TRANSPORT POLICY ANALYSIS FOR DEVELOPING COUNTRIES USING A NESTED LOGIT MODEL OF VEHICLE USAGE, MODE CHOICE AND TRIP-CHAIN

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Abstract: Traffic congestion and environmental pollution are becoming severe in developing countries with increasing mobility and intense vehicle usage. An attempt is made on finding effective transport policies to alleviate the problems. Policy issues focus mainly on "push and pull" strategy using a road-pricing scheme together with fare reduction of public transportation. The suggested road pricing scheme treats CBD and inner suburb zones with different charges, especially for car and motor cycle travel. In addition, it considers three different time spans such as restricted, partly restricted and free entry basis corresponding to the peak congestion periods. A multi-level Nested Logit (NL) model is initially developed to capture the recent variations of household decisions on vehicle usage, mode choices and trip chains in daily commuting for two-traveler households. Developed model is then applied for policy analysis, using Bangkok Metropolitan Region (BMR) as a case study.

Key Words: Household travel, Urban congestion, Pollution emissions, Developing countries.

1. INTRODUCTION

In conjunction with economic development, metropolitan areas in developing countries concentrate centrally without proper planning of land use. Increase in land prices encourages urban dwellers to move outside of the city centers. Due to this suburban sprawling and increasing mobility, commuting patterns have been subjecting to great variations over private vehicle usage.

Although metropolitan areas in developing countries acquired some reasonable achievement from development, transportation infrastructures such as roads and transit systems are not properly reformed in quality improvements and capacity expansion. The service provision of public transportation is also in a deficient level with insufficient supply and inferior quality. Therefore, travelers in such countries depend greatly on private vehicles such as cars and motor cycles devastating the urban environment with heavy traffic congestion and air pollution. In contrast, the extensive vehicle usage is mainly due to increasing demand of mobility and inefficient service provision of public transportation. In addition, advantages of vehicle usage such as comfort, convenience, safety and privacy also encourage travelers to buy and use vehicles for their daily commuting. According to the recent findings, transport related emissions are found as a major threat for both local and global environments. Therefore, globally sustainable transport is the main target for many investigations, and the attention is mainly placed for reducing private vehicle usage. Improvements of public transport facilities, for instance, service improvements, fare reductions and capacity expansions, can be a solution to promote transit services. However, recent investigations found that the resulting effect from such policies is inadequate to change the prevailing trend of vehicle usage (Acutt, 1996; Dissanayake and Morikawa, 2001). Therefore, effective policies have to be decided with wider perspective to change the travelers' attitudes.

Considering the vehicle usage patterns in developing countries, trip chains are very popular among the car-using and motorcycle-using households that contributes some additional behavioral complexity into the simple commuting pattern. Although most of the previous studies have been investigated the trip chains that are created by the individuals, attention on household serving trip chains is very rare due to its complex modeling procedure. To create a household serving trip chain, the vehicle user, in most cases the commuter has to bear the burden to serve other household members regarding their travel requirements.

Travel demand models relating to one-traveler households are very common in transport sector due to its simple analyzing procedure. However, the models with one-traveler households can not be effectively used to represent the actual travel conditions in developing countries where strong interrelationships, for instance, mode choices and trip chains, among the household members exist. Therefore, investigating households with two or more travelers are very important, especially for modeling travel behavior in developing countries. In this study, emphasis is made on analyzing two-traveler households by using a Nested Logit (NL) modeling approach. Although three-traveler households can be also analyzed using the similar modeling techniques, the model analysis will be rather complicated with vast variety of mode choice combinations.

Considering the two-traveler households in this study, one of the travelers makes a commuter trip. The travel purpose of the second traveler of the same household can be any type such as work, shopping, private business, social or recreation. When the both travelers make a trip chain, commuter has to touch the destination of the second traveler before reaching to his destination. The commuter trip can be either home-to-work or work-to-home.

This study attempts to investigate congestion reduction policies with explicit consideration of recent travel behavioral variations in developing countries. The basic modeling structure is developed as a multi level NL model to analyze household behavior on vehicle usage, mode choices together with the formation of trip chains. Emphasis is mainly placed on investigating commuter based traveling for two-traveler households. The developed NL model is successfully applied to investigate congestion reduction policies, using Bangkok Metropolitan Region (BMR) as a case study.

2. EXISTING APPROACHES ON TRANSPORT POLICIES

In recent years, substantial attention has been placed on finding effective solutions for traffic congestion and related environmental impacts. According to Himanen (1993), congestion is a common problem not only for developing countries but also for developed countries as well. In Asian region, several studies investigated transport policies, especially for Singapore and Bangkok. Improvement of the traffic congestion in Bangkok, however, is still staying behind the desirable level.

