A MICRO-ANALYTIC RESIDENTIAL MOBILITY MODEL FOR ASSESSING THE EFFECTS OF TRANSPORT IMPROVEMENT

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1. INTRODUCTION

Residential locational pattern is an essential factor in transport planning as a determinant of the distribution of transport demand. However, it is not easy to forecast because it is influenced not only by physical planning such as transport improvement but also by socio-economic conditions such as the progress of the life cycle , increase in the income level of households and changes in the interest rates of housing loans.

To forecast the changes of residential locational pattern in an urban area, it is necessary to simulate the life cycle of individuals, who are decision makers, and intra/interzonal migration behaviour.

Recently, to make more emphasis on the behavioural aspects, land use - transport models such as housing type choice (e.g. (1),(2)) and housing locational choice (e.g. (3),(4)) have been developed in the forms of disaggregate behavioural models, which describe locational behaviours with relation to their socio-economic characteristics.

However, these disaggregate behavioural models cannot be easily applied to long term forecasts because these models don't have the function to forecast changes of a household's attributes due to the progress of the life cycle.

The aim of this paper is to develop a residential mobility model which can forecast changes of transport demand considering the changes of households' attributes and the socio-economic conditions such as interest rates. To consistently simulate a dynamic progress of the life cycle of a household and the consequent residential mobility, a micro-simulation technique is employed.

2. MODEL FRAMEWORK AND FORECASTING METHODS

2.1 Model framework

This model is composed of three submodels; 1) a life cycle model, 2) a residential mobility model, and 3) a land price model. Figure 1 shows the relationship of these models as follows: as housing demand which basically depends on the mismatches of a household's attributes with the current dwelling, is generated, the model first forecasts the life cycle changes of the household and estimates the migration decision and finally determines the residential zone where it will relocate. The location is chosen

