An Activity Location Model for the Osake Metropolitan Area

By

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Abstract

The aim of this paper is to propose an Activity Location Model and to present an attempt at validation by applying it to the Osaka Metropolitan Area. The Activity Location Model estimates the activity level of various kinds of employment and population in each zone, considering an economic base mechanism between activities. The total model is calibrated using various kinds of data in the Osaka Metropolitan Area, whose results are fairly good as well as those of validation. Moreover, the effective use of this model to predict the change of activity pattern caused by transport improvements is shown in this paper.

1. Introduction

It is important to establish an appropriate landuse system and make the best use of land in order to create a sound urban environment. When public and private projects are planned, it is sometimes required to estimate the impact of these projects upon the landuse pattern beforehand. To do so, various types of comprehensive models have been developed in the North American and European countries since the 1960s[1)2)].

In this paper, an Activity Location Model is proposed and its validity is examined by applying it to the Osaka Metropolitan Area in Japan. The Activity Location Model is originally a modified version of S. H. Putman's empiric model[3)], and the new model proposed in this paper is a revised version of our proto-type model[4)]. This model estimates the activity level of various kinds of employment and population with several hypotheses of quantitative and spatial relationships among activities.

The Activity Location Model is also a submodel of our hierarchical urban model, the Osaka Model. The Osaka Model is composed of two subsidiary models, an Activity Location Model and a Landuse Model. The total activities in a metropolitan area are allocated stepwise using these two models, as shown in Fig. 1. The Activity Location Model estimates the activity level of various kinds of employ-

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ment and population in each large zone. These employment and population estimates are converted into a demand for land. This demand is allocated to small zones using a Landuse Model[6]. The detail of the Activity Location Model is described in this paper.

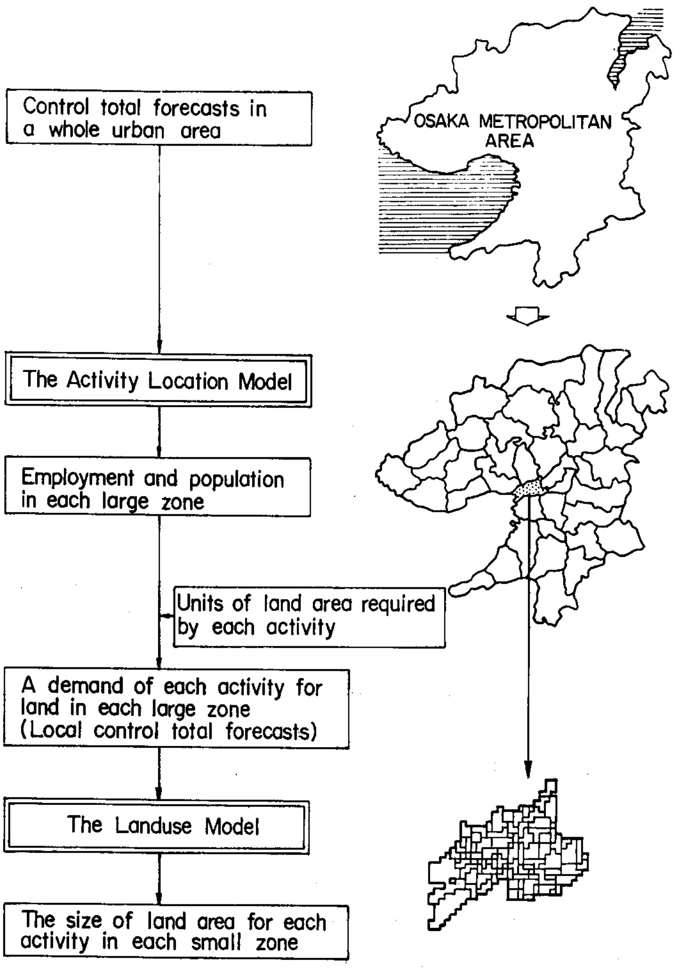

Fig. 1. The Basic Structure of the Osaka Model.

