Progress Report

Research Grant 2010

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ASIAN TRANSPORTATION RESEARCH SOCIETY

Strategic Modelling for Sustainable Urban Transportation and Land Use Development in Bangkok

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Table of Contents

CHAPTER 1 Introduction

Since rapid growth of urbanization in many large Asian cities such as Bangkok, attention has recently been paid to the concept of a “sustainable transportation system” (STS) in urban areas that both improves quality of life and makes efficient use of the available resources (Emberger et at., 2008; Sumalee and Emberger, 2008). Many cities have made efforts to develop an STS, but it has proved difficult to achieve.

Typically, developing countries strive to raise economic growth by placing most of their resources into the development of business and infrastructure, without much concern over longer-term effects. Such development can increase the prosperity of the country in the short term by a trade-off with a damaged environment, particularly in urban areas. One of the first sectors suffering from such development is the land use and transport system.

Transport and land use policy formulation is a difficult process, particularly in a complex and rapidly-changing city especially if, as is usually the case, the policy makers have no guidance of any kind. To formulate effective policies, these countries need an understanding of how the urban land use and transport system works and interacts and the longer term consequences of failing to follow the sustainability path. They have to be equipped with a scientific approach and a knowledge of the policy options available to them, and guidance on how to use these to formulate a strategy to achieve both efficiency and sustainability.

To understand all of these issues, the technical level of an analytical approach (using some kind of quantitative model) to formulate the problem and define the best sustainable policy is also highly advanced.

This study aims to develop a user-friendly tool for pre-appraisal of the sustainability of urban transport and land use development (e.g. bus rapid transit and mass transit railway systems) in Bangkok. The analytical core of this research is a pre-appraisal planning tool, which combines an innovative strategic land use/transport model utilizing global and temporal-spatial data available from developing cities and an optimization model. This research appears to be the first devoted exclusively to the initial sketch planning topic for appraisal of social, financial and environmental sustainability of land use and transport systems with taking account the effects of integrated land use and transport development simultaneously. This tool will also be useful for the evaluation of the future transit oriented development (TOD) in Bangkok in which there is a large scale future plan to extend the transit network in Bangkok in the next decade. The interaction of this rapid expansion of transit system, land-value, land-use, and financial implication is very critical to achieve a sustainable urban development in Bangkok.

Thus, the objectives of this research are:

1. To develop a framework for integrated multi-modal transport and land-use model for the Bangkok metropolitan region
2. To collect relevant related past and current land-use and transport data for calibrating the modeling framework as defined in (1) for the purpose of strategic policy evaluation
3. By using (1) and (2) to investigate the possible sustainable transport policy package in the Bangkok metropolitan region; in particular the project aims to evaluate the synergies of the transit and land-use development in Bangkok as well as other pricing and travel demand management strategies
4. Based on (3) to draw a strategic recommendation on the future prospects and possible strategies for sustainable transport and land-use development in Bangkok

CHAPTER 2 Methodology

2.1 Time marching model

In order to represent: 1) the immediate effect of land use to travel pattern, and; 2) the delayed effect of travel characteristics on land use pattern, a time-marching approach is proposed for the dynamics of an integrated land-use and transport system. The time-marching paradigm for the integrated land-use and transport system could be represents by the following figure:

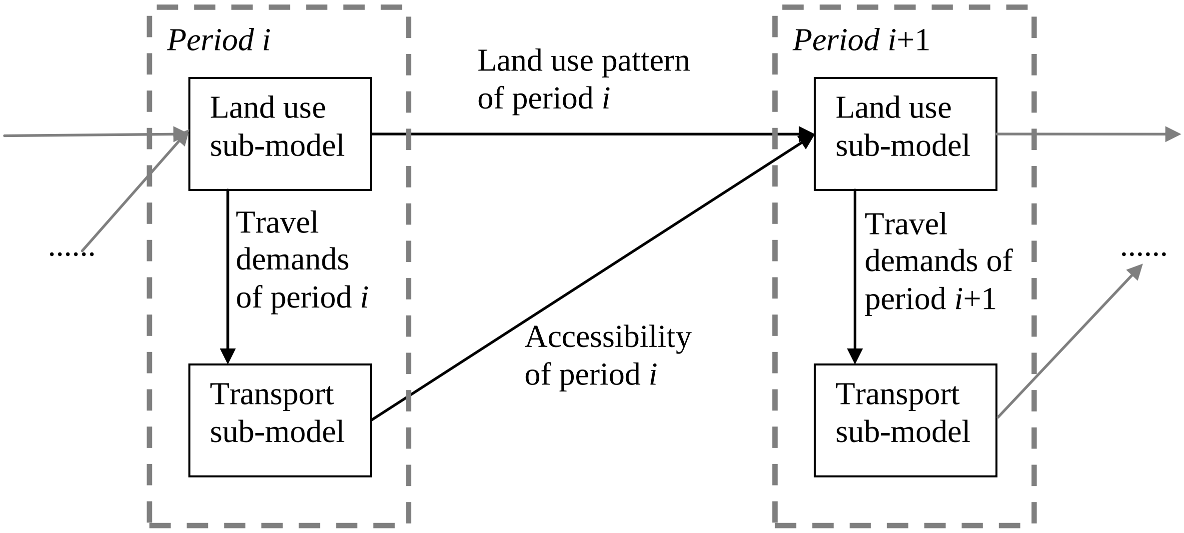

Figure 2.1 General framework of the time–marching approach

For the framework shown in Figure 2.1, the time-marching scheme is applied in between the land-use and transport sub-models. The details of each of the sub-models will be discussed in the subsequent sections while the general flow of information/data will be described in this section. First, the land use sub-model will take in: i) land use pattern from the land-use sub-model in the previous period, and; ii) accessibility information from the transport sub-model in the previous period, to evaluate for the travel demands (auto and public transport OD matrices) and the land use pattern for the current period. Given the travel demands, the transport sub-model will make use of the multimodal transportation system developed in EMME (Sumalee et al., 2010) for finding different accessibility indexes such as auto travel time, public transport travel time and waiting time. These accessibility indexes will serve as the input of the land use sub-model in the next period. Finally, the land-use and transport sub-models will then be solved sequentially and iteratively for the land-use and travel patterns within the design horizon.