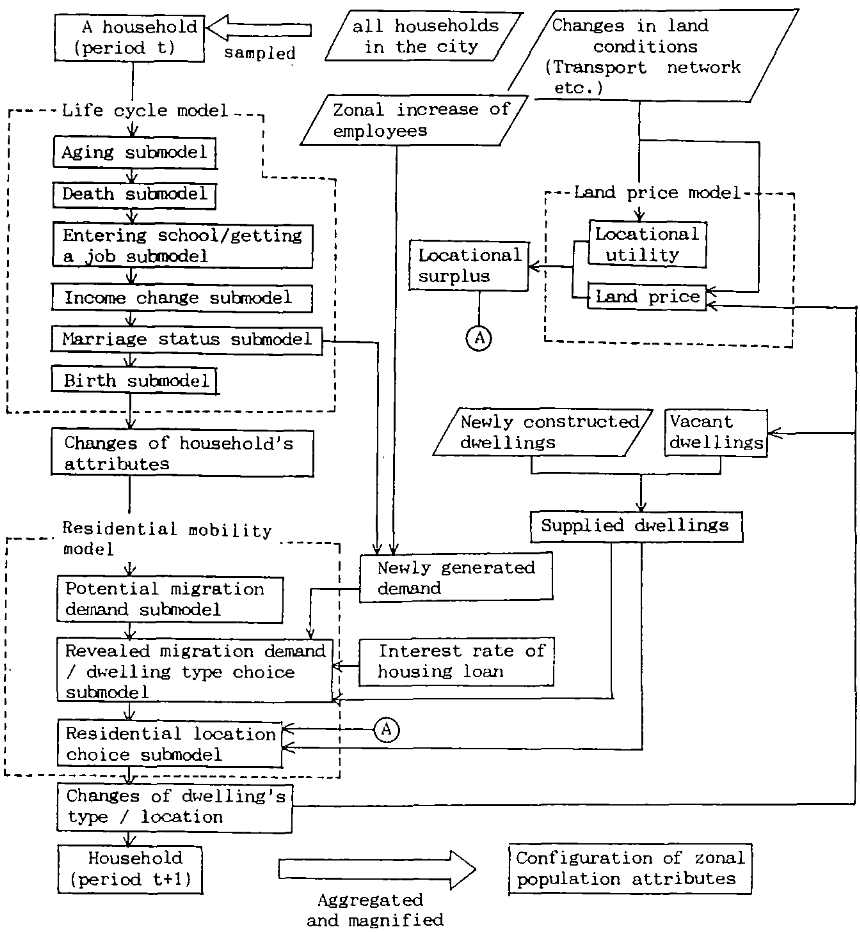

FIGURE 1. Structure of the Model

according to the locational surpluses (5) for the household as well as the perceived sizes of dwelling supply in different zones. As households locate in a zone, the land price increases and the amount of location is consequently saturated.

In the above model, the land conditions, which change due to transport improvement, are the exogenous variables for the land price model. For the residential mobility model, economic conditions such as interest rates of housing loans, increases in land price and the income of the household, as well as large scale residential development plans, are given as exogenous variables. Thus the influence of socio-economic conditions on residential location, which is a long term effect of transport improvement, as well as the effects of other policies, can be analyzed by this model.

2.2 Forecasting method

2.2.1 Micro simulation technique and its existing applications

In this paper, to consistently simulate a dynamic progress of the life cycle of a household and the consequent residential mobility, a micro-simulation technique is employed. The micro simulation is a simulation technique whose analytic unit is a micro-unit, here, an individual /household. The Monte-Carlo technique is usually used in the micro simulation to simulate the determination of an individual's/household's behaviour. List processing is also used to save the individual/household data volume in the form of a list.(Clarke,M. and Williams,H.C.W.L.(6))

There are some existing applications of micro simulation in the area of land-use transport analysis, particularly in residential location models. For example, in Japan, micro simulation has been applied since Kumada(7). Recently in Europe, Wegener(8) applied it to the market clearance process as a part of a housing market simulation model. Mackett(9) presented a full micro simulation model of residential location involving the effects of households' life cycles. However the model gives fixed probabilities of each event's occurrence simply according to the empirical data. In this study, each event composing life cycle changes is formulated in aggregate or disaggregate logit models which can provide future changes of probabilities of each event's occurrence in the micro-simulation process.

2.2.2 Simulation process

Figure 2 is a conceptual figure of the micro simulation process in this paper. First, a large enough number of households with the attributes shown in Table 1, is sampled from the study area. The life cycle change and migration behaviour of each household are traced. The probability of changes in household attributes and decision making for migration is given respectively by the life cycle model (see chapter 3) and the residential mobility model (see chapter 4) both of which are formulated in disaggregate models.

Figure 2 shows that one household has a child in the period ($t=t_1$ - $t=t_2$), the child grows up and enters school in the next period ($t=t_2$ - $t=t_3$), and as a result the household will move to live in a bigger

