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THE BANGKOK AREA LAND USE - TRANSPORT ANALYSIS SYSTEM*

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The Bangkok Area Land Use - Transport Analysis System (BALUTAS) has been developed mainly for assessing impacts caused by improvement of transport facilities. It consists of four main models; namely the Residential Location Model (RLM), the Housing Supply Model (HSM), the Business Location Model (BLM) and the Transport Model. The RLM and HSM are formulated by using the discrete choice analysis, the former is based upon the consumer theory while the latter is based upon the firm theory. The BLM is a spatial interaction model taking into account of neighborhood service and wide-area service. Being modified with considering the useful outputs of the above-mentioned three models, the transport model is mostly based on a conventional four-step model which is widely applied in Thailand. The BALUTAS is implemented on NEC 9801 personal computer with two disk drives. The predictability tests of the BALUTAS reveal good fitness. In this paper, an application of the system for forecasting impacts of the Cable-Stayed Bridge Project in Bangkok is also presented.

1 Introduction

In general, the future land use has been given as an exogenous (policy-option) variable to transport planning. In other words, land use has been treated as one-side effect to transport. But, in reality, both land use and transport have influence to each other simultaneously. Indeed, there is a quite tight relationship between changes of land use and transport.

The purpose of this study is to develop an integrated land use - transport model for the evaluation of impacts of new transport facilities in Greater Bangkok Area (GBA).

During the past two decades, several land use and transport models have been developed in various developed countries. However, to apply these models to the GBA may face various problems since the characteristics of the GBA differ from those of metropolises in developed countries. Furthermore, those models may require large amount of data, and in

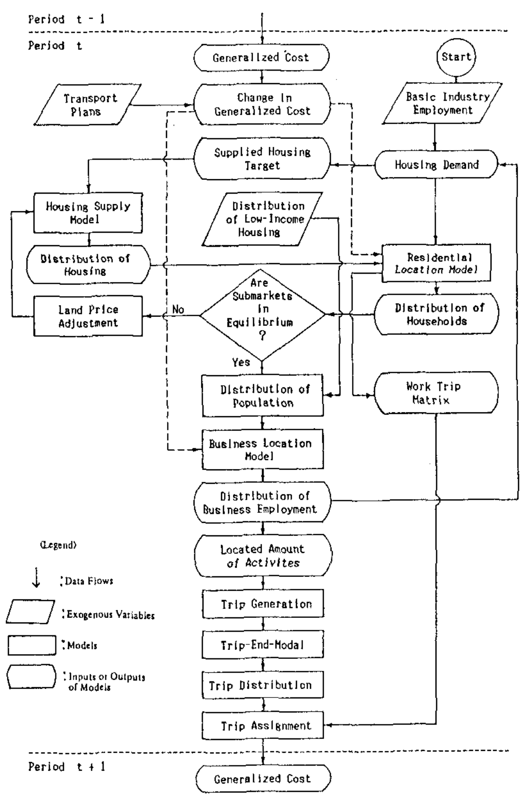

Fig. 1 Structure of the BALUTAS

* Key Words: Residential Location Model, Housing Supply Model, Transport Model

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order to implement them, large scale computer facilities are required. The development of the new system, 'The Bangkok Area Land Use - Transport Analysis System (BALUTAS)', is necessary to conduct to solve the aforementioned problems. The lessons from the past twenty years of experiences in this field will be seriously taken into account in this study.

2 System Structure

The system structure is given in Fig. 1. It consists of two parts; land use and transport. The transport part can be performed after the equilibrium of demand and supply of land has been reached in the land use part. The system performs recursive predictions which is considered a quasi-dynamic way.

It is obvious that the BALUTAS assumes the slum areas will be demolished through slum clearance programs and low-income housing will be provided.

The business location model was discussed in Hidano (1984).

2.1 Procedure of Housing Submarket Equilibrium

This procedure checks the equilibrium between housing supply and demand in each zone. It is necessary to set the following assumptions.

i) The housing stock of the GBA is divided into submarkets and each submarket is a group of dwelling with similar attributes such as accessibility, housing rent or price. For this study, the submarket is supposed to be spatially disaggregate; that is a zone is equivalent to a submarket which is practicable when one considers attributes of housing in a zone.

ii) Assuming that there are few number of vacant housing units in the GBA. This is reasonable since there is great demand of housing in the GBA as well as other metropolises in developing countries.

