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Integrating Congestion Charging Schemes and Mass Transit Systems in Bangkok

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CHAPTER 1 Introduction

1.1 Introduction

Since 1980s, the London Planning Advisor Committee (LPAC) concluded that improvement of public transport by itself was not seen as sufficient; there was a need for direct measures to restraint road traffic and to obtain a better balance between the demand and supply of road space, which congestion charging was seen as the most favourable.

Various governments have been interested in introducing urban congestion charging in their cities, but only few of them have actually succeeded (i.e. Singapore, UK and Sweden). Public acceptability was probably the greatest barrier to the implementation of congestion charging (Jones, 1998). In general, congestion may be seen as unacceptable, but there is also evidence of interaction effects between levels of public acceptance of travel-demand management measures, when considered separately and in combination with other measures (Thorpe et al., 2000), and it is possible to design congestion charging schemes which are effective and acceptable to the public (Jeansirisak et al. 2002).

Various road user charging features have been studied; for example, those reviewed by May et al. (1991), May (1992), Hau (1992a), Lewis (1993), Gomez-Ibanez and Small (1994), Small and Gomez-Ibanez (1998), May and Sumalee (2003), and Hau (2006). These show many practical features of road pricing. In addition to setting objectives of the system, there are a number of key issues, which need to be addressed when designing a congestion system (Jones, 1998), including: type of traveller/vehicle to be charged, charged area, charged period, charging level, and charging basis (e.g. cordon-based, cellular-based, supplementary licence, time-based, distance-based, congestion-based and externality-based).

It is clear that a package of instruments is likely to be more effective than selecting any one instrument on its own. “Road pricing encourages greater use of light rail and generates revenue to pay for the light rail. Conversely the use of revenue to invest in light rail which makes road pricing more acceptable and provides an alternative for those no longer able to drive.” (May et al., 2003).

In Bangkok, recently, congestion charging has been suggested for managing demand of car use, as in Traffic and Transportation Development Master Plan for the 9th National Economic and Social Development Plan 2002-2006 (TDRI, 2001). In addition, the Urban Rail Transportation Masterplan (OCMLT, 2001) proposed a rail transit network in Bangkok, and also recommended that road pricing should be combined to support this rail development. However, the government is only considering approval of the rail network as an independent measure, i.e. decoupling it from the pricing scheme.

Currently, in Bangkok there are three routes of mass transit system in total about 84 kilometres (which Airport Link 39.1 kilometres just started operating in August 2010). The "Mass Rapid Transit Master Plan in Bangkok Metropolitan" (OTP, 2010) is set to have 12 routes in total 509 kilometres in 2029 (see Appendix A).

For Bangkok, ATRANS research project (Jaensirisak, Sumalee, Ongkittikul, 2008) suggested that road pricing should be considered as a part of the effective transport strategy.

Thus this research aims to integrate congestion charging to support mass transit systems in Bangkok, in order to improve the overall transport system.

The objectives of this research are:

- to evaluate the performance and benefit of different road pricing schemes in Bangkok
- to review and investigate possible integration plan of public transport scheme and road pricing scheme in Bangkok
- to assess the benefits and impacts of the integrated policy of road pricing and public transport package in Bangkok
- To conclude and recommend an appropriate integrated package of road pricing/public transport implementation in Bangkok

1.2 Study framework

One of the key elements in this framework development is the revision of the definition of "full revenue recycling". In the traditional social welfare evaluation of the road pricing scheme, the revenue collected from the scheme is assumed to be fully recycled to users without a specific mean. In this study, we consider the case where the utilization of the revenue through public transport investment and improvement is the main channel to recycle the benefit back to the users. An approach considered to introduce such a requirement is the maximum level of revenue recycling benefit (without passing through a form of investment). In this way, the assumption of full revenue recycling can be relaxed and an integrated package will become more advantageous.

The research project devised different pricing scheme options for Bangkok ranging from corridor based pricing, distance based toll, to cordon scheme. The approach to define these realistic options will follow the judgmental approach proposed in May et al. (2002). Each of the road pricing schemes will be first implemented in the multi-modal network model to evaluate the initial impact of the scheme in terms of route diversion and depressed demand. The traffic and demand data from the model was then be used to devise different possible public transport packages in which the strategy used in the package may include:

- Introduction of new major public transport services, e.g. underground lines
- Improvement of bus services (i.e. fare reduction or frequency increase)
- Introduction of new feeder buses

Once the possible public transport packages was designed (according to the MRT development by the government), the road pricing schemes were then be evaluated again using the multi-modal traffic model with the introduction of the public transport package. The outcomes of the model were then be used as inputs to the evaluation framework.

CHAPTER 2 Design of Road Pricing Schemes

2.1 Introduction

In this chapter, the design of road user charging systems is presented. This includes general criteria of design and main structure of the systems.

2.2 General criteria of design

In the UK pricing measures have been studied sine the early of 1960s. The Smeed Committee (Ministry of Transport, 1964) specified the nine most important requirements of the system as following:

- Charges should be closely related to the amount of use made of the road;
- It should be possible to very prices;
- Prices should be stable and readily ascertainable by road users before they embark upon a journey;
- Payment in advance should be possible;
- The incidence of the system upon individual road users should be accepted as fair;
- The method should be simple for road users to understand;
- Any equipment used should possess a high degree of reliability;
- It should be reasonable free from the possibility of fraud and evasion; and
- It should be capable of being applied, if necessary, to the whole country.

Eight desirable features which were also considered, but not so important are as following:

- Payment should be possible in small amounts and at fairly frequent intervals;
- Drivers in high-cost areas should be made aware of the rate they are incurring;
- The method should be applicable without difficulty to road users entering from abroad;
- Enforcement measures should impose as little extra work on the police forces as possible;
- It would be preferable if the method could also be used to charge for street parking;
- The method should, if possible, indicate the strength of demand for road space in different places; and
- The method should be amenable to gradual introduction commencing with an experimental phase.

For the design of road user charging, although each city and country has its own constraints, some general criteria should be considered (Ministry of Transport, 1964; Thompson, 1990; Hau, 1992a):

- fairness, the charges should be perceived as fair by most travellers. This may involve basis of charge (e.g. based on quantity of road use), charged areas, time periods, and the travellers who are charged;
- simplicity, the charging system should be easy to understand by the public;
- accuracy, the charging system should always be accurate and be able to be verified by users;
- enforcement, the system should be capable of protecting against fraud and evasion;
- privacy, the system should be designed to protect users' privacy;
- flexibility, the system should be able to integrate with other systems, e.g. driver information system and roadside information system, etc.;
- technology, to achieve all above issues technologies should be appropriately applied.

These cover the four characteristics of a 'good' tax proposed by Smith (1776) in his book 'The Wealth of Nations', in which the objectives of a good tax should be considered as equity, certainty, convenience and efficiency.

Furthermore, The High Level Group on Transport Infrastructure Charging (1998), convened by the European Commission, in considering the general concept of charging, commented that "the consequence of introducing the proposed charging systems should be to reduce rather than to increase total transport related costs to the economy as a whole". This decrease of overall costs could be achieved because the charge should increase efficiency of operation and use of infrastructure, and the 'external' costs which are incurred somewhere in the economy will be paid directly by those who cause them.

More recently, a number of research has attempted to explain success and failure of urban road pricing from the international experiences. For example:

Jaensirisak (2003) concluded that major issues should be concerned in implementation of road pricing schemes, in order to achieve public acceptability, effectiveness and practicability, including:

- Existing circumstance. Congestion and pollution must be bad enough, in order to gain support from the public.
- Benefits and objectives need to meet the public concern. It is found that using the scheme as a financial instrument is more easily to be acceptable than using it for demand management. Specification of the scheme's objectives needs to keep simple and straightforward.
- System characteristics need to be simple to understand for the public. A scheme would also be preferable if the charge can be predicted.
- Revenue allocation needs to meet the public preference. The most frequent suggestions are using revenue to improve public transport and reduce tax. The scheme proposal needs to specify precisely how the revenue would be used.

- Equity issues need to be considered. This relates to the distribution of cost and benefits. If road user charging is perceived as unjust and unfair, acceptance will be difficult to achieve. It must also not be perceived as a kind of punishment. This issue can be added by revenue distribution.
- Alternative means of travel need to be available. This must be part of a policy package, which can compensate those who cannot afford the charge, as well as contribute to perception of freedom of choice.
- Technology needs to retain flexibility once implemented, so that it could be easily later adjusted to overcome unpredicted problems.
- Communication and marketing strategy can be of use to improve public understanding. It also can be used to create public awareness of the transport problems, and then to enable a scheme to be perceived as effective solution. It is important to consult with all of those who might be affected, both positively and negatively, by the scheme.

May and Sumalee (2003) found that where proposals fail, the barriers to progress include: lack of political commitment reinforced by limited public acceptance and specific concerns over equity, economic impacts and, to a lesser extent, technology.

A recent European project named CURACAO (Co-ordination of Urban RoAd-user ChArging Organisational issues, 2006-2009) aims to coordinate research and monitor the results of the implementation of road user charging as a demand management tool in urban areas. The project attempts to identify the barriers to road pricing implementation, and provide evidence on ways of overcoming those barriers. This project addresses a series of themes which relate to road pricing design and implementation. The issues include:

- the possible objectives of road pricing schemes;
- the ways in which road pricing schemes can be designed to meet those objectives;
- the technologies available to support such scheme designs;
- the Business Systems affecting the technology choice and operation of the scheme;
- techniques for predicting the effects of road pricing schemes;
- techniques for appraising/evaluating the effects of road pricing schemes;
- specific evidence of impacts on the economy;
- environment;
- equity;
- factors affecting the acceptability of road pricing schemes; and
- the potential transferability of experience from one city to another.

The previous ATRANS research project (Jaensirisak, Sumalee, Ongkittikul, 2008) analysed road pricing experiences and local circumstances in Bangkok and suggested some broad strategies (a road map), in order to help Bangkok moving towards the implementation, as follows:

(i) The national government has a responsibility to develop a clear transport strategy and legislation to support the local government.
(ii) Road pricing should be considered as a part of an effective transport strategy.
(iii) An independent expert study group should be set to formulate the effective strategy.
(iv) Effective communication should be done continuously through a two-way dialogue to raise public awareness and knowledge.
(v) Road pricing revenue allocation plan is a critical issue.
(vi) Implementation plan of improvement of alternative transport modes needs to be clear and convincible to the public in the early stage of planning process.
(vii) Political will and leadership to commit the scheme is a key success of the scheme.

2.3 Structure of road user charging system

Various road user charging features have been studied; for example, those reviewed by May et al. (1991), May (1992), Hau (1992b), Lewis (1993), Gomez-lbanez and Small (1994), and Small and Gomez-lbanez (1998). These show many practical features of road pricing. In addition to setting objectives of the system, there are five key issues, which need to be addressed when designing a road pricing system (Jones, 1998):

- type of traveller/vehicle to be charged;
- charged area;
- charged period;
- charging level;
- charging basis.

2.3.1 Type of traveller/vehicle to be charged

To classify categories of travellers to be charged, the objectives of the scheme should be specified. Jones (1998) suggests that exemption of some types of traveller or vehicle can be made; for example: of pedestrians, cyclists and drivers of electric vehicles, when pollution reduction is an objective of the scheme; of pedestrians, cyclists and public transport users, when congestion reduction is an objective of the scheme; and of disabled drivers and goods vehicles, according to 'need' to use vehicles. Moreover, occasional users, visitors, high occupancy vehicle users and residents in the charged area should also be considered when designing the system. However, designers of the system needs to be concerned that if residents in the charged area were exempt from the charge, this is likely to affect the effectiveness of the scheme.

2.3.2 Charged area

Evidence from road pricing studies and implementation has shown various scales of implementation that can be divided into three (Decorla-Souza, 1993; Bhatt, 1993). Firstly, single facility pricing (small scale) involves charging for use of a segment of motorway or bridge, e.g. in USA, UK and France. Secondly, area-wide pricing (medium scale) involves charging within a small area such as a city centre or a central business area. For example, this has been implemented in Singapore and Norway's cities and also researched for Hong Kong, Cambridge, Stockholm, Leeds and London. Finally regional-wide pricing (large scale) involves charging within a regional area covering urban areas and road networks; for example, studied for Randstad region (Netherlands).

The design of road pricing scales is dependent on the objectives of the scheme, and local geographical factors. For example, when the objective is to reduce congestion the scale of charged area (covering a congested area) may be smaller than when the objective is to reduce pollution (Jones, 1998). Single facility pricing may be for the objective of covering the construction costs or reducing congestion on a particular section. If the objective is to generate revenue, the scale should be adequate to prevent 'rat running' and bypassing.

2.3.3 Charged period

The charged period is closely related to the objectives of the scheme (Jones, 1998). Many time periods could be used. A charge could be installed 24 hours a day when revenue raising is a major issue; for example, in Oslo. It could be applied only to the daytime for reducing congestion and pollution. At weekends some reasons for having no charge are that there are fewer problems and the scheme can gain more public acceptance (MVA, 1995).

2.3.4 Charging level

The level of charge is dependent on the policy objectives and local circumstances (Jones, 1998). For example, a low charging level could be applied for generating revenue, e.g. in Norway's cities, while a high charging level could be used for reducing traffic and pollution, e.g. in Singapore (Small and Gomez-Ibanez, 1998), as well as social benefit optimality. The level of charge could vary by categories of user or vehicle (e.g. high charge for vehicles which cause the problem, and low or free for others), by time of day (e.g. same charge all day, charge peak time only, or charge all day with higher charges in peak times), by areas (e.g. high charge in the central area and low charge in the suburbs), and by direction of traffic (e.g. inbound only or both directions).

2.3.5 Charging basis

Two broad charging bases are categorised in the design: point-based and area-based (MVA, 1995; Milne, 1992; Jones, 1998). There are two types of point-based charging: cordon-based and cellular system, while there are five types of area-based charging: supplementary licence, time-based, distance-based, congestion-based and externality-based. These are described as follows.

Firstly, for point-based charging, drivers are charged when entering specific areas, defined by a single or series of boundaries. The charge is directly dependent on the number of boundary crossings made by the vehicle (Milne, 1992). Two types of point-based charging: cordon-based and cellular systems are suggested (MVA, 1995). Cordon-based systems involve one, two or more boundary lines around a specified area, and sometimes with screen lines. For example, single toll cordons have been implemented around three Norwegian cities. Cellular systems include many cells; for example, a system of hexagonal cells, each with a radius of about a mile.

Secondly, for area-based charging, many types have been considered.

A supplementary licence system requires a licence to be purchased for and displayed on any vehicle used within a charged area (May, 1975). This system had been used in Singapore since 1975, before being replacing by an automatic point-based charging system, electronic road pricing (ERP) in 1998 (see URL: www.lta.gov.sg/erp/index.html). While the original Singapore scheme used manual enforcement, enforcement can now be achieved by video or digital camera studied for Leeds (Richards and Harrison, 1999) and London (GOL, 2000).

Distance-based charging involves a charge calculated from the distance travelled within a charged area. This charging basis would be predictable based on route choice, and would not lead to dangerous driving behaviour (Milne, 1992; MVA, 1995).

Time-based charging involves a charge calculated from the time spent travelling within a charged area. This charging method is perceived by the public as a fair system (Thorpe et al., 2000). However, it leads to fast driving, which in turn may induce unsafe driving behaviour (Bonsall and Palmer, 1997).

Congestion-based (delay-based) charging is that vehicle users are charged when using their vehicles on a congested road in a charged area but they are not charged when the road is not congested. For example in the study for Cambridge, a congested road is specified as being when a vehicle using the road has four stops within 0.5 km, or when the time taken to travel any 0.5 km is above three minutes (Oldridge, 1995). The delay-based charging is related to congestion levels, so the charge tends to be difficult for users to predict. This regime also may induce unsafe driving behaviour (Bonsall and Palmer, 1997).

Externality-based charging involves a charge linked directly to the negative impact being caused by the vehicle (Jones, 1998); for example, the charge could be related to exhaust emissions from vehicles.

2.4 Summary

This chapter presented the general criteria and the charging system features, which are important in the design. These criteria and system features will be considered in setting integrated road pricing schemes in Bangkok, which were tested in the i-MODEs model (see Chapter 3) later in this research.

CHAPTER 3 Methodology

3.1 Basic concept

Traffic assignment models have been used to evaluate the performances of road pricing scheme in several on-desk studies, see e.g. May and Milne (2000), May et al (2002), Sumalee (2004), and Sumalee et al (2005). The principle of traffic model is based on the equilibrium assignment of traffic flows on different routes taking into account the congestion effect/feedback. Simultaneously, the relationship between the demand and supply must be satisfied. The impact of road pricing in terms of route diversion and trip depression can be evaluated directly by this type of traffic model. Nevertheless, this type of model may not evaluate directly the impact in terms of modal shift and induced congestion on public transport system (due to diversion of travelers from cars to public transport).

The concept of multi-modal transport model was then proposed to allow for such effects to be explicitly considered. There has been a long history of the development of an underlying transit or multi-modal network model. Boyce and Bar-Gera (2004) provided an excellent review on this topic. One of the main difficulties in modelling public transport system is the representation of travellers' strategies in choosing the service route and line which is different from the car driver. Earlier developments have been on the representation of the static strategic route choice of transit passenger (Chiriqui and Robillard 1975; Spiess and Florian 1989; De Cea and Fernandez 1993). These models were later extended to case with a congested network where waiting time and in-vehicle costs (crowding effect) are functions with passenger flows (De Cea and Fernandez 1993; Wu et al. 1994). The resulting congested transit model involves the asymmetric travel cost function and hence the equilibrium condition for the transit assignment problem is formulated as a variational inequality (VI). In relation to the congested transit network, the limitations of explicit capacity constraints in static assignment models for the transit services are well recognized in the literature (De Cea and Fernandez 1993; Lam et al. 2002; Comminetti and Correa 2001). Sumalee et al (2009) recently proposed a transit model considering the seat allocation and seat capacity constraint explicitly. Extensions of the transit model to the case with multi-modal trip have also been made considering a single journey comprised of different modes, e.g., park and ride, (Fernandez et al. 1994) and a complex fare structure, e.g., transfer fare (Lo et al. 2003). Uchida et al (2007) utilized the multi-modal network model to study the network design problem which aims to optimize the frequency of public transport service.