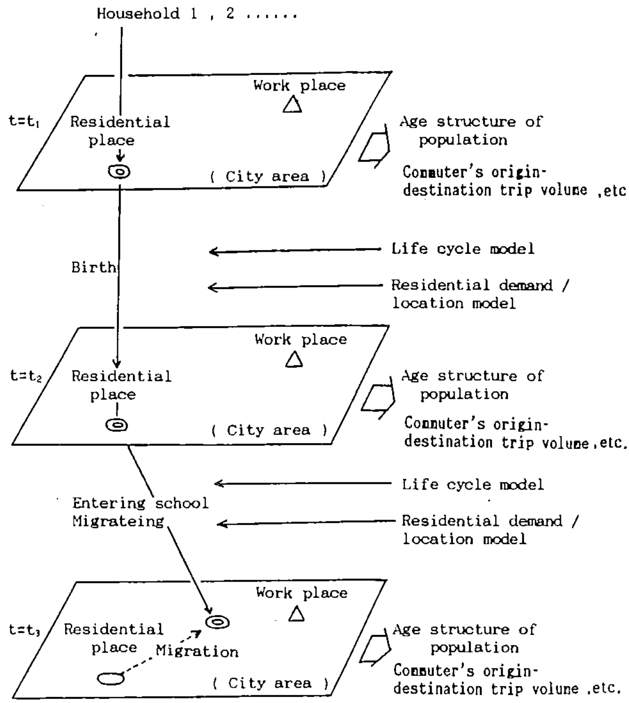

FIGURE 2. Conceptual Figure of the Micro-Simulation

TABLE 1. Attributes of the individuals/households/dwellings treated in the model

Individual attributes	Age, Sex, Student/Employed/Unemployed, Job location, Annual income, Statust of marriage
Household attributes	Number of household members, Number of couples
Dwelling attributes	Residential location, Dwelling type, Owner occupied/ Rental, Housing loan/rental payment, Size of dwelling

dwelling. In each period all of the sampled households are simulated, and by aggregating data of every household, model outputs such as age structure of population and commuter's origin-destination trip volume at any discrete time point are produced.

3. LIFE CYCLE MODEL

3.1 The model structure and specifications of the submodels

The life cycle model simulates the changes of each household's attributes, specifying such events in the life of an individual as 1)aging, 2)death, 3)entering school/getting a job, 4)income change, 5)change of marriage status, and 6)birth.

Each event is simulated by the following submodels.

1) Aging submodel

This simply adds a simulation period to the age of each individual.

2) Death submodel

This determines whether each individual dies or not during the period. The death probability is a function of the age and sex of the person and the period when the person exists.

3) Entering school/getting a job submodel

This determines the economic activity status of the person with categories of student, employee, and retired person. The transition rate between status is a function of the sex and age of the person.

4) Income change submodel

This determines the transitions of income level of household. The transition rate is a function of the sex, age and educational qualification of the person.

5) Marriage status submodel

This describes the transition of marriage status: married or not married. The transition rate is a function of the sex, age, and marriage status of the person.

6) Birth submodel

This determines the number of babies a married female is expected to have in a period.

The above mentioned transition rates can be generally formulated as a function of the person's attributes, such as the sex and age, and the period (calendar year).

$$\ln((P_{ij}/(1-P_{ij}))=m_0 + m^A{}_i + m^P{}_j \quad (\sum_i m^A{}_i=1, \ \sum_j m^P{}_j=1) \qquad (1)$$

P_{ij} : transition rate of the person whose attribute is i in the period j

m_0 : constant parameter

$m^A{}_i$: the parameter for the effect of attribute i

$m^P{}_j$: the parameter for the effect of period j

3.2 Estimated results

Equation(1) is calibrated by the method of maximum likelihood using population census data and statistics of the population's movement in 1965, 1970, 1975 and 1980. The goodness-of-fit of each submodel is high; the correlation coefficients are more than 0.98.

4.RESIDENTIAL MOBILITY MODEL

4.1 The structure of the model

The residential mobility model describes mainly migration processes. The migration of households is formulated in two steps as follows:

Step-1 estimates whether a household wishes to move due to the mismatch between the dwelling and its life stage.

Step-2 determines whether the household will succeed in finding a suitable dwelling in terms of level of locational surplus and the household ability to spend.

4.2 Potential migration demand submodel(Step-1)

This submodel gives the probability that a household is satisfied with the current dwelling in which it lives.

As households satisfied with their current dwellings would not search for new dwellings, they should be excluded from the residential demand in modeling choices of dwelling types and locational zones.

The probability(P) of a household's(h) not being satisfied with the existing dwelling(d) is specified in the following logit equation:

$$P= 1 / (1+\exp(V_{hd})) \tag{2}$$

V_{hd} : measurable utility of the current dwelling(d) for a household(h) which is explained by the attributes of the household and its dwelling.