2. The Structure of the Activity Location Model

2.1. The Model Structure and Submodels

The Activity Location Model is a linear urban model, which considers an economic base mechanism among various activities. In this model, activities are classified into three large sectors: manufacturing employment, service employment and population. Fig. 2 shows the structure of the Activity Location Model. The

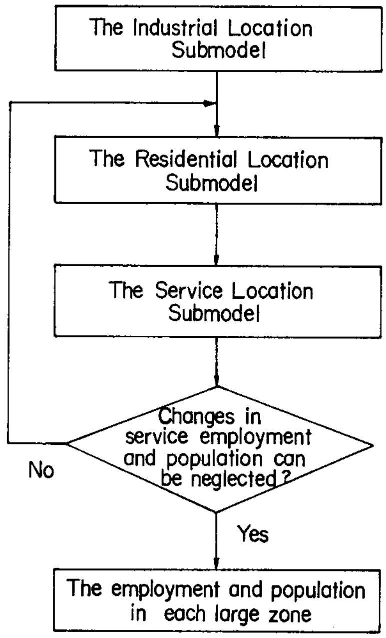

Fig. 2. The Structure of the Activity Location Model.

model is composed of three submodels.

First, the change of manufacturing employment is estimated for each zone by the industrial location submodel. This change in manufacturing employment brings about a change in resident population in each zone, which is estimated by the residential location submodel. Second, the change of service employment, which provides various services to the above manufacturing employment and population, is estimated by the service location submodel. The change of service employment in turn changes resident population, which will generate further change in service employment.

This iterative procedure stops when the changes in service employment and population become small. The control total forecast of each actity 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 pattern in the metropolitan area is determined.

2.2. The Classification of Activities

The employment is further disaggregated in each submodel. Eleven kinds of manufacturing employment are disaggregated in the industrial location submodel, whereas six kinds of service employment are disaggregated in the service location submodel.

Table 1 shows the classification of activities in the Activity Location Model.

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
	9	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

The disaggregation of population is not considered in this model.

2.3. The Estimation Function for Each Activity

A linear function is formulated for each activity to estimate the activity distribution in the study area. A general form of estimation function is represented as follows.

$$Y_{ki}=b_0+\sum_{h} b_h X_{hi} \tag{1}$$

where, Y_{ki}: the amount of activity k in zone i,

X_{hi}: an explanatory variable in the estimation function,

b_0, b_h: regression coefficients.

In Equation (1), Y_{ki} is defined by the change in activity during a given time period or the total level of activity at one point in time.

(1) The Industrial Location Submodel

The industrial location submodel estimates various kinds of manufacturing employment in each zone at one point in time. The locational preference of the industrial location is generally influenced by factors, such as trade conditions with other manufacturing industries, labour force conditions, industrial site conditions, and so on.

In this submodel, the index of locational preference is defined by the following accessibility measure:

$$ACS_{ki}=\sum_j\{(\sum_l \beta_{kl}\cdot\rho_l\cdot E_{lj})/\exp(\alpha T_{ij})\}$$
$$+\sum_j\{(\sum_l \beta_{lk}\cdot\rho_l\cdot E_{li})/\exp(\alpha T_{ij})\} \qquad (2)$$

where, k, l : manufacturing industries k and l,
E_{lj}: the amount of employment in manufacturing industry l in zone j,
β_{kl}: the number of units of inputs from industry k to industry l,
β_{lk}: the number of unts of inputs from industry l to industry k,
ρ_l: a productivity ratio (output/employee) in industry l,
T_{ij}: the travel time between zones i and j by car,
α : a distance exponent.

This index represents the convenience of trade with other manufacturing industries in the study area. However, it is difficult to estimate the location of all kinds of manufacturing industries with this index, because various factors influence the locational preference of each manufacturing industry. Several manufacturing industries are given exogenously in this submodel. These industries are concerned with the production of primary goods, and they do not make notable trade with the other industries in the Osaka Metropolitan Area. Thus it is difficult to estimate the location of these industries with the index (2). Table 2 shows these exogenous manufacturing industries. The estimation functions for other industries are formulated by using the index (2).

Table 2. The Exogenous Manufacturing Industries and the Indogenous Manufacturing Industries.

Exogenous manufacturing industries	1	Timber and Furniture
	2	Pulp and Paper
	3	Leather Products and Rubber Products
	4	Chemical Products
	5	Petroleum and Coal Products
	6	Ceramics
Indogenous manufacturing industries	7	Food Products
	8	Textiles and Clothes
	9	Metals and Nonferrous Metals
	10	General Machinery
	11	Others

The amounts of indoor service employment of manufacturing industries are calculated in proportion to the number of outdoor service employment in each zone.