3.2 Multi-modal traffic assignment

In this study, the multi-modal traffic assignment was used as the evaluation tool of different road pricing package together with the public transport improvement/investment schemes. The model which has been previous developed by DLT (2010), called "i-MODEs" (Integrated MODEs model of Bangkok) based on EMME3 package was updated, so that the effects of elastic demand condition can be fully considered.

The current version of the Bangkok EMME3 model is capable of evaluating the car route choice, modal split, public transport passenger route choice (Figures 3.1 and 3.2). However, the fixed total demand is considered to be unrealistic when applied to the case of road pricing policy. Also, in the current model, it is assumed that travelers are free to choose between the auto and public transport based on the dis-utilities they experienced. Such assumption is not realistic as some of the travelers may be captive to some mode of travel due to their geographical location or car availability. The elastic demand conditions and the separate modeling of captive/non-captive demand will be introduced in this chapter. For the non-captive demand, the elastic demand condition will be introduced at the higher level of the modal split model using the log-sum of the total travel dis-utility of both modes. For the captive demand, separate elastic demand functions are setup for auto and public transport. The project will evaluate an appropriate value of demand elasticity using secondary dataset and values reported in literature.

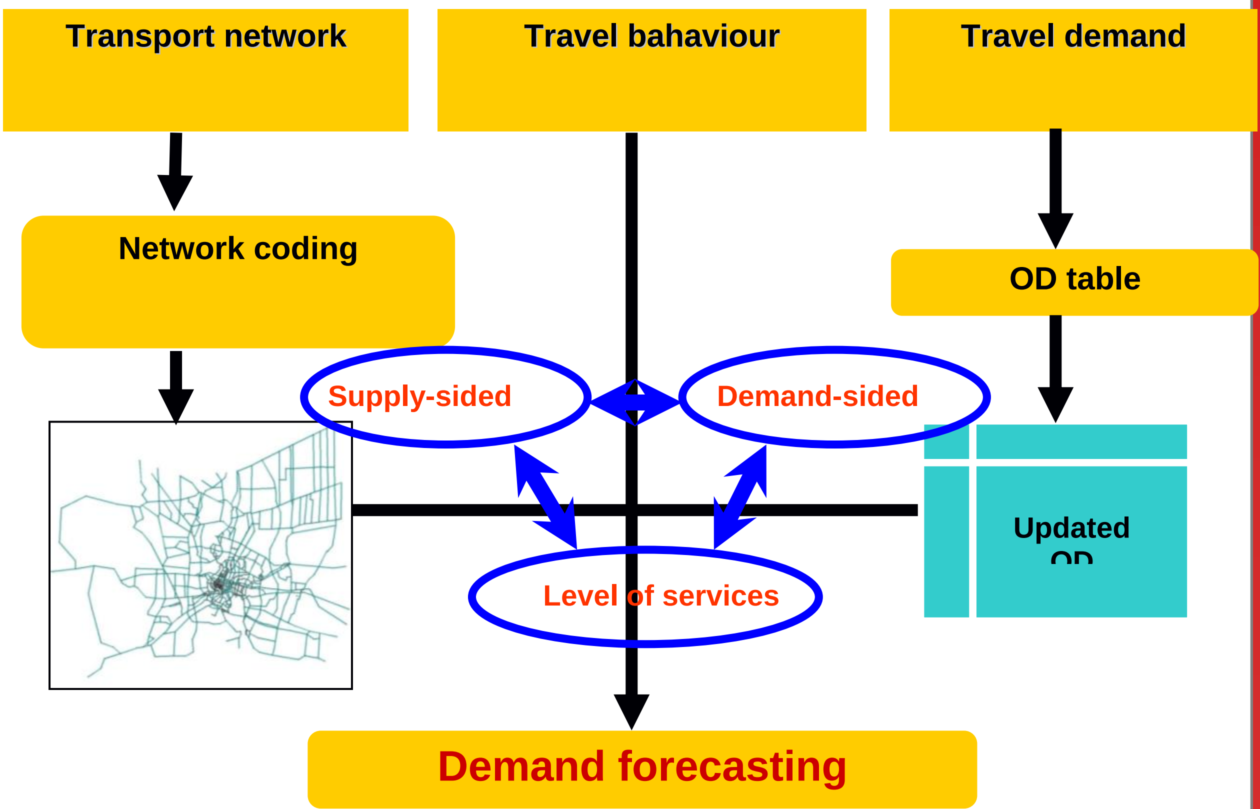

Figure 3.1 Framework of the integrated MODEs model of Bangkok (i-MODEs)

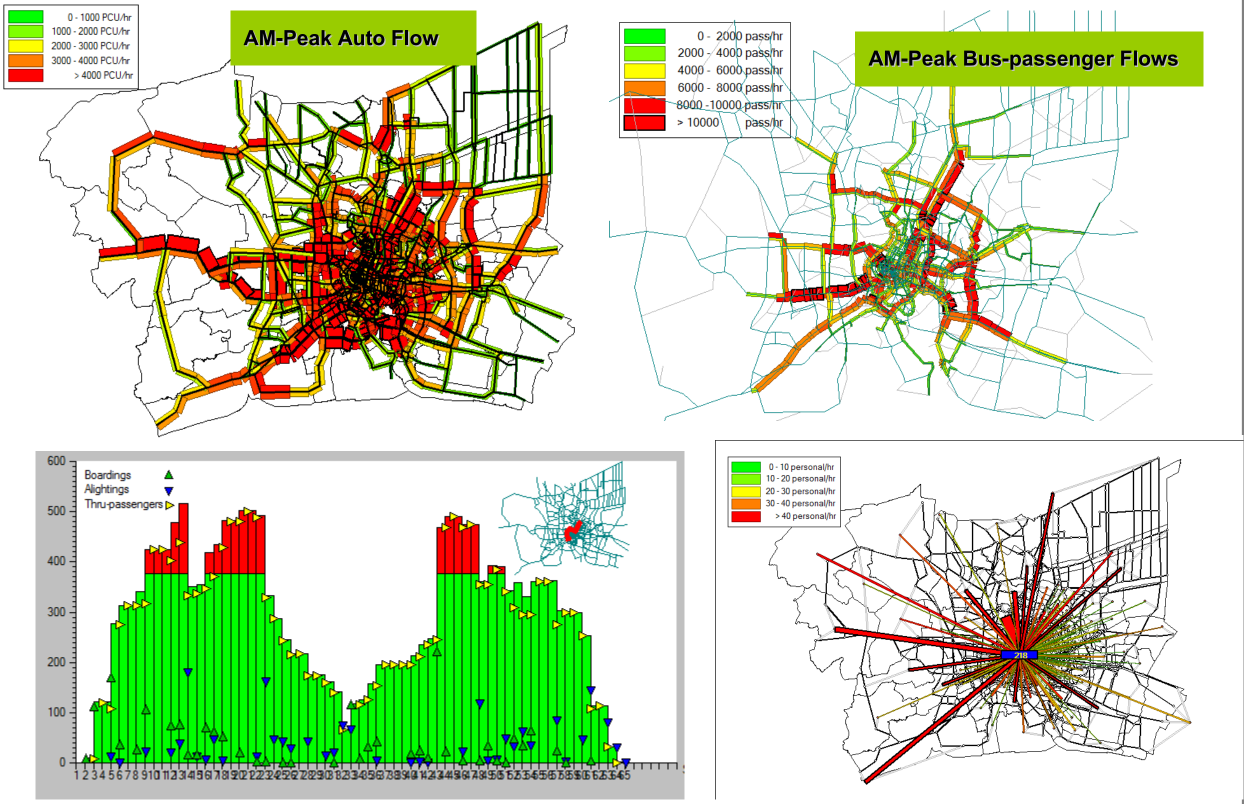

Figure 3.2 Example of outputs from the integrated MODEs model of Bangkok (i-MODEs)

3.3 Model description

In this study, the EMME models of road and public transport network is setup for the Bangkok metropolitan area (BMA) in 2007, 2010, 2019 and 2029. The BMA includes Bangkok and five surrounding provinces, i.e. Nonthaburi, Samut Prakan, Pathum Thani, Samut Sakhon and Nakhon Pathom. It covers an area of 7,762 km2 and has an approximate population of 9,014,470 as of December 31, 2008 (DOPA, 2009). The road network, including the national highways and major arterial roads within BMA, is shown in Figure 3.3. The BMA network consists of 243 zones, 58,806 OD pairs and 4,598 road links, which are represented by green lines in Figure 3.3.

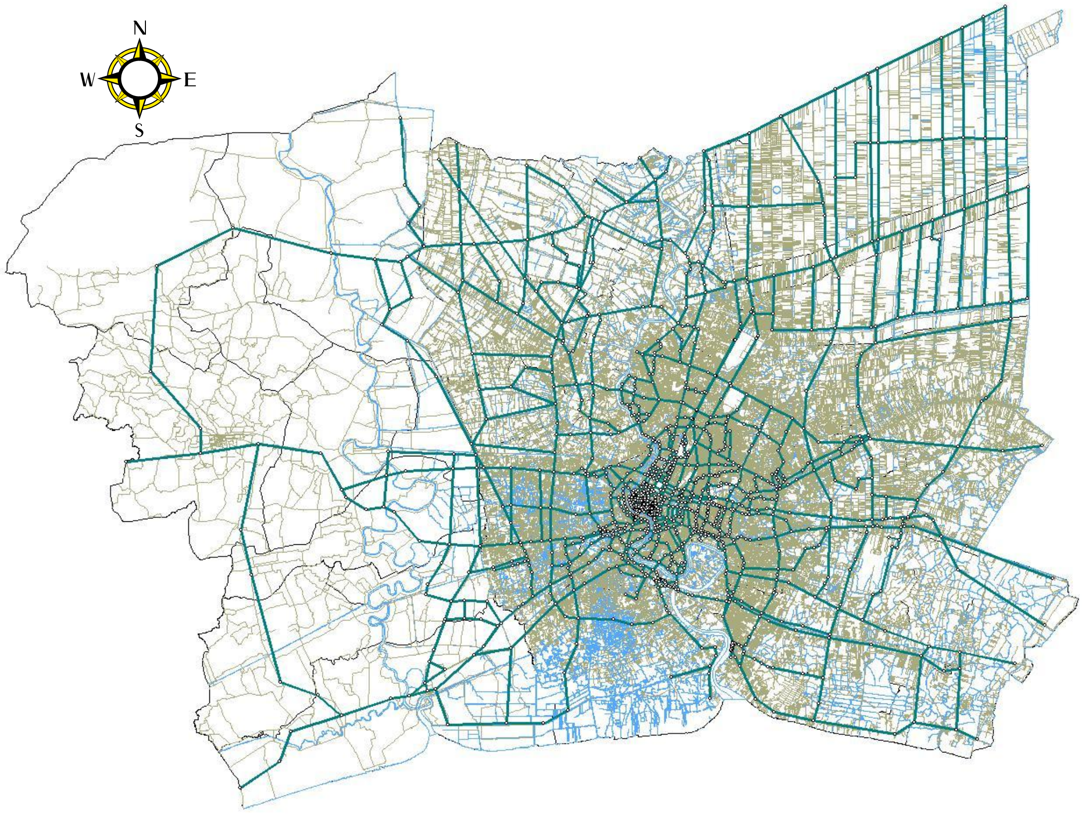

Figure 3.3 Bangkok metropolitan area network

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 2010 and two future networks in 2019 and 2029. The 2019 and 2029 networks are considered as the first and second stage of MRT extension will be completed in these two years. This study aims at finding the impact of the implementation of road pricing and public transport services on traveler's choice and network conditions in 2010, 2019 and 2029. The road and public transport network is the same in 2007 and 2010. 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 3.4, 3.5 and 3.6 respectively shows the railway services (BTS and MRT) in the 2010, 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.

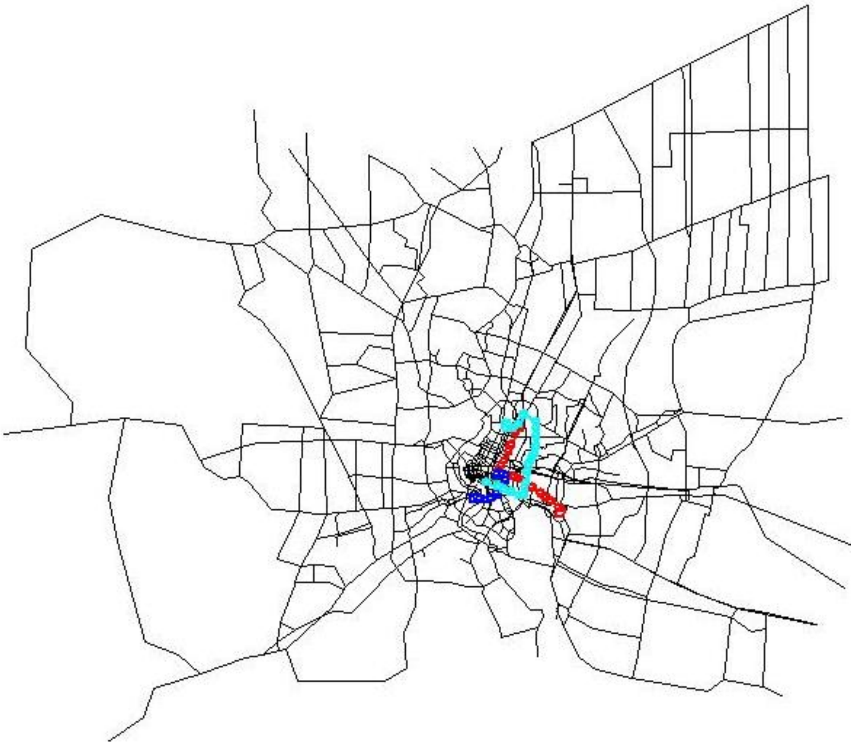

Figure 3.4 BTS and MRT network in 2010

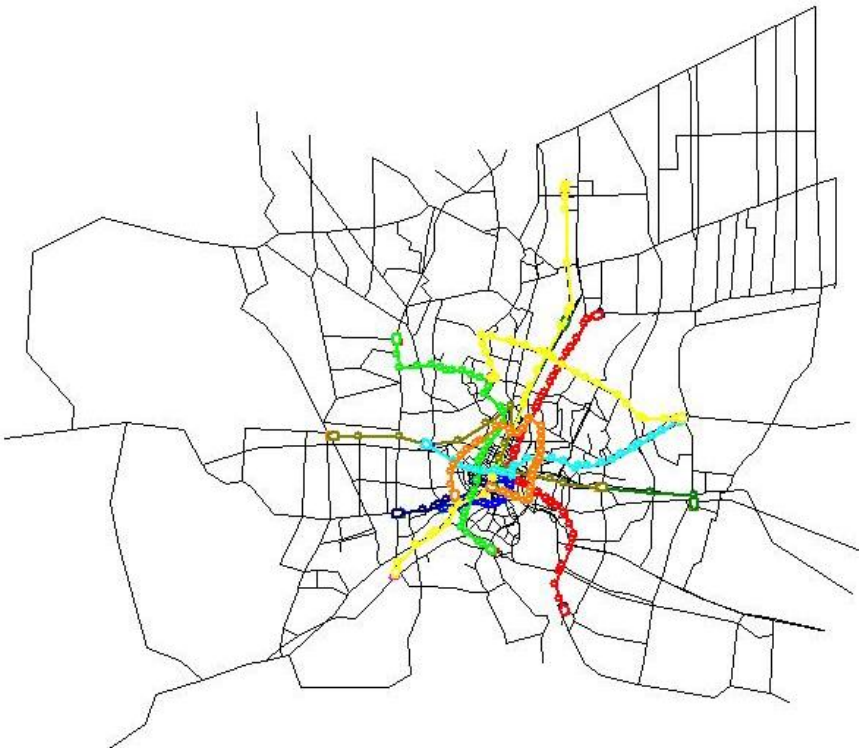

Figure 3.5 BTS and MRT network in 2019

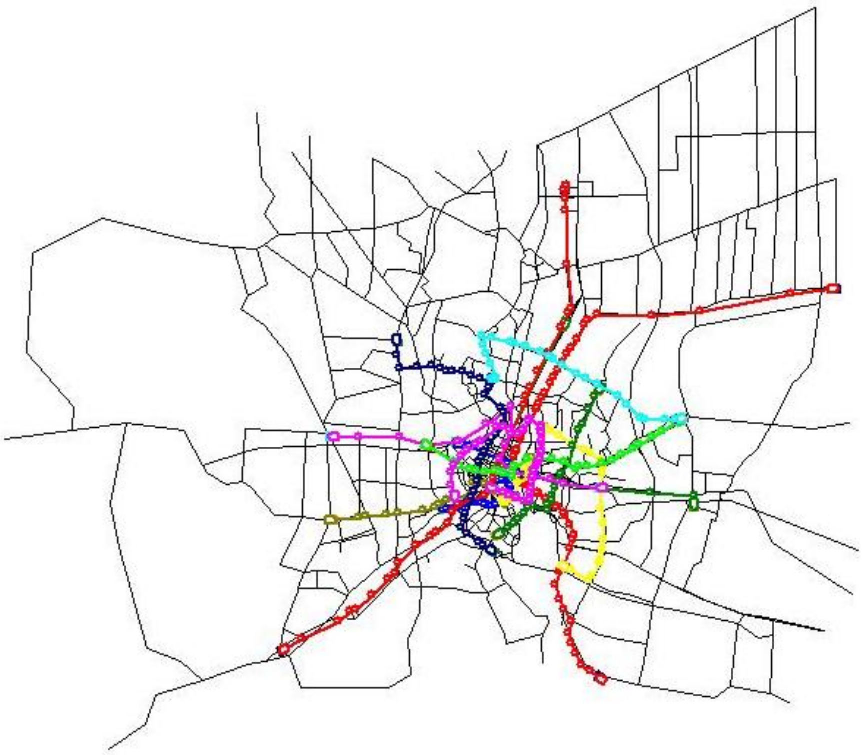

Figure 3.6 BTS and MRT network in 2029

Table 3.1 below gives the summary of the change of railway services (BTS and MRT) among these four networks (2007, 2010, 2019 and 2029). For the future 20 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 3.1 Summary of railway services in 2007, 2010, 2019 and 2029

