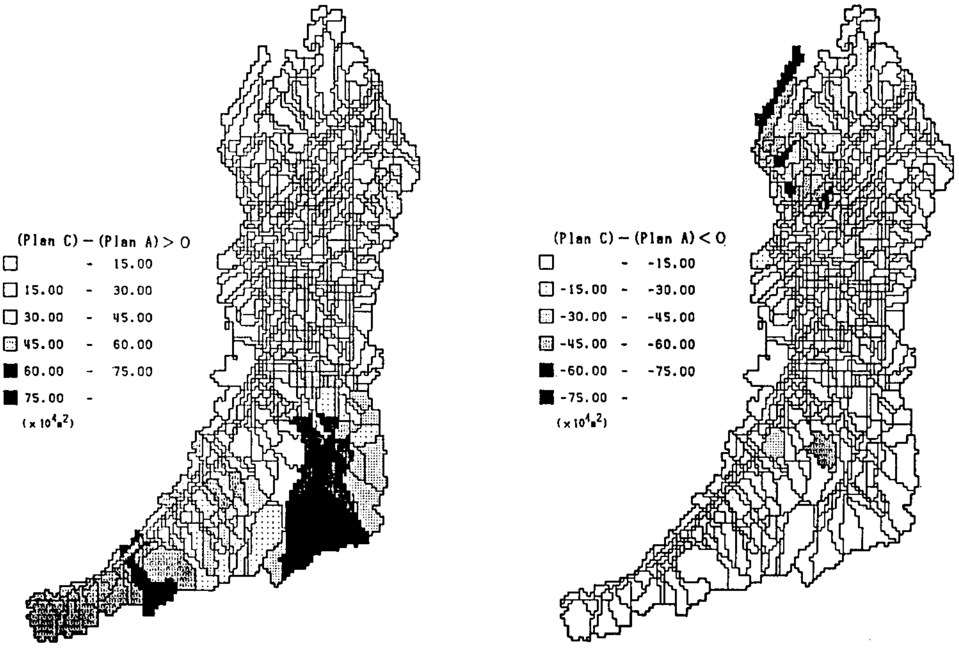


Fig. 16. The Comparison of Residential Land Area between Alternative Plan C and A

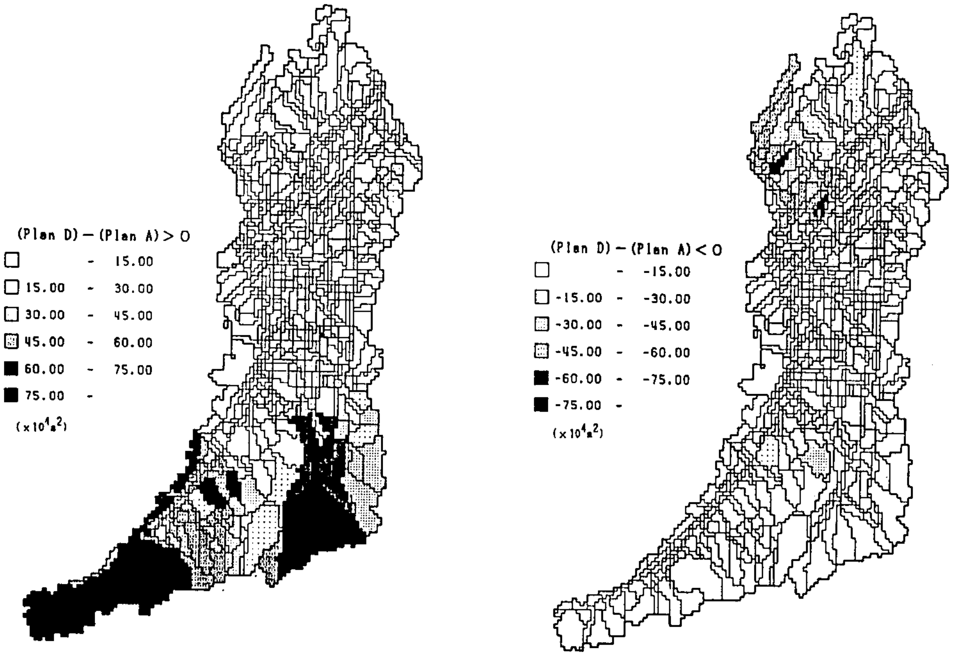


Fig. 17. The Comparison of Residential Land Area between Alternative Plan D and A

Figures 15, 16 and 17 show the predicted residential areas under the alternative plans. The results for service and agricultural land uses are ommitted in this paper. The residential land use was predicted to increase greatly in the southern part of the study area. These small zones are located close to the railways and roads which are newly constructed in the airport project. These results indicate large improvements of locational attractiveness in these small zones by the alternative plans.

7. Conclusions

A Hierarchical Land-use Model, which estimates the distributions of employment and population and the land-use pattern in a metropolitan area, has been presented. The model is composed of two subsidiary models and is applied to the study region in a hierarchical manner. Each subsidiary model is based on different concepts of land-use modelling. Especially, in the lower Land-use Model, the locational competition among land-use activities are modelled using the idea of bid price.

The application of the model to the Osaka Metropolitan Area revealed that the model's estimation reliability was generally satisfactory. Moreover, the effective use of the model for regional transport network planning was presented. However, in order to increase the reliability of the model, additional refinements are required for a few activities.

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