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Urban Growth Modeling Under The Limitation Of Transportation Facilities - The Case Of Bangkok

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This study introduces the concept of linking together the Urban Transportation Planning (UTP) and Urban Dynamics (UD) models using some key indices, such as transportation accessibility, population and economic development (i.e. Gross Provincial Product, GPP). It was found that, by iteration, a certain level of socioeconomic development can be achieved which will reflect future transportation conditions in the city. In addition, this study also proposed some new MOEs (Measures of Effectiveness), such as population, total number of jobs, GPP (Gross Provincial Product), concerned with socioeconomic development, which can be used to measure and evaluate the effectiveness of transportation investment policies on urban growth.

Introduction

The four-step UTP model - trip generation, distribution, modal split and traffic assignment - takes advantage of statistical analysis in order to forecast land use and socioeconomic characteristics which are the input of the model. With regard to different transportation investment alternatives, the model reveals the trip patterns and the travel time between zones for different modes of transportation. However, this model is based on the assumption that socioeconomic development maintains the same pace, regardless of the different transportation alternatives.

With the trip distribution theory, trip pattern is determined by travel cost and/or travel time, which means that the number of trips involving all activities is firmly related to accessibility. In addition, it is recognized that accessibility is a clear indicator in the evaluation of various alternative land use and transportation plans (Black 1980). Therefore, the scenarios generally reflect the level of investment in improving the urban infrastructure, which in turn, influences socioeconomic development.

The traffic problem in Bangkok is already very serious and the situation is still deteriorating. It is recognized that the problem will hamper socioeconomic development if appropriate countermeasures are not taken. Various feasibility studies of proposed transportation projects have been conducted to measure their potential impact and to facilitate decisions on priorities. However, this traditional UTP model has failed to deal with the relationship between accessibility and socioeconomic development.

A model, designed to solve the above-mentioned problem with the UTP process and to clarify the advantages of linking it to an UD model, is explored in this paper. Although the planning model is quantitative, it can be used to describe qualitative policy statements.

The Transportation Issue in Bangkok

The ratio of traffic volume to road capacity (Q/C ratios) in 1989 exceeded 1.0 for almost all the major roads in the central and northern part of the Bangkok Metropolitan Area (BMA). The average Q/C ratio of the network as a whole is 0.90 and the average speed on at-grade roads is 8.1 km/hr. Traffic congestion occurs not only during rush hours but also during off peak hours in many locations. If the network remains as it is in the year 2006, most road sections will be fully saturated, with their Q/C ratio higher than 1.5; where running speed would fall below 5 km/hr. It is estimated that the average Q/C ratio will be 2.24 in the year 2006 (JICA 1990).

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This model is based on the URBAN1 model which was developed by Alfeld and Graham in 1976. The URBAN1 model represents an area in which housing and business structures both occupy land and influence migration (Alfeld 1976).

For testing transportation investment policy, this study disaggregates the industrial stock into three industrial sectors and considers the relationships between the revised business structure and the following factors : GPP, housing construction and transportation policy.

The following are the key assumptions of the model :

(1) Industrial development depends on land occupancy, job availability and the business structure.
(2) The business structure is based on GPP which is contributed to from each industrial sector. When GPP rises, both household size and birth rate are smaller, but this is not true in reverse. When GPP decreases, they remain at the lowest point of the previous GPP.
(3) House construction is determined according to land occupancy and available housing. When economic development slows down, it is also affected by the growth rate of secondary industries.
(4) Immigration rises, depending on job availability and available housing.
(5) The size of the labor force depends on population structure.
(6) Since the level of transportation investment, apart from routine maintenance, is completely determined by government policy which is outside the system, it is regarded as exogenous to the system.
(7) Accessibility is adopted as the variable for transportation policy in the urban dynamic model. The relative accessibility, denoted by TI (Transportation Index), is a function of the ratio, TR, of average travel time between the CBD and other zones with comprehensive investment to that between the CBD and zones with alternative investment policies in the design year.
(8) Agricultural land use policy has not changed over time, which means the area involved remains constant.
(9) According to the Bangkok Metropolitan Region Housing and Urban Poor Sector Study, published by the National Housing Authority, NHA, full land occupancy is based on an average gross residential density of 3750 families per sq. km.
(10) The land used to construct roads is considered in the average gross residential density. Therefore, whether the government plans to implement new transportation projects or not will not greatly affect land occupancy and, thus, this can be ignored.
(11) GPP is calculated using the 1972 price as a constant and, hence, inflation-related effects are excluded.