Submarket equilibrium is obtained if the following land price reaches a stable value.

$$LP_i^{c+1} = LP_i^c(\Delta P_i/\Delta H_i)^\gamma \qquad (1)$$

where:

LP_i = average land price in zone i;

ΔP_i = new households in zone i obtained from the RLM;

ΔH_i = new supplied houses in zone i obtained from the HSM;

c = counting number of iteration;

γ = a parameter to accelerate the convergence.

Land price, LP, is input to both the HSM and the RLM; therefore, it affects the distribution of housing as well as population. After some iterations between these two models, the equilibrium is obtained. How fast the equilibrium can be reached depends upon the value of γ. If this value is too large, the oscillation will occur, on the other hand if it is too small the time approaching the equilibrium will be longer.

3 Residential Location Model (RLM)

3.1 Model Formulation

Before the model can be formulated, there is a need to set the following assumptions.

i) Assuming that employment in every zone is increasing; that is the negative flow does not exist. This is reasonable as the GBA is a growing city.

ii) The number of relocators is considered small; therefore, the new housing demanders are new households and new migrants only.

The RLM is formulated based on a major component of microeconomic theory, the theory of consumer: households choose housing location that maximizes their utilities (surplus for this study).

$$\Delta P_i = \sum_j \Delta E_j \frac{\Delta H_i e^{\beta LS_{ji}}}{\sum_i \Delta H_i e^{\beta LS_{ji}}} \qquad (2)$$

where:

ΔP_i = increment of number of households in zone i;

ΔE_j = increment of number of employment in zone j;

ΔH_i = increment of numer of houses in zone i;

LS_{ji} = locational surplus of workers who work in zone j and reside in zone i;

β = a parameter.

3.2 Derivation of the Model

The RLM can be derived by either using the discrete choice theory or the entropy maximization method; however, the former one is explained here.

Defining the locational surplus of a zone as the maximum of the elemental alternatives' locational surpluses (Lerman 1975). For this study, a housing unit is considered an elemental alternative. Thus, the locational surplus of workers who work in an employment zone j and live in a residential zone i can be expressed by

$$LS'_{ji} = \max_{h \in H_i}(LS_{jh} + \S_{jh}) \qquad (3)$$

where:

LS_{jh} is locational surplus of workers in an employment zone j and live in housing h;

$h \in H_i$ denotes all housing units of set H_i.

It is possible to determine the expected value of LS'_{ji} as follows:

Under the assumption that all $\S_{jh}$s are IID and Gumbel distributed, which its cumulative function is

$$F(LS) = \exp\{-\exp[-\beta'(LS - \eta)]\} \quad (4)$$

where:

β' = a positive scale parameter;

η = mode of distribution; and mean is $\eta + 0.577/\beta'$ where 0.577 is Euler's constant.

$$\text{Prob}(\max LS_{jh} \leq LS)$$
$$= \text{Prob}(LS_{j1} \leq LS) \;\ldots.\; \text{Prob}(LS_{jh} \leq LS)$$
$$= \exp(-\sum_{h=1}^{H_i} \exp(-\beta'(LS - \eta_h)))$$
$$= \exp(-\exp(-\beta' LS) \sum_{h=1}^{H_i} \exp(\beta' \eta_h)) \quad (5)$$

Let $\exp(\beta'\eta) = \sum_{h=1}^{H_i} \exp(\beta'\eta_h)$

$$\eta = \frac{1}{\beta'} \ln \sum_{h=1}^{H_i} \exp(\beta'\eta_h) \quad (6)$$

Assuming that all housing units have equal means, LS_{ji}; then the expected value is obtained as follows.

$$\eta = \frac{1}{\beta'} \ln(\Delta H_i \exp(\beta' LS_{ji} - 0.577)) \quad (7)$$

mean $(\eta + 0.577/\beta')$

$$= LS_{ji} + \frac{1}{\beta'} \ln \Delta H_i \quad (8)$$

$$\text{thus,} \quad LS'_{ji} = LS_{ji} + \frac{1}{\beta'} \ln \Delta H_i + \S_{ji} \quad (9)$$