Year	2007	2010	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

3.3.1 Link and transit travel time functions

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:

$$t_{k'a'}^{rail}=\frac{L_{a'}}{S_{k'}^{rail}} \quad (3)$$

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

3.3.2 Utility functions and nested logit for non-captive demand

In this study, a nested logit model is adopted to capture the choice behavior of the non-captive demand. For the non-captive demand, travelers will change their mode choice (in this case between auto and public transport) based on the utilities they experienced. In the nested logit model, the potential non-captive demand for OD pair *d* first choose between the choice of travel and not-travel based on the utility of these two choices. Then, the demand chose to travel make another choice between auto and public transport based on the utilities from these two modes. The utility function for travelers in OD pair *d* making the choice of auto (U_d^{auto}) is defined as follows:

$$U_d^{auto}=-ASC_d-\gamma_{travel}\times u_d^{auto}-FC_d \quad (4)$$

where ASC_d is the alternative specific constant for OD pair *d.* This constant could be estimated from the calibrated auto and public transport OD matrices, which will be discussed in Section 3.4.1; u_d^{auto} is the auto travel time between OD pair *d*; FC_d is the fuel cost for OD pair *d*. This fuel cost could be calculated based on the travel distance of OD pair *d* (D_d) and the unit fuel cost, which is 3 Baht/km in this study. For the public transport mode, the utility function between OD *d* (U_d^{PT}), which is the same for both bus and rail, is defined as follow:

$$U_d^{auto} = -\gamma_{travel} \times u_d^{PT} - F_d - \gamma_{wait} \times w_d - p_d \tag{5}$$

where u_d^{PT} is the public transport travel time between OD pair *d*. This public transport travel time included the in-vehicle travel time and the boarding time; F_d is the total fare paid for traveling between OD pair *d*; γ_{wait} is the value of time for waiting and is taken as 1.46 Baht/min in this study; w_d is the total waiting time spend in taking public transport to travel between OD pair *d*; p_d is the non-air-conditioned penalty for travelers travel between OD pair *d* and is taken as 5 Baht per boarding of any non-air conditioned public transport services. This non-air conditioned penalty is imposed only on the non-air conditioned public transport services to reflect passengers' preference of air conditioned services. Based on the above utility functions, the demand of auto and public transport users for OD pair *d* are, respectively, defined by equation (6a) and (6b)

$$Q_d^{auto\_nc} = Q_d^{travel\_nc} \frac{\exp\left(\xi_l U_d^{auto}\right)}{\exp\left(\xi_l U_d^{auto}\right) + \exp\left(\xi_l U_d^{PT}\right)} \tag{6a}$$

$$Q_d^{PT\_nc} = Q_d^{travel\_nc} \frac{\exp\left(\xi_l U_d^{auto}\right)}{\exp\left(\xi_l U_d^{auto}\right) + \exp\left(\xi_l U_d^{PT}\right)} \tag{6b}$$

where $Q_d^{auto\_nc}$, $Q_d^{PT\_nc}$ and $Q_d^{travel\_nc}$ are respectively the non-captive auto demand, non-captive public transport demand and non-captive travel demand for OD pair *d*; ξ_l is the elasticity parameter for the logit split model between auto and public transport. For modeling the choice between travel and not-travel, the utility for the choice of travel in OD pair *d* (U_d^{travel}) is represented by the logsum of the auto and public transport utilities:

$$U_d^{travel} = \frac{1}{\xi_l} \ln\left[\exp\left(\xi_l U_d^{travel}\right) + \exp\left(\xi_l U_d^{PT}\right)\right] \tag{7}$$

For the utility of not-travel ($U_d^{not-travel}$), no specific functional form could be defined and could only be estimated from the demand elasticities, which will be discussed in Section 3.4.2. With the above definitions, the travel and not-travel demand for OD pair *d* are, respectively, defined by equation (8a) and (8b),

$$Q_d^{travel\_nc} = N_d \frac{\exp\left(\xi_u U_d^{travel}\right)}{\exp\left(\xi_u U_d^{travel}\right) + \exp\left(\xi_u U_d^{not-travel}\right)} \quad (8a)$$

$$Q_d^{not-travel\_nc} = N_d \frac{\exp\left(\xi_u U_d^{not-travel}\right)}{\exp\left(\xi_u U_d^{travel}\right) + \exp\left(\xi_u U_d^{not-travel}\right)} \quad (8b)$$

where N_d, and $Q_d^{not-travel\_nc}$ are respectively the total non-captive demand and not-travel demand for OD pair *d*; ξ_u is the elasticity parameter for the logit split model between travel and not-travel. Besides the parameters that could be externally input (i.e. *FC*, γ_{travel}, etc), ASC_d, N_d and $U_d^{not-travel}$ are the remaining parameters in the above nested logit model that need to be estimated. The details for estimating these parameters could be found in Section 3.4. As ASC_d and $U_d^{not-travel}$ are calibrated in the current study, the elasticities of the of the logit split models will be aggregated in these calibrated parameters. Thus, the elasticity parameters ξ_u and ξ_l is assumed to be unity in the current study for simplicity.

3.3.3 Captive auto and public transport demand

Apart from the non-captive demand, which is estimated by the nested logit model discussed in the previous section, this study also considered the captive counterparts. Captive demand refers to the travelers that are not able to change their mode of travel due to their geographical location or availability of car. As the captive demand will not change their mode choice, the auto and public transport demand for this kind of travelers is defined by the following elastic demand functions:

Captive auto demand: $$Q_d^{auto\_c} = Q_{d0}^{auto\_c}\left[1 + e_{fuel}\left(\frac{C_d^{auto} - C_{d0}^{auto}}{C_{d0}^{auto}}\right)\right] \quad (9a)$$

Captive public transport demand: $$Q_d^{PT\_c} = Q_{d0}^{PT\_c}\left[1 + e_{fare}\left(\frac{C_d^{PT} - C_{d0}^{PT}}{C_{d0}^{PT}}\right)\right] \quad (9b)$$

where $Q_d^{auto\_c}$ and $Q_d^{PT\_c}$ are respectively the captive auto and public transport demand for OD pair *d*; C_d^{auto} and C_d^{PT} are respectively the travel cost of auto and public transport demand for OD pair *d*; C_{d0}^{auto} and C_{d0}^{PT} are respectively the travel cost of auto and public transport demand for OD pair *d* in the calibrated base case (i.e. the 2007 network); $Q_{d0}^{auto\_c}$ and $Q_{d0}^{PT\_c}$ are respectively the captive auto and public transport demand for OD pair *d* in the base case; e_{fuel} and e_{fare} are respectively the elasticities of demand with respect to the fuel cost and public transport fare.

3.3.4 Combined modal split and assignment process

In this paper, the multi-modal transportation system in BMA is formulated as a combined modal split and assignment process. In the proposed process, auto and public transport (transit) demand will be separately assigned to the same network for determining the corresponding travel utilities which will be used in the modal split. Due to the interdependence of the modal split and auto/transit assignment process, an iterative approach is adopted for this combined modal split and assignment model (Figure 3.7). The proposed iterative approach is adopted separately for the captive and non-captive demand. For the non-captive demand, the iteration starts with the potential OD matrix for the total non-captive demand (N_d), which is estimated from the calibration process describe in Section 3.4.2. By using Equation (6) and (8), the non-captive auto demand ($Q_d^{auto\_nc}$), non-captive public transport demand ($Q_d^{PT\_nc}$) and the not-travel demand for the non-captive travelers ($Q_d^{not-travel\_nc}$) could be found. For the captive demands, the iteration will be considered separately for the auto and public transport users. The captive auto demand ($Q_d^{auto\_c}$) and captive public transport demand ($Q_d^{PT\_c}$) could be respectively estimated from Equation (9a) and (9b). Then, the captive and non-captive demand for auto (public transport) will be summed for the auto (transit) assignment. The auto and transit assignment in the proposed model will be solved by using EMME (INRO, 2008) and the results (i.e. travel times and distance of auto and public transport users) will be used to update the modal split models and the elastic demand functions. With these updates, the OD matrices will be re-estimated and the above process will be repeated until the differences of OD matrices between successive iterations are less than the predefined tolerance.

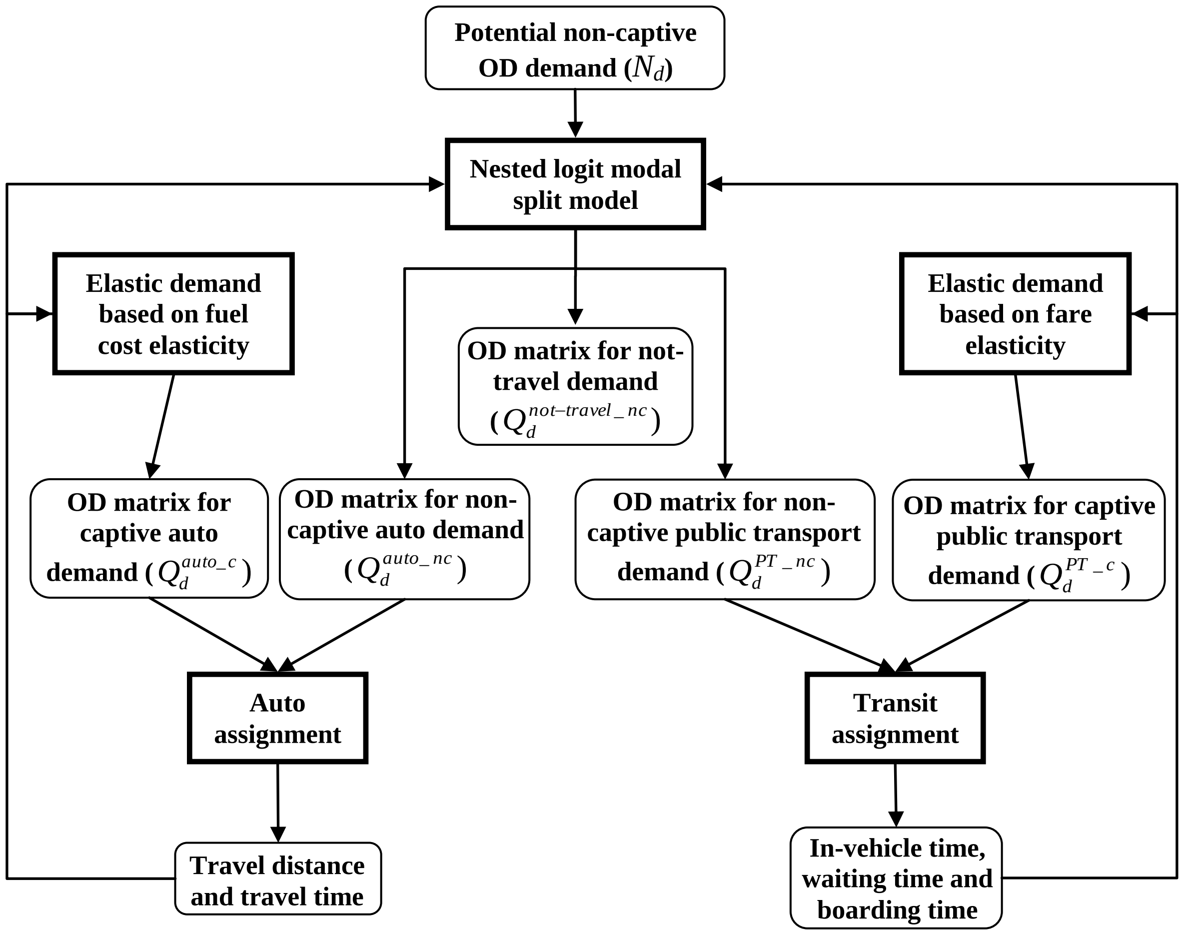

Figure 3.7 Combined model split and assignment process

3.4 Model calibration

In order to setup the model described in the previous section, the alternative specific constant (ASC_d), potential non-captive demand (N_d), and not-travel utility ($U_d^{not-travel}$) for each of the OD pair are needed. But in reality, these information are less available and more difficult to collect as compared to traffic volumes and public transport passenger counts. Thus, this section introduces the procedure for calibrating these parameters based on: i) observed link volume/speed; ii) public transport passenger count; iii) fuel cost elasticity; iv) public transport fare elasticity. In this study, as the above information is in 2007, the base case is calibrated for the 2007 network of the Bangkok Metropolitan Area (see Section 4). The calibration will be completed in two steps: First, calibrate the total travel demand and ASC for each OD pair. Then, the potential demand and not-travel utility for each OD pair is estimated.

3.4.1 Calibration framework for ASC and total travel demand

As the link volumes and public transport passenger counts used in the calibration is undistinguishable between the captive and non-captive demands, the calibrated auto ($\mathbf{Q}^{auto}$) and public transport ($\mathbf{Q}^{PT}$) OD matrix are the sum of the captive and non-captive demands. After calibration, the captive and non-captive demands for auto and public transport are estimated by applying the percentage of captive demand for each these modes in the base year (i.e. 2007). The framework for calibrating the ASCs and total travel demand ($\mathbf{Q}^{travel}$) for BMA is summarized in a flowchart (Figure 3.8) and the details of the calibration process is described in the following procedure:

Step 1: For each of the zone defined in the Bangkok metropolitan model, hourly trip attraction and trip production information is extracted from the Extended Bangkok Urban Model (eBUM) (Office of Transport and Traffic Policy and Planning, Ministry of Transport, Thailand) ***(a)***.

Step 2: Evaluate the entropy between each of the OD pair defined in the network ***(b)***. Entropy between OD pair d, E_d, is defined as:

$$E_d = \exp\left(-\frac{u_{fd}}{\bar{u}_f}\right) \tag{10}$$

where u_{fd} is the free flow travel time between OD pair d and $\bar{u}_f$ is the mean of free flow travel time between all OD pairs within the network. With this definition of entropy, an OD pair with short free flow travel time will gives a higher entropy values.

Step 3: Matrix balancing method (Furness, 1965) is adopted in this trip distribution step for finding the prior OD matrix ***(c)***. In this matrix balancing approach, trip production and attraction data from EBUM ***(a)*** will take as constraints while the entropy ***(b)*** will be the weight for distribution. Thus, based on the definition of entropy, more demand will be distributed to OD pairs with shorter free flow travel time. Noted that the prior OD matrix estimated in this step only gives a general pattern of the OD matrix (such as OD pairs with relatively high or low demand) to serve as the starting point of the calibration in the subsequent steps. It does not give any estimation on the level of demand between any OD pairs.

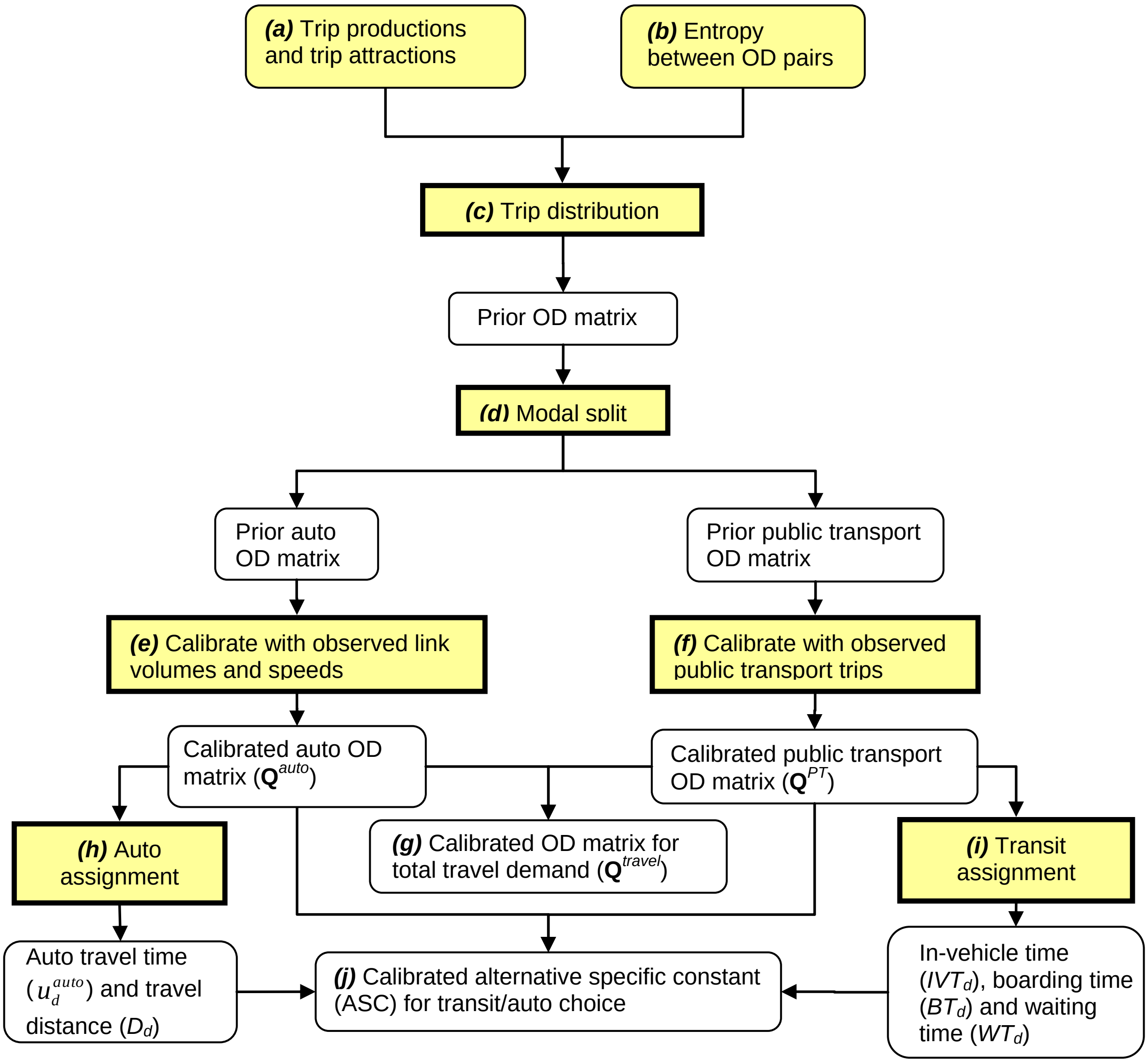

Figure 3.8 Calibration process

Step 4: With the prior OD matrix from the previous step, this modal split process will split the matrix into the prior OD matrices for auto and public transport ***(d)***. At this point, as there is no network conditions (e.g. travel time) that is needed in the logit modal split model (Equation 6 and 8), an arbitrary modal split (0.5) is adopted.