Fig. 3 depicts the complete flow diagram of the urban dynamic model. The model is applied to simulate the impact of various transportation policies on socioeconomic development, after it has been tested for its applicability. The first step in the application of the model is to run the model using trial parameters to obtain an output that matches the data for the past 14 years in the study area. This also includes data which forecasts the level of socioeconomic development over the next 43 years, by testing each alternative transportation policy when urban transportation facilities are insufficient, which includes those periods when project construction is staggered, as well as project life.

In Table 1, the values of scenario A are very close to the existing traffic conditions. Thus, this study uses comprehensive investment as the underlying assumption of the basic urban dynamic model, which means that socioeconomic development will be sustained sufficiently during the period of construction and the life of the project.

In the study, the average travel time between the CBD and other zones within the study area, denoted by ATT, is calculated by the following equation:

$$ATT = \sum_{i=1}^{n} TT_i \ / \ n$$

where

TT_i = Travel time between CBD and ith zone

n = Number of zones, except CBD, in the study area

In the future, appropriate investment in transportation is required to sustain continuous economic growth and urban development. Otherwise, it is not difficult to imagine that economic growth and urban development will be restricted, or will even decelerate, given the inadequate transportation facilities.

In order to meet the requirements of rapid economic growth, the Bangkok Metropolitan Administration is planning an appropriate transportation investment policy. This study evaluates three scenarios which are selected from about 140 alternatives in the link tests of a JICA study (1990). These scenarios are :

(1) Scenario A: Comprehensive Investment

This scenario includes those projects to which commitments have already been made, as well as those which have been proposed. Scenario A should provide adequate support for socioeconomic development. This is an expressway-oriented alternative, including more at-grade main roads, with a good rapid transit system, such as HRT (Heavy Rail Transit), LRT (Light Rail Transit) and busways.

(2) Scenario B: Investment only in those projects to which commitments have been made

This scenario involves only those projects to which commitments have already been made. It mainly consists of a radial pattern with few new roads, but with an LRT system surrounding the CBD.

(3) Scenario C: No Investment (Do-nothing)

This is the existing network, remaining as it is in the year 2006, without any new investment.

In order to evaluate the impact of these scenarios on socioeconomic development, a sensitivity analysis was carried out.

Model Design

The study extends this planning model one step further in order to determine the relevant growth rates for different transportation conditions, based on the idea that any transportation network is closely related to the socioeconomic development of a city. The purpose of this study is to discover the equilibrium point between accessibility and socioeconomic development for each alternative.

In this study, application of the model is divided into two phases as shown in Fig. 1. The first phase is the application of the UTP model. The second phase is the application of the UD model, using a systems dynamics approach, to explore the cause and effect relationships in socioeconomic development. The UD model is also used to calibrate the parameters so that the complete model can be regarded as a quantitative planning model.

Accessibility, population and GPP variables are the key links between the two phases. Accessibility represents the attractiveness of opportunities for all activities in the study area, and socioeconomic development is directly affected by it, and vice versa. The actual number of trips is the result of the various demands of socioeconomic activities.

The study assumes that GPP is relevant to the number of trips per person and, therefore, that the product of population and GPP is proportional to the total number of trips. When the values of the key indices for the first and second phases are equal, it means that the equilibrium point between accessibility and socioeconomic development has been found. As a result, no matter which alternative policy is implemented, the importance of this balance and interdependence becomes very clear, especially in attempting to solve Bangkok's deteriorating traffic situation. The search for this equilibrium point is carried out by iteration.

