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

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Abstract

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

Introduction

The UTP model which has four steps - trip generation and distribution, modal split and traffic assignment - takes advantage of statistical analysis in order to forecast land use characteristics and socio-economic 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 transport. However, this model is based on the assumption that socio-economic development maintains the same pace, regardless of the different transportation alternatives.

With the trip distribution theory, trip pattern is basically 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 different degrees of accessibility, from the best to worst case scenarios, generally reflect the level of investment in improving the urban infrastructure, which, in turn, influences socio-economic development.

The traffic problem in Bangkok is already very serious and is still deteriorating. It is recognized that the problem will hamper socio-economic development, if appropriate counter-measures are not taken. Various feasibility studies of proposed transportation projects in Bangkok City have been conducted to measure their potential social impact and to facilitate decisions on priorities. However, this traditional UTP model has failed to deal with the relationship between accessibility and socio-economic 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, which might be usefully applied in Bangkok City, is explored in this paper. Although the planning model is quantitative, it can be used to describe qualitative policy statements and to represent the relationship between accessibility and socio-economic development.

Transportation and Urban Growth : Some Theories

With regard to spatial allocation and interaction of activities between zones, the traditional UTP model is appropriate. Although the UTP model is an essential and integral part of city or town planning, there is a weakness at the stage when economic forecasts are made which is fundamental to the whole procedure (Bruton 1970).

In order to explore the nature of urban problems, the causes, and possible remedies, in 1969 Forrester developed urban dynamics using system dynamics and simulation techniques. But the initial urban dynamics model was developed under the assumptions incorporated in the model of an urban system containing implications about urban transportation systems. After Forrester, the modified urban dynamics models, including the transportation sector, were developed.

It is found that transportation has a significant influence on the demographic and economic sectors of a region. Transportation is, therefore, not merely a derived demand but a determinant of new production possibilities (Hobeika 1981). To plan successfully for the development of a region, one must understand the possible causal relationships, feedbacks, and interactions among the different sectors of the region, including the transportation sector (Budhu 1985). Budhu's paper presents a good example of an integrated system approach to determining the strategic transportation needs under various manufacturing and business investment policies in a city.

Although urban dynamics explains successfully the interaction between elements of an urban system with the advantage of forecasting long-term trends, it does not take the spatial allocation and interaction of activities between zones into account. This study attempts to overcome this shortcoming.

It is recognized that accessibility is strongly related to socio-economic development in a city. The original ideal of measuring accessibility based on zones was proposed by Hansen in 1959. This type of measurement of a zone's accessibility adds together the opportunities available in each other zones, weighted by the function of the difficulty of reaching that zone. This type of measurement reflects the decreased attractiveness of opportunities that are difficult to reach and aims to calculate the combined effect of the transportation and land-use systems. It considers all the opportunities in the study area to be relevant. Thus, it is more suited to measuring access to activities for which a large choice is relevant, such as jobs, than measuring to activities for which little or no choice is really required (Jones 1981).

Transportation Issue In Bangkok

The ratios of the traffic volume to road capacity (Q/C ratios) in 1989 have already exceeded 1.0 for almost all the major roads in the central and northern part of the Bangkok Metropolitan Area. 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 takes place not only during rush hours but also during off peak hours in many locations. If the network remains as it is in 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). It is obvious that the inadequate transportation facilities will not meet the demand, if there is no investment in transportation.

The existing traffic congestion is caused by continuous population growth, associated with a sharp increase in socio-economic activities. The traffic situation is aggravated due to the rapid socio-economic development. This kind of over-saturated situation spoils the effectiveness of many existing traffic measures, such as bus-lanes and one-way system (JICA 1990). 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, with inadequate transportation facilities.

In order to meet the requirements of rapid economic growth, the Bangkok Metropolitan Administration is planning to propose 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, which involves comprehensive investment in transportation facilities, including those projects which have already been committed to and those which have been proposed, should provide adequate support for socio-economic development. This is an expressway-oriented alternative, including more complete 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 investment only in those projects to which commitments have already been made and without busways or HRT, it mainly considers a radial pattern with few new roads, but the LRT 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 three scenarios on socio-economic development, a sensitivity analysis is carried out.

Model Design

The purpose here is to propose a solution to one of the shortcomings of the UTP model, which is that, hitherto, the rate of socio-economic development has been largely ignored when devising alternative transportation policies. The traditional UTP model assumes the same rates of socio-economic development, even in the two extreme cases, namely, when there is comprehensive investment and when there is no investment in transportation facilities. This study extends this planning model one further step 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 socio-economic development of the city. The purpose of this study is to discover the equilibrium point between accessibility and socio-economic development for each alternative.