4.3 Revealed migration demand, dwelling type choice and residential location choice model (Step-2)

4.3.1 Revealed migration demand / dwelling type choice submodel

Households not satisfied with the current dwelling will search for another dwelling having a utility higher than that of the current dwelling. The probability(P_d) that a household will choose a dwelling(d) is formulated in the following equation:

$$P_d=\exp(V_d)/ \sum_d \exp(V_d) \quad (d=0,1,\dots,n) \tag{3}$$

V_d : measurable utility of dwelling type d

d : dwelling type

n : number of dwelling types

In this equation, P_0 represents the probability that a household chooses its current dwelling, that is, the household wants to migrate, but it can not search or afford to spend for a dwelling of higher utility. P_d (d=1,.,n) refers to the probability that the household moves to the dwelling type d.

In this submodel, the household's ability to spend for a dwelling is measured by annual expenses in terms of the following:

1) the annual rent for rental dwellings
2) the annual loan payment for owner occupied dwellings calculated by the following equation:

$$r=(C-C_0)(i(1+i)^t)/((1+i)^t-1) \quad (4)$$

r : annual payment
C : dwelling price
C_0: average payment by cash
i : interest rate of housing loan
t : term for repayment

4.3.2 Residential location choice submodel

The residential location choice model is specified according to the following three hypotheses:

1) A household chooses a zone which has as large a utility and as small a cost as possible i.e. as large a locational surplus as possible.(5)
2) A zone is chosen in proportion to the size of its dwelling supply if the locational surpluses are indifferent between zones.
3) Households have more information about dwellings closer to their living zone than any other zone, and therefore often perceive them more.

According to these hypotheses, the model is specified as ,

$$P_{jioi}=A_{ioi} \exp(c X_{ji}) / \sum_i A_{ioi} \exp(c X_{ji}) \quad (5)$$

P_{jioi} : the probability that a household living in zone i_0, its head commuting to zone j, chooses zone i
X_{ji} : locational surplus of zone i for a household whose head commutes to zone j. (The locational surplus is obtained by subtracting the land price at the previous period, which is calculated by equation (7), from the bidding price.)
A_{ioi} : the number of the perceived dwellings in zone i for a household that lives in zone i_0
c : parameter

where $$A_{ioi}=(S_i)^a \exp(bt_{ioi}) \quad (6)$$

S_i : amount of supplied dwellings in zone i
t_{ioi} : travel time from zone i_0 to zone i
a, b : parameters

4.4 Estimation of the residential mobility model

The residential mobility model is estimated using the survey data of residential demand in the Nagoya metropolitan area, which was conducted for 2,434 households in 1978, of which 1,620 households migrated between 1974 and 1978.

4.4.1 Estimation of the potential migration demand submodel

Table 2 shows the explanatory variables and the estimated result of the model. According to the estimated results, the goodness-of-fit is comparatively high; the likelihood ratio is 0.27 and the proportion of the correctly estimated samples is 70% (number of samples is 2,434).

TABLE 2. Estimated Results of Potential Residential Demand

Variables description	Categories Variables	Coefficients	t-statistics
Size of dwelling (m^2) / Number of household members		3.00	7.48
Number of years after construction		-0.01	-3.86
Age of household's head	50 years -	-0.85	-3.54
	30 - 40 years	-0.60	-2.58
	- 29 years	–	
Current dwelling type dummy variables	a(*)	0.65	6.14
	b(*)	0.99	2.54
	c(*)	–	
constant		2.36	10.0
Number of samples		2434	
Likelihood ratio		0.27	
Percentage of correctly estimated samples		70 %	

* a = owner occupied single dwelling
b = owner occupied apartment dwelling, c = rental dwelling

4.4.2 Estimation of the revealed migration demand / dwelling type choice submodel

Table 3 shows the explanatory variables and the estimated results. It can be observed that the larger the coefficient of the dwelling type, the higher the probability of choosing that type. The estimated results show as follows:

1) A large and cheap dwelling type is likely to be chosen.
2) Households tend to live in the zone where locational surplus is highest.

3) Households living in owner occupied dwellings tend not to migrate compared with households living in rental ones.

The goodness-of-fit is comparatively high; the likelihood ratio is 0.47 and the proportion of the correctly estimated samples is 73% (the number of samples is 1620).