2.2 Land use sub-model

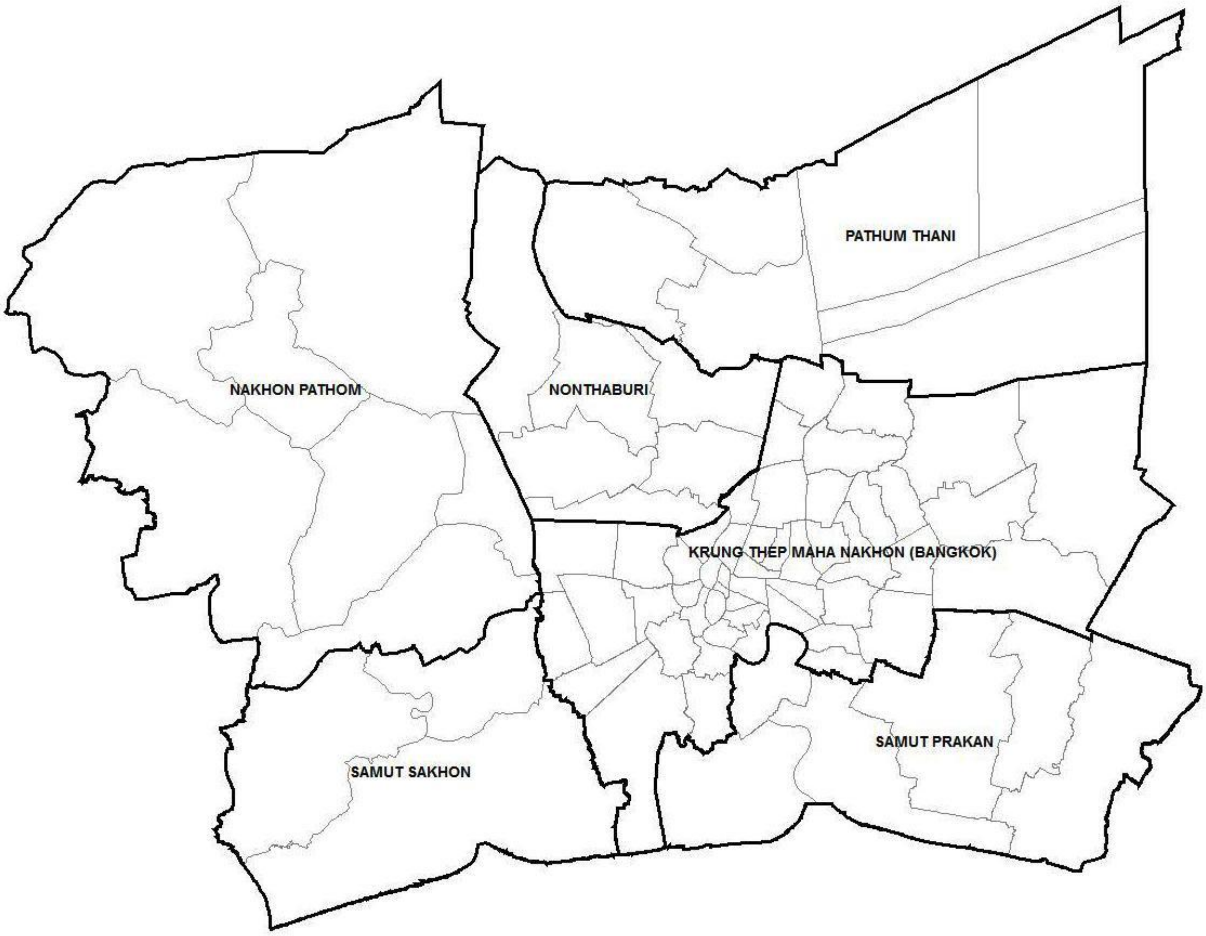

Figure 2.2 Provinces and amphoes in Bangkok Metropolitan Area

The proposed land use sub-model aims at forecasting the change of land use pattern (e.g. housing development pattern, workplace location, residential location, etc) under the future the growth of population/travel demand, extension of the railway system, and implementation of different road pricing policies. As compared to the transport sub-model, which will be described in more details in the next section, the land-use sub-model is formulated at a more aggregated level. The proposed land-use sub-model will cover the Bangkok Metropolitan Area (BMA) that includes Bangkok and the five surrounding provinces: Nonthaburi, Samut Prakan, Pathum Thani, Samut Sakhon and Nakhon Pathom (Figure 2.2). The study area covers an area of 7,762 km^2 and has an approximate population of 9,014,470 as of December 31, 2008 (DOPA, 2009). In the proposed land-use model, each of the 77 amphoes, which is defined by the grey lines in Figure 2.2, will be modeled separately for their land use characteristics. In this study, the land-use model in the Metropolitan Activity Relocation Simulator (MARS), which is developed by Pfaffenbichler (2003), is modified and adopted to model the land use changes. The MARS is developed based on the concept of Casual Loop Diagram (CLD), which clearly defined the causes and effects between different components of the model, for modeling the interactions in the land-use model.

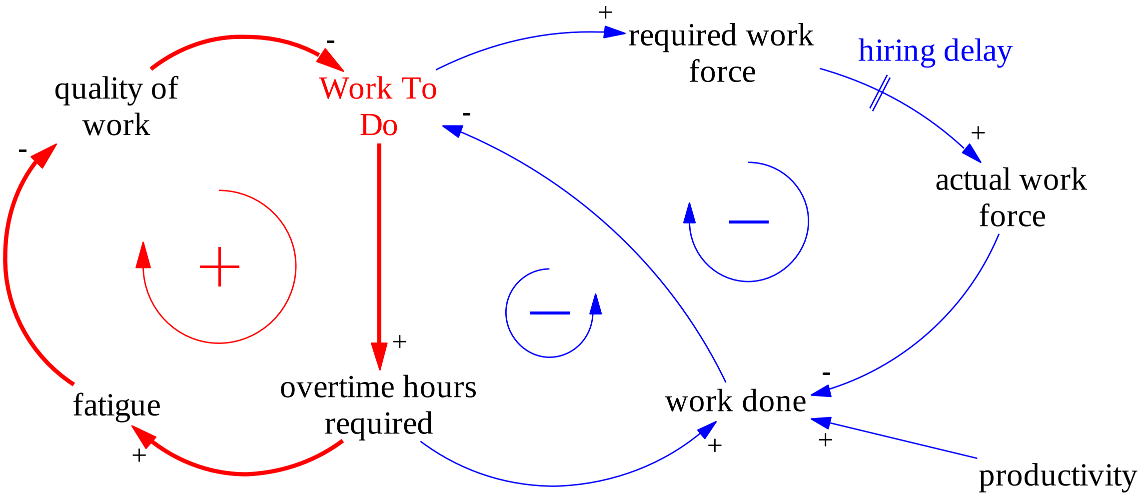

Figure 2.3 Example of Casual Loop Diagram (CLD)

Figure 2.3 shows an example of a simple CLD for the causes and effects of different components related to the quality/quantity of work and the workforce. For example, increase the “Work to do” will increase the “overtime hours required”, which will then increases the “fatigue” of the workers. The increase of “fatigue” will then decrease the “quality of work” and finally increases the “Work to do”. Such relations demonstrate a positive feedback loop, which the increase of work to do will be amplified by the system and causes more work to be completed. In this study, the CLD of the MARS is implemented in VENSIM and could be divided into the following components: (i) Land development model; (ii) Housing development model; (iii) Residential location model; (iv) Workplace location model; (v) Trip generation model; and (vi) Trip distribution and modal split model.

Figure 2.4 shows the land development model adopted in MARS. The aim of this model is to determine the availability of land for different purposes (e.g. residential and business). The land development model could be separately into two parts: i) initializing the land availabilities for year 0 based on the current observations, and; ii) updating the land availabilities for each time step based on the change of demand of housing and workplace unit, which come from the housing development model (Figure 2.5) and workplace location model (Figure 2.7). Figure 2.5 shows the housing development model adopted in MARS. The aim of this model is to determine the number of housing unit to be developed in each zone based on its attractiveness and the availability of land. The housing development model could be divided into three parts: i) estimation of housing rent based on the excess zonal demand; ii) estimation of housing provision cost based on the availability of land and the corresponding land price, and; iii) estimation of additional housing provision based on the unsatisfied housing unit from the previous time period. The attractiveness of housing provision in each zone, which is defined by housing rent and provision cost, is then used to distribute the additional housing among the zones.