In this study, therefore, application of the model is divided into two phases as shown in Fig.1. The first phase is the application of the traditional UTP model, which has four steps, namely, trip generation, and distribution, modal split and traffic assignment. The second phase is the application of the UD model, using a system dynamics approach, in order to explore the cause and effect relationships in socio-economic development. The second is also applied using actual data for the Bangkok Metropolitan Area, in order to calibrate the parameters and so that the complete model can be regarded as a quantitative planning model.

The accessibility, population and Gross Provincial Product (GPP) variables are the key links between the two phases. Accessibility represents the attractiveness of opportunities for all activities in the study area, and socio-economic development is directly affected by it, and vice versa. The actual number of trips is the result of the various demands of socio-economic activities, in general, so the study concentrates on the accessibility, population and GPP variables.

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. And, when the

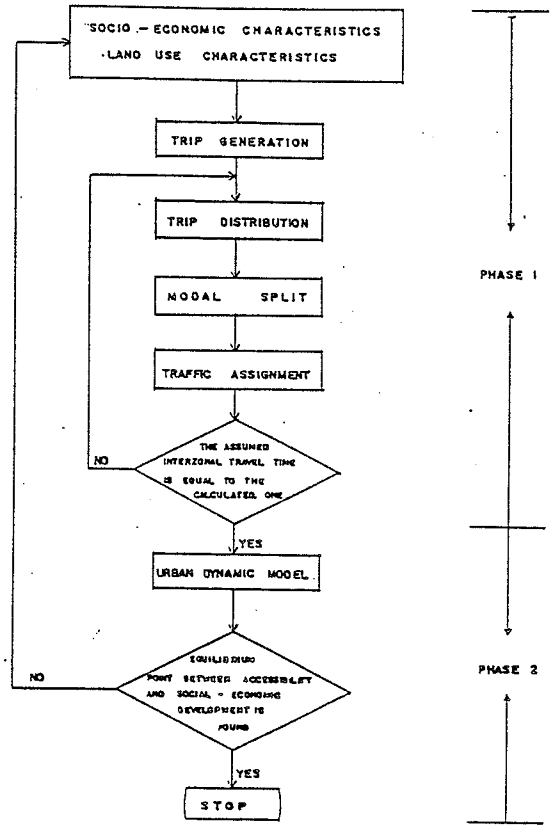

Fig. 1 Model Design Diagram

values of the key indices for the first and second phases are equal, it means that the equilibrium point between accessibility and socio-economic 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 the context of attempting to solve Bangkok's deteriorating traffic problem. The search for this equilibrium point is carried out by repeating the procedure, for which this study concentrates on the area of traffic assignment, in detail.

A System Dynamics Model Of Urban Growth

The causal loop is constructed to understand the relationships between the elements of the urban system. For the purposes of this study, Fig.2 summarizes the principal interactions between population, housing and industrial structures in the urban dynamic model.

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).