TABLE 3. Estimated Results of Revealed Demand / Dwelling Type Choice Model

Variables description	Categories Variables	Coefficients	t-statistics
Size of dwelling (m^2) / Number of household members		0.99	2.01
Annual residential expenditure / Annual affordable residential budget		-0.68	-4.50
Current dwelling type dummy variables	a(*)	-15.42	-12.74
	b(*)	-13.23	-7.82
	c(*)	1.17	10.33
	d(*)	-	-
Log-sum variables	a(*)	0.60	4.17
	b(*)	0.82	2.29
	c(*)	0.25	1.97
	d(*)	0.46	2.83
Amount of supplied dwellings		0.78	5.11
Number of samples		1620	
Likelihood ratio		0.47	
Percentage of correctly estimated samples		73 %	

* a = owner occupied single dwelling, b = owner occupied apartment dwelling,
c = rental single dwelling, d = rental apartment dwelling

4.4.3 Estimation of the residential location choice submodel

Table 4 shows the explanatory variables and the estimated results. The coefficients of the variables show as expected, that households are likely to choose the zone that has a larger locational surplus, is closer to their current living zone, and where more dwellings are supplied. According to the t-values of the variables, the distance from the current living zone (t_{ioi}) is the most significant among all the variables.

The goodness-of-fit is comparatively high; the likelihood ratio of any of the models is more than 0.42 and the correlation coefficients between the real and the estimated number of households to migrate to each zone, are between 0.82 and 0.90.

TABLE 4. Estimated Results of Residential Location Choice Submodel

Variables description	Variables	Coefficient (t-statistics) Model-1	Model-2	Model-3	Model-4
Locational surplus	ln(Xji)	2.47 (9.62)	2.39 (4.03)	1.50 (4.96)	0.78 (2.96)
Travel time from residential zone to dwelling's supplied zone	tioi	-0.04 (-14.3)	-0.03 (-4.91)	-0.03 (-4.96)	-0.06 (-2.09)
Amount of supplied dwelling	ln(Si)	0.41 (3.40)	-	0.30 (2.29)	0.41 (2.03)
Number of samples		239	41	93	126
Likelihood ratio		0.54	0.42	0.43	0.46
Correlation coefficient		0.90	0.84	0.82	0.88

Model-1 : a model estimated by data of choosing owner occupied single dwelling
Model-2 : a model estimated by data of choosing owner occupied apartment dwelling
Model-3 : a model estimated by data of choosing rental single dwelling
Model-4 : a model estimated by data of choosing rental apartment dwelling

5. LAND PRICE MODEL

5.1 The formulation of the land price model

The land price model is formulated by a random bidding model (10). A land price (P_i) in zone i is specified assuming that there are households, whose heads commute to work zone j, that bid a bidding price (b_{ji}) to residential zone i (number of the households is N_{ji}, which is given by the output of the residential mobility model) , as follows:

$$P_i = (1/w)\ln \sum_j \exp(wb_{ji} + \ln N_{ji}) \quad (\text{where } b_{ji} = \sum_k a_k z_{ki}) \qquad (7)$$

Z_{kji} : the kth land condition of residential zone i for households whose heads commute to work zone j

w, a_k : parameter

5.2 Estimated results

The land price model is estimated by using land price data in the Nagoya metropolitan area in 1980 (number of samples is 520). Table 5 shows the variables and the estimated coefficients. The goodness-of-fit is comparatively high; the coefficient of correlation is 0.87.

TABLE 5. Estimated Results of Land Price Model

Variables description	Coefficients	t-statistics
Generalized commuting cost from residential zone to work zone (1000 yen)	-1.49	-6.54
Distance to nearest railway station (km)	-1.10	-4.06
Gas facility dummy variables	1.50	7.17
Sewerage facility dummy variables	2.38	12.2
Designation of non-urban permission area dummy variables	-2.05	-5.39
Number of samples	520	
Correlation coefficient	0.87	

6. VALIDITY TEST AND POLICY TESTS

The validity of the model has been proved based on the result that the correlation coefficient of zonal forecast of population age structure for 1978 to 1983 was 0.96.