Step 5: The prior auto OD matrix from the previous step will be calibrated based on the observed link volumes and speeds ***(e)***. The details of calibrating this auto OD matrix could be found in Section 3.4.1.1.

Step 6: The prior public transport OD matrix from Step 4 will be calibrated based on the observed public transport passenger count ***(f)***. This matrix should be calibrated after the calibration of auto OD matrix as the auto link travel time is needed in the transit travel time function for transit assignment. The details of calibrating this public transport OD matrix could be found in Section 3.4.1.2.

Step 7: By summing up the calibrated auto OD matrix ($\mathbf{D}^{auto}$) from Step 5 and the calibrated public transport OD matrix ($\mathbf{D}^{PT}$) from Step 6, the calibrated OD matrix for total travel demand ($\mathbf{Q}^{travel}$) could be found ***(g)***.

Step 8: With the calibrated auto OD matrix ($\mathbf{D}^{auto}$), perform auto assignment in EMME to estimate the auto travel time and travel distance between each of the OD pair ***(h)***.

Step 9: With the calibrated public transport OD matrix ($\mathbf{D}^{PT}$), perform transit assignment in EMME to estimate the in-vehicle time, boarding time and waiting time for each of the OD pair ***(i)***.

Step 10: With the information from Step 8 and 9, and the calibrated auto and public transport OD matrices, ASC for each of the OD pair could be found by using Equation (4), (5) and (6) ***(j)***.

3.4.1.1 Calibration of auto OD matrix

In this study, two sources of data: observed hourly link count and observed speed, are used in the calibration of the auto OD matrix. Currently, there are 401 links with observed volume data (7.2% of the total number of link) and 847 links with observed speed data (15.2% of the total number of link) that could be used in the calibration. As the demand adjustment procedure in EMME, which adopts the gradient approach introduced in Spiess (1990), only takes in the observed link volumes for calibrating the auto OD matrix, a conversion of observed link speed to the equivalent link volume is necessary to optimize the use of available data. By rearranging Equation (1), the following function is adopted for finding the equivalent volume of link *a*, $\overline{V_a^*}$:

$$\overline{V_a^*} = C_a \sqrt[3]{\left(\frac{1}{0.73}\right)\left(\frac{S_a^{\max}}{S_a^*} - 1\right)} \tag{11}$$

where S_a^* and $S_a^{\max}$ are respectively the observed speed and speed limit of link *a*. The reason of having such conversion is that by matching the equivalent link volumes through the adjustment of auto OD matrix, the actual observed speed (and also the travel time) could be reproduced in the EMME model. After the above conversion and remove the observed speed information for links with both observed link count and speed data, there are 899 links (16.18% of the total number of links) with volume data for the auto OD calibration. Noted that for links with both link count and speed data, link count data will be used for calibration as it is more reliable than the equivalent volume data evaluated from the speed data.

3.4.1.2 Calibration of public transport OD matrix

In this study, two sets of observed data: bus passenger count of 116 bus lines and railway passenger count of 3 railway lines are used in the calibration of the hourly public transport OD matrix. These line data make up of 43% of the total number of public transport lines modeled in this Bangkok metropolitan model. Considering the above passenger count data, there are two major deficiencies for adopting them in calibrating the hourly public transport OD matrix. The first deficiency comes from daily rate of the passenger count information. It is difficult to determine by what proportion of this daily rate should be allocated in the peak hour for estimating the hourly rate. Second, these data only provides the total passenger counts for the whole public transport line. There is no information on the number of passengers in each of the segment of the public transport lines, which is crucial in calibrating the public transport OD matrix.

In order to resolve the first deficiency, additional information of total peak hour OD trips for public transport is used. Using this information to constrain the total hourly public transport trips, the 116 bus passenger count data will be used to define the relative distribution of bus trips among these 116 bus lines. Thus, in the calibration of public transport OD matrix, it is trying to match 1) Hourly passenger counts of the 3 railway lines *l'* ($T_{hr}^{rail\_l'}$); 2) Relative distribution of bus trips among the 116 bus lines based on the bus passenger count data for each of the line *l* ($T_{*}^{bus\_l}$), and; 3) Total peak hour OD trips for public transport. For the second deficiency, an iterative approach is proposed for estimating and updating the segment volume, which based on the line passenger counts and segment volume estimated from EMME. For addressing the above two deficiencies, an iterative approach with one outer loop and one inner loop is considered. The objective of the outer loop is to resolve the first deficiency by adjusting an hourly-bus-trip factor (α) such that the total hourly OD trips for public transport calibrated by the inner loop will match the observed one. For the inner loop, the objective is to adjust the public transport OD matrix and the estimated segment volumes ($\mathbf{V}_{seg\_n}^{bus\_l}$ and $\mathbf{V}_{seg\_n}^{rail\_l'}$) for matching: 1) observed hourly trips of each of the public transport lines ($T_{hr\_m}^{bus\_l}$ and $T_{hr}^{rail\_l'}$), and; 2) segment volumes evaluated by EMME ($\tilde{\mathbf{V}}_{seg\_n}^{bus\_l}$ and $\tilde{\mathbf{V}}_{seg\_n}^{rail\_l'}$). The following is the procedure for the proposed iterative approach in calibrating of the public transport OD matrix:

Step 1: Set *m* = 0 and assume an initial hourly-bus-trip factor α^0 for transforming the bus passenger data ($T_{*}^{bus\_l}$) of each bus line *l* into hourly bus trip $T_{hr\_0}^{bus\_l}$

Step 2: Set *n* = 0 and 1) For each bus line *l* assume a set of initial hourly bus segment volumes, $\mathbf{V}_{seg\_0}^{bus\_l}$, based on the hourly bus trip $T_{hr\_m}^{bus\_l}$; 2) For each rail line *l'* assume a set of initial hourly rail segment volumes, $\mathbf{V}_{seg\_0}^{rail\_l'}$, based on the hourly passenger count $T_{hr}^{rail\_l'}$.

Step 3: By using the transit demand adjustment procedure of EMME, which also adopt the gradient approach introduced in Spiess (1990), the bus and rail segment volumes, $\mathbf{V}_{seg\_n}^{bus\_l}$ and $\mathbf{V}_{seg\_n}^{rail\_l'}$ are used to adjust the public transport OD matrix.

Step 4: Assign the adjusted public transport OD matrix to the transit network and estimate: 1) EMME segment volumes, $\tilde{\mathbf{V}}_{seg\_n}^{bus\_l}$ and $\tilde{\mathbf{V}}_{seg\_n}^{rail\_l'}$, and; 2) EMME hourly trips, $\tilde{T}_{hr\_m}^{bus\_l}$ and $\tilde{T}_{hr}^{rail\_l'}$, for each of the bus line *l* and rail line *l'*.

Step 5: Evaluate R-squares between the set of EMME ($\tilde{T}_{hr\_m}^{bus\_l}$ and $\tilde{T}_{hr}^{rail\_l'}$) and observed ($T_{hr\_m}^{bus\_l}$ and $T_{hr}^{rail\_l'}$) hourly trips. Goto step 9 if both R-square of public transport (R_{PT}^2) and R-square of bus services (R_{bus}^2) is greater than 0.6; otherwise goto step 6.

Step 6: For each bus line *l* and rail line *l'*, calculate the EMME-to-observed ratio r_l and $r_{l'}$, which is defined as $r_l = \tilde{T}_{hr\_m}^{bus\_l} / T_{hr\_m}^{bus\_l}$ and $r_{l'} = \tilde{T}_{hr}^{rail\_l'} / T_{hr}^{rail\_l'}$, respectively.

Step 7: Update the bus and rail segment volumes, $\mathbf{V}_{seg\_n}^{bus\_l}$ and $\mathbf{V}_{seg\_n}^{rail\_l'}$, for each line *l* and *l'* by $\mathbf{V}_{seg\_n+1}^{bus\_l} = r_l \mathbf{V}_{seg\_n}^{bus\_l}$ and $\mathbf{V}_{seg\_n+1}^{rail\_l'} = r_{l'} \mathbf{V}_{seg\_n}^{rail\_l'}$ respectively.

Step 8: Set *n* = *n* + 1 and goto Step 3.

Step 9: Calculate the total hourly public transport OD trip from EMME ($\tilde{D}_{hr\_m}^{PT}$) by $\tilde{D}_{hr\_m}^{PT} = \sum_{d \in OD} \tilde{D}_{hr\_m}^{PT\_d}$ where $\tilde{D}_{hr\_m}^{PT\_d}$ is the hourly public transport trips for OD pair *d*. Then, update the hourly-bus-trip factor α^m by $\alpha^m = D_{hr}^{PT} / \tilde{D}_{hr\_m}^{PT}$ where D_{hr}^{PT} is the observed total hourly public transport OD trip.

Step10: If $\alpha^m \in [0.95, 1.05]$, stop; otherwise goto Step 11.

Step11: Set $T_{hr\_m+1}^{bus\_l} = \alpha^m \tilde{T}_{hr\_m}^{bus\_l}$, *m* = *m* + 1 and goto Step 2.

3.4.2 Estimation of potential demand and not-travel utility

The potential non-captive demand (N_d) and not-travel utility ($U_d^{not-travel}$) could be estimated by considering the following definition of fuel cost and public transport fare elasticities,

Fuel cost elasticity:
$$e_{fuel} = \frac{\partial Q_d^{auto\_nc}}{\partial FC_d} \frac{FC_d}{Q_d^{auto\_nc}} \tag{12a}$$

Fare elasticity:
$$e_{fare} = \frac{\partial Q_d^{PT\_nc}}{\partial F_d} \frac{F_d}{Q_d^{PT\_nc}} \tag{12b}$$

By Equation (4)~(8), Equation (12) is solved simultaneously for the potential non-captive demand (N_d) and the not-travel utility ($U_d^{not-travel}$) of each OD pairs, Potential demand: $$N_d = Q_d^{auto\_nc}\left(\frac{e_{fuel}}{FC_d}+1\right)^{-1} \quad (13a)$$

Not-travel utility: $$U_d^{not-travel} = \ln\left[\exp\left(U_d^{auto}\right)\left(\frac{e_{fuel}}{FC_d}+1\right)^{-1} - \exp\left(U_d^{auto}\right) - \exp\left(U_d^{PT}\right)\right] \quad (13b)$$

Based on: i) the calibration and assignment results from section 3.4.1; ii) the fuel cost and fare elasticities from survey, and; iii) the assumption of unity for the logit split elasticities (ξ_u and $\xi_{l\,l}$), the potential demand and not-travel utility of OD pair *d* could be directly estimated by Equation (13).

3.4.3 Calibration results

Following the procedures described in section 3.4.1.1 and 3.4.1.2, 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 total peak hour public transport OD trips. For the auto OD matrix, the scattered plot of observed link volumes versus the link volumes from assigning the calibrated auto OD ($\mathbf{D}^{auto}$) to the Bangkok metropolitan network is shown in Figure 3.9.

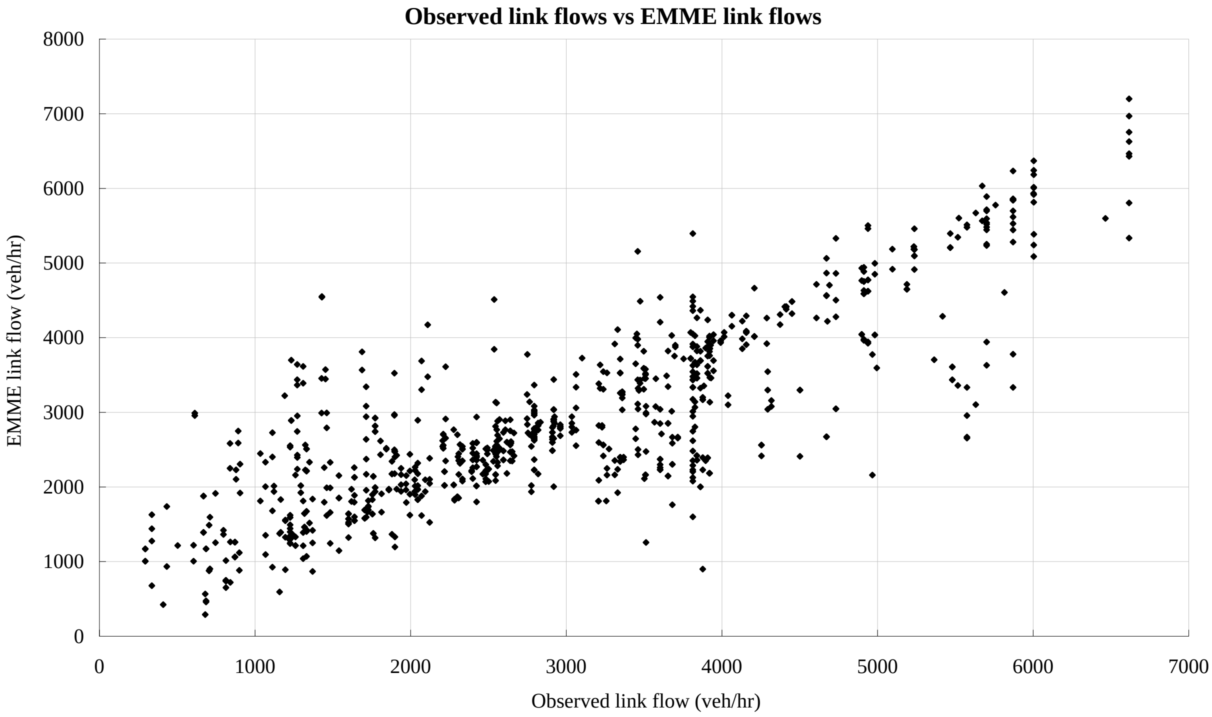

Figure 3.9 Observed link volumes vs EMME link volumes

R-square between the observed link flow and the EMME link flow is 0.7024. Based on the calibrated auto OD matrix ($\mathbf{D}^{auto}$) there are 839,252 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

($T_{hr\_m}^{bus\_l}$ and $T_{hr}^{rail\_l'}$) versus the hourly public transport trip ($\tilde{T}_{hr\_m}^{bus\_l}$ and $\tilde{T}_{hr}^{rail\_l'}$) from assigning the calibrated public transport OD matrix (**D**^{PT}) to the Bangkok metropolitan network is shown in Figure 3.10. Noted that the observed hourly trips for each of the bus lines ($T_{hr\_m}^{bus\_l}$) is adjusted based on the total peak hour bus trips of 350,000. The R-squares for all public transport lines is 0.5407 in this case. Based on this calibrated public transport OD matrix (**D**^{PT}) there are 315,829 travelers per hour choosing to use public transport which creates 428,842 bus trips and 88,272 trips on railway. Thus, on average, each traveler, who chooses to travel with public transport, makes 1.6 trips on either bus or rail. In Figure 3.10, the three line with hourly trip larger than 30,000 are the three railway lines (MRT Chaloem Ratchamongkhon Line, BTS Sukhumvit Line, and BTS Silom Line) included in the 2007 network.

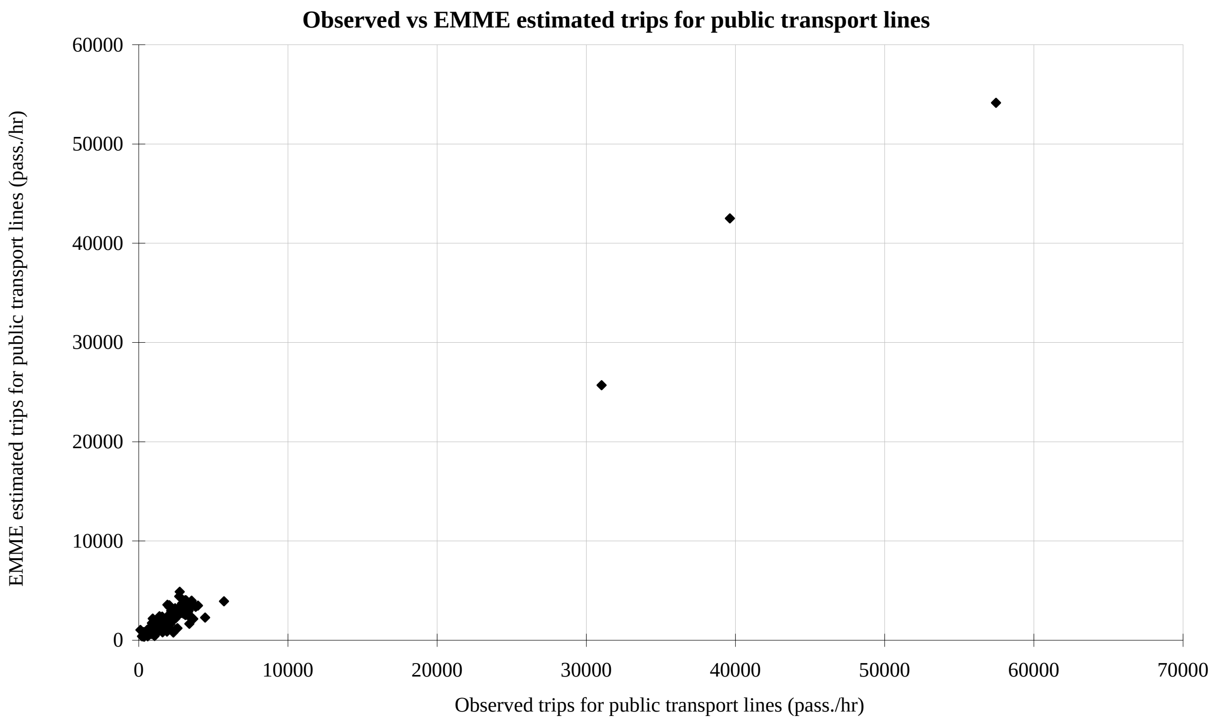

Figure 3.10 Observed public transport trips vs EMME public transport trips

3.5 Summary

This chapter presented basic concept and the study's framework, which is based on multi-modal transport model. The model, called "i-MODEs" (Integrated MODEs model of Bangkok) is based on EMME3 package was developed, which separately consider the captive and non-captive demand for the auto and public transport. In i-MODEs, the non-captive demand is modeled by a nested logit model that represents traveler's sequence of choices. This nested logit model is setup based on the utility for the choice of auto, public transport and not-travel. For the captive demand, elastic demand functions, which based on the travel cost, are setup separately for the auto and public transport demand.