Traffic situation is very well improved in Singapore as mentioned in the recent investigations (Watson and Holland, 1976; Olszewski *et al*., 1995; Phang and Asher, 1997). According to Watson and Holland (1976), the policies implemented in Singapore are very effective to the congestion problem. Basically, a congestion pricing policy, named Area Licensing Scheme (ALS), was adopted for morning and evening peak-hours. It was accompanied by other types of sub policies including promotion of public transportation with exclusive bus lanes, land use plans with new industrial zones locating outside of CBD, additional road construction, car pooling and staggered work hours. The policies were defined in two folds: short run and long run aspects, aiming to reduce congestion in CBD and to change the attitudes of motorists over car-ownership and usage, respectively. The Area Licensing Scheme was further extended to cover whole day with implementing reduced fee for off-peak hours (Olszewski *et al*., 1995). ALS that allowed unlimited entries to CBD for license holders was finally changed to Electronic Road Pricing (ERP) system of per-entry charging basis. Phang and Asher (1997) discussed the implementation issues of ERP along with the related policies on vehicle ownership in Singapore. They mentioned that the restrictions made on the vehicle ownership and usage were very effective to reduce the air pollution concentration levels, and also it contributes to increase the government revenue.

Hayashi *et al.* (1998) discussed about the congestion crisis prevailing in Bangkok City, and investigated the user preferences for the introduction of new MRT system. They mentioned that the introduction of feeder modes to the MRT stations will be an effective solution to change the user preferences on vehicle usage. Dissanayake and Morikawa (2000) conducted a study to investigate the travel behavior for new MRT system in Bangkok by combining stated preferences (SP) and revealed preferences (RP) of transport users. The findings of this research explain that the transport users belong to low and middle income groups intend to change their modes to new MRT system. But, the travelers in high-income group prefer to own and use a vehicle rather than changing their modes to new MRT. They also mentioned that attitudes of travelers who belongs to high-income group is not very easy to change since their preference is mainly depending on comfort, privacy and convenience of vehicle use. A NL model was recently estimated for the analysis of vehicle-ownership and trip chaining in developing countries and the model was used to analyze the congestion policies by reducing bus fares to promote the usage of the public transportation services (Dissanayake and Morikawa, 2001). Rujopakarn (2000) investigated the validity of 8th transport plan in Bangkok and found that the proposed plan will not be successful due to its incompatibility with the existing land use plans.

Scott *et al.* (1997) investigated the methods for reducing traffic congestion and environmental pollution in North America, and found that the policies on improving commuting efficiency is an effective method. Promotion of job-housing balance was mainly investigated in their study and found that the choices of work places and house locations are very important for minimizing the commuting distances. As mentioned by Wee (1996), people in Netherlands are greatly suffering from air and noise pollution, especially due to road traffic, and investigated some policy measures to reduce vehicle usage. The important measures were identified as pricing policies, policies for parking, land use as well as the public transportation facility improvement. Although emissions from car travel were able to reduce substantially with the policies, the usage of lorries and other types of commercial vehicles is still on a raising trend.

Acutt (1996) developed a model to explain the air pollution from heavy car usage in Great Britain, and emphasis was made on raising fuel prices, reducing public transport fares and a vehicle taxation scheme depending on the engine size. It was found that the reduction of public transport fares shows a very small effect to achieve the desirable pollution levels.

3. STUDY AREA

3.1 General

In this study, Bangkok Metropolitan Region (BMR) in Thailand is selected for the empirical analysis (Figure 1). The BMR consists of Bangkok Metropolitan Area (BMA) and five adjacent provinces of Samut Prakan, Nonthaburi, Pathum Thani, Nakorn Pathom and Samut Sakorn. The study region includes 505 internal traffic zones. The area of the BMR is about 7760 km^2 and the total population is 13.8 million in 2001.

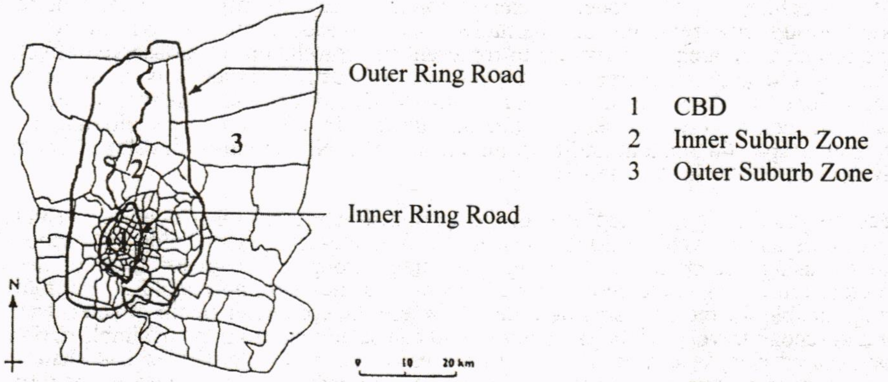

Figure1. Area Map of the Bangkok Metropolitan Region
(Source: Hayashi *et al.*, 1998)

As indicated in Figure 1, BMR is split into three major zones: CBD, inner suburb and outer suburb and the inner and the outer ring roads are considered as the zone separation cordons. Total daily person trips in BMR are about 22 million in 2001 and 90% of those are generated within the CBD and the inner suburb zones.