The model developed in this paper can analyze many kinds of policies and the influences of the socio-economic conditions on the residential location. Several policy tests are conducted below from the view point of the effect of transport improvement.

6.1 Changes of age structure of population

Figure 3 shows changes in the age structure by zone after simulating from 1978 to 1998. This shows that the proportion of the people older than 65 years will increase rapidly, especially in the city centre.

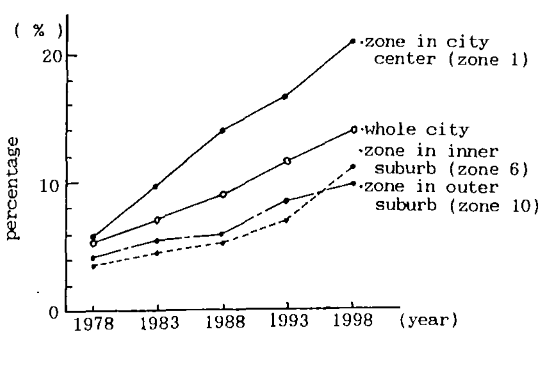

FIGURE 3.
Changes in proportion of people older than 65 years by zone

6.2 Influences of changes in the interest rates of housing loans

Figure 4(a) shows as expected that the reduction of the interest rate causes an increase in residential demand, especially the demand of single owner occupied dwellings. The zonal locations of this type are shown in Figure 4(b), which shows that more dwellings of this type are located in outer zones than in inner zones. Thus population is more decentralized.

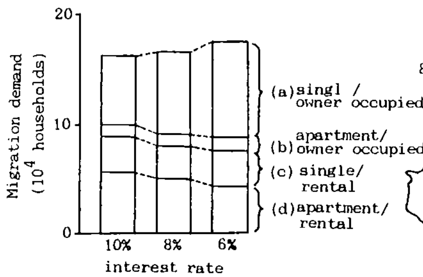

FIGURE 4.(a)
Influences of changes in interest rate of housing loan on migration demand by dwelling type(1978-1983)

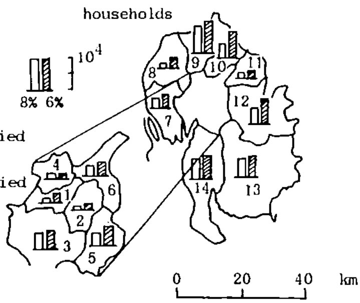

FIGURE 4.(b)
Influences of changes in interest rate of housing loan on residential relocation pattern (1978-1983)

6.3 Influences of changes of land price in inner areas

Figure 5(a) shows that an increase at 10% in land price in the city centre and inner suburb (zone 1-6) causes a decrease in total migration

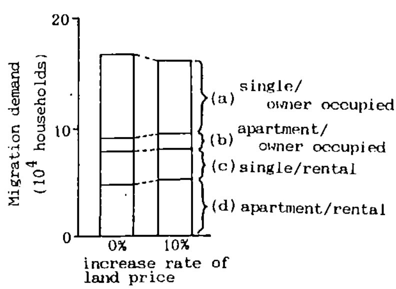

FIGURE 5.(a)
Influences of increase in land price in the city center and inner suburb on residential demand by dwelling type (1978-1983)

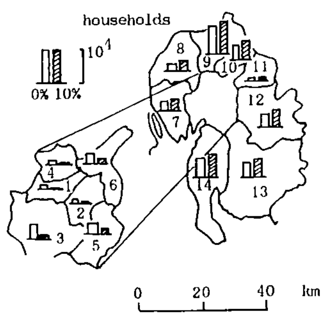

FIGURE 5.(b)
Influences of increase in land price in the city center and inner suburb on residential relocation pattern (1978-1983)

demand, especially in the demand for a single owner occupied type. On the other hand, the demand for a rental apartment type increases. Figure 5(b) shows zonal locations of a single owner occupied type, which illustrates that the decrease of the type's demand causes the decrease in locations especially in the inner zones.