The i-MODES model of road and public transport network is setup for the Bangkok metropolitan area (BMA). The model is based on combined modal split and assignment process. In this process, the captive and non-captive demand (for auto and public transport) is generated separately but assigned together to the same network for finding the network conditions (travel time, link volume, etc). In this study, the alternative specific constant, potential non-captive demand, and not-travel utility of the i-MODES model are calibrated based on: i) observed link volume/speed; ii) public transport passenger count; iii) fuel cost elasticity; iv) public transport fare elasticity.

CHAPTER 4 Impacts of the integrated policy of road pricing and public transport

4.1 Introduction

In this chapter, the calibrated multi-modal transportation system for Bangkok Metropolitan Area (BMA) is adopted to evaluate the impact of different road pricing schemes on mode and route choice of the travelers within BMA. 8 different road pricing schemes, which consists of distance-based and/or area-based charging method, will be tested in this chapter for finding the most beneficial scheme to be implemented in BMA.

4.2 The case of do-nothing (Base case in 2010)

Based on the calibrated auto and public transport OD matrices for 2007 (Section 3.4), potential demand for the non-captive travelers in 2010 is calculated by assuming a 2% annual growth in demand. Based on this matrix, the combined modal split and assignment process the 2010 network is completed by using EMME for obtaining the flows and travel times. Figure 4.1 and 4.2 respectively shows the spatial distribution of link volumes and the corresponding speeds of the BMA network in 2010. Generally, these figures give the results as expected: high link volumes (and low link speeds) around the downtown area of Bangkok and a low link volumes (and higher link speeds) in the surrounding areas. For the links on the western part of the network, the link volumes are relatively high (the link speeds are relatively low) despite their locations at the suburban area. It is because all the demand in the western part of BMA is only served by those few links and resulted in a high congestion level. On the other hand, the links located at the north-east part of BMA seems to be less congested than it is expected (Figure 4.2). This is mainly due to the aggregated definitions of zones and centroid connectors in those areas causing the demand not flowed to some of the links.

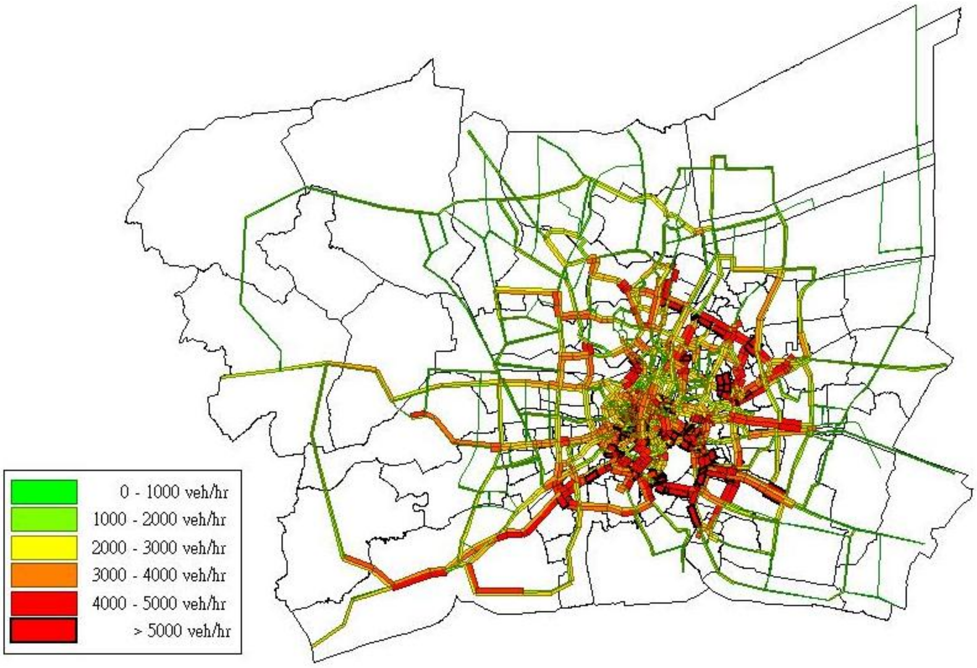

Figure 4.1 Spatial distribution of link volume

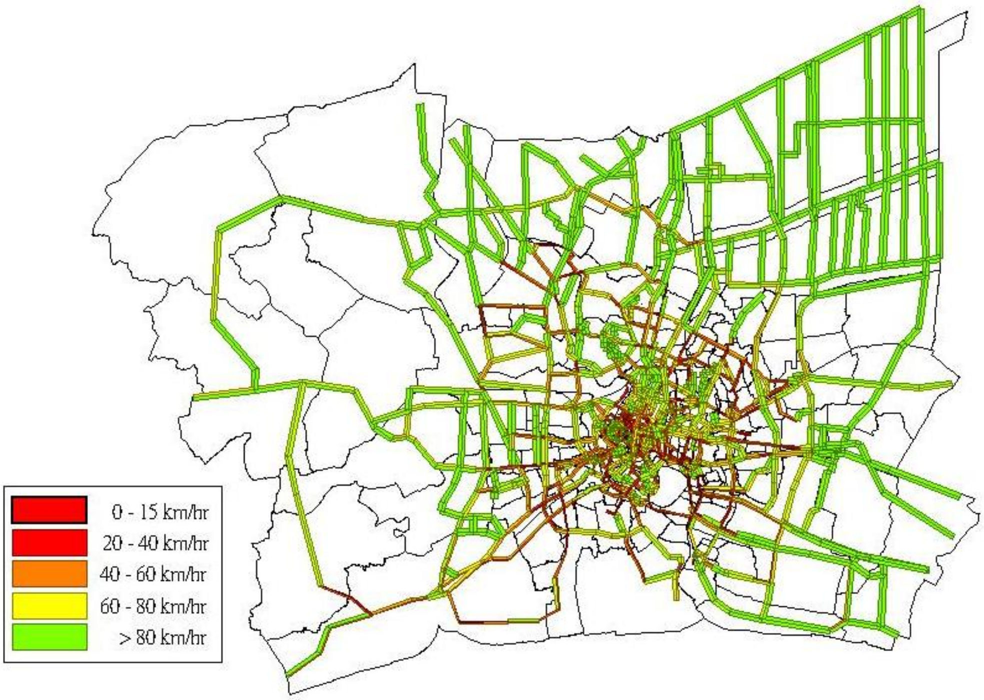

Figure 4.2 Spatial distribution of link speed

Figure 4.3 and 4.4 respectively show the distribution of auto trip length and public transport in-vehicle time from the assignments. For the based case in 2010, the mean auto trip length is 16 minutes and 90% of auto trips have a trip length less than 38 minutes. For Public transport, the in-vehicle time is 25 minutes while 90% of the in-vehicle time is less 65 minutes. Besides, the maximum trip length for auto and public transport trips are 106 minutes and 94 minutes respectively

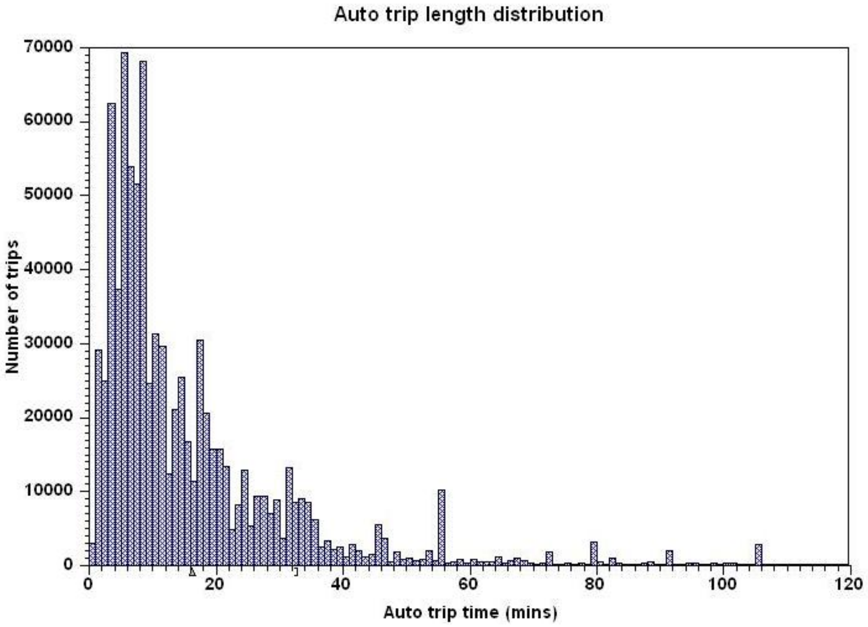

Figure 4.3 Distribution of auto trip length (min)

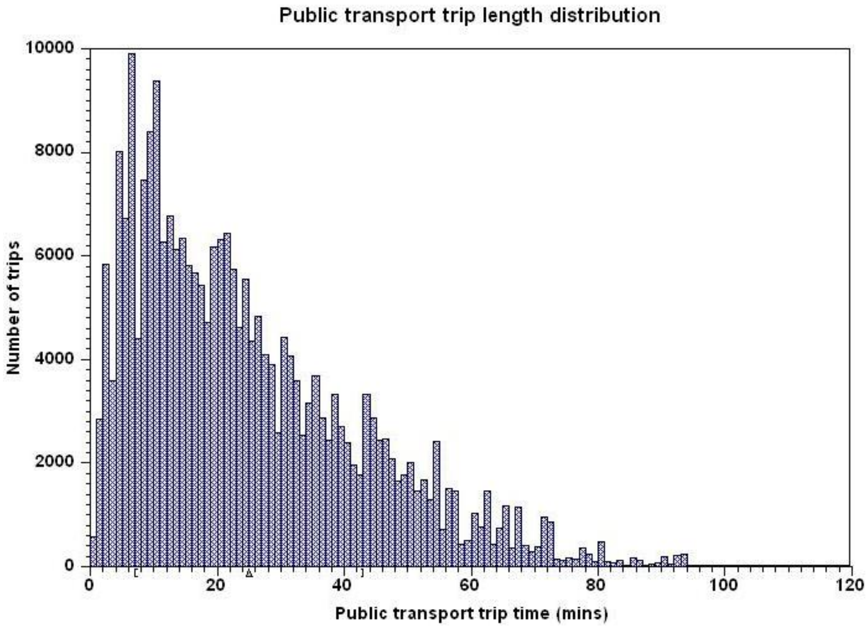

Figure 4.4 Distribution of public transport trip length (min)

Figure 4.5 and 4.6 respectively show the distribution of volume and the corresponding volume-to-capacity (V/C) ratio of the 4,598 links within the Bangkok metropolitan model. In Figure 4.5, it could be seen that the maximum link volume is up to 8,900 vehicle/hr and with a mean of 2,038 vehicle/hr. For the volume to capacity (V/C) ratio, the 2010 base network have a mean of 0.88 and 90% of links is with V/C ratio less than 2.85.

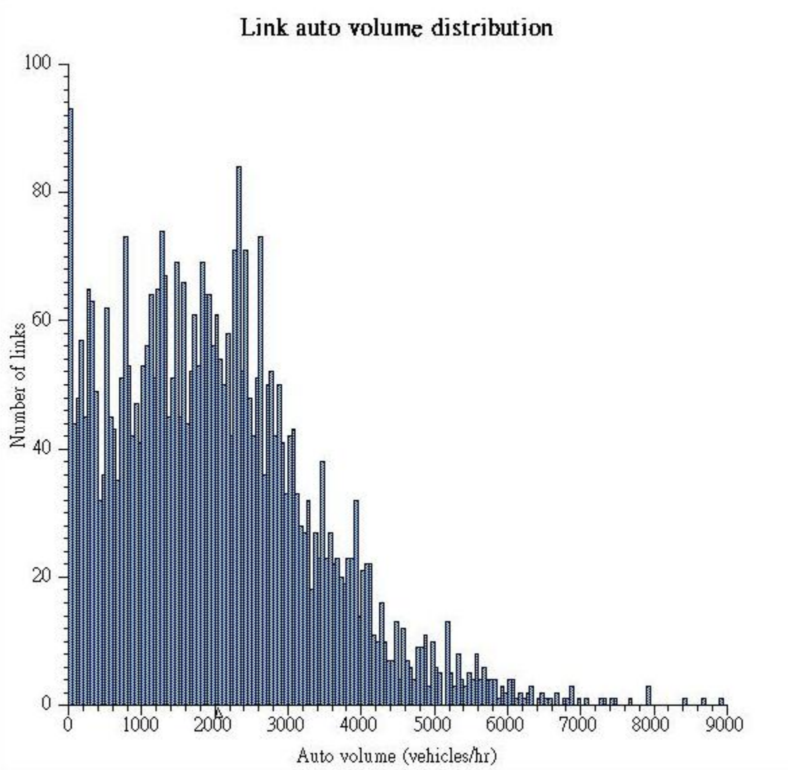

Figure 4.5 Distribution of link volume (veh/hr)

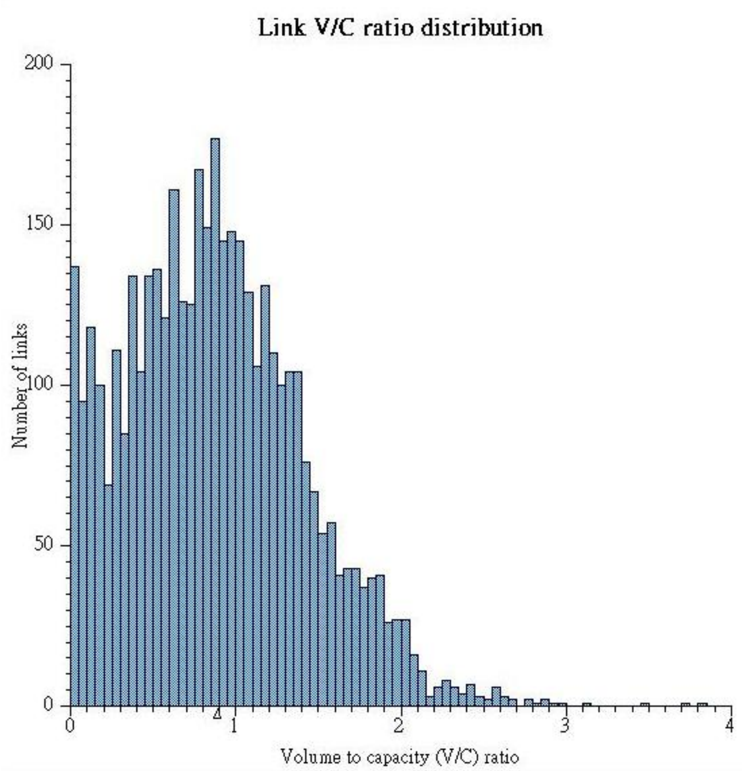

Figure 4.6 Distribution of link volume/capacity (V/C) ratio

Figure 4.7 shows the spatial distribution of the hourly public transport passenger within the 2010 network. As the public transport (bus, MRT and BTS) network does not cover the entire network, not all the links in Figure 4.7 have the public transport passenger volume. The public transport passenger volume varies from low volumes (0 – 2,000 passengers/hr) in the north-west and east part of the network, to high volumes (over 6,000 passengers/hr with a maximum of 13,183 passenger/hr) in the central and southern part of the network. The public transport volume is relatively high in two corridors leading to the south-west part of the network. Such high passenger volumes could be explained by the shift of demand from the auto modes due to the highly congested network in that area.

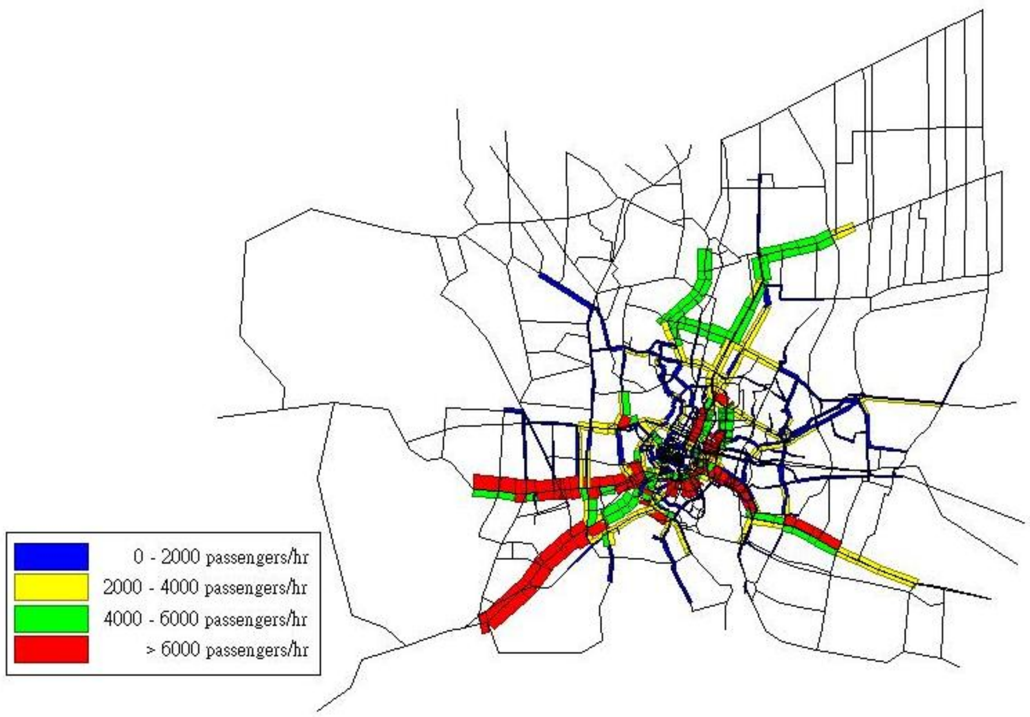

Figure 4.7 Spatial distribution of public transport passenger volume

4.3 Impacts of mass transit system alone

As mentioned in Section 3.3, extensions of MRT line will be opened in 2019 and 2029. The increased coverage of the MRT network from these years will provide an additional mode choice to travelers that are previously not covered by the railway network. As a result, the mode choice, route choice, link volume and travel time of the BMA network will be substantially affected. In order to better understand and prepare for the impact caused by the opening of MRT extensions, analyses on the change in mode choice and traffic volume is necessary. In this study, an annual growth rate of 2% is assumed for the demands (both captive and non-captive) in the future years.