A Systems Dynamics Model of Urban Growth

A causal loop is constructed to provide an understanding of the relationships between the elements of the urban system. Fig. 2 summarizes the principal interactions between population, housing and industrial structures in the urban dynamic model.

The Search for an Equilibrium Point between Accessibility and Socioeconomic Development

In this study, the initial UD model is designed for the comprehensive investment alternative. This accessibility should provide adequate support for socioeconomic development. The other inferior alternatives are compared with the comprehensive investment alternative to obtain relative accessibility. The index of relative accessibility is considered the exogenous factor in the UD model in order to evaluate the alternative inferior transportation policies, by iteration until the equilibrium point between accessibility and socioeconomic development is reached. The procedure for policy tests is shown in Fig. 4, as follows: assuming that socioeconomic development follows past trends, the initial input for phase one (the UTP model) is forecast, based on this assumption, and is the highest number of trips that is considered within the complete procedure or cycle. The first output of phase one is the lowest value for the level of accessibility within the procedure and, becomes the first input for phase two (UD model). The first output for phase two is the lowest value for the number of trips. This becomes the second input for phase one which as output, is the highest value for the level of accessibility values. These values which directly follow one another, are identical. When accessibility and the number of trips are of equal value finally, then the accessibility and the number of trips are damped level with the asymptotic line.

The test procedures are as follows:

(1) from the traffic assignment results, the average travel time, ATT, between CBD and other zones for the year 2006 is calculated;
(2) the ratio, TR, of the average travel time with comprehensive investment to that of the alternative policies for the year 2006 is calculated;
(3) the TR is assumed to be a linear relationship between 1990 (TR=1 in 1990) and 2006 (TR is calculated in step (2) for the year 2006). After 2006, TR remains constant (which assumes that the construction period is staggered);
(4) TR is assumed to be a negative exponential function of Transportation Index (TI) that represents relative accessibility affecting economic development in the urban dynamic model, i.e. $TR = \exp(Z*(TI-1))$;
(5) the product of population and GPP, simulated in the urban dynamic model, divided by the simulation results under comprehensive investment, is denoted by RATIO in this study. Parameter Z is an empirically determined exponent which expresses the wide-ranging effect of accessibility on socioeconomic development;
(6) if the new TR and the product of population and GPP (i.e. RATIO) are equal (or close enough) to those of the last iteration, then the procedure is stopped; otherwise, the next step is to
(7) use the percentage from step (5) as the proportional reduction of the number of trips between zones in the O-D matrix;
(8) the traffic assignment model is rerun, and then step (1) is returned to.

Examination of the Restrictions on Urban Growth with Inadequate Transportation Facilities

The study experiments with three parameter Z values: 0.5, 1, and 2.

The outputs for Z=1 and Z=2, when each stage of the procedure is repeated, are shown in Figs. 5 and 6. It is found that the oscillations of the two indices, TR and RATIO, are damped level with the asymptotic line, when either Z=1 or Z=2.

When Z=1, population and industrial stock remain at a constant level when there is no investment. Thus, it is very probable that socioeconomic development is restricted as a result of inadequate transportation facilities.

When parameter Z=1, the differences in population, jobs and GPP trends, when the three alternative policies are applied, are shown in Figs. 7-9. The study has revealed that, during the next 3-5 years, the rate of socioeconomic development will be the same in all three situations. This means that socioeconomic development is not initially affected by investment in new transportation facilities. On the other hand, after the design year, 2006, socioeconomic development when there is no investment, becomes almost asymptotic. In fact, the annual growth rate will decrease by less than 0.1% each year, after 2006.

In order to show transportation accessibility, the contour lines of travel time from CBD are drawn based on the traffic zones, as shown in Fig. 10. Accessibility for scenario C, both before and after the two models have been jointly applied, is represented in Figs. 11 and 12.

Conclusion

It is found that, by linking together the UD and UTP models and repeating the procedure several times, certain predictions concerning socioeconomic development are possible, which will reflect future transportation conditions in the city. The linking together of the UTP and the UD models also results in a good explanation of the relationship between spatial structure and long-term forecasting in urban growth.