6.4 Influence of interest rate on zonal population's changes due to transport improvement

Figure 6 shows how the difference in the interest rate of housing loans influenced zonal population changes between 1978 and 1982 due to transport improvement. The following three cases are simulated:

case(a) : without a new rail and with an interest rate of 8%,
case(b) : with a new rail and with an interest rate of 8%,and
case(c) : with a new rail and with an interest rate of 6%.

Comparing the total population increases in the zones along the new rail, case (b) is about 18,000 persons more than case (a), while case (c) is about 25,000 persons more than case (a).

Thus the decrease of the interest rate enhances the effects of transport improvement on the residential location. These additional effects are generated mainly due to the consequent increase of total housing demand, especially that of owner occupied single dwellings which tend to locate in suburban areas, attracted by the lower land prices, thus the higher locational surpluses.

The influences of changes of the other socio-economic conditions can be analysed by this model in a similar way.

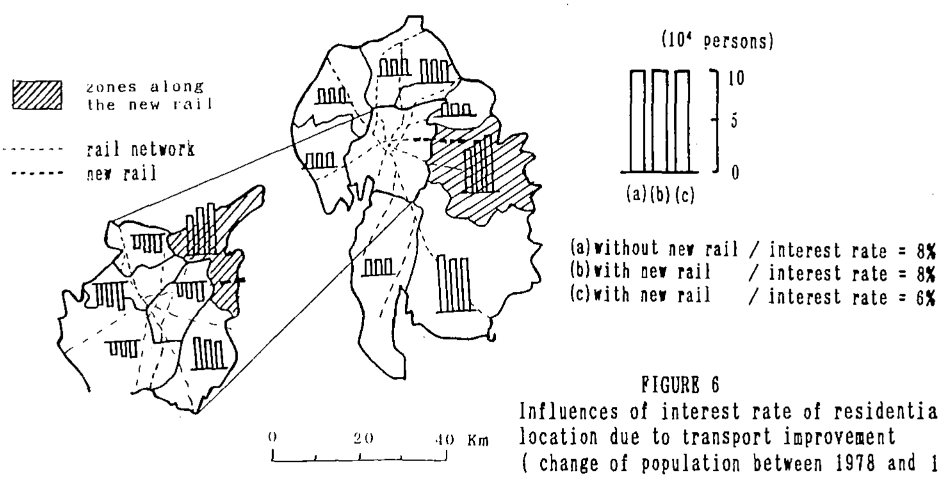

FIGURE 6
Influences of interest rate of residential location due to transport improvement
(change of population between 1978 and 1982)

7. CONCLUSION

In this paper, the households' life cycles and their migration behaviours have been modeled by means of the disaggregate behavioural models, and a micro simulation technique has been applied as the simulation method. This model can analyze land use changes due to changes in socio-economic conditions and transport improvements. Through the applications in the Nagoya metropolitan area, the validity of the model was proved. The model takes only seventeen seconds for one simulation period with the computer system FACOM M-382.

The main results of the model are summarized as follows:

Firstly, the model can analyze the whole migration process of households including potential demand, dwelling type choice and residential location choice. The ability to forecast in the changes of origin-destination trip volume of commuters was improved substantially by considering the perceived dwelling supplies and also the segregation of captive groups in the migration demand generation.

Secondly, the model can analyze the influences of a variety of policies and socio-economic changes such as a life cycle progress, changes in the interest rate of housing loans and housing supply plans.

Thirdly, the output of the model can be presented at any time period and at any aggregation level such as zonal population, the number of migrated households by their attributes between zones and changes of origin-destination. This was enabled by introducing the micro simulation technique.

Fourthly, the above zonal population attributes given by the model are useful as input data for disaggregate behavioural models in middle and long term forecasting.

Finally, as a result of the above mentioned main features of the model, it can analyze differences in the influences of socio-economic conditions on the changes of residential locations, which occur due to the same transport improvement.

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