(2) The Service Location Submodel

The service location submodel estimates the locations of various kinds of service employment during a time period τ (i. e. from time $t-1$ to time t). The service employment provides various services to other activities. The amount of service employment changes in proportion to the number of activities which need to be served. The following assumptions on the service demands are made to formulate the service location submodel.

(i) Services are mainly demanded by four groups; the total employment, the total manufacturing 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.

(ii) 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 3 shows the explanatory variables, which are defined on the basis of these two assumptions. It is also assumed that service demands arise from both the total activites at time $t-1$ and the additional activities that locate during a time period τ (i. e. from time $t-1$ to time t). The demand for regional services is defined by the following accessibility index:

$$ACS(A)_{ki}=\sum_{j} A_j/\exp(\alpha T_{ij}) \tag{3}$$

where, A : an activity which need to be served,

A_j: the total amount of activity A in zone j,

T_{ij}: the travel time between zones i and j,

α : a distance exponent.

Table 3. The Explanatory Variables in the Service Location Submodel.

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

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

(3) The Residential Location Submodel

The residential location submodel estimates the change of resident population in each zone. The resident population in zone i at time t is defined by the following equation.

$$P_i^t = P_i^{t-1} + (B_i^\tau - D_i^\tau) + (I_i^\tau - O_i^\tau) \tag{4}$$

where, P_i^t, P_i^{t-1}: the resident population in zone i at time $t-1$ and time t,

B_i^τ: the number of births in zone i during a time period τ (from time $t-1$ to time t),

D_i^τ: the number of deaths in zone i during a time period τ,

I_i^τ: the net in-migration in zone i during a time period τ,

O_i^τ: the net out-migration in zone i during a time period τ.

The term $(I_i^\tau - O_i^\tau)$ in Equation (4) represents the social change of population.

Since the natural change generally does not depend on the economic behaviour of residents, it is difficult to formulate the causality of the natural change in population. Furthermore, birth rates and death rates do not vary much from zone to zone in the same urban region. Thus, we assume that the natural change in population occurs in proportion to the amount of resident population in zone i.

$$(B_i^\tau - D_i^\tau) = \alpha \cdot P_i^{t-1} \tag{5}$$

In contrast with the natural change, the social change of population in a zone mainly results from the econimic behaviour of its residents. The major determinants of social change are the availability of employment opportunities, housing conditions, environmental conditions, and so on. We assume the social change of zone i during a time period τ to be a function of these factors.

$$(I_i^\tau - O_i^\tau) = \sum_h \beta_h \cdot F_{hi} \tag{6}$$

where, F_{hi}: factors which influence the social change of the population in zone i,

β_h: a regression coefficient.

The change of population in zone i during a time period τ is estimated in the following equation derived from Equations (4)-(6).

$$\Delta P_i^\tau = P_i^t - P_i^{t-1} = \alpha \cdot P_i^{t-1} + \sum_h \beta_h \cdot F_{hi} \tag{7}$$

This Equation (7) is used to estimate the change in resident population of zone i in the residential location submodel.

3. The Application of the Model to the Osaka Metropolitan Area

The Activity Location Model is applied to the Osaka Metropolitan Area and its reliability is examined. The model is calibrated using data for 1968 and 1973. Then, the employment and population for 1978 are estimated for each zone. The reliability of this model is examined by comparing these estimated values with their real values in 1978.

3. 1. The Study Area and Data Base

The study area and zoning system in the Activity Location Model are shown in Fig. 3. There are 174 administrative districts, which are aggregated in this study into 39 zones referring to previous zoning studies. A recent survey by the Ministry of Construction reports that the number of commuters from external administrative zones is less than 1. 5 percent of its population.