This study reveals that, by iteration, the equilibrium point between accessibility and socioeconomic development can be found, no matter whether the value of Z is 1 or 2. When the Z=1 value is applied in the case of no projects being implemented, the asymptotic values for population growth, jobs and GPP stock almost converge, after the procedure is repeated for the fifth time. In this case, it is very likely that socioeconomic development is restricted as a result of inadequate transportation facilities.

Furthermore, the study has revealed that several socioeconomic activities and certain other factors, such as population, the total number of houses, the total number of jobs, and GPP, can be regarded as new MOEs for evaluating the different investment policies, with regard to urban growth. In particular, one of these new MOEs, such as GPP, will become the new MOE, in addition to the traditional time-saving and cost-saving aspects, when performing benefit and cost analysis.

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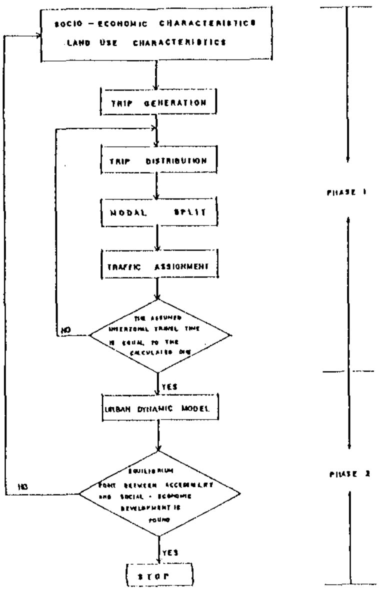