If all unobserved random components, $\S_{ji}$, are IID and Gumbel distributed, the probability of choosing zone i is

$$Pr_{ji} = \frac{e^{(\beta LS_{ji} + \frac{\beta}{\beta'} \ln \Delta H_i)}}{\sum_i e^{(\beta LS_{ji} + \frac{\beta}{\beta'} \ln \Delta H_i)}} \quad (10)$$

The square of the scale parameter of a logit model is proportional to the inverse of the varience of the random locational surplus, and since the varience can not decrease with aggregation; therefore $0 \leq \beta/\beta' < 1$ must hold. However, the β/β' is assumed to be one for this study. Thus the probabilty of workers in zone j to choose a residential zone i is

$$Pr_{ji} = \frac{\Delta H_i e^{\beta LS_{ji}}}{\sum_i \Delta H_i e^{\beta LS_{ji}}} \quad (11)$$

3.3 Estimation of Parameter

The maximum likelihood method is employed for this study. The likelihood function for the aggregate model is

$$L = \left(\frac{N!}{\prod_{ji}\prod N_{ji}!}\right) \prod_{ji}\prod (Pr_{ji})^{N_{ji}} \quad (12)$$

where;

N_{ji} = observed number of trips between zone j and zone i;

Pr_{ji} = probability of workers in zone j will live in zone i and it is given as:

$$Pr_{ji} = \frac{\Delta H_i e^{\beta LS_{ji}}}{\sum_i \Delta H_i e^{\beta LS_{ji}}} \quad (13)$$

The function (L) can be rewritten in order to simplify the maximization by taking the natural logarithm and dropping the constant multiplier $(N!\prod_{ji}\prod N_{ji}!)$ to give

$$L^* = \sum_{ji}\sum N_{ji} \ln Pr_{ji} \quad (14)$$

However, it is obvious that this approach requires the spatial interaction data which is difficult to obtain. Therefore, the above function is adopted to (Putman 1978)

$$L = \left(\frac{\Delta P!}{\prod_i \Delta P_i!}\right) \prod_i (Pr_i)^{\Delta P_i} \quad (15)$$

and the simplified log-likelihood function becomes

$$L^* = \sum_i \Delta P_i \ln Pr_i \quad (16)$$

where:

ΔP_i = observed number of population flow in zone i;

Pr_i = probability of choosing zone i, as given below.

$$Pr_i = \Delta P'_i / \sum_i \Delta P'_i \quad (17)$$

where $\Delta P'_i$ is the predicted number of population flow in zone i, given by

$$\Delta P'_i = \sum_j \Delta E_j \frac{\Delta H_i e^{\beta LS_{ji}}}{\sum_i \Delta H_i e^{\beta LS_{ji}}} \quad (18)$$

Substitute (17) in (16)

$$L^* = \sum_i \Delta P_i(\ln \Delta P'_i - \ln(\sum_i \Delta P'_i)) \quad (19)$$

The second term of equation (19) is total predicted number of population. Assuming that it is equal to total observed number of population which is a constant, thus this term can be neglected and equation (19) is then rewritten as

$$L^* = \sum_i \Delta P_i \ln \Delta P'_i \quad (20)$$

The maximization of L^* can be carried out by a variety of standard iteration procedures. For this study, the gradient-search technique is utilized. The gradient function is given by

$$\nabla L^* = \frac{\partial L^*}{\partial \beta} = \frac{\partial L^*}{\partial \Delta P'_i}\frac{\partial \Delta P'_i}{\partial \beta}$$

$$= \sum_i \frac{\Delta P_i}{\Delta P'_i}\left[\sum_j \Delta E_j \frac{\Delta H_i e^{\beta LS_{ji}}}{\sum_i \Delta H_i e^{\beta LS_{ji}}}\left(LS_{ji} - \frac{\sum_i LS_{ji}\Delta H_i e^{\beta LS_{ji}}}{\sum_i \Delta H_i e^{\beta LS_{ji}}}\right)\right] \quad (21)$$

The result of parameter reveals good fitness. The 'β' parameter which associates with the location surplus has the positive sign as expected.