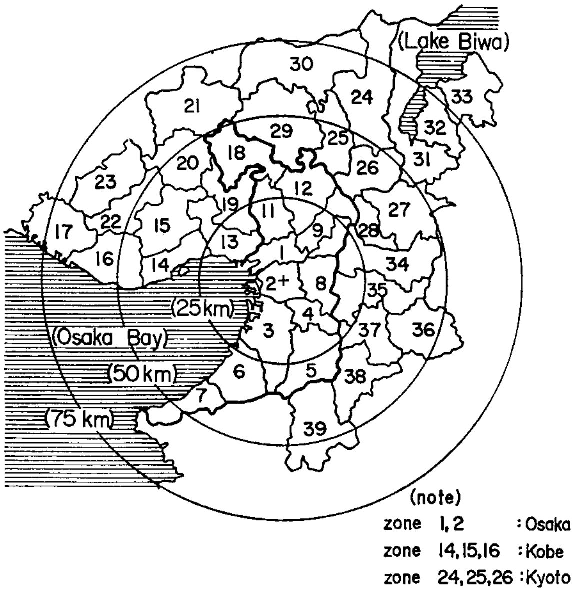

Fig. 3. The Study Area and Zoning System in the Activity Location Model

In the Activity Location Model, various kinds of employment and population are used as the indices for activity levels. Data are processed from formal statistics, such as the Population Census of Japan, Census of Manufactures, Census of Commerce, Establishment Census of Japan, and so on. The parameter of distance exponent α is estimated using the trip-distribution data from the 1970 Transportation Study in this area.

3. 2. Calibration and Validation of the Activity Location Model

(1) The Results of Calibration for the Industrial Location Submodel

The estimation functions for five endogenous manufacturing industries are calibrated. Table 4 shows the results of calibration. The calibration results are good as indicated by their coefficients of determination and F-values.

The estimation function for indoor service employment of manufacturing industries is calibrated using the total outdoor service employment. The result of

Table 4. The Results of Calibration for the Industrial Location Submodel.

Industry	Parameter for ACS_{ki}	Constant term	$\bar{R}^2$
Food Products	0.242 (92.6)	−537.8	0.715
Textiles and Clothes	0.265 (83.2)	−2272.2	0.692
Metals and Nonferrous Metals	0.049 (142.9)	−1352.5	0.794
General Machinery	0.348 (181.6)	−3136.1	0.831
Others	0.283 (155.3)	−2365.9	0.808

(note) The number in a parenthesis shows a F-value.

calibration is shown in Equation (8).

$$EMI_i = 0.375 \cdot EMO_i \quad (\bar{R}^2 = 0.808) \tag{8}$$
(12.7)

where, EMI_i: the number of indoor service employment of manufacturing industries in zone i,

EMO_i: the number of outdoor service employment of manufacturing industries in zone i.

(2) The Results of Calibration for the Service Location Submodel

The estimation function for each service employment is calibrated using the explanatory variables in Table 3. The results of calibration are shown in Table 5. These estimation functions are determined by reference to several conditions, e. g.

Table 5. The Results of Calibration for the Service Location Submodel.

Industry	Estimation function (F-value)
Construction	$\Delta ECM^{\tau} = 0.0043 \cdot (TE^{t-1} + P^{t-1}) + 0.0694 \cdot \Delta ES^{\tau} - 269.17$ (7.1) (2.1) $(\bar{R}^2 = 0.766)$
Wholesale	$\Delta EWM^{\tau} = 0.0199 \cdot ACS(ELS)^{t-1} + 0.0588 \cdot \Delta ACS(ELS)^{\tau} - 571.75$ (4.6) (2.3) $(\bar{R}^2 = 0.653)$
Local Service	$\Delta ELS^{\tau} = 0.018 \cdot (TE^{t-1} + P^{t-1}) + 0.047 \cdot (\Delta TE^{\tau} + \Delta P^{\tau}) - 977.00$ (16.57) (4.22) $(\bar{R}^2 = 0.881)$
Finance, Insurance and Real Estate	$\Delta EFM^{\tau} = 0.0123 \cdot TE^{t-1} + 0.0368 \cdot \Delta ES^{\tau} - 156.93$ (19.4) (1.4) $(\bar{R}^2 = 0.830)$
Transport and Communications	$\Delta ETM^{\tau} = 0.0271 \cdot \Delta P^{\tau} + 0.0602 \cdot \Delta ACS(EM)^{\tau} - 585.47$ (31.8) (2.1) $(\bar{R}^2 = 0.666)$
Electricity, Gas and Water Services	$\Delta ERM^{\tau} = 0.224 \cdot 10^{-3} \cdot (TE^{t-1} + P^{t-1}) + 0.0017 \cdot (\Delta TE^{\tau} + \Delta P^{\tau})$ (6.9) (3.4) $+2.07$ $(\bar{R}^2 = 0.211)$

the coefficient of determination $\bar{R}^2$, the sign conditions of parameters and the F-values for independent variables.

(3) The Results of Calibration for the Residential Location Submodel

The population in each zone is estimated using Equation (7). The change of accessibility for commuters and the activity density variable are used in Equation (7) to explain the social change of population.