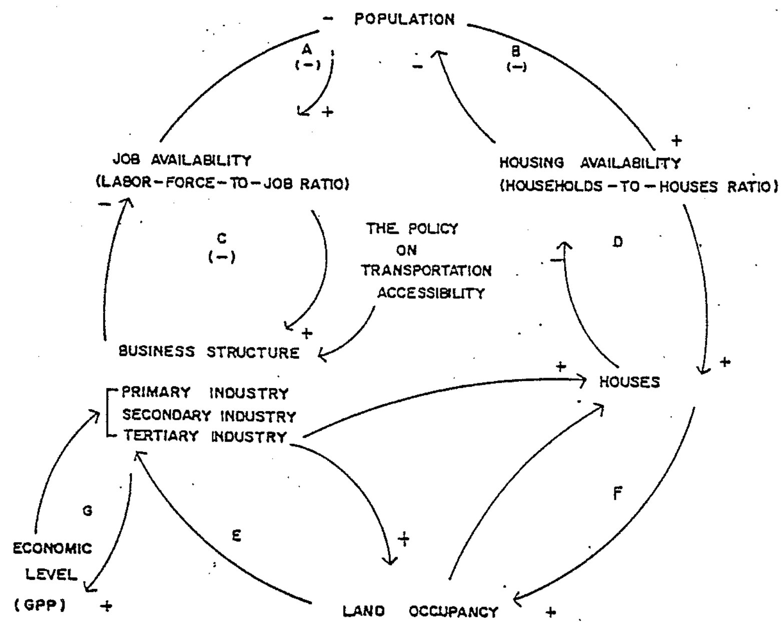

Fig. 2 Interactions Among Population, Houses, and Business Structure

For the purpose of 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 Gross Provincial Product (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) Living house construction is decided 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 size of transportation investment, apart from routine maintenance, is completely determined by government policy that is outside of 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 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) Agriculture 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, NESDB, 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 1972 price as a constant hence, money-related inflationary 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 socio-economic 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 socio-economic development when urban transportation facilities are sufficient. Secondly, the model is used to simulate socio-economic development over the next 43 years, by testing each alternative transportation policy when urban transportation facilities are insufficient, which includes these 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, here, socio-economic development will be sustained sufficiently during the period of construction and the life of the project.

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

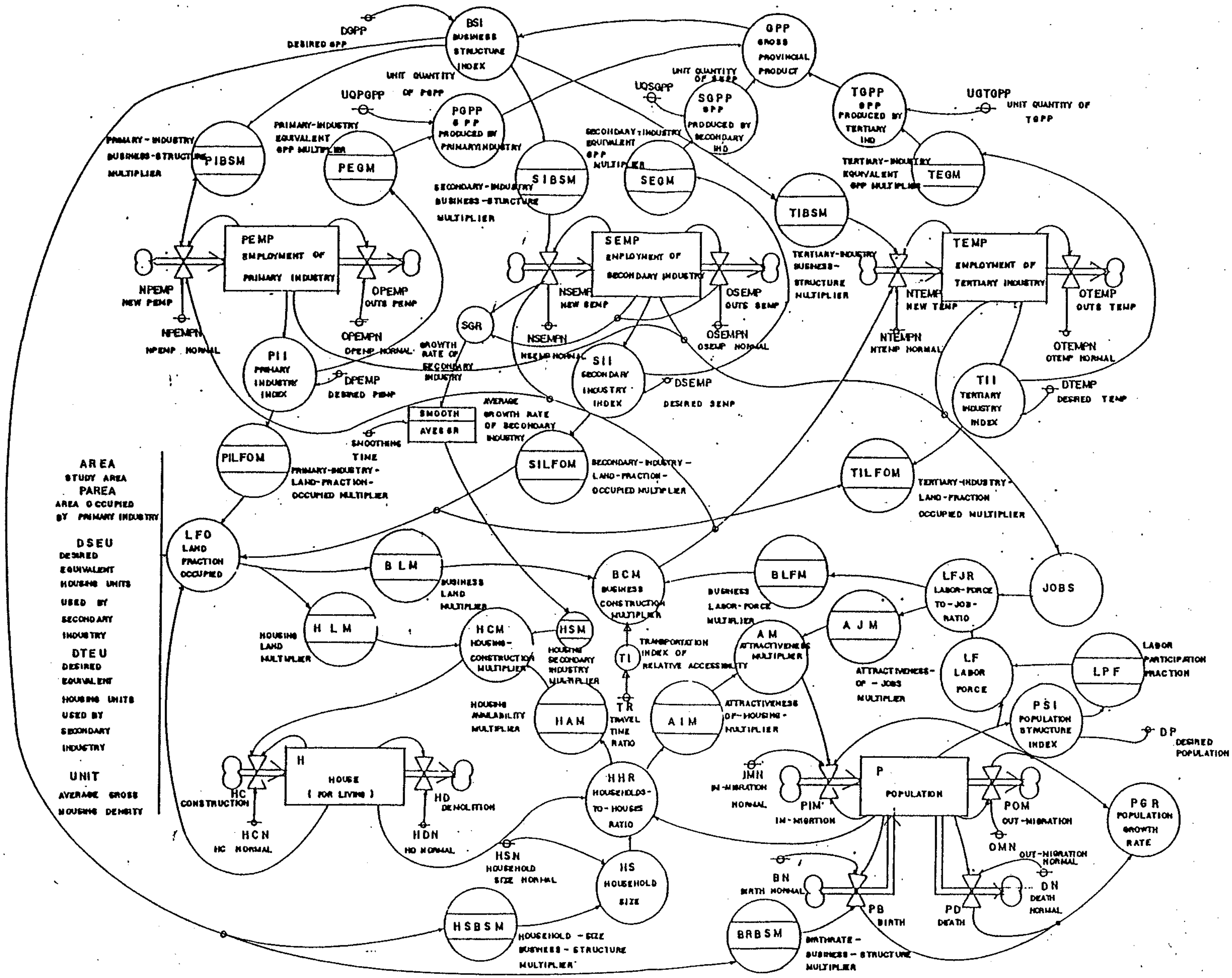

Fig. 3 The Urban Dynamic Model : System Dynamic Flow Diagram

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

The Search for an Equilibrium Point between Accessibility and Socio-economic Development