FIG. 1 MODEL DESIGN DIAGRAM

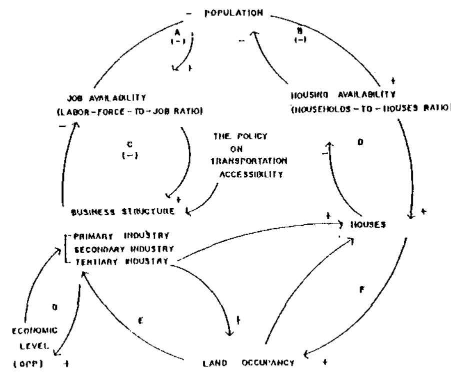

FIG. 2 INTERACTIONS AMONG POPULATION, HOUSES AND BUSINESS STRUCTURE

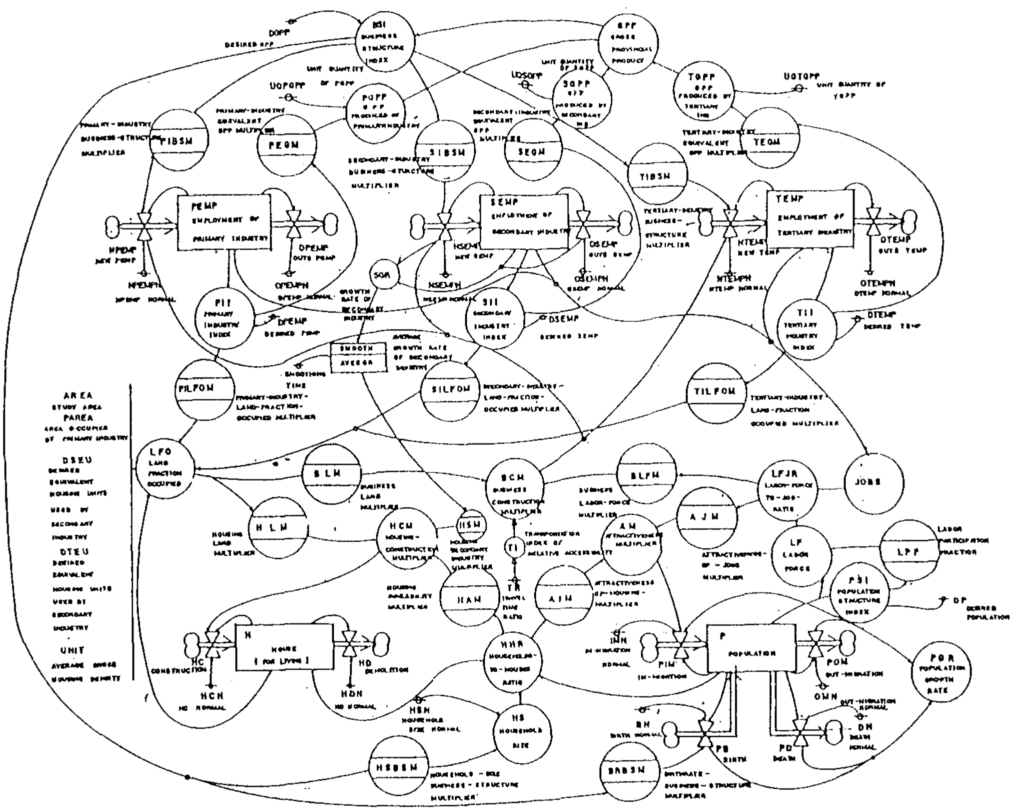

Fig. 3 The Urban Dynamic Model : System Dynamic Flow Diagram

TABLE 1 SUMMARY OF TRAFFIC ASSIGNMENT RESULTS

ITEM	1989	2006		
		Scenario A	Scenario B	Scenario C
AVE. Q/C RATIO	0.90	0.90	-	2.24
AVE. TRAVEL TIME (MIN.)	60.54	58.68	90.72	141.60

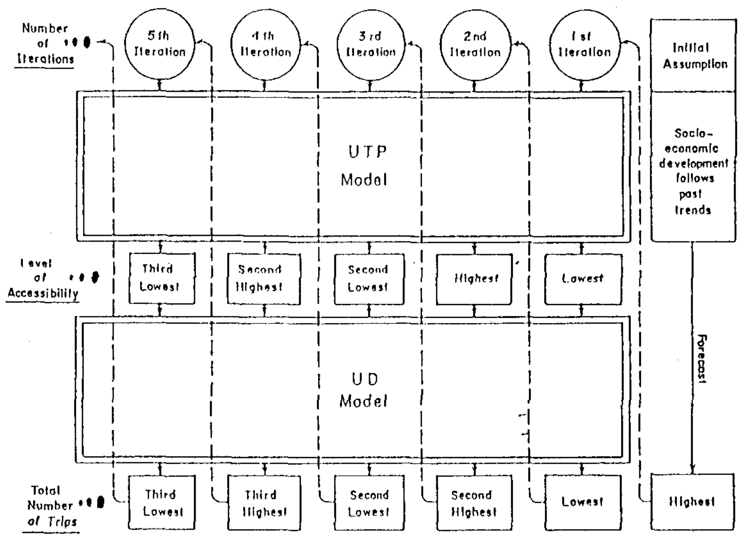

Fig. 4 Example Procedure and States of Output and Input to Obtain an Equilibrium Point between Accessibility and Socio-economic Development