An accessibility index for commuters is defined by the following equation:

$$ACS_i=\sum_j TE_j/\exp(\alpha \cdot T_{ij}) \tag{9}$$

where, ACS_i: the accessibility for commuters in zone i,

TE_j: the total employment in zone j,

T_{ij}: the travel time between zones i and j by railway,

α : a distance exponent.

The activity density variable is introduced to consider the decline of population in large cities. It is defined by the product of population P_i^{t-1} and total employment of each zone TE_i.

The result of calibration is shown in Equation (10).

$$\begin{aligned} \Delta P_i^{\tau} = {} & \underset{(0.5)}{0.029} \cdot P_i^{t-1} + \underset{(15.5)}{1.45} \cdot \Delta ACS_i^{\tau} - \underset{(55.3)}{0.209} \cdot 10^{-6} \cdot (P_i^{t-1} \cdot TE_i^{t-1}) \\ & -11089.1 \end{aligned} \tag{10}$$

$$(\bar{R}^2=0.686)$$

where, ΔP_i^{τ}: the change of population in zone i during a time period τ,

P_i^{t-1}: the population in zone i at time $t-1$,

ΔACS_i^{τ}: the change of accessibility for commuters in zone i during a time period τ,

TE_i^{t-1}: the number of total employment in zone i at time $t-1$.

(4) The Results of Validation for the Activity Location Model

The Activity Location Model is applied to predict the location of each activity in 1978. The reliability of the model's predictions is examined by comparing the predicted values with the real values. The quality of the predictions is measured with the correlation coefficients. Table 6 shows the correlation coefficient for each activity.

The correlation coefficients about activity levels in 1978 are rather high, which shows that the model has a good ability to predict future activity patterns. This table also shows the relationship between the estimated and real values of the change in activity from 1973 to 1978. Most of correlation coefficients are fairly good, whereas those for several industries such as food products, indoor services and electricity, gas and water services are not so good. Thus, further studies on locational factors for these activities will be necessary to improve the model.

Table 6. The Results of Validation for the Activity Location Model.

Industry			Correlation coefficient: Activity in 1978	Correlation coefficient: 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

Table 7. 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. Pule 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

3.3. Case Studies of the Activity Location Model

(1) The Outline of Case Studies

The Activity Location Model determines an activity pattern in each zone with control total forecasts of various activities given exogenously.

We have carried out a "do nothing" prediction as a base run and two kinds of policy tests as follows:

Test 1 : All mechanized transport mode speeds increased by 20%.

Test 2 : All mechanized transport mode speeds reduced by 20%.

The following four premises are assumed in applying policy tests to the Activity Location Model.

(1) Employment can be aggregated into three sectors; employment in retail service activities (EMRT), employment in non retail service activities (EMNR) and