Figure 4.8 shows the change of auto volumes within the BMA network in 2029 as compared to the auto volumes in 2010. The green (red) color indicates that there is an increase (decrease) in the link auto volume in 2029. In Figure 4.8, it could be seen that the majority of links have an increase in the auto volume despite to the openings of MRT extensions in 2019 and 2029. The increase in auto volume, which causes the 2029 network more congested, could be explained by the annual growth (2%) of the potential demand. In Figure 4.8, a large reduction in congestion appeared along the corridor located in the south-west part of the BMA network. By comparing Figure 4.8 to the extended BTS and MRT network in Figure 3.6, it could be concluded that such decrease is due to the implementation of the MRT line between Bang Sue and Thammasat University. This MRT line will attract the auto demand traveling from the south-west part of the network to central Bangkok and caused a decrease of auto volume along that corridor.

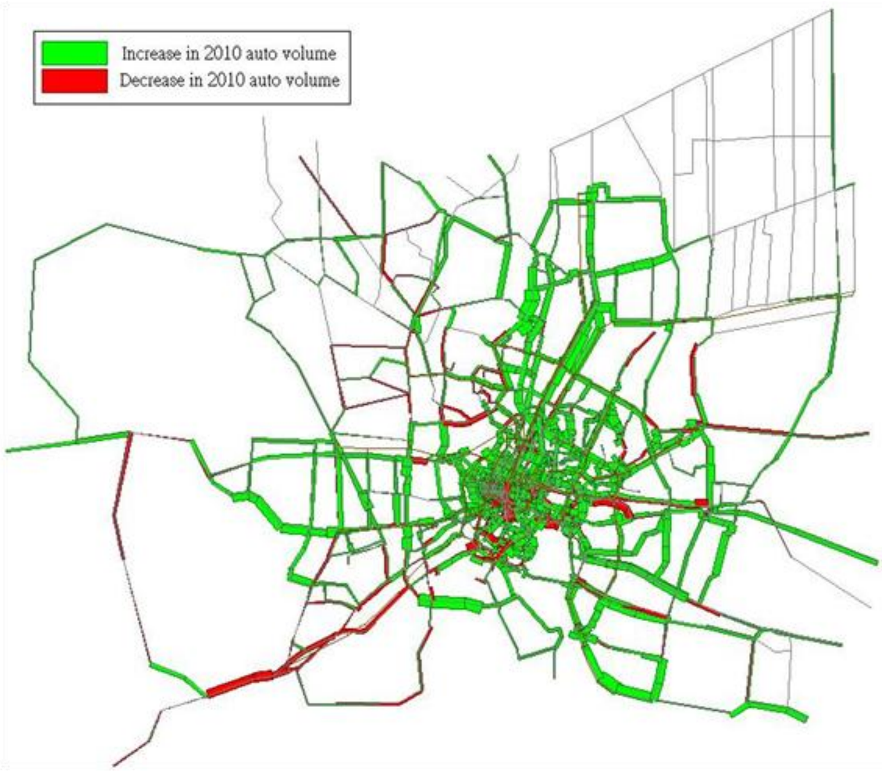

Figure 4.8 Change of auto volume in 2029

Figure 4.9 shows the change of demand for different mode of transport (auto, bus, MRT and BTS) from 2010 to 2029. The demand of MRT and BTS increases (290,000 passengers for MRT and 53,000 passengers for BTS) due to the shifting of the travelers from the congested road network to the railway system. For MRT, the increase in demand is also resulted from the increased coverage of the services over the future years. In Figure 4.9 the auto trip also increases from 2010 through 2019 to 2029 regardless of the extensions of MRT line in 2019 and 2029. It is because the shift of auto demand to public transports (especially to MRT) could not compensate the increase in auto demand, which comes from the 2% annual growth of the total potential demand, for reducing the overall auto demand. Due to the increase of auto volumes, the road network in BMA is becoming more congested with the average journey speed decreased from 44km/hr in 2010 to 41 km/hr in 2029. These results indicate that the sole introduction/extension of public transport services could not effectively shift the demand from auto to public transport (especially for the high demand growth scenario). This shed light on the necessity of road pricing which provides additional incentive to the auto users to switch their mode choice.

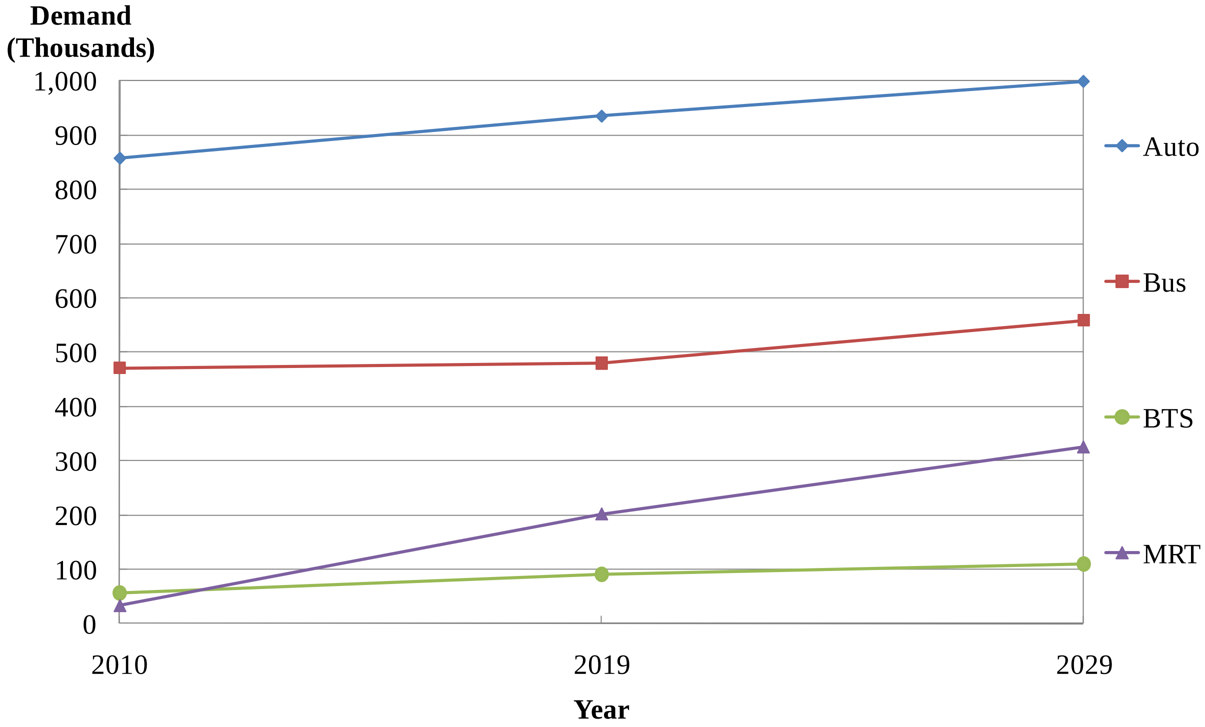

Figure 4.9 Demand of different mode for 2010, 2019 and 2029

4.4 Road pricing schemes

By adopting the ASCs, potential demands and not-travel utilities calibrated for the base case in 2007, the do-nothing scenario, which road pricing is not implemented, of 2010 network is solved by assuming a 2% annual growth in potential demands (Section 4.2 & 4.3). Based on the spatial distribution of link volume and volume-to-capacity ratio of the do-nothing scenario in 2010, three basic pricing schemes (location and charging method), are proposed for reducing the congestion. The three basic charging schemes are: 1) Radial toll scheme that will adopt a distance-based charging method (red lines in Figure 4.10); 2) Inner cordon toll scheme that covers most of the Pathum Wan district (green dotted-line in Figure 4.10) will adopt an area-based charging method, and; 3) Outer cordon toll scheme that located in the central of Bangkok Province (blue doted-line in Figure 3.10) will also adopt an area-based charging method. The detail locations of these basic pricing schemes are given as follows:

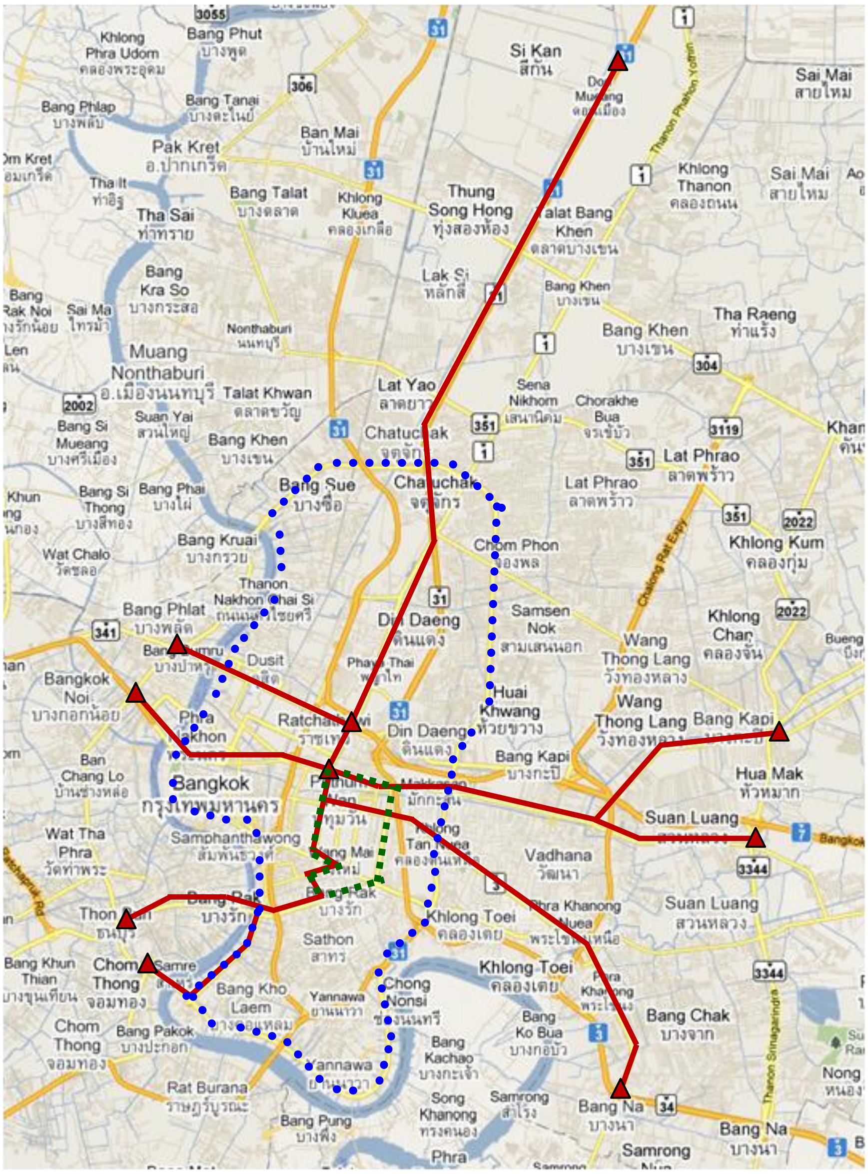

Figure 4.10 Locations for the radial toll, inner area toll and outer area toll schemes

Radial toll scheme

1. Wipha Wadi Rangsit road from Din Daeng junction to Don Muang railway station
2. Ratchawithi road from Din Daeng junction to Charan Sanitwong intersection
3. Phetchaburi road from Ratchawithi BTS station to Lan Luang junction, Lam Luang road, Ratchadamnoen Klang road, and Somdet Phra Pinklao road.
4. Phaya Thai road from victory monument to Si Phraya intersection, Rama IV road from Si Phraya intersection to Surawong junction, Surawong road from Surawong junction to Naradhiwas Rajanagarindra junction, Naradhiwas Rajanagarindra road from Naradhiwas Rajanagarindra junction to Sathon intersection, Sathon road, Krung Thonburi road, and Ratchapruk road
5. Charoen Krung road from Saphan Tak Sin BTS station to Rama III intersection, and Mahai Sawan road

6. Rama I road from Siam BTS station to Chit Lom BTS station, Phloen Chit road from Chit Lom BTS station to Phloen Chit BTDS station, Sukhumvit road from Phloen Chit BTS station to Bang Na intersection.
7. Phetchaburi from Rachathewi BTS station to Ramkhamhaeng intersection, and Phatthanakan road from Ramkhamhaeng intersection to Srinagarindra intersection.
8. Ramkhamhaeng road from Ramkhamhaeng intersection to Lam Sali intersection.

Inner area toll scheme

1. Phetchaburi road from Ratchawithi BTS station to Witthayu-Phetchaburi intersection
2. Witthayu road from Witthayu-Phetchaburi intersection to Rama IV MRT station
3. Sathon road from Rama IV MRT station to Naradhiwas Rajanagarindra-Sathon intersection
4. Naradhiwas Rajanagarindra road from Naradhiwas Rajanagarindra-Sathon intersection to Naradhiwas Rajanagarindra-Suwarong junction
5. Surawong road from Naradhiwas Rajanagarindra-Suwarong junction to Surawong-Rama IV intersection
6. Rama IV road from Surawong-Rama IV intersection to Sam Yan MRT station
7. Phaya Thai road from Sam Yan MRT station to Rachathewi BTS station

Outer area toll scheme

1. North: Wong Sawang and Ratchadaphisek roads
2. Easts: Ratchadaphisek and Rama III roads
3. South: Rama III road
4. West: Chao Phraya river

The aim of having the radial toll scheme is to shift the auto users on the highly congested trunk roads to the MRT lines which are along the roads or to the less congested parallel routes. Inner and outer cordon toll schemes are adopted to reduce the number of cars entering the congested area by shifting them to public transport or to different times of day. In this paper, combinations of these three basic pricing schemes with different toll levels are tested for their performances in the current and future networks. Table 4.1 shows the 8 pricing schemes that will be tested in this study.

Table 4.1 Road pricing schemes

Scheme	R1	R2	RI1	RI2
Radial toll	2 baht / km	4 baht / km	2 baht / km	2 baht / km
Inner cordon toll	-----	-----	30 baht	50 baht
Outer cordon toll	-----	-----	-----	-----

Scheme	RI3	RI4	OU	RIO
Radial toll	4 baht / km	4 baht / km	-----	2 baht / km
Inner cordon toll	30 baht	50 baht	-----	30 baht
Outer cordon toll	-----	-----	50 baht	50 baht

4.5 Impacts of road pricing on the multi-modal transportation system

For each of the road pricing schemes defined in the previous section, the combined modal split and assignment process, described in Section 3.3.4, is carried out for years 2010, 2019 and 2029. In this section, the impact of road pricing schemes on road network and public transport system will be presented and discussed. Figures 4.11 and 4.12 respectively show the change in auto and public transport volume as the road pricing scheme R1 is implemented. The thick-black lines in Figure 4.11 and 4.12 represent the charging location of scheme R1. The red color in these figures represents a decrease in the corresponding volume, while a green color represents an increase. In Figure 4.11, it could be seen that the auto volume along the charging location decreases (the red band) after the implementation of the road pricing. It is because auto users, who originally used the charging corridor, have diverted to other non-tolled parallel routes causing an increase in auto volume in the nearby network. Apart from the route diversion, the change of mode choice resulted from the implementation of road pricing is also considered in the current study (Figure 4.12). Figure 4.12 shows that the majority of public transport line segments have an increase in demand after the implementation of R1. Also, segments with large increases in volume (the wide green bands) tend to distribute along the charging locations (the think-black lines). This distribution indicates the shift of demand from auto to pubic transport after the implementation of road pricing, as the shifted auto demand tries to switch to public transport line with route that is similar their previous one. Considering different road pricing schemes, similar changes of auto and public transport volume will also occur.