In this study, the initial UD model is designed for the alternative of comprehensive investment. This accessibility should provide adequate support for socio-economic development. The other inferior alternatives are compared with the alternative of comprehensive investment 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 repeating the procedure until the equilibrium point between accessibility and socio-economic development is found. The procedure for policy tests is shown in Fig.4, as followings : assuming that socio-economic 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

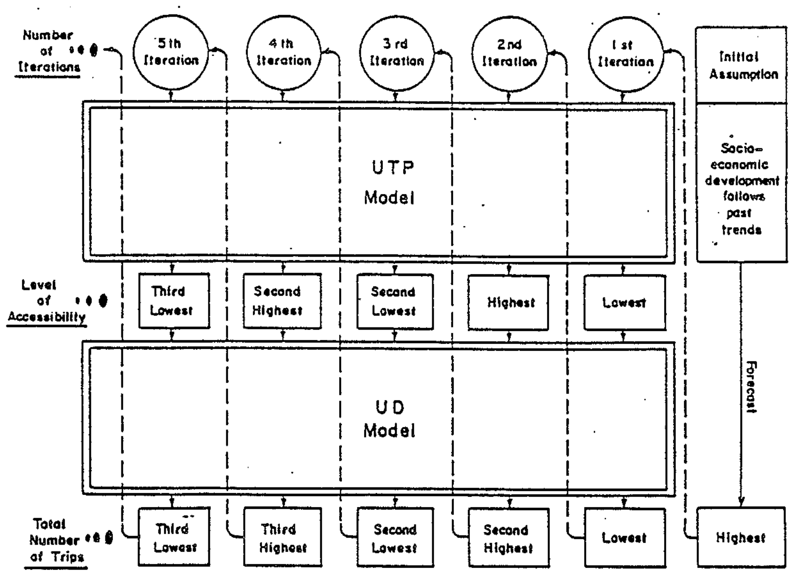

Fig. 4 Example Procedure and State of Output and Input to Obtain an Equilibrium Point Between Accessibility and Socio-economic Development

or cycle. The first output of phase one is the lowest value for the level of accessibility within the procedure and, also, becomes the first input for phase two (the UD model). The first output for phase two is the lowest value for the number of trips and becomes the second input for phase one which, as output, is the highest value for the level of accessibility. This process continues until two accessibility values, which directly follow one another, are identical, and until this stage is also reached for the total number of trips, i.e. two identical values. At this point, finally, accessibility and the number of trips are damped level with the asymptotic line.

The verified model is used to test the impact of the different transportation alternatives on socio-economic development. In this study, two more cases (i.e. scenario B and C) were chosen for comparison with comprehensive investment,in order to understand what would happen in the future if one of them was implemented. This study has simplified the procedure, as intended. The test procedures are as follows :

(1) from the traffic assignment results, calculate the average travel time, ATT, between CBD and other zones in 2006;
(2) calculate the ratio, TR, of the average travel time with comprehensive investment to that with the alternative policies in 2006;
(3) assume the TR is 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 (This 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 is, divided by that for the simulation results under comprehensive investment, which is denoted by RATIO in this study. Parameter Z is an empirically determined exponent which expresses the wide-ranging effect of accessibility on socio-economic 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 stop; 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) rerun the traffic assignment model, and then go back to step (1).

By following the above procedure, the study finds the equilibrium point between accessibility and socio-economic development.

<u>Examination of the Restrictions on Urban Growth with Inadequate Transportation Facilities</u>

The study experiments with three parameter Z values: 0.5, 1 and 2. It is found that, when parameter Z = 0.5, the total number of jobs and GPP fall close to zero after 30 years of non-investment. This value is found to be an unjustifiable result.