3.2 Data Description

The data, which is used in this study, were obtained from the household travel survey that was conducted in BMR during 1995/96. The Urban Transport Database and Model Development Project was responsible for the survey. The survey provides wide variety of data relating to the travel behavior implications by considering all attributes of the trips that were made on the date of the survey as well as information of household members. Although there were large amount of households in the database, 1205 households are selected for the empirical analysis according to the model requirement of two-traveler households, among them one traveler is a commuter.

In the database, trips were indicated using the zones of origins and destinations with all independent mode (unlinked) trips. Therefore, it is easy to distinguish interrelations among the trips for both travelers such as trip purposes, trip patterns (chained or unlinked), origin and destination zones, transfer zones, travel times and time of day. Geographical information of the study region was originally computerized by MAPINFO Geographical Information System based Arc-view software, which is helpful for easy reference and meaningful comparison whenever necessary. Furthermore, location-based information such as trip length is measured using the criteria of the shortest distance between origin and destination zones. Additional database for home interview survey was provided by Bangkok Environmental Improvement Project (BEIP), which helps to strengthen the database.

4. THE BASIC MODEL

4.1 NL Approach

In the BMR, the available transportation modes are bus, rail, car, motor cycle (mc), hired motor cycle (hmc), taxi and ferry. Since rail and ferry provide insufficient services and limited accessibility, usage of such modes is comparatively low. Therefore, the universal choice set of transport modes for the study excludes the options of rail and ferry. Choice options for no vehicle-using households are bus, hmc and taxi.

The discrete choice model with random utility maximization is employed in this study. The deterministic component of utility can be obtained by the measurable attributes for each travel option. The random component includes all other effects on the choice context, which can not be observed. Development of the modeling structure basically relies on the nature of this random component of utility. Among the vast variety of techniques existing for the analysis of travel behavior, a NL model is selected for this study, mainly due to the requirement of taking group-wise relations of alternatives into consideration. A NL model generally develops as a hierarchical structure to represent the correlation of unobserved effects, in the forms of mutually exclusive and collectively exhaustive choice sets to relax the strict assumptions of IIA in the Multinomial Logit (MNL) Model. Alternatives in the same nest share the common component of random utility. In addition, each alternative has the alternative specific random utility component. The NL structure developed for the two-traveler households is shown in Figure 2.

According to the Figure 2, top level of the nesting structure has two categories: vehicle using-households and no vehicle-using households. Vehicle-using households are further divided into car-using and motor cycle-using (mc-using) groups. The lowest level of the nesting structure represents mode choices for car-using and mc-using households. Alternatives 1~4 are applicable for the car-using households, where the commuter (main traveler) travels by a car and second traveler of the same household can select one from the available options of car chain/shared ride, bus, hmc or taxi. In the car-using nest, alternatives 1~4 share common component of random utility considering the level of comfort, safety, convenience, privacy as well as all other unobserved attributes relating to the car using facility. Similarly, alternatives 5~8 are applicable for the mc-using nest.

For no vehicle-using households, alternatives 9~11 are applicable where both travelers use bus, hmc or taxi depending on their modal preferences. According to the data, which was obtained from the household travel survey, distribution of households over alternatives 1~11 are 159, 144, 8, 3, 198, 161, 35, 3, 449, 38 and 7 respectively. It indicates that the bus alternative has the highest travel demand (37%) followed by the mc chain (16%) and the car chain (13%).