'β' value = 0.178325 (R=0.9412)

4 Housing Supply Model (HSM)

4.1 Model Formulation

The HSM of the BALUTAS is formulated according to the behavior of developers. It is based upon a component of the microeconomic theory, the theory of firm: housing developers maximize their profits in choosing the location for new housing.

$$\Delta H_i = \Delta H \frac{\Delta P_i e^{\alpha PF_i}}{\sum_i \Delta P_i e^{\alpha PF_i}} \quad (22)$$

where:

ΔH_i = increment of number of houses allocated to zone i;

ΔH = number of new houses to be produced which is assumed to be equal to number of new demanders;

ΔP_i = increment of number of households in zone i;

PF_i = expected profit in zone i.

The profit function, PF, is

$$PF = SP - DC \quad (23)$$

where:

SP is selling price per unit area;

DC is development cost per unit area.

Since it is a difficult task to obtain such data for formulation the profit function; therefore, it is adopted as follows:

$$PF_t = LP_t - LP_{(t-1)} \quad (24)$$

where: LP is land price at time t;

$LP_{(t-1)}$ is land price at time (t-1).

This is a reasonable approach since in the GBA developers hold a large amount of land for speculation purpose.

4.2 Derivation of the Model

The profit of developers in seeking a location (zone) is defined as the maximum of the elemental alternatives' profits (Lerman 1975). A household represents an elemental alternative for this study. This explanation is expressed in mathematical terms as:

$$PF'_i = \max_{p \in P_i}(PF_p + \S_p) \quad (25)$$

where:

PF_p = profit of developers in building new housing for a household p;

$p \in P_i$ denotes all households of set P_i.

If all $\S_p$s are IID and Gumbel distributed, the expected value of PF'_i can be calculated in the same manner with that of the RLM.

$$PF'_i = PF_i + \frac{1}{\alpha'}\ln \Delta P_i + \S_i \quad (26)$$

Under the assumption that all $\S_i$s are IID and Gumbel distributed, probability to build new housing in zone i is:

$$Pr_i = \frac{e^{(\alpha PF_i + \frac{\alpha}{\alpha'}\ln \Delta P_i)}}{\sum_i e^{(\alpha PF_i + \frac{\alpha}{\alpha'}\ln \Delta P_i)}} \quad (27)$$

As described for the RLM, the α/α' must be one, zero or between these two values. It is assumed to be one for this study, thus probability is then

$$Pr_i = \frac{\Delta P_i e^{\alpha PF_i}}{\sum_i \Delta P_i e^{\alpha PF_i}} \quad (28)$$

4.3 Estimation of Parameter

The parameter, α, which associates with the profit function is estimated by maximizing the likelihood of observed choices. This study must work with the aggregate data, thus the likelihood function is

$$L = \left(\frac{\Delta H!}{\prod_i \Delta H_i!}\right) \prod_i (Pr_i)^{\Delta H_i} \quad (29)$$

and the simplified-log function becomes

$$L^* = \sum_i \Delta H_i \ln Pr_i \quad (30)$$

where:

ΔH_i = observed increment of number of houses in zone i;

Pr_i = probability of choosing zone i for development, given by

$$Pr_i = \frac{\Delta P_i e^{\alpha PF_i}}{\sum_i \Delta P_i e^{\alpha PF_i}} \quad (31)$$

The maximization of L^* can be achieved by using the technique described in subsection 3.3.

The calibrated value of 'α' is 0.1674 (R=0.9534) which has positive sign as expected.

5 Transport Model

The located amount of activities which is the output from land use models is used as the input to transport model. It should be noted that the work trip matrix is obtainable from the RLM. Concerning with this is explained in subsection 5.3.

5.1 Trip Generation Model

This study employs the model which was developed for the Bangkok Transportation Study (BTS) by Kocks 1975. It is a linear regression model and its formulation is

$$G_i, A_i = a_0 + a_1 POP_i + a_2 JOB_i + a_3 CAR_i \quad (32)$$

(for all trip purposes, 24 hours)

where:

G_i, A_i = generated and attracted trips in zone i;

POP_i = number of population in zone i;

JOB_i = number of job opportunities in zone i;

CAR_i = number of private cars in zone i.

5.2 Trip-End Modal Split Model

This model allocates total generated trips to private and public transport prior to trip distribution stage. The model was developed for the BTS and was recalibrated by the JICA (1983).

$$P = b_0 + b_1 MOT^{\varsigma} \quad (33)$$

where:

P = percentage of using private modes;

MOT = private-car ownership per 1000 inhabitants.