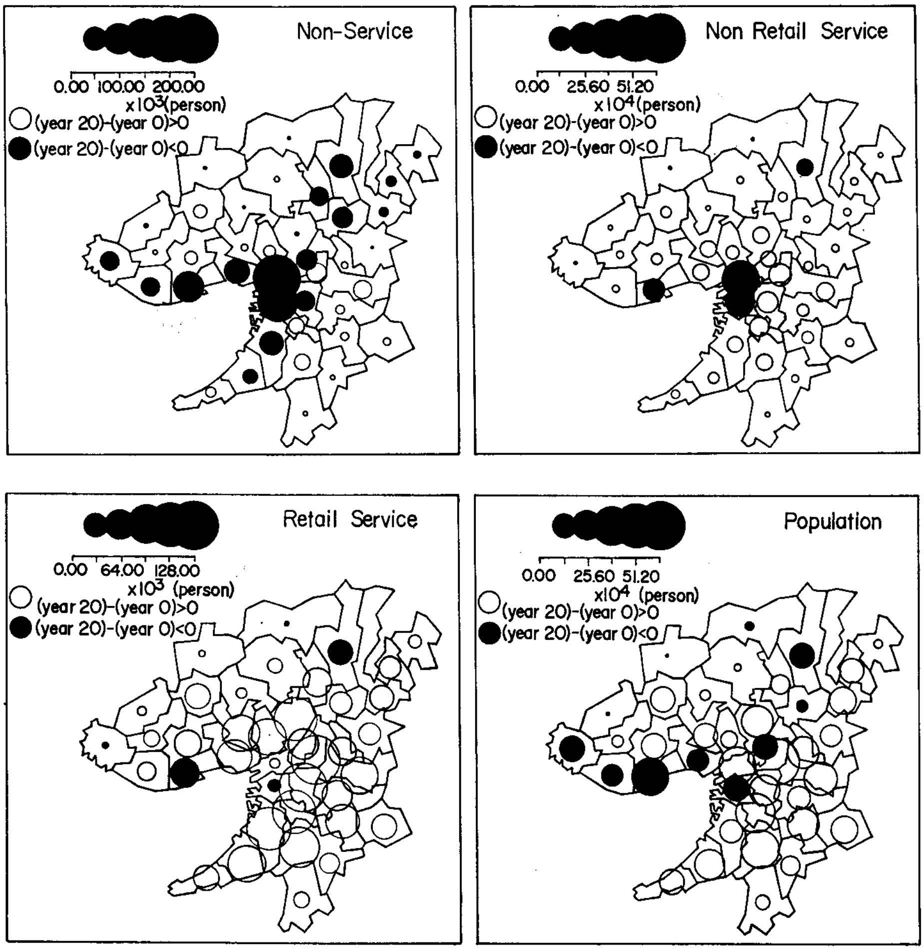

Fig. 4. The Changes of Employment and Population from 1973 (base year) to 1993 (20 th year), (Base run)

employment in non-sevice activities (EMNS). Table 7 shows the comparison among these sectors and industries in the Activity Location Model.

(2) The Activity Location Model predicts the activity patterns at five year intervals. Therefore, the model is run in a recursive manner in order to predict the activity pattern over a long forecast period.

(3) The parameters of estimation functions are assumed to be constant during the prediction time period.

(2) The Results of the Base Run

The base run is carried out from 1973 to 1993, and the activity patterns in the metropolitan area are predicted at five year intervals. It is assumed that throughout the prediction period employment and population will be growing at the same rate

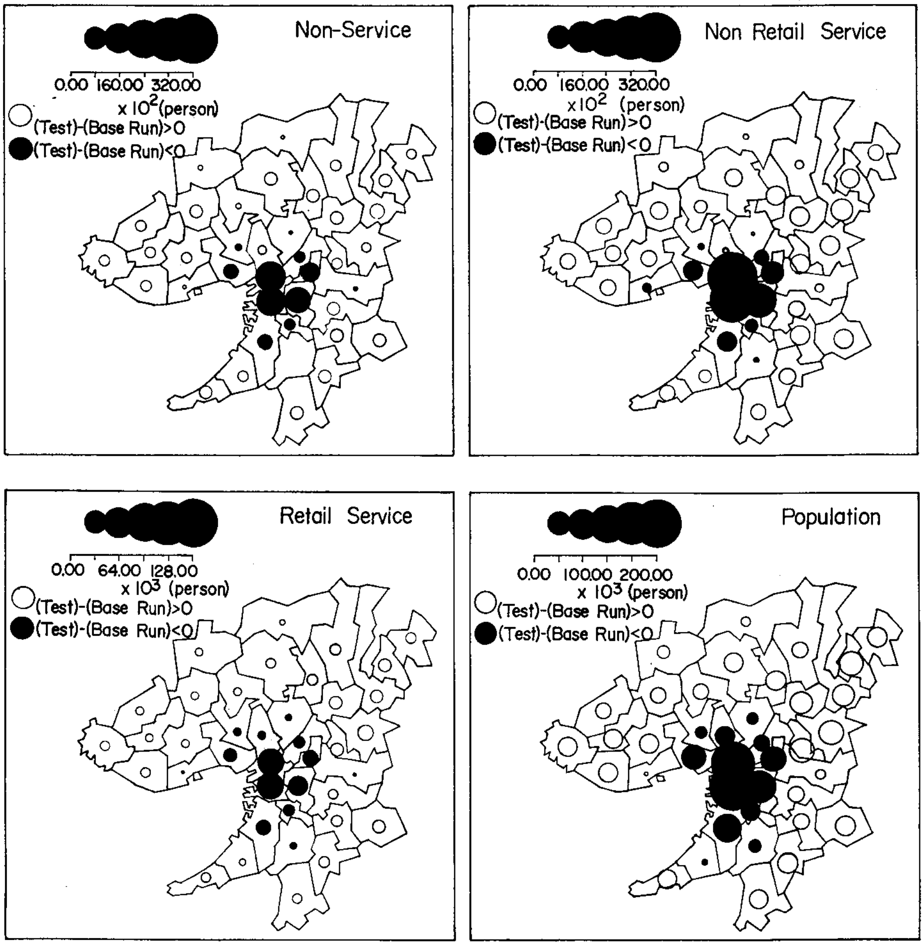

Fig. 5. The Difference between Predictions for the 20 th Year, (Policy test 1)

as they did during the period from 1968 to 1973.