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

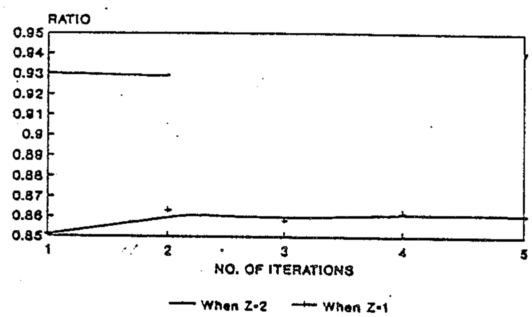

Fig. 6 Percentage Reduction of Product of Population and GPP of Scenario C

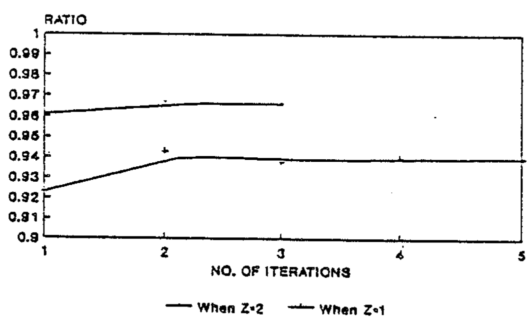

Fig. 5 Percentage Reduction of Product of Population and GPP of Scenario B

When Z=2, socio-economic development still sustains a high growth rate, even when there is no investment, and this is also found to be an unjustifiable result.

When Z=1, population and industrial stock remain at a constant level when there is no investment. Thus, it is very probable that socio-economic 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 socio-economic development will be the same in all three situations, which means that socio-economic development is not initially affected by investment in new transportation facilities. On the other hand, after the design year, 2006, socio-economic 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 the year 2006.

The cumulative difference in GPP, in the cases of comprehensive investment and no investment, is 3 trillion baht, for the period from 1990 to 2033. The cumulative difference in GPP, in the cases of comprehensive investment and investment in only those projects to which a commitment has been made, is 1 trillion baht for the same period, involving the construction stage and the project life.

In order to show transportation accessibility, the contour lines of travel time from the 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 11-12.

Conclusion

It is found that, by linking together the UD and UTP models and repeating the procedure several times, certain predictions concerning socio-economic development are possible, which will reflect future transportation conditions in the city. The linking together of the UTP and 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 repeating the procedure, the equilibrium point between accessibility and socio-economic 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 stocks almost converge, after the procedure is repeated for the fifth time. In this case, it is very likely that socio-economic development is restricted as a result of inadequate transportation facilities.

Furthermore, the study has revealed that several socio-economic 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 (Measures of Effectiveness) 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.