5.3 Trip Distribution Model

It is a typical gravity model which was introduced to the BTS and was recalibrated by the JICA (1983).

$$T_{ij} = C \frac{(G_i \times A_j)^{\kappa}}{t_{ij}^{\sigma}} \quad (34)$$

where:

T_{ij} = number of trips between zone i and zone j;

G_i = number of trips generated in zone i;

A_j = number of trips attracted to zone j;

t_{ij} = travel time between zones i & j;

C = constant;

κ, σ = parameters.

The home-to-work trip matrix is possible to be obtained from the RLM which is given in Eq. 2. This equation can be rewritten as follows.

$$\sum_j \Delta T_{ij} = \sum_j \Delta E_j \frac{\Delta H_i e^{\beta LS_{ji}}}{\sum_i \Delta H_i e^{\beta LS_{ji}}} \quad (35)$$

where ΔT_{ij} is increment of number of trips from zone i to zone j.

Thus, the work trip matrix can be determined by

$$\Delta T_{ij} = \Delta E_j \frac{\Delta H_i e^{\beta LS_{ji}}}{\sum_i \Delta H_i e^{\beta LS_{ji}}} \quad (36)$$

The work trip matrix produced from Eq. 36 ensures that sums of row (i) and column (j) will equal to zonal population and employment, respectively. This might or might not be obtained from the conventional procedure.

5.4 Trip Assignment Model

The purpose of trip assignment model for this study is to estimate the proportion of trips likely to divert to a new transport facility, the cable-stayed bridge, thus the diversion curve is employed. This diversion curve was developed by the Japan Highway Public Corporation (Nihon Doro Kodan) and was calibrated to fit the observed divert-traffic to the GBA's expressway by the JICA (1983).

$$P = \frac{K}{1 + \theta (T/S)^{\lambda}} \quad (37)$$

$$T = F/(T_o - T_e) \quad (38)$$

where:

P = traffic diversion ratio to expressway;
K = upper limit of diversion;
F = toll fare (Baht);
T_o = travel time via ordinary road (min.);
T_e = travel time via expressway (min.);
S = shifting coefficient which was assumed to increase with the growth of gross provincial product.

6 Predictability Tests

In order to evaluate the performance of the BALUTAS, the predictability tests were conducted.

The output of the RLM is population flow. The observed flow of population from 1973 to 1978 in each zone was compared with the predicted one, the correlation coefficient is 0.9443. This output is shown in Fig. 2. It is obvious that with the exception of zone 1 and zone 26, discrepencies between observed and predicted population flows are not significant. Zone 1 is concentration of workplaces, especially public institutes. The number of earners per household in this zone may be higher than in other zones, however average earner size was used. This may lead to over-estimation. Zone 26 is located on the border of the GBA which is connected to the other city by a major highway, it is possible that workers who reside in this zone may commute to work outside the GBA.

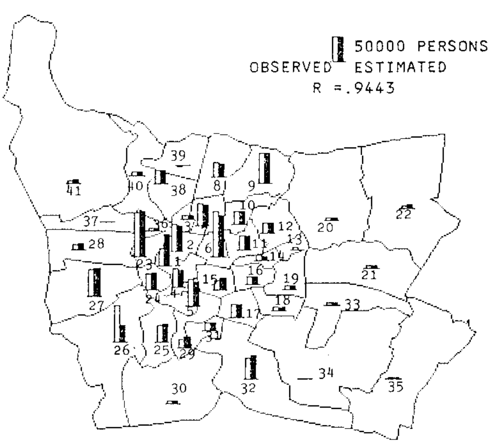

Fig. 2 Distribution of Population Flow 1973-1978

The output of the HSM, flow of housing, is shown in Fig.3. The R value (0.8664) reveals lower fitness than the population's case, probably because the average household size was applied to every zone which yields over-estimation in central zones.