The results are summarized in Fig. 4, which shows the changes of employment and population from 1973 (base year) to 1993 (20th year). The model predicts a large growth in employment and population in the suburban areas, whereas employment and population in the city central area declines. The suburbanization process can be distinguished clearly in these results.

(3) The Results of Policy Tests 1 and 2

Two kinds of policy tests about transport mode speeds have been carried out, and the results are shown in Fig. 5 and Fig. 6. Each figure shows the comparison between the test result and the base run. Fig. 5 corresponds to the policy test 1 (a 20% increase in transport speed) and Fig. 6 shows the results of the policy

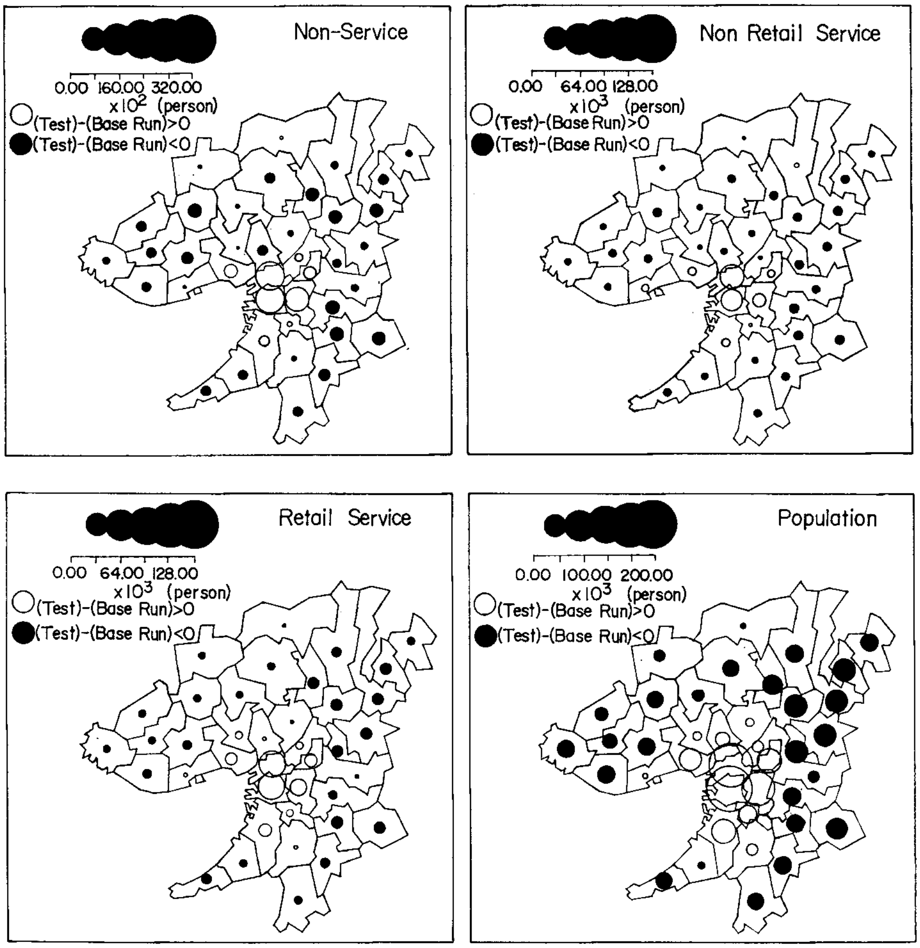

Fig. 6. The Difference between Predictions for the 20 th Year, (Policy Test 2)

test 2 (a 20% decrease in transport speed). These results indicate that all activities are decentralized by increasing the speeds of modes and centralized by decreasing the speeds of modes.

4. Conclusion

An Activity Location Model which predicts a future activity pattern in a metropolitan area has been presented. 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 this model to predict the change of activity pattern caused by transport imporivements is shown. To increase its reliability, especially for some activity such as food products, and to make the model operational, additional refinements are still required.

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