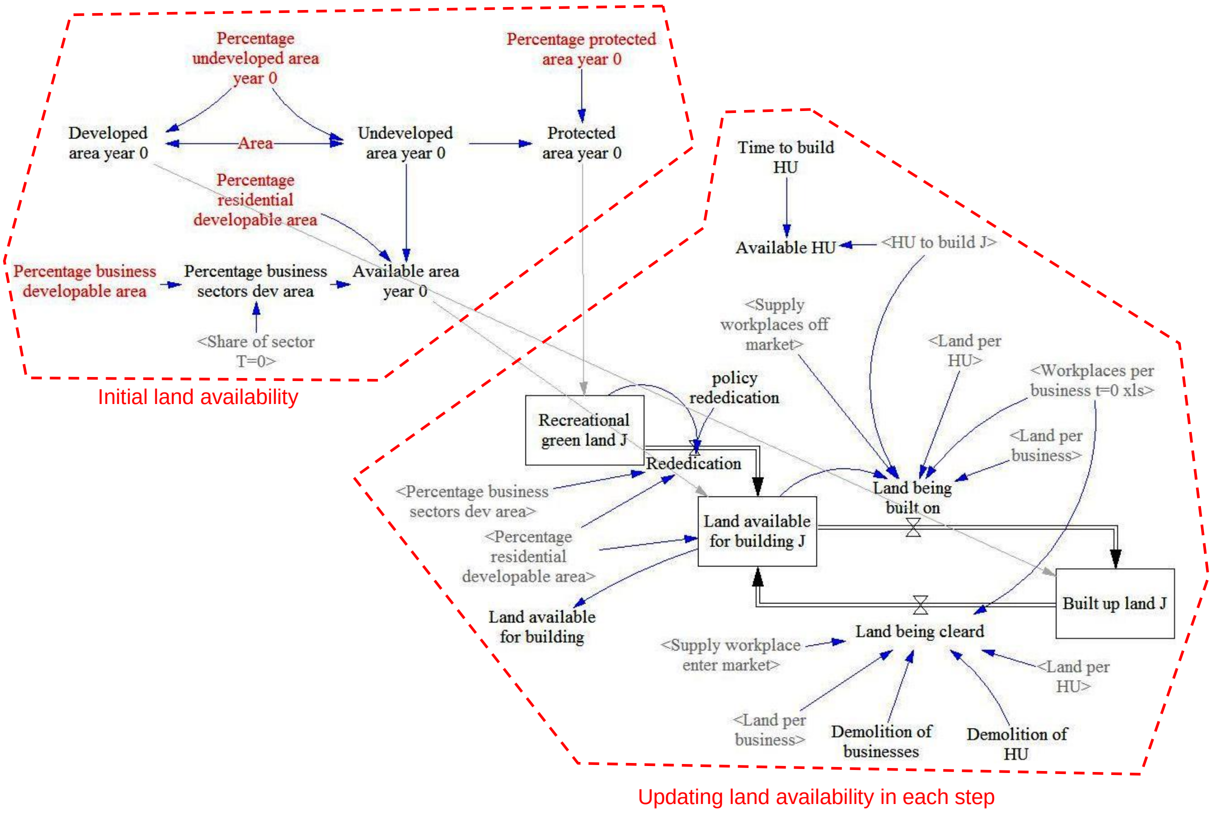

Fig. 2.4 Land development model

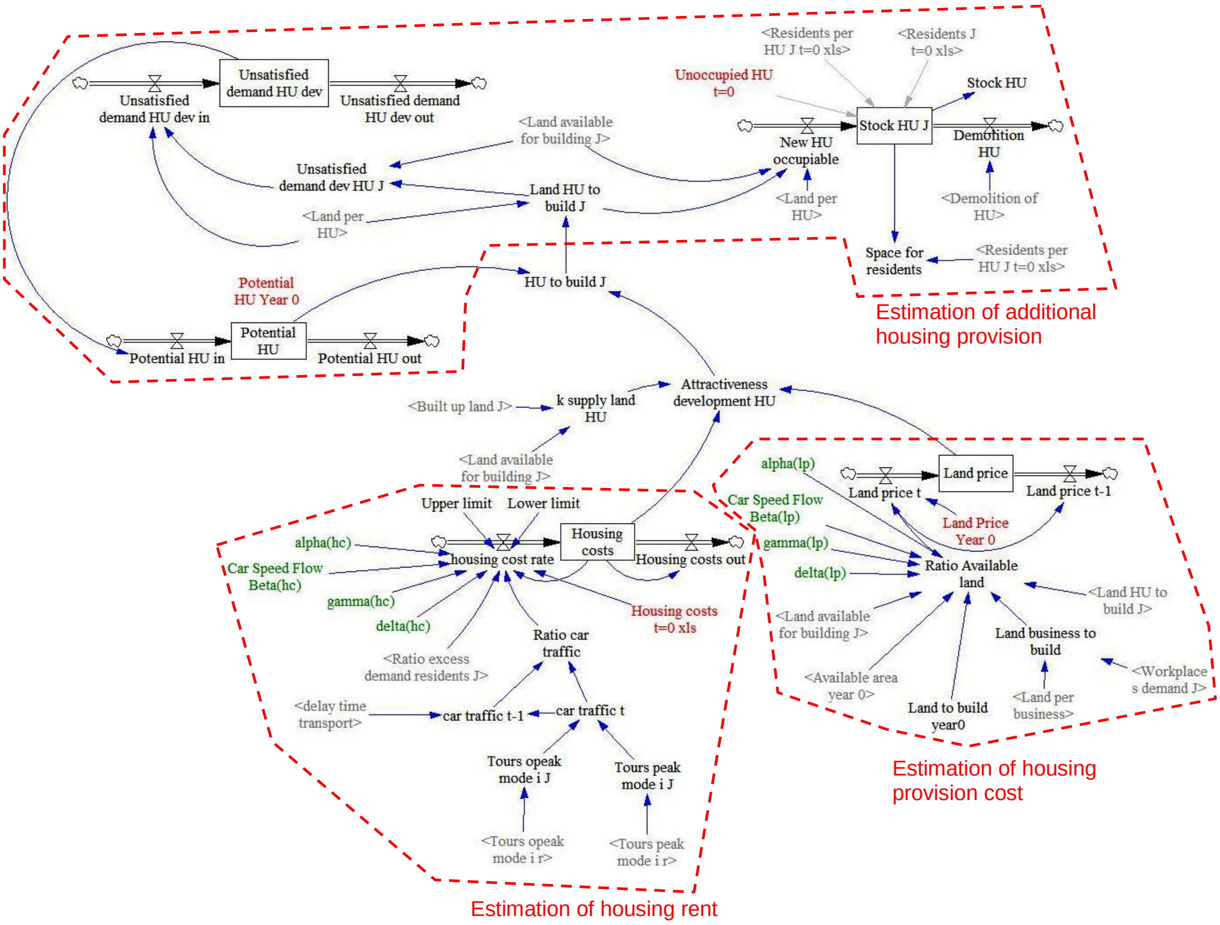

Fig. 2.5 Housing development model

Figure 2.6 shows the CLD of residential location model adopted in MARS. This model aims at evaluating the attractiveness of each modeling zone to the residents and, based on this attractiveness, residents are allocated to the modeled zones. In determining the attractiveness of the residential location, this model will considered the rent, which is determined by the housing cost estimated in the housing development model (Figure 2.5), accessibility of the zone, which will be determines by the travel times estimated by the transport sub-model (section 2.3) and the proportion of green and recreational area, which is determined by the land development model (Figure 2.4). Based on the determined attractiveness of each zone, the number of resident, who will prefer move in, will be determined by the resident relocation model. Then the residential relocation model will allocate these potential residents based on the available housing unit, which is determined by the housing development model (Figure 2.5).

Figure 2.7 shows the workplace location model adopted in MARS. This model aims to determine the number of workplace based on the attractiveness of the modeled zones. Similar to the determination of attractiveness in the residential location model, the attractiveness of a workplace is determined by the land price, availability of land for workplace, which determined by the land development model (Figure 2.4), accessibility of the zone, which is determined by the travel times estimated by the transport sub-model (section 2.3) and current business/workplace within the zone. Different from the residential location model, the attractiveness of the business to move out the zone is considered in this workplace location model. This attractiveness to move out is determined based on the accessibility and the rent of the zone. With the attractiveness for move-in to determine the demand of workplace, and the attractiveness of move-out together with the availability of land for workplace to determine the supply of workplace, the number of workplace provided in each zone could be updated.

Apart from modeling different types of land use activities (Figure 2.4 ~ Figure 2.7), the land use sub-model in MARS will also determine the OD matrices for different mode of transport based on the estimated residential locations (Figure 2.6) and workplace locations (Figure 2.7). Figure 2.8 shows the trip generation model that aims to determine the number of trips generated in each modeled zone by its residents, which is determined by the resident location model (Figrue 2.6). In this model, the employed and non-employed populations, which have different trip rates, are modeled separately to determine the total number of trips. Figure 2.9 shows the combined trip distribution and modal split model adopted in MARS. In this combined model, peak and off-peak period are modeled separately due to the different characteristics of travel demands. In this combined model, trips from each zone, which is generated by the trip generation model (Figure 2.8), is distributed to different zones and modes based on the number of workplace, which is determined by the workplace location model (Figure 2.7), the travel time (cost) for each mode, which is determined from the assignment results of the transport sub-model (Section 2.3). The OD matrices determined by this model will be input to the transport sub-model, which is introduced in Section 2.3, for network assignment to estimate the travel time and travel cost of each mode.