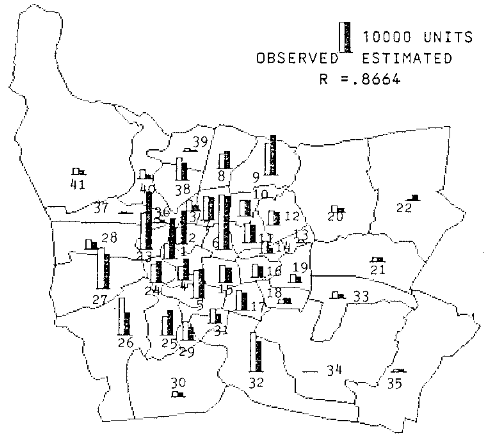

Fig. 3 Distribution of Housing Flow 1973-1978

7 A Policy Simulation

The cable-stayed bridge (CSB) project which is now under construction crossing the Chao Phaya river in Bangkok was chosen as a policy test. The location of the CSB is shown in Fig. 4. The BALUTAS will, at first, forecast amount of land users both in case the CSB will be realized (case 1) and in case it will not be realized or do-nothing (case 0). Then it will forecast traffic volume on the CSB.

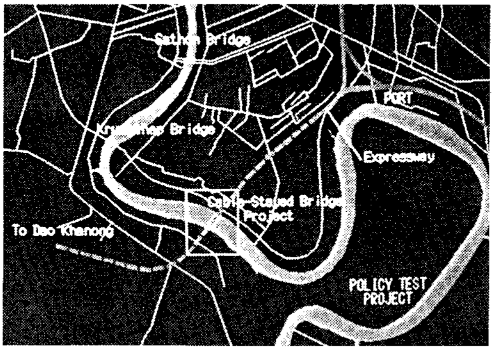

Fig. 4 Location of A Policy Test Project

Fig. 5 compares distribution of the housing flows between both cases in year 2005. It is obvious that for case 1 (with CSB), flow of housing in central area is lower than that of case 0 (do-nothing). On the other hand, it is higher in zone 5 and zone 25 which will be linked by the CSB. The new demanders will be attracted to locate there owing to the increase in accessibility. The output of employment flow is shown in Fig. 6.

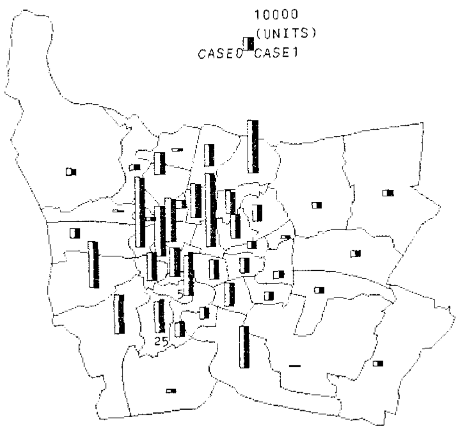

Fig. 5 Comparison of Population Flows Between Case 0 and Case 1

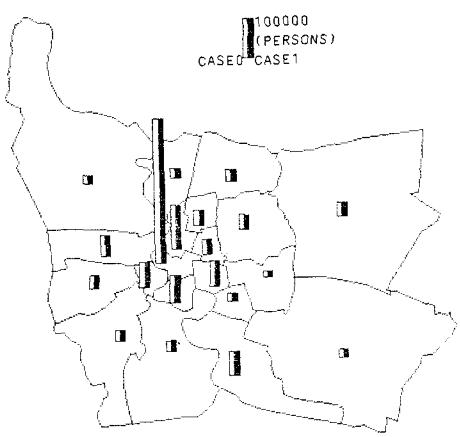

Fig. 6 Comparison of Employment Flows Between Case 0 and Case 1

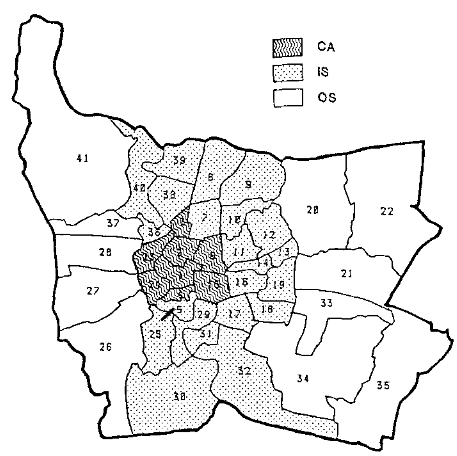

Fig. 7 Division of GBA into Subregions

The study area (GBA) was divided into three subregions, shown in Fig. 7, based on the definition of the International Study Group on Land Use and Transport Interaction (Miyamoto 1984). The central area (CA) should cover the core where land is used primarily by commerce and industry. The inner surburb (IS) and outer suburb (OS) should divide the rest of the town into areas with roughly similar population.