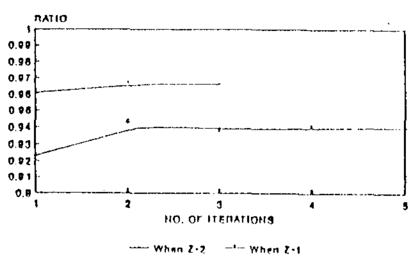

Fig. 5 Percentage Reduction of Product of Population and GPP of Scenario B

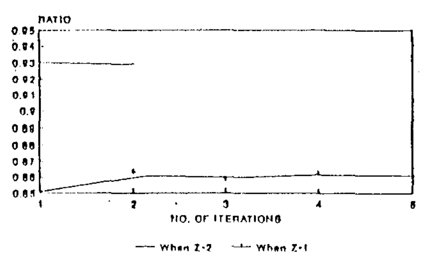

Fig. 6 Percentage Reduction of Product of Population and GPP of Scenario C

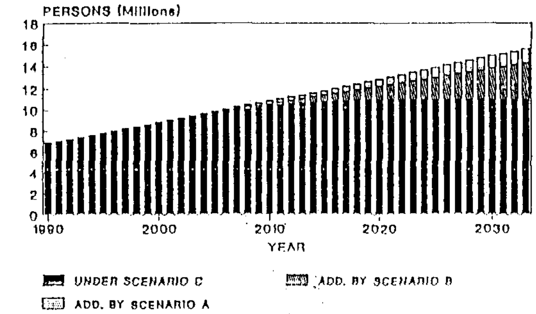

Fig. 7 Simulated Population for Scenarios

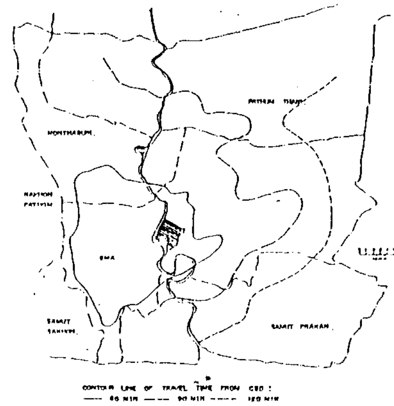

Fig. 10 Transportation Accessibility of Scenario A in 2006

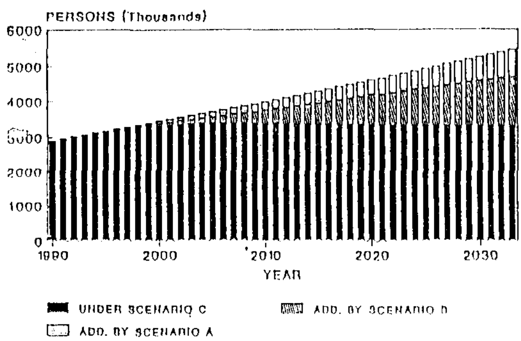

Fig. 8 Simulated Jobs for Scenarios

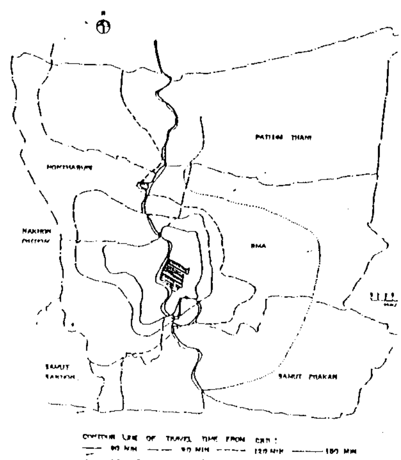

Fig. 11 Transportation Accessibility of Scenario B in 2006 for TR=0.7230

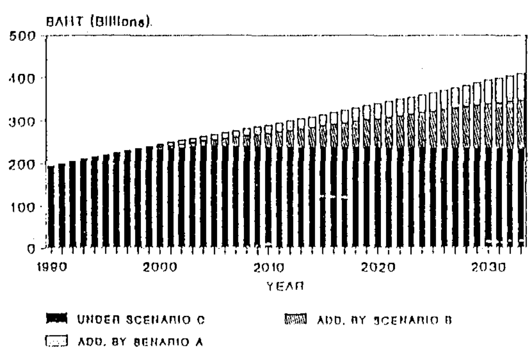

Fig. 9 Simulated GPP for Scenarios

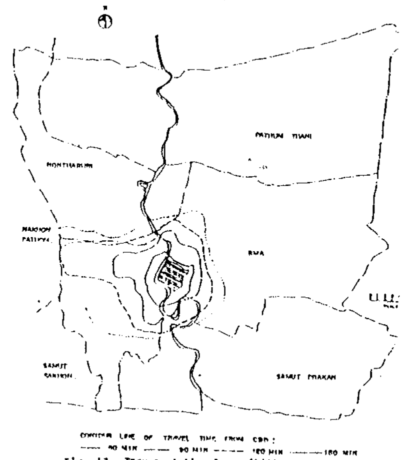

Fig. 12 Transportation Accessibility of Scenario C in 2006 for TR=0.4500