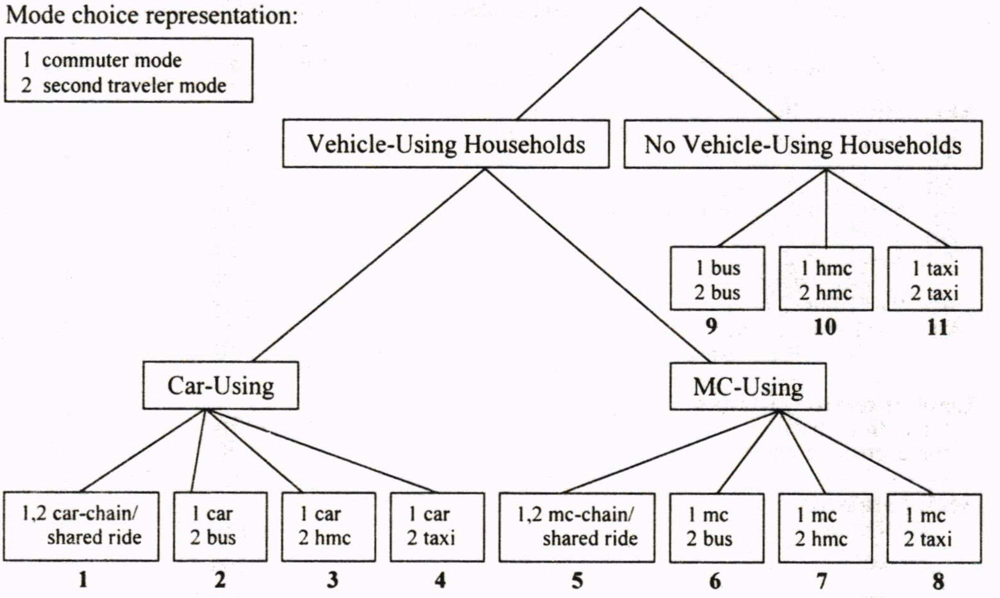

Figure 2. Nested logit (NL) Model for Two-traveler Households

4.2 Estimation Procedure

Simultaneous estimation (full information maximum likelihood) method is used to estimate the developed NL model. The variance of the random utilities increases with increasing level of the NL model (Ben-Akiva and Lerman, 1985). It also means that the largest scale parameter exists at the bottom level, and it decreases with increasing level. Another important insight of the NL model is a measure of the composite utility, also called the expected value of the maximum utility, which can be obtained by taking log-sum of the nested utilities for all alternatives included in the nest. The composite utility (log-sum) relating to the lower nest has to be appeared in the utility function of the upper level after adjusting it with the appropriate scale.

Basically, it is assumed that the scale parameter for the mc nest is unity and then, scale parameters for the other levels are estimated. Attributes, which are obtained from the database, are explicitly incorporated for the analysis to contrast the behavioral realism relating to vehicle usage and associated effects on trip chains for two-traveler households.

5. MODEL ESTIMATION RESULTS AND DISCUSSION

Table 1 shows the parameter estimation results for the developed NL model. Most of the parameters are reasonably significant with expected signs in the sense of explaining household travel behavior in developing countries.

The alternative specific constants for alternative 2 (1 car, 2 bus) as well as alternative 6 (1 mc, 2 bus) are significantly positive indicating the household attraction for those alternatives. In other words, commuters use their own vehicles, for instance, car or mc, allowing the second traveler to travel by bus. The alternative specific constant for alternative 1 (1,2 car-chain/shared ride) and alternative 8 (1 mc, 2 taxi) are negative and significant, which indicates that the households have negative intention to use those alternatives if all other attributes remain the same.

Coefficients for the travel time and the travel cost/income are significantly negative as expected. According to the estimation results, all the scale parameters fall within the specified limits between 0 and 1, and magnitude of those decreases with increasing level of the nesting structure as expected and the estimates are considerably significant.

Table 1. Parameter Estimation Results for the Nested Logit (NL) Model

Variable description	Estimated parameters	t-statistics
Alternative specific constants		
Alt. 1 – (1,2 car-chain/shared ride)	-4.46	-2.8
Alt. 2 – (1 car, 2 bus)	2.50	3.1
Alt. 4 – (1 car, 2 taxi)	-0.08	-0.1
Alt. 5 – (1,2 mc-chain/shared ride)	-0.98	-1.3
Alt. 6 – (1 mc, 2 bus)	1.04	4.4
Alt. 8 – (1 mc, 2 taxi)	-1.43	-2.3
MC-using	0.98	0.3
Alt. 9 – (1 bus, 2 bus)	11.24	1.3
Alt.10 – (1 hmc, 2 hmc)	3.32	1.0
No vehicle-using	3.01	0.3
Level-of-service variables		
travel time (hrs)	-0.76	-2.7
travel cost/income/10^2	-4.56	-3.8
Scale parameters		
$\mu^{cch/cb/chm/ct}$	0.810	4.2
$\mu^{car/mc}$	0.294	2.0
$\mu^{bus/hmc/taxi}$	0.288	1.6
$\mu^{vehicle/no\ vehicle}$	0.285	2.1
Alternative specific dummies		
male commuter, Alt 1,5	1.27	3.4
time compatibility, Alt