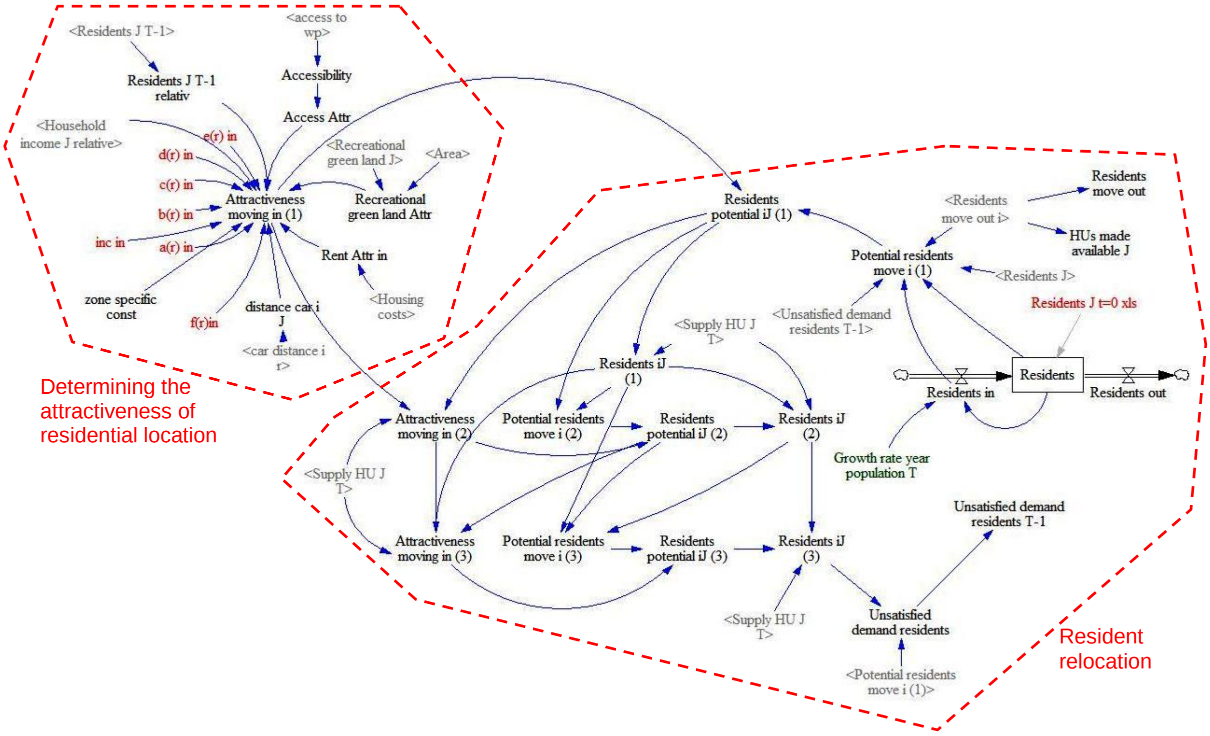

Fig. 2.6 Residential location model

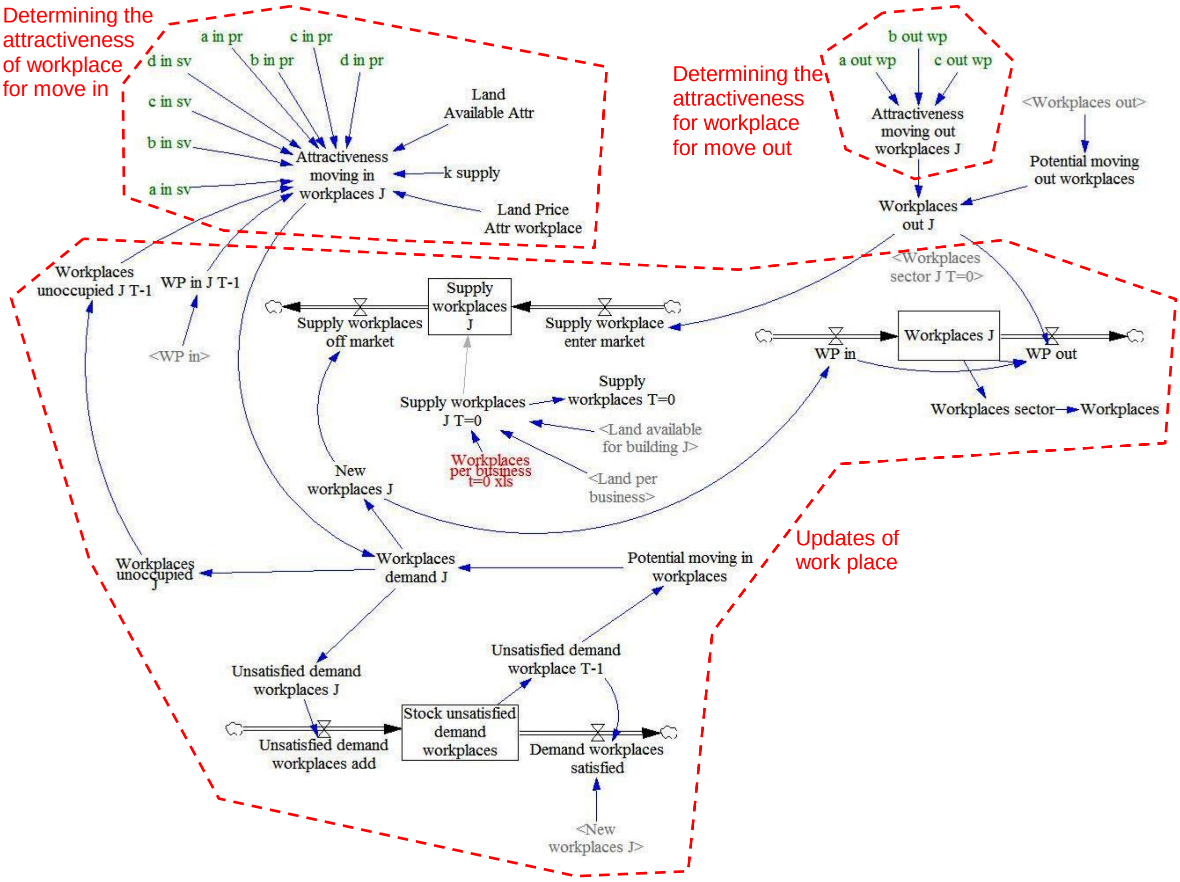

Fig. 2.7 Workplace location model

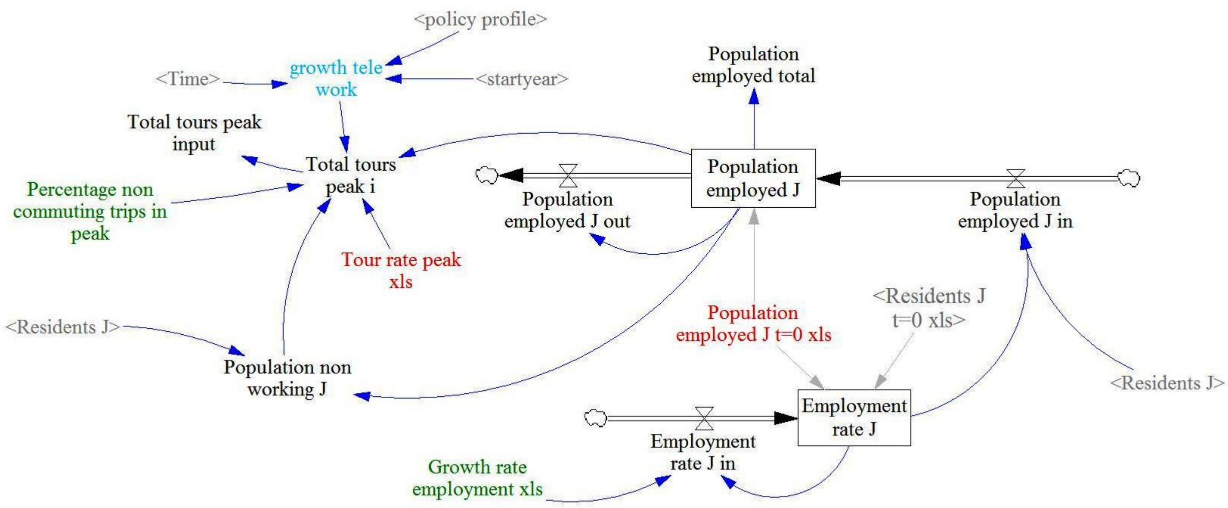

Fig. 2.8 Trip generation model

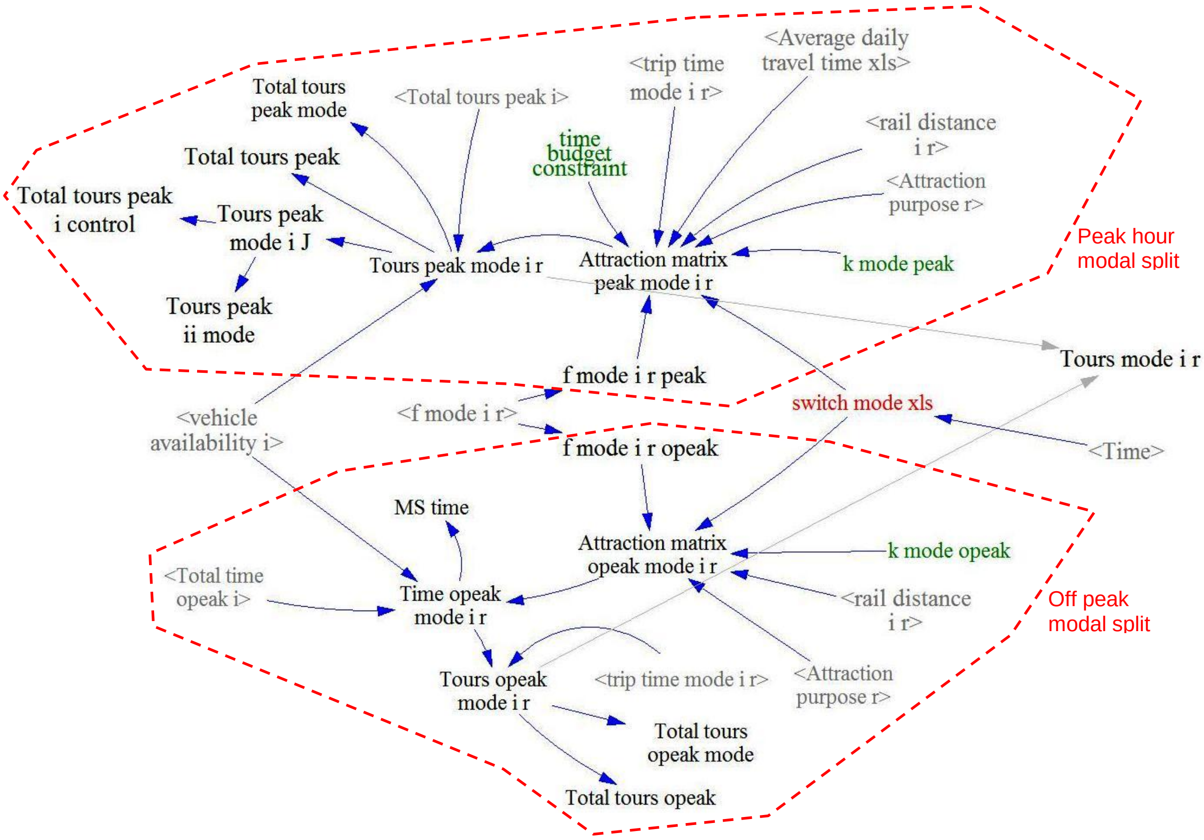

Fig. 2.9 Trip distribution and modal split model

2.3 Transport sub-model

In this study, the transport sub-model is modeled separately by the EMME model developed in Jaensirisak et al. (2010) for the modeling region described in the previous section. Due to the extension of the rail network, the 4 different road and public transport networks are setup separately in 2007, 2010, 2019 and 2029. The road network, including the national highways and major arterial roads within BMA, is shown in Figure 2.10. The BMA network consists of 243 zones, 58,806 OD pairs and 4,598 road links, which are represented by green lines in Figure 2.10.

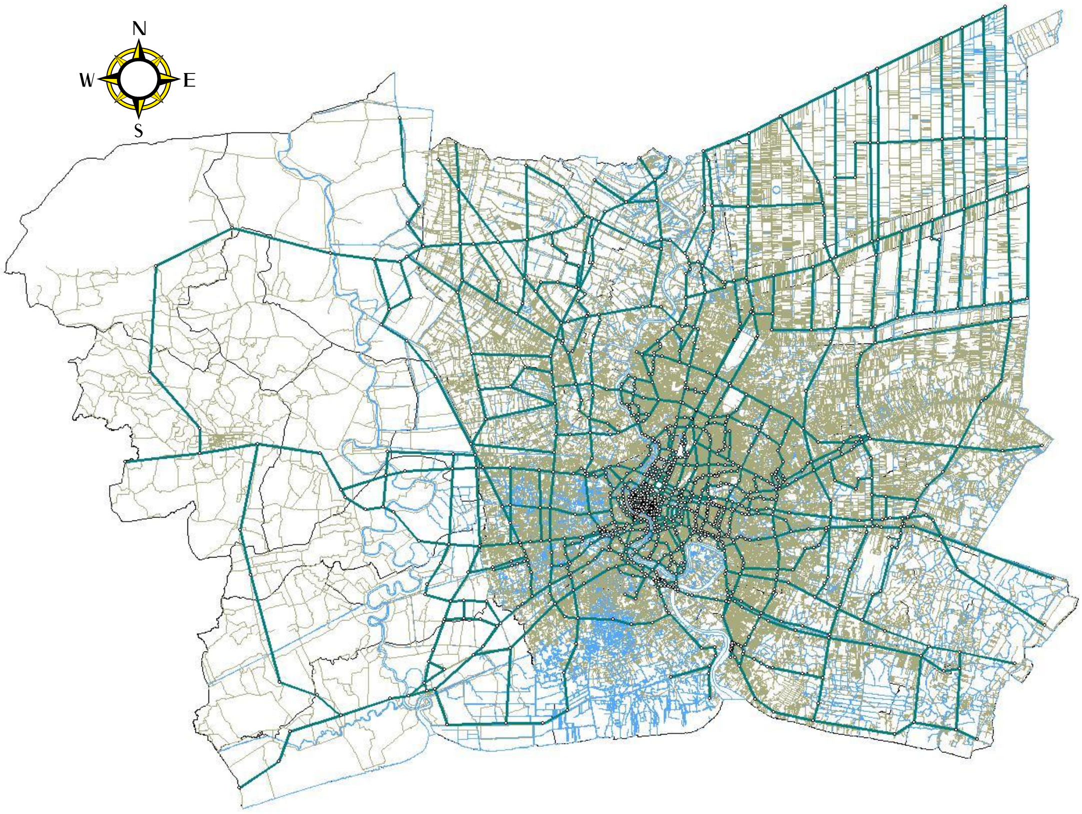

Figure 2.10 Bangkok metropolitan area network

For public transport, the 2007 network, which included a total of 261 public transport services serving within the BMA, is taken as the base network. Among these 261 services, 3 of which are railway services (MRT Chaloem Ratchamongkhon Line, BTS Sukhumvit Line, and BTS Silom Line) while the others are bus services. For the bus services, the fare is ranging from 6.5 Baht to 11 Baht while the fare for railway services is 15 Baht. Among the modeled public transport services, 64 lines are air conditioned that charged an extra distance-based fare of 0.25 Baht/km for bus and 1.25 Baht/km for rail.

Apart from the base network in 2007 used in calibration, this study also considers the current network in 2011 and two future networks in 2019 and 2029. The road and public transport network is the same in 2007 and 2011. The 2019 and 2029 networks are considered in this study as the first and second stage of MRT extension will be completed in these two years. For these future networks, the road networks and bus services are considered to be the same as in 2007 and 2010, while the railway services are improved by extending the original services or introducing new services. Figure 2.11, 2.12 and 2.13 respectively shows the railway services (BTS and MRT) in 2011, 2019 and 2029. Comparing these figures, it could be seen that the major extensions/implementations of railway will be completed in 2019, while some minor extensions will be completed in 2029.