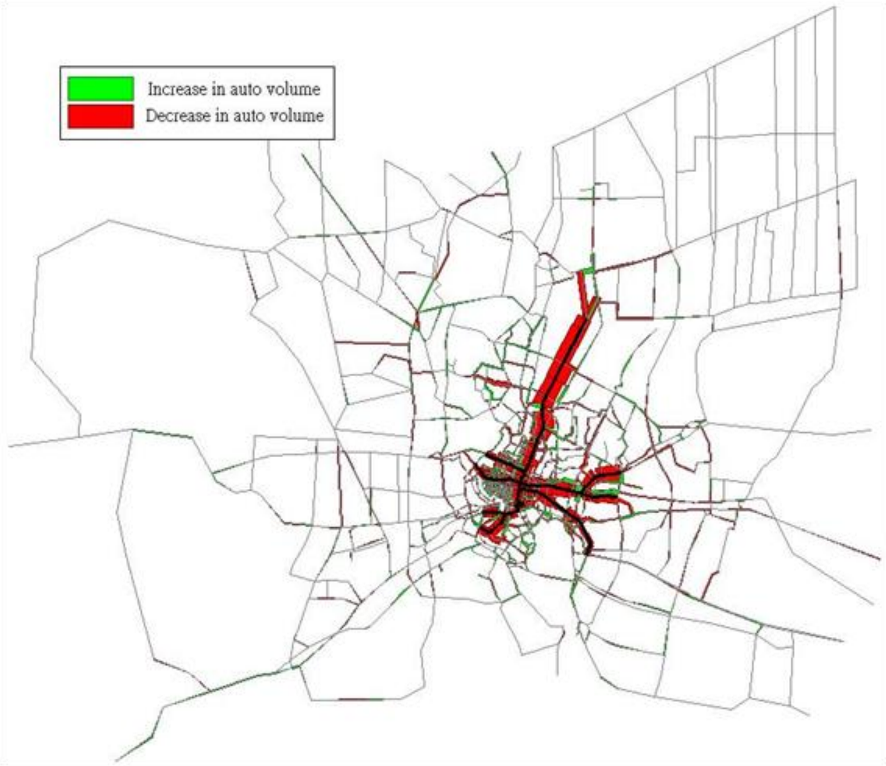

Figure 4.11 Change of auto volume after R1 is implemented in 2029

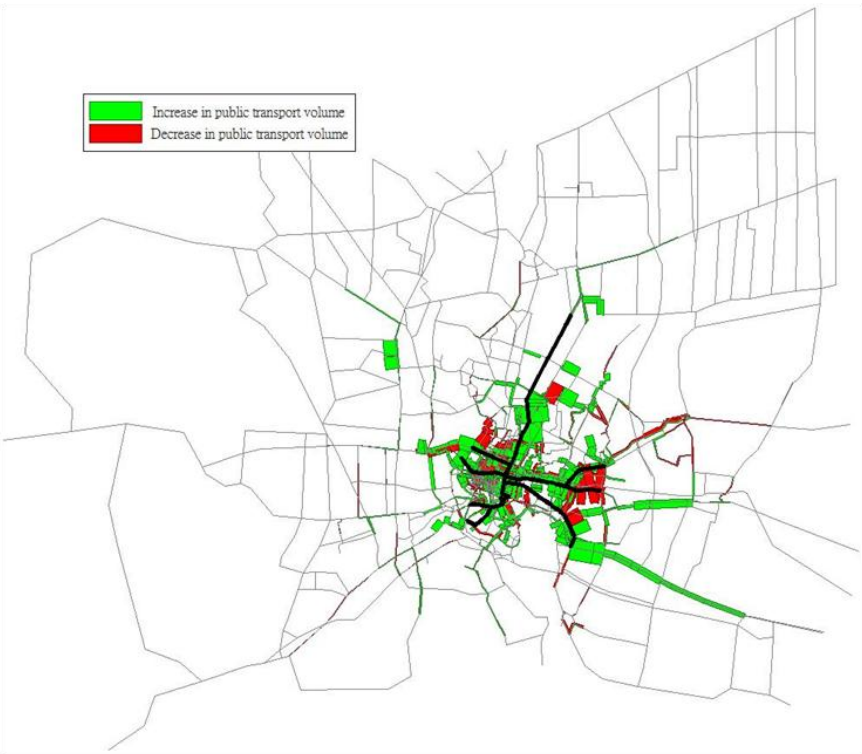

Figure 4.12 Change of public transport volume after R1 is implemented in 2029

Apart form the spatial change of auto and public transport volumes, impacts of different road pricing schemes are compared in a more aggregated level. Figure 4.13 shows the total auto trips for the do-nothing scenario and the 8 road pricing schemes in 2010, 2019 and 2029. In this figure, the auto trips for all tested road pricing schemes are less than that of the do-nothing scenario. Such decrease is from the shift of demand to public transport and not-travel choices (or travel at different time) after the implementation of the schemes. Among the tested schemes, RIO and RI4 are the two schemes that give the largest decreases in auto trips for all years. RIO scheme gives a 14% reduction (while a 12% reduction for RI4 scheme) of auto trips in 2029 as compare to the do-nothing scenario. Such large reduction is mainly due to the implementation of inner and/or outer cordon toll schemes to ensure the charging of auto users as they enter the most congested area. R1, R2 and OU are the three schemes that give the least reduction of auto demand over in the three tested years. Compare to the area toll schemes, the radial toll scheme (R1 and R2) is less effective in shifting the auto demand to public transport or not travel choice. It is because under the radial toll scheme, auto users could be easily diverted to other non-tolled parallel routes for traveling to their destinations. As a result, the implementation of radial toll scheme will mainly shift the route choice, but not the mode choice. As an area based charging scheme, OU, which only consists of the outer area toll scheme, is not effective in reducing the auto volume than it is expected. It is because the reduction of auto demand from outside will be offset by the induced demand within that large charging area.

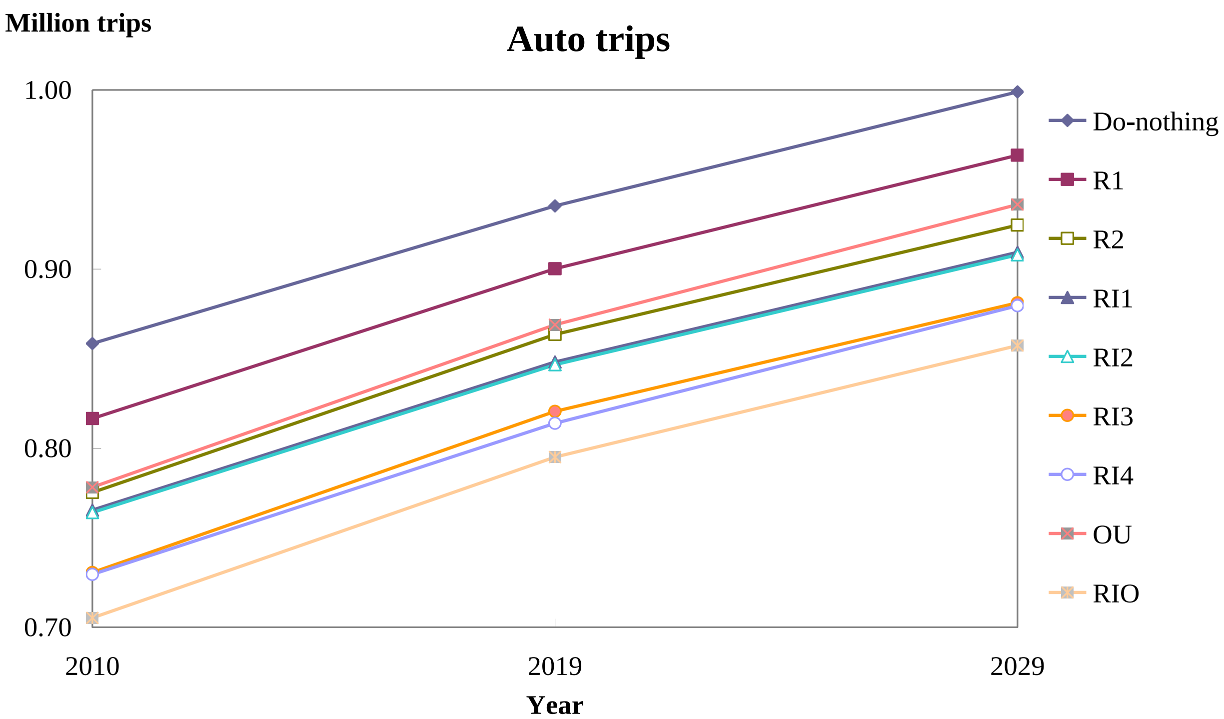

Figure 4.13 Number of auto trip in BMA

In general, the number of public transport trip for different road pricing schemes and the do-nothing scenario is increased in 2019 (by 8% to 20%) and 2029 (by 37% to 58%) as compared to 2010 (Figure 4.14). Such increases are resulted from the extensions of MRT lines, which increase the attractiveness of the MRT system, and the increase in network congestion resulted from the demand growth. For the 8 road pricing schemes, the increase in public transport demand is also from the auto demand that is forced out from the auto mode by the implementation of road pricing. Comparing within each year, the implementation of congestion pricing schemes generally increase the public transport demand. Owning to the similar explanations for the changes in auto trips, RIO and RI4 give the largest increase in the public transport demand, while R1 and R2 give the smallest increase.

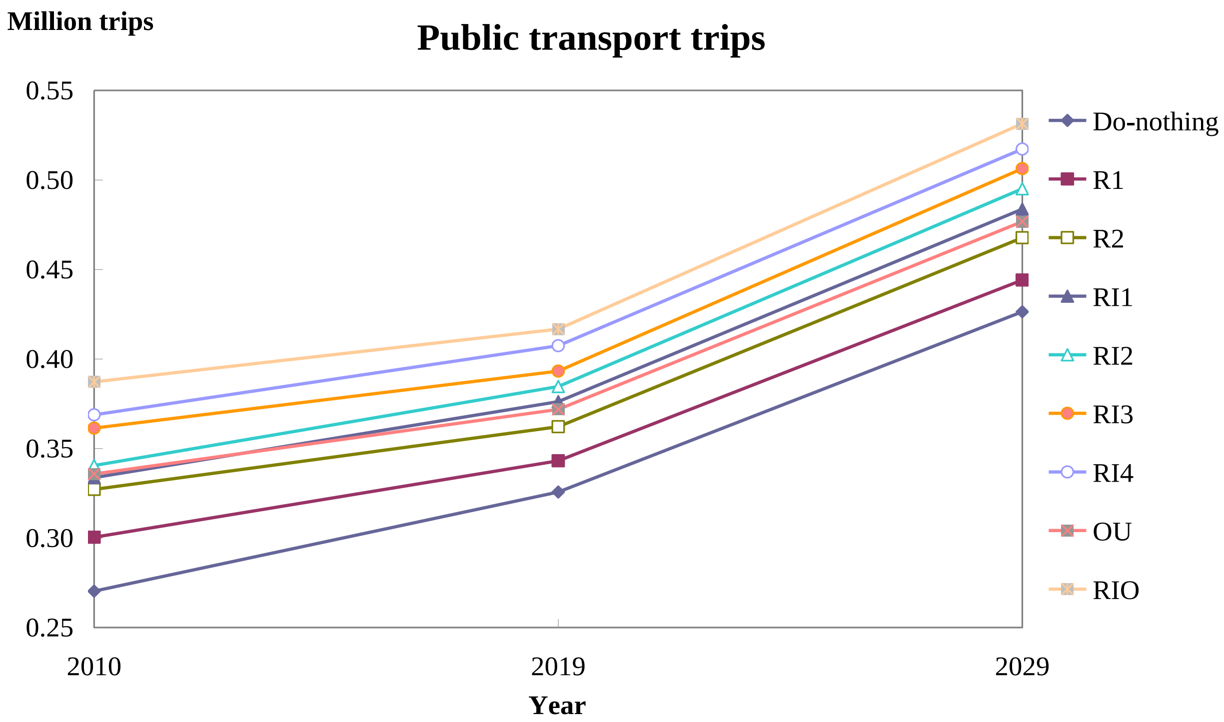

Figure 4.14 Number of public transport trip in BMA

As the average journey time is highly influenced by the network structure and the OD demands, average journey speed of auto travelers (Figure 4.15) is adopted as the measure of different congestion pricing schemes in reducing network congestion in this multi-modal transportation system. For 2010, 2019 and 2029, all tested road pricing schemes increases the average journey speed: 2.3%~8.7% in 2010; 1.2%~4.1% in 2019; 1.2%~3.4% in 2029 as compared to the do-nothing scenario. As the travel demand increases (Figure 4.13 and 4.14), the effect of road pricing reduces. It is because with the higher travel costs, which are resulted from the more congested environment. The same level of toll could not provide similar effect in shifting the auto demand to public transport as in the less congested case. Similarly, the RIO scheme gives the largest increase in average journey speed in 2029, while R1 and R2 gives the least increase in the average journey speed as compare to the do-nothing scenario.

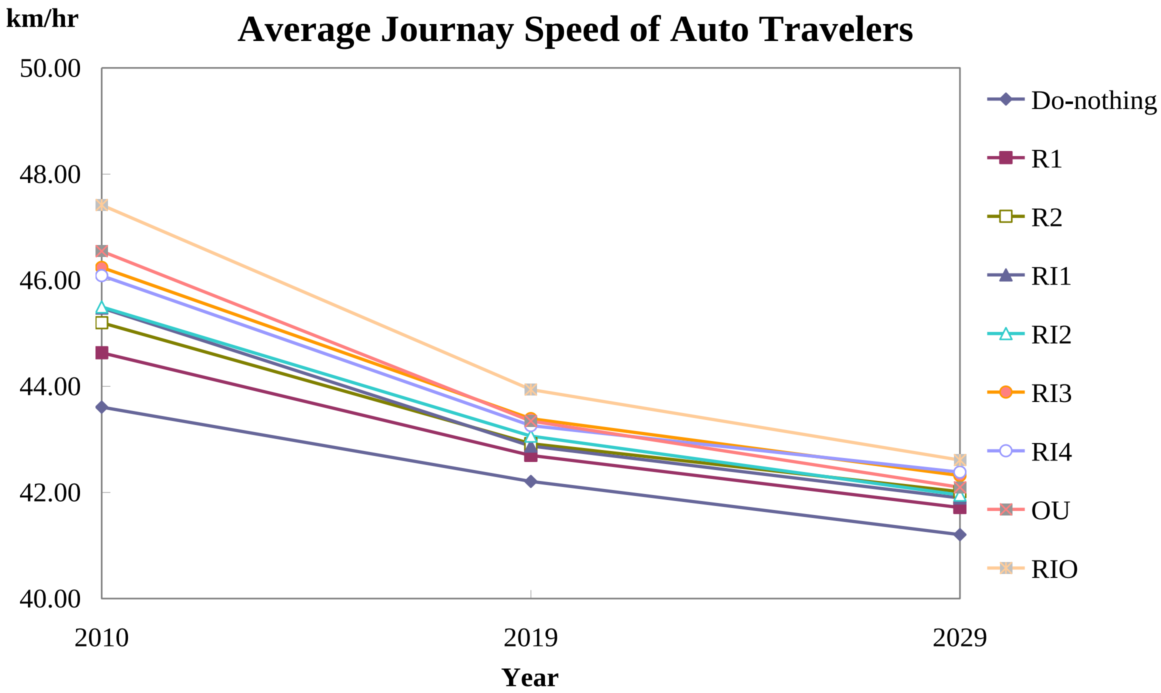

Figure 4.15 Average journey speed of auto travelers in BMA

4.6 Benefit evaluation of road pricing and public transport integration

In the previous section, different impacts (e.g. shifting the auto demand to public transport and reduction of congestion) of road pricing on the multi-modal transportation system are presented and discussed. Despite the usefulness of these analyses in understanding the characteristics of the eight tested road pricing schemes, it is difficult for decision makers to choose the most suitable scheme only based on these analyses. In this section, three different indexes are proposed for evaluating the benefit of different road pricing schemes in a multi-modal transportation system. The three indices are: *Travel time saving*, *Toll collected from road pricing* and *Increase in public transport revenue*. *Travel time saving* refers to the decrease of total travel time under the road pricing scheme as compare to the do-nothing scenario. This value is transformed to the monetary value by multiplying the value of time. *Toll collected from road pricing* refers to the total toll collected from the distance-based or area-based charging methods. *Increase in public transport revenue* refers to the increase in total fare collected from bus, MRT and BTS under the road pricing scheme as compared to the do-nothing scenario. Travel time saving and toll collected from road pricing scheme are the usual indexes adopted in road pricing studies for evaluating the benefit of different schemes. As the model adopted in this study (i-MODEs) is a multi-modal transport model that also consider the public transport/transit system, the *Increase in public transport revenue* is used to measure the benefit of road pricing came from the public transport system.

Table 4.2 listed out the travel demand and the above three indexes for the do-nothing scenario and the 8 tested road pricing schemes. Note that the values in Table 4.2 is the sum of the corresponding value for each year over the study period (2010 ~ 2029). The value for each year is estimated from the hourly results of the multi-modal transportation system proposed in Section 3, The *Travel time saving*, *Toll collected from road pricing* and *Increase in public transport revenue* in Table 4.2 are the sums of present (year 2010) values, which are calculated based on a 9% interest rate, of the corresponding index for the period 2010 ~ 2029.

Table 4.2 Comparison of different road pricing scheme[1,2](per hour)

Scheme	Auto demand ('000)	Public transport demand ('000)	Travel time saving[3,4] ('000 Baht) (a)	Toll collected from road pricing ('000 Baht) (b)	Increase in public transport revenue[5] ('000 Baht) (c)	Total ('000 Baht) (a) + (b) + (c)
Do-nothing	18,671	6,791	0	0	0	0
R1	17,934	7,205	7,120	3,664	4,610	15,393
R2	17,165	7,649	12,902	3,576	8,221	24,700
RI1	16,886	7,902	11,432	4,326	10,594	26,352
RI2	16,856	8,079	11,539	4,529	13,131	29,198
RI3	16,294	8,327	16,997	4,556	14,121	35,674
RI4	16,217	8,559	16,147	4,841	17,527	38,515
OU	17,294	7,833	12,188	249	13,942	26,379
RIO	15,794	8,818	18,619	3,559	23,331	45,509

[1] The numbers in this table is the total for the corresponding values in the period 2010 ~ 2029.
[2] Future values are discounted back to year 2010 by using the an interest rate of 9%
[3] Travel time saving is compared to the do-nothing scenario
[4] Value of time is taken as 1.27 Baht per minute.
[5] Increase in public transport revenue is compared to the do-nothing scenario

Considering the *Travel time saving* column, the RIO scheme gives the largest saving in travel time as it provide the least congested network (i.e. the largest reduction in auto demand, see the column of *Auto demand*) after the implementation of scheme. Comparing the travel time savings of R1 to R2 (also RI1 and RI2 to RI3 and RI4) it could be seen that the 2 Baht/km distance based toll is not sufficient to change the mode/route choice of auto travelers for reducing the travel time as compared to the 4 Baht/km distance based toll. For the *Toll collected from road pricing* column, RI4, instead of RIO, gives the largest amount of toll collected from road pricing. Although the RIO scheme includes all of the three basic charging schemes introduced in Section 4.4, the toll revenue generated by this scheme is only better than OU. It is because the RIO has excessively forced the auto users to other choices (see the column of *Auto demand* and *Public transport demand*), such as public transport. With the smaller number of auto travelers, the amount of toll collected from this RIO scheme will be constrained. Considering the column for *Increase in public transport revenue*, RIO gives the largest increase as it has forced a huge number of auto travelers to use public transport.