The changes of housing and employment relative to their base year states are shown in Fig. 8. It is obvious that activities in every subregion are increasing as the GBA is a growing city. Housing change in inner suburb is remarkable. Employment, especially basic employment, will locate mostly on the outer suburb.

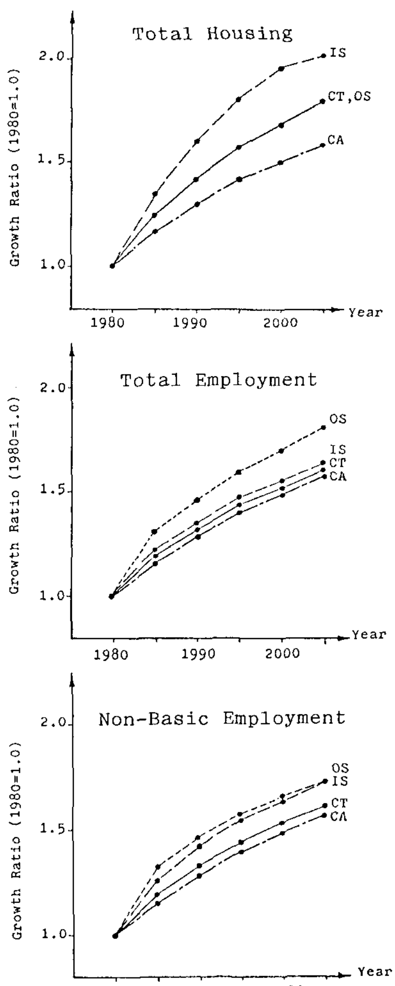

Fig. 8 Changes in Activities During Simulation Period

Fig. 9 is a bar chart using the following equation.

$$\left[\left(\frac{A^a}{A^{CT}}\right)_P - \left(\frac{A^a}{A^{CT}}\right)_B\right] \times 100 \qquad (39)$$

where:

A = Activities;
P = Policy test (the CSB project);
B = Base run;
a = Subregions: CT, CA, IS, OS;
CT = City total (CA+IS+OS).

The impacts caused by the implementation of the CSB to land use can be seen clearly in Fig. 9. Shares of housing in CA and OS will decrease due to the allocation of new demanders in IS.

Using the diversion curve which was given in Eq. 37, the diversion rates were then calculated with the assumption that toll fare will be 20 Baht in year 2005. Applying these rates to O/D trip matrix, it was found that number of passenger cars on the CSB will be 96900 vehs./day (two-direction flows) in year 2005.

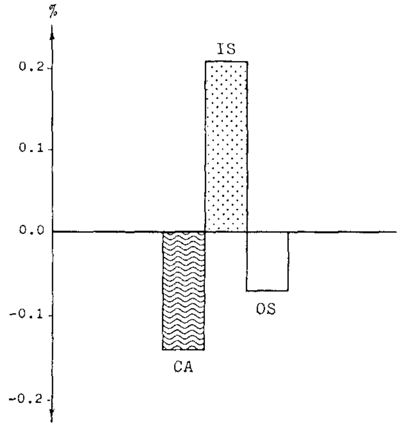

Fig. 9
Change in Housing Ratio (Year 2005) Caused by Implementation of the CSB

8 Concluding Remarks

The development of land use - transport analysis system for the GBA has led to the following conclusions.

i) The BALUTAS shows better performance than the CALUTAS/GBA (Samart 1984). The better performance of the BALUTAS is probably because the RLM was calibrated to fit the observed flows of population while the CALUTAS/GBA's was not. Furthermore, the CALUTAS/GBA does not consider supply of land or housing explicitly. This is not a desirable feature as a big amount of land in the GBA is held by land developers.

ii) As the BALUTAS requires not so much data; moreover, it can be implemented on a personal computer, the authors believe that it is possible to develop such a system for other metropolises in developing countries.

9 Acknowledgement

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