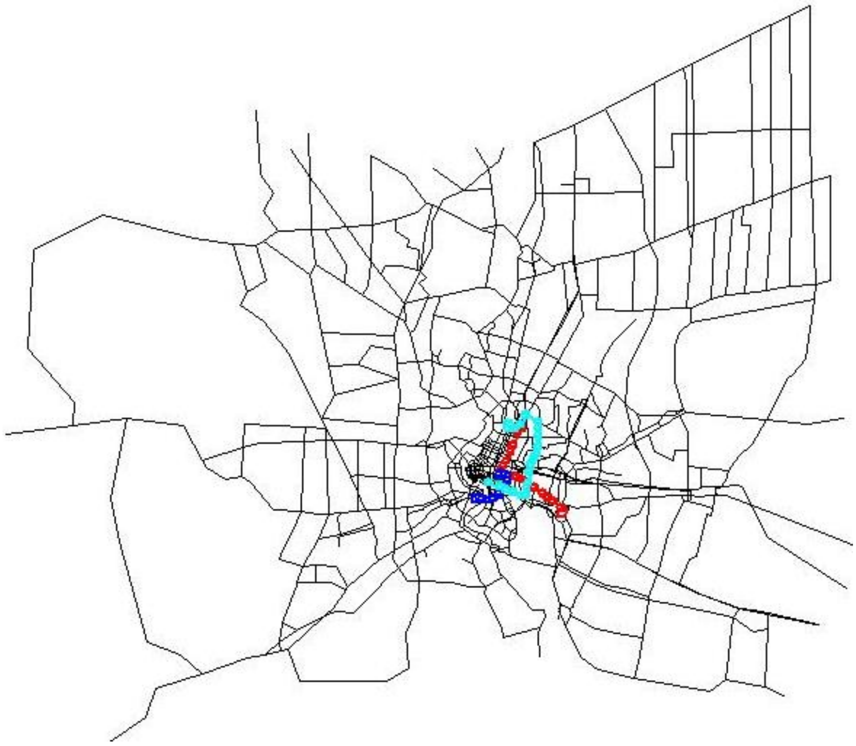

Figure 2.12 BTS and MRT network in 2011

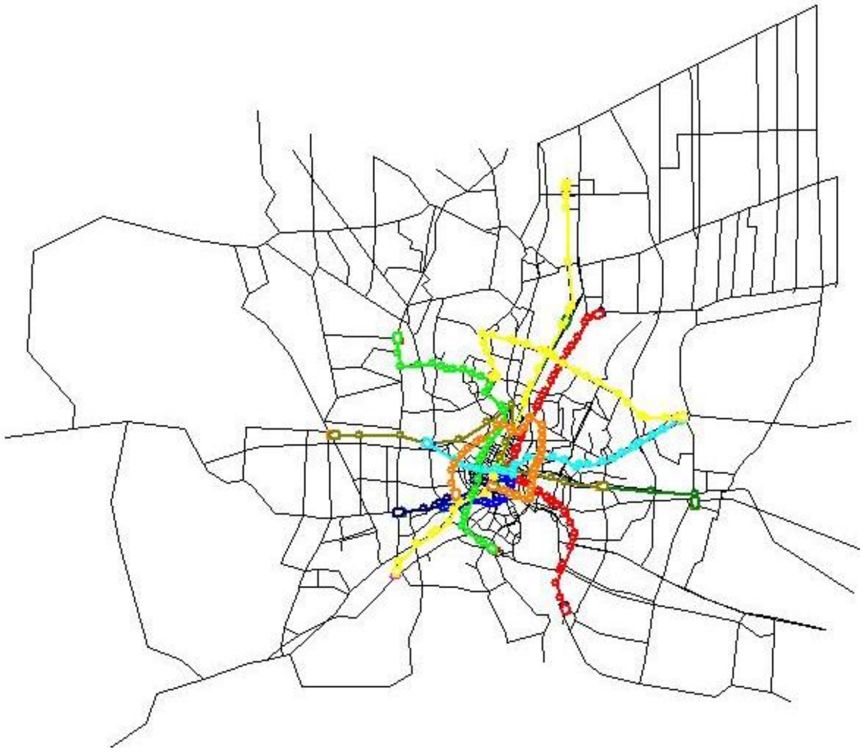

Figure 2.13 BTS and MRT network in 2019

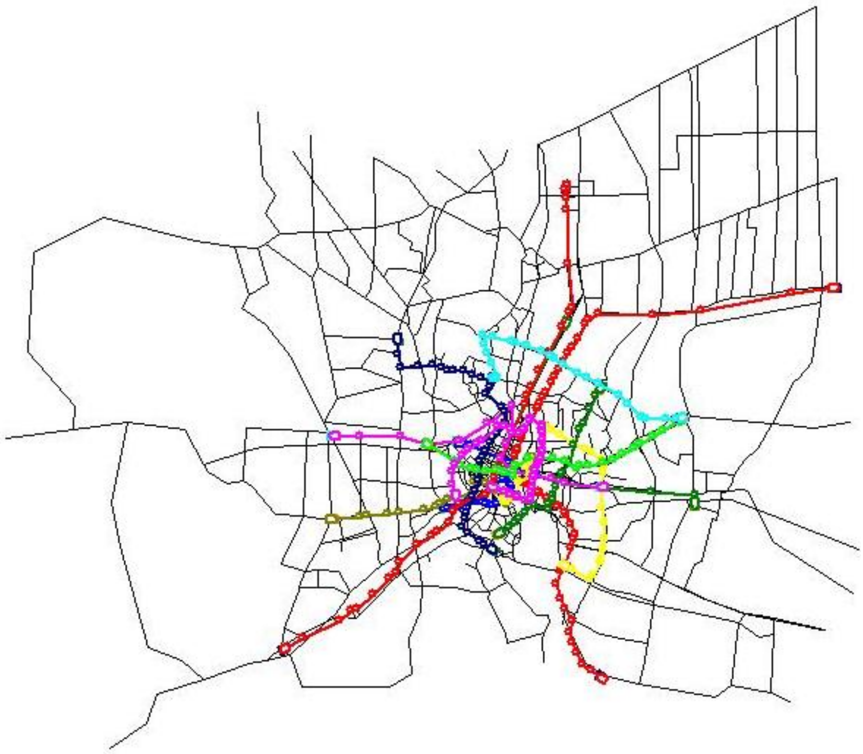

Figure 2.14 BTS and MRT network in 2029

Table 2.1 below gives the summary of the change of railway services (BTS and MRT) among these four networks (2007, 2011, 2019 and 2029). For the future 18 years, there will be a substantial extension in the railway network: number of lines will increase from 3 to 16, number of station will increase from 43 to 312 and, total length of rail will increase from 46 km to 508 km.

Table 2.1 Summary of railway services in 2007, 2011, 2019 and 2029

Year	2007	2011	2019	2029
Number of railway lines	3	3	11	16
Number of stations	43	43	237	312
Total length of railway (km)	45.7	45.7	384.8	507.7

The transport sub-model will take in the OD matrix for auto and public transport demand from the combined trip distribution and modal split model in MARS (Figure 2.9). With these two OD matrices, auto and transit assignment will be performed in EMME for finding the travel times (costs) between each OD pair. Lastly, the travel times (costs) will be input back to the resident location model of MARS (Figure 2.6), workplace location model (Figure 2.7) and combined trip distribution and modal split model (Figure 2.9) for determining the accessibility of the locations. Noted that, as the land use sub-model (77 zones) is more aggregated than the transport sub-model (243 zones), aggregation and disaggregation is necessary in transferring information in between these two sub-models.

In this study, the generalized cost (in minutes) for autos to travel on link *a* is defined by the following generalized link cost function, c_a^{auto}:

$$c_a^{auto}\left(V_a^{auto}\right) = t_a^0\left(1 + 0.73\left(\frac{V_a^{auto}}{C_a}\right)^3\right) + \frac{\tau_a}{\gamma_{travel}} \quad (1)$$

where V_a^{auto} is the hourly volume of autos on link *a*; t_a^0 is the free flow travel time (in minute) of link *a*, which is estimated by the length of that link and its speed limit; C_a is the capacity of link *a* in veh/hr; τ_a is the toll that auto users have to pay as they used link *a*; γ_{travel} is the value of time for travel and is taken as 1.27 Baht/min in this study. The first term on the RHS of Equation (1) represents the time needed for auto users to travel on link *a*, while the second term is the equivalent time value of toll that the auto users have to pay as they use that link. Apart from the generalized link cost function for autos, a separate travel time function is adopted to represent the time needed for the bus passengers to travel on a link within the modeled network. The travel time function for the bus passengers (in minutes) is defined as follow:

$$t_a^{bus}\left(V_a^{auto}\right) = 1.1\, t_a^0\left(1 + 0.73\left(\frac{V_a^{auto}}{C_a}\right)^3\right) \quad (2)$$

As buses share the same road space with autos, its speed (or travel time) will depend on the speed (or travel time) of autos on that link. Also, as bus is generally moving slower than autos, it is assumed that the bus travel time on any link is equal to 1.1 times of the corresponding time for autos. For railway, as it has its exclusive track, its speed (or travel time) will not be affected by the surface traffic. For segment *a'* of railway line *k'*, the travel time function (in minutes) is defined as follow:

$$t_{k'a'}^{rail} = \frac{L_{a'}}{S_{k'}^{rail}} \tag{3}$$

where $L_{a'}$ is the length of the rail segment *a'*; $S_{k'}^{rail}$ is the designed speed of trains on railway line *k'*.

CHAPTER 3 Data Collection and Model Calibration

Before applying the land use and transport model described in the previous chapter for policy evaluation, the proposed model has first to be calibrated to the current and past scenarios with the available information. This chapter will describe the calibration process for the land-use and transport sub-model introduced in chapter 2 and discuss the necessary information to carry out the calibration process.

3.1 Calibration of the land-use sub-model

In this study, the calibration of the land-use sub-model aims at finding a set of model parameters (e.g. weight of recreational area in evaluating the attractiveness of residential location, etc) that gives the best fit of the model output (e.g. area of land allocated for housing, number of zonal workplace, distribution of population, etc). In order to calibrate the land-use sub-model, the time marching model (Section 2.1) should be considered and the calibration of the transport sub-model, which is discussed in section 3.2, should first be completed. In this study the backcasting approach is adopted in calibrating the land-use sub-model and the details of this approach is shown in Figure 3.1.

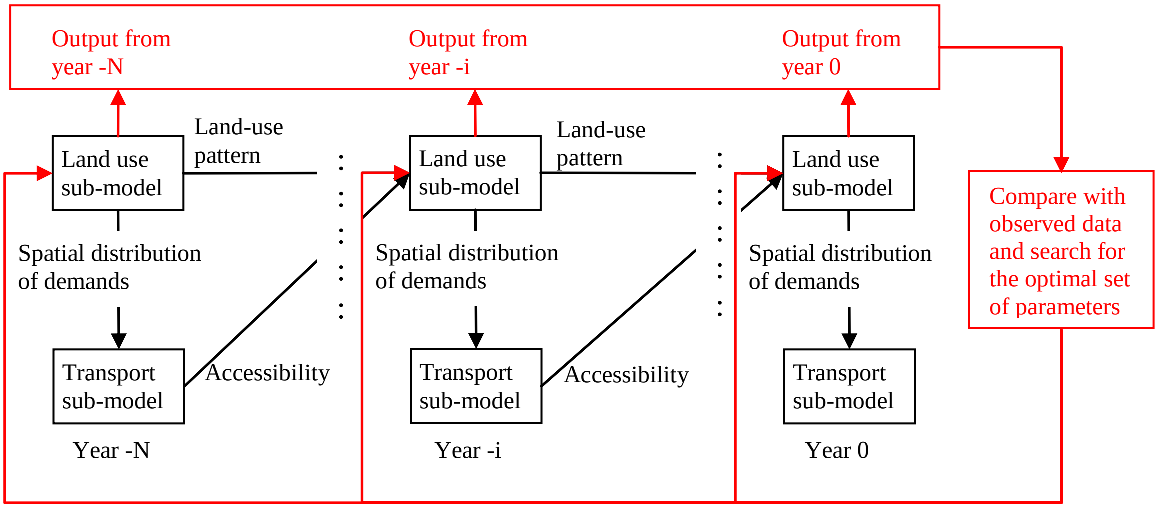

Figure 3.1 The backcasting approach

For the time marching model setup for the calibration of land-use sub-model, it will not be started from the base year (year 0). Instead, the time marching model will start from the earliest year with observed land use data (year -N) and end in the base year (year 0). For the backcasting approach, an initial set of parameters for the land use sub-model will be assumed and the time marching model will be solved based on this set of parameters. Then, the outputs of the land-use sub-models in different years will be compared with the available observed data. Based on the comparisons between the observed and modeled output, metaheuristic approaches (e.g. G.A.) is adopted for searching the optimal set of parameters that gives the model outputs closest to the observed data.

3.2 Calibration of the transport sub-model

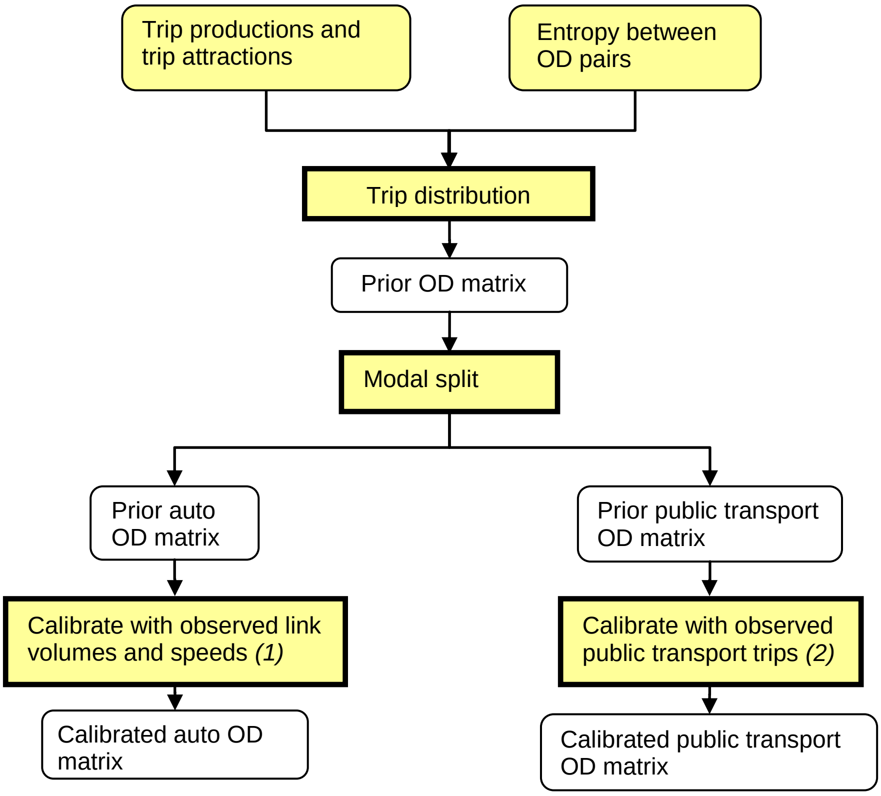

Figure 3.2 Calibration process of the transport sub-model

Calibration of the transport sub-model aims at finding the OD pattern for the auto and public transport demand in the base year (2007) for matching the observed link counts and public transport link volumes. Calibration procedure for the transport sub-model is similar to that discussed in Jaensirisak et al. (2011) except the calibration of the nested logit model for the travel and mode choice is not needed. It is because in the current setup, these choices are already modeled and calibrated in the land-use sub-model and should not be considered again in the transport sub-model. Figure 3.2 shows a flowchart for the calibration process of the transport sub-model, which is the first half of the calibration process described in Jaensirisak et al. (2011). For the details of each step readers should refer to Jaensirisak et al. (2011). Note that the trip generation, trip distribution and modal split in Figure 3.2 is defined on the disaggregated zone in the transport sub-model, which is different from that of the aggregated zones (77 amphoes) of the land-use sub-model). As discussed in Jaensirisak et al. (2011), the following information is necessary for the calibration of the transport sub-model:

- Observed hourly link volume counts and observed speeds for the calibration of the auto OD matrix
- Passenger counts of bus and rail lines for the calibration of the public transport OD matrix

- Total peak hour OD trips of public transport for the calibration of the public transport OD matrix

In the study of Jaensirisak et al. (2011), it is found that the standard OD demand adjustment algorithm for auto (transit) adopted in EMME (Spiess, 1990) tends to overfit the link counts (transit segment volumes) in the BMA network. Such overfit will cause a bias allocation of demand to the OD pairs that contribute to the observed link counts (transit segment volumes) and cause the remaining OD pairs to have a very low, or zero, demand. As a result, the OD demand patterns from trip generation and trip distribution steps are disrupted. In order to retain the demand pattern, a lower bound, which is defined as a percentage of the prior demand, is adopted for the OD demand in the calibration process. The setting of this lower bound will directly affect the calibration results. For example, if the lower bound is set to high, the calibrated OD matrix will close to the prior OD matrix and the assigned link flows (transit segment volumes) may not match with the observed values. On the other hand, if this lower bound is set too low, the OD pattern may not be preserved. Thus, in this study, different lower bounds are tested such that the calibrated OD matrices will give a reasonable match to the link counts (transit segment volumes) and preserve the original OD pattern.

Following the flowchart shown in Figure 3.2 and the procedures described in Jaensirisak et al. (2011), the auto and public transport OD matrices for the 2007 BMA network are calibrated with respect to the observed link volumes/speeds, public transport passenger counts, and observed modal split. Based on the considerations discussed in the previous paragraph, the lower bound of the auto and public transport OD demand is preferable to set at 8.7% and 6.8%, respectively, of the corresponding prior OD matrix. For the auto OD matrix, the scattered plot of observed link volumes versus the link volumes from assigning the calibrated auto OD matrix to the Bangkok metropolitan network is shown in Figure 3.3.

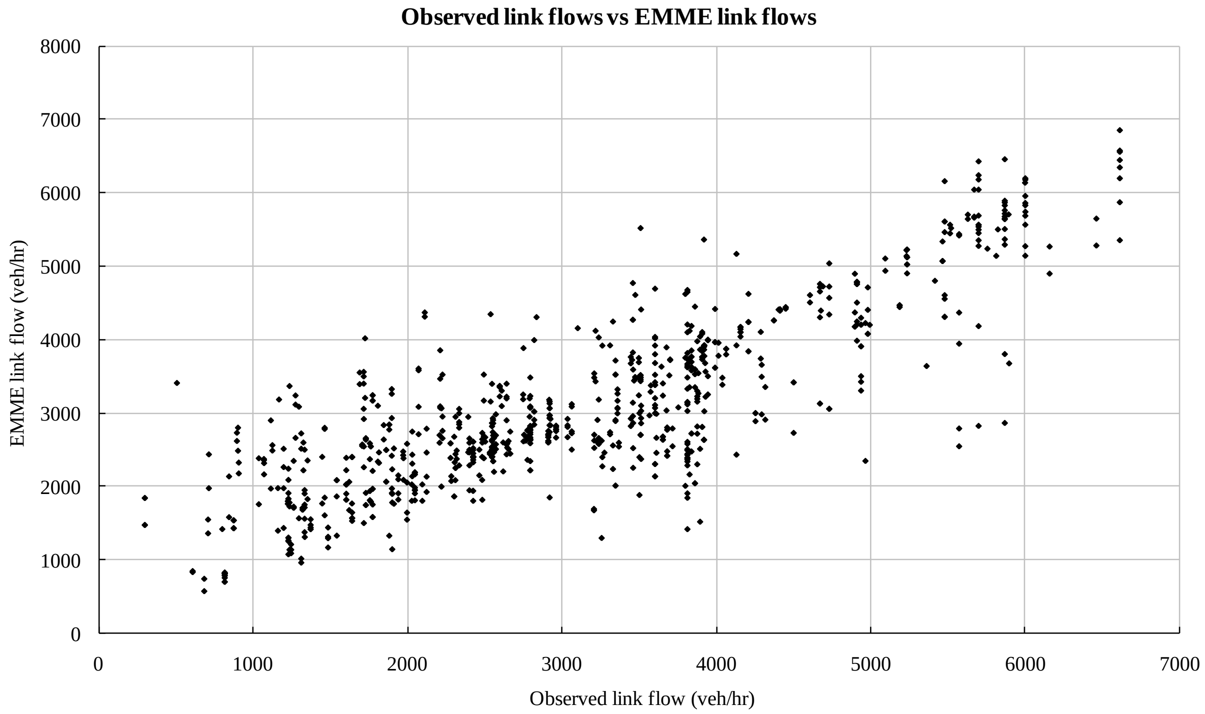

Figure 3.3 Observed link volumes vs EMME link volumes

R-square between the observed link flow and the EMME link flow is 0.705. Based on the calibrated auto OD matrix there are 829,426 travelers per hour choosing to use auto in making their trips. For the public transport OD matrix, the scattered plot of observed hourly trips of public transport lines versus the hourly public transport trip from assigning the calibrated public transport OD matrix is shown in Figure 3.4. The R-squares for all public transport lines is 0.874 in this case. Based on this calibrated public transport OD matrix there are 79,653 travelers per hour choosing to use public transport which creates 149,505 bus trips and 63,138 trips on railway. Thus, on average, each traveler, who chooses to travel with public transport, makes 2.7 trips on either bus or rail. In Figure 3.4, the three lines with hourly trip larger than 15,000 are the three railway lines (MRT Chaloem Ratchamongkhon Line, BTS Sukhumvit Line, and BTS Silom Line) included in the 2007 network. The calibrated auto and public transport OD matrix will be aggregated by zone and used in calibration of the land-use sub-model

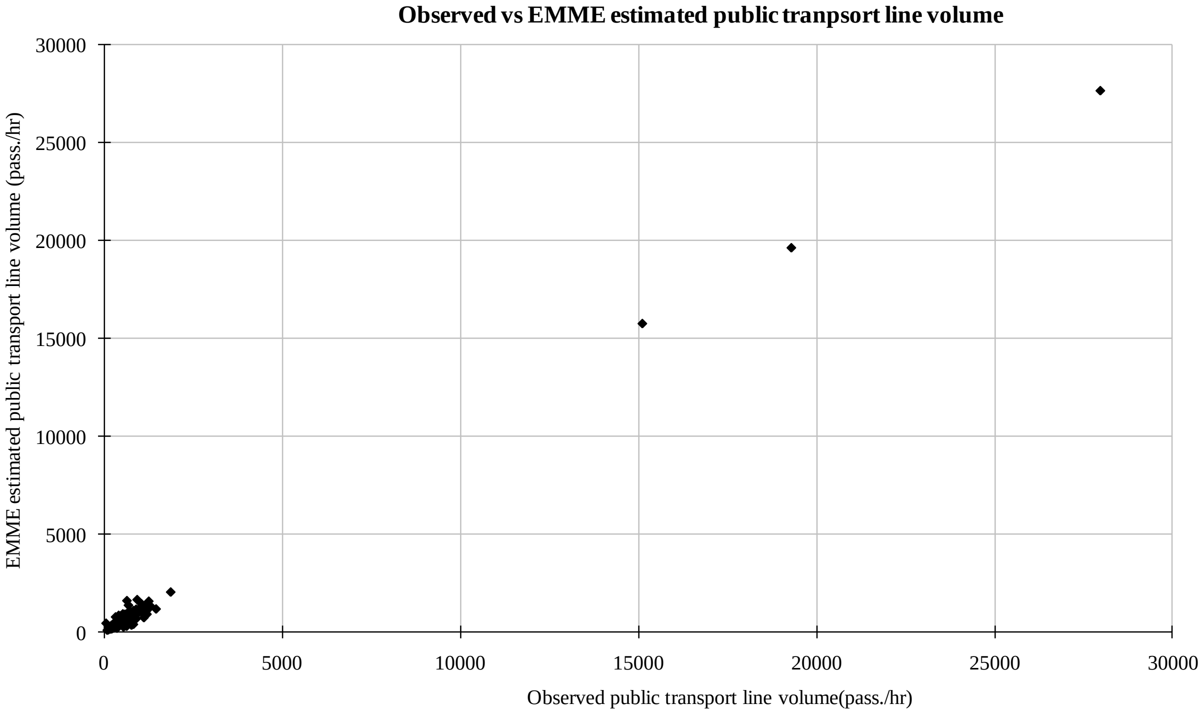

Figure 3.4 Observed public transport trips vs EMME public transport trips

CHAPTER 4 Summary and Future Works

In this report, the land use and transport model for the Bangkok Metropolitan Area (BMA) is formulated as a time-marching model that iterates between the land use and transport sub-models with time lag. The land use sub-model will adopt the MARS model, which is built in a form of Causal Loop Diagram (CLD), introduced by Pfaffenbichler (2003). In the land use sub-model, land development, housing development residential location, workplace location, trip generation, trip distribution and modal split is considered to provide the OD travel demand matrices for different travel mode in the transport sub-model. The transport sub-model, which is a multi-modal transportation system built in EMME (Jaensirisak et al., 2010), will assign the OD matrices from the land use sub-model to the BMA network. The travel times and travel costs found in this transport sub-model will be feedback to the land use sub-model for estimating the accessibility each of the modeled zone.

After setting up the time-marching model for this study, calibration approaches and the required data for each of the sub-model are discussed. Backcasting approach with metaheuristic searching algorithm is proposed for the calibration of the land use sub-model. With the observed land used pattern (e.g. number of housing unit), the parameter of the land use sub-model could be calibrated. For the transport sub-model, procedure similar to that described in Jaensirisak et al. (2010) is adopted in this study. In the calibration of transport sub-model, the OD matrix of auto and public transport is calibrated based on the link counts, transit segment volumes and the observed modal split. With the calibrated land-use and transport model the following scenario testing will be completed:

1) Evaluate the impact of the extension of railway system on land use patterns and travel behaviors
2) Evaluate the impact of different road pricing schemes on land use pattern and travel behaviors
3) Develop and test integrated transport and land use policies with the calibrated time-marching model for the Bangkok Metropolitan Area
4) Discuss and compare the evaluation results in 1~3, and propose the most promising set of land use and transport policy package for the implementation in the Bangkok Metropolitan Area.

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Research Grant 2010

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