Considering the three indexes in Figure 4.2, it is difficult to determine whether RIO (2 first ranks and 1 seventh rank) or RI4 (1 first rank, second rank and third rank) is more beneficial for the implementation in BMA. In order to resolve this problem, a weighted sum of the indexes should be used to give the final rank of the road pricing schemes. The weight for each of the indexes should be based on the preference of the decision makers and the actual needs of the region. For the current study, as there is no preference to any of these indexes, the weight is assumed to be unity and gives the last column in Table 4.2. Based on the weight sum of indexes, RIO is considered to be the most beneficial road pricing scheme for implementing in BMA. Although the RIO scheme is the most beneficial scheme based on the indexes considered, the actual benefit for implementing RIO may varies as the current analysis have not consider the implementation and maintenance cost of the scheme.

4.7 Summary

This chapter has adopted the multi-modal transportation system for evaluating different road pricing schemes. By considering the *Travel time saving*, *Toll collected from road pricing* and *Increase in public transport revenue*, the scheme with 2 baht/km radial toll, 30 baht inner cordon toll and 50 baht outer cordon toll is the most beneficial to implement in BMA for the period 2010 - 2029.

CHAPTER 5 Conclusions

5.1 Summary

Currently, in Bangkok there are three routes of mass transit system in total about 84 kilometres. The "Mass Rapid Transit Master Plan in Bangkok Metropolitan" (M-MAP, 2010) is set to have 12 routes in total 509 kilometres in 2029.

This research has integrated congestion charging to support mass transit systems in Bangkok, in order to improve the overall transport system. It has investigated possible integration plan of public transport scheme and road pricing scheme in Bangkok, then assessed the impacts and benefits of the integrated policy package.

In this study, the multi-modal traffic assignment was used as the evaluation tool of different road pricing package together with the public transport improvement/investment schemes. The transport demand model called "i-MODEs" (Integrated MODEs model of Bangkok) that fully considering the effects of elastic demand was developed.

With the MRT development alone (without road pricing), the demand of MRT and BTS increases due to the shifting of the travelers from the congested road network to the railway system. The increase of demand is also resulted from the increased coverage of the MRT services over the future years. However, due to the increase of auto volumes, the road network in BMA is becoming more congested with the average journey speed decreased from 44km/hr in 2010 to 41 km/hr in 2029. These results indicate that the sole introduction/extension of public transport services could not effectively shift the demand from auto to public transport. This reflects the necessity of road pricing which provides additional incentive to the auto users to switch their mode choice.

Three basic pricing schemes (location and charging method), are proposed for reducing the congestion. They are: 1) Radial toll scheme that adopts a distance-based charging method, 2) Inner cordon toll scheme that covers most of the central business district (Pathum Wan district) that adopts an area-based charging method, and 3) Outer cordon toll scheme that located in the central of Bangkok Province.

The aim of having the radial toll scheme is to shift the auto users on the highly congested trunk roads to the MRT lines which are along the roads or to the less congested parallel routes. Inner and outer cordon toll schemes are adopted to reduce the number of cars entering the congested area by shifting them to public transport or to different times of day.

As expected, along the charging roads the study found that car traffic volume decreases after the implementation of the road pricing. It is because: (1) car users divert to other non-tolled parallel routes causing an increase in auto volume in the nearby network, and (2) car users change their travel mode from car to MRT. This results that number of passengers on MRT increase.

For impacts of road pricing on the whole network for all tested road pricing schemes, number of car trips are less than that of the situation without road pricing. Such decrease is from the shift of demand to public transport and not-travel choices (or travel at different time) after the implementation of the schemes.

Among the road pricing schemes, the radial toll scheme is less effective in shifting the car demand to public transport or not travel choice. It is because under the radial toll scheme, car users could be easily diverted to other non-tolled parallel routes for traveling to their destinations. Thus, the implementation of radial toll scheme will mainly shift the route choice, but not the mode choice. The outer cordon charging scheme is not effective in reducing the car volume. It is because the reduction of car demand from outside will be offset by the induced demand within that large charging area.

The most effective scheme in reducing car trips is the integration of radial toll, inner cordon and outer condor. The scheme with 2 baht/km radial toll, 30 baht inner cordon toll and 50 baht outer cordon toll can reduces 14% of car trips in 2029, compared to the scenario without road pricing.

Overall, number of public transport trips increases over the next 20 years, by 8%-20% in 2019 and by 37%-58% in 2029, as compared to the results in 2010. Such increases are resulted from the extensions of MRT lines, which increase the attractiveness of the MRT system, and the increase in network congestion resulted from the demand growth. Comparing within each year, the implementation of congestion pricing schemes generally increase the public transport demand.

For 2010, 2019 and 2029, all tested road pricing schemes increases the average journey speed: 2.3%~8.7% in 2010; 1.2%~4.1% in 2019; 1.2%~3.4% in 2029 as compared to the scenario without road pricing.

For evaluating the benefit of different road pricing schemes, three different indexes are used. They are: (1) Travel time saving, (2) Toll collected from road pricing, and (3) Increase in public transport revenue.

The integrated scheme (with 2 baht/km radial toll, 30 baht inner cordon toll and 50 baht outer cordon toll) gives the largest travel time saving and the largest increase in public transport revenue. It is because the scheme has excessively forced the auto users to other choices. The scheme with 4 baht/km radial toll and 50 baht inner cordon toll, gives the largest amount of toll collected from road pricing.

For the current study, as there is no preference to any of these indexes, the weight is assumed to be unity. The integrated scheme (with 2 baht/km radial toll, 30 baht inner cordon toll and 50 baht outer cordon toll) is considered to be the most beneficial road pricing scheme for implementing in BMA.

However, in order to select the most beneficial scheme for the implementation in BMA, a weighted sum of the indexes should be used to give the final rank of the road pricing schemes. The weight for each of the indexes should be based on the preference of the decision makers and the actual needs of the region. In addition, other factors, e.g. public acceptability and physical barriers in implementation, may be included in the decision process (see Jaensirisak et al., 2008).

Furthermore, inverse impacts from road pricing schemes should be concerned in details. For example, the implementation of road pricing may induce longer trip (hence results in the increase in travel time per trip).

5.2 Further research

This study has assessed the impacts of road pricing on transport network. The i-MODEs model cannot assess the impacts on land use changes. To understand how the urban land use and transport system works and interacts, the technical level of an analytical approach (using some kind of quantitative model) to formulate the problem and define the best sustainable policy is highly advanced.

The further study should develop a user-friendly tool for pre-appraisal of the sustainability of urban transport and land use development 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 should be 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.

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Appendix A MASS TRANSIT MASTERPLAN IN BANGKOK

The first Masterplan of mass transit system in Bangkok was developed in 2000 under the project called “Mass Trans: Urban Rail Transportation Master Plan” (URMAP). Then it was revised in 2004 in the project “Bangkok Mass Transit” (BMT). Lately, during 2009-2010 the Thai Government is updating the masterplan called M-MAP “Mass Rapid Transit Master Plan in Bangkok Metropolitan”.

Currently, in Bangkok there are three routes of mass transit system in total 45.7 kilometres, and 39.1 kilometres under construction. The M-MAP masterplan is set to have 12 routes in total 509 kilometres in 2029. The masterplan set three stages of development.

The first stage is to develop the five routes mass transit project which approved by the cabinet on November 7, 2006. In this stage there will be a construction of 151 kilometres of mass transit (as shown in Figure A1, which is expected to open in 2016.

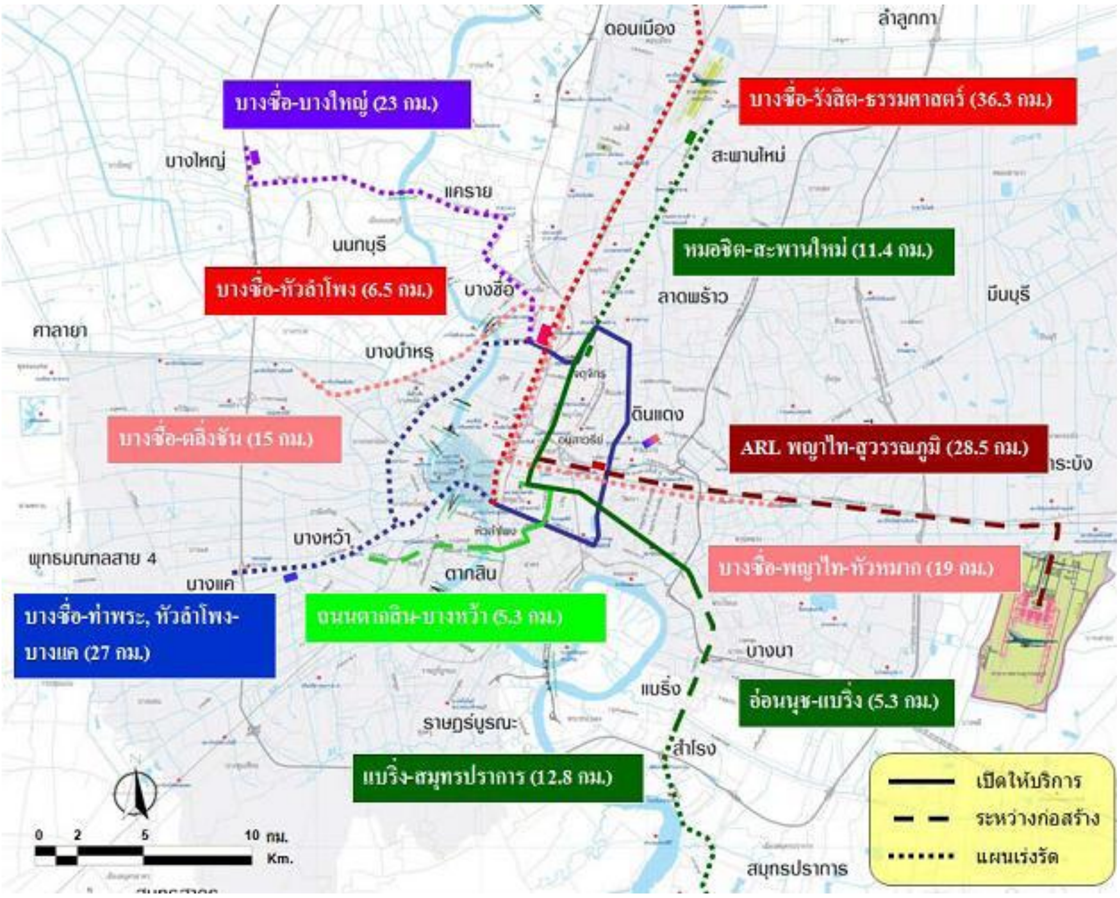

Figure A1 Mass transit network in Bangkok in 2016

The second stage is to develop the 155.1 kilometres of mass transit (as shown in Figure A2, which is expected to open in 2019.

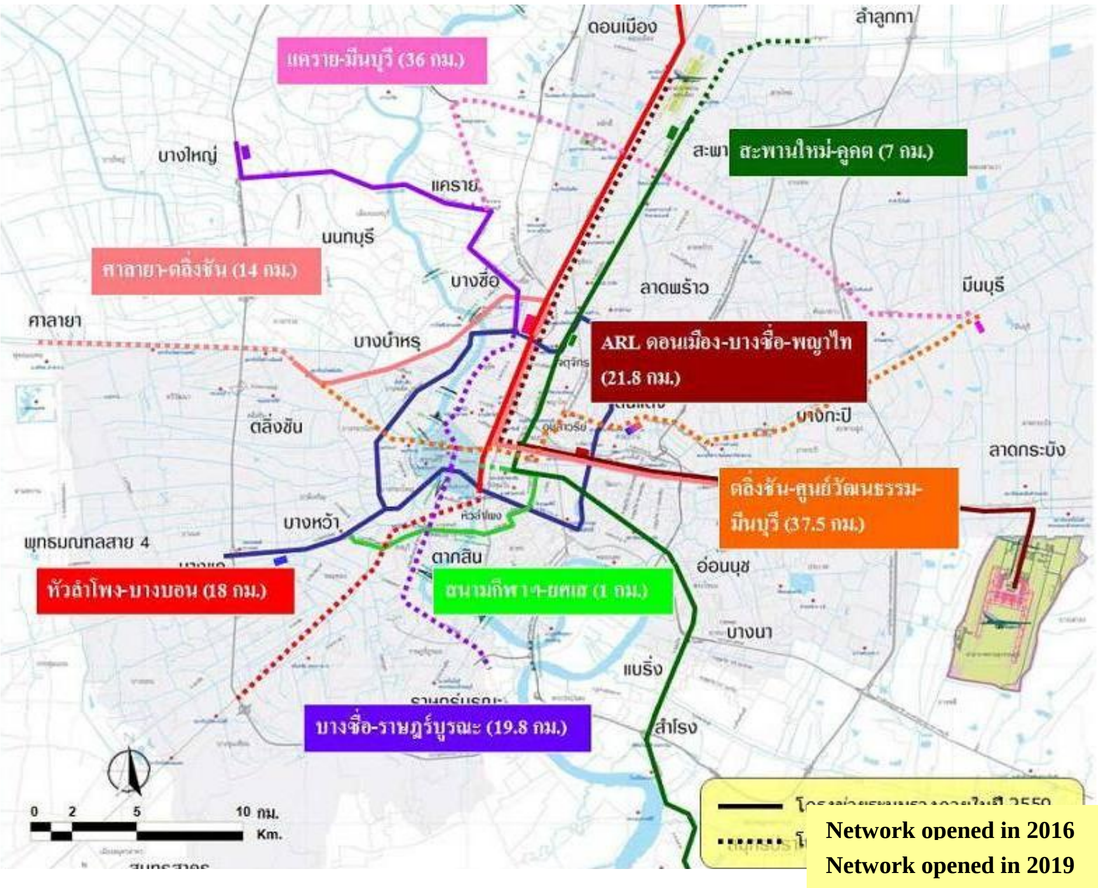

Figure A2 Mass transit network in Bangkok in 2019

The third stage is to develop the 117.9 kilometres of mass transit (as shown in Figure A3, which is expected to open in 2029.

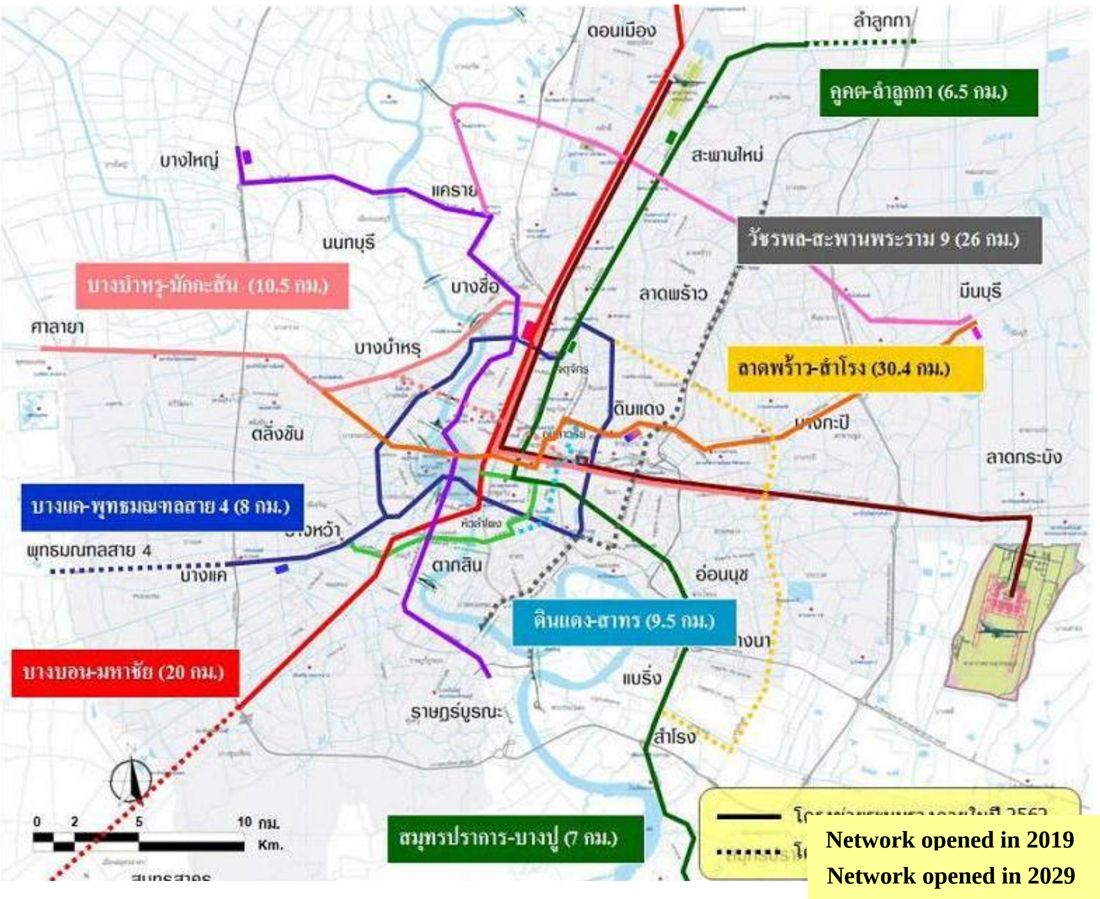

Figure A2 Mass transit network in Bangkok in 2029

Interim Report

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