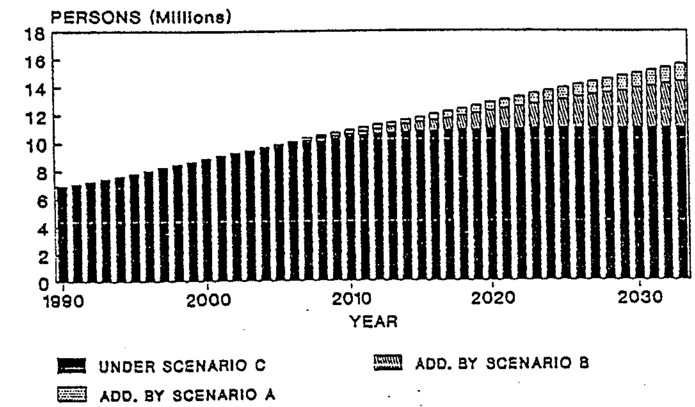

Fig. 7 Simulated Population for Scenarios

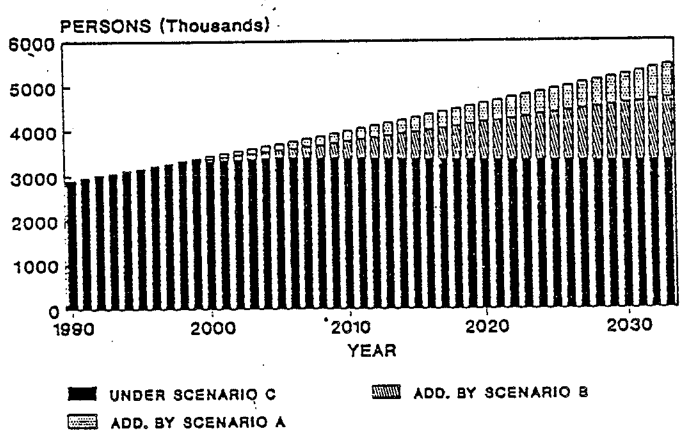

Fig. 8 Simulated Jobs for Scenarios

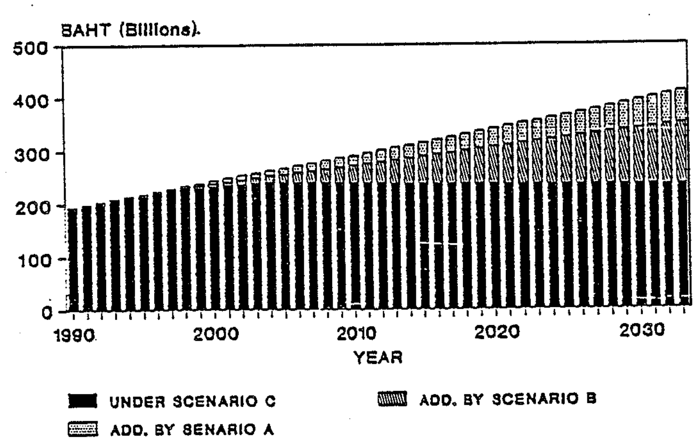

Fig. 9 Simulated GPP for Scenarios

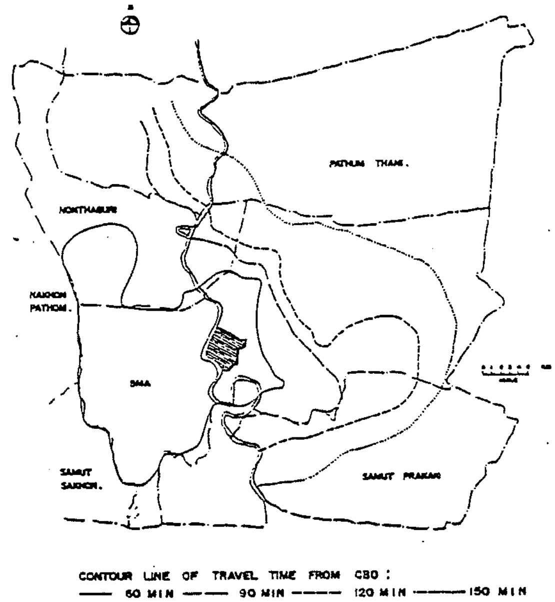

Fig. 10 Existing Transportation Accessibility (1989)

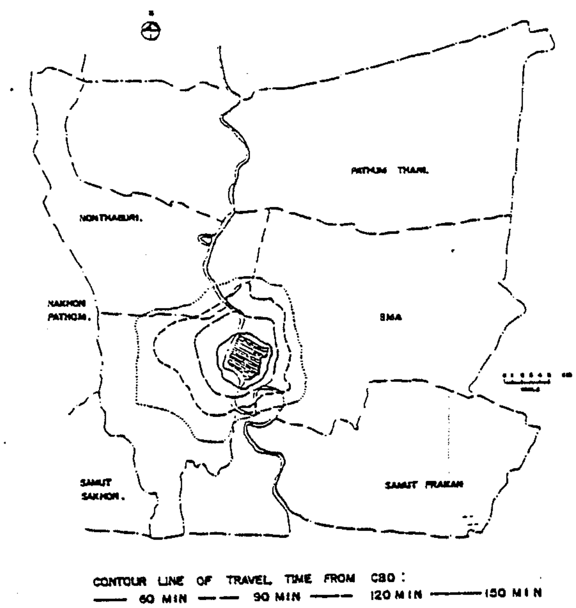

Fig. 11 Transportation Accessibility of Scenario C in 2006 for TR=0.4144 (Before)

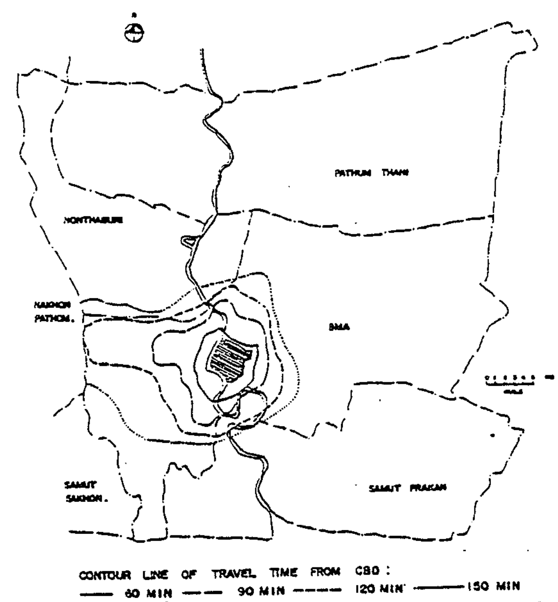

Fig. 12 Transportation Accessibility of Scenario C in 2006 for TR=0.4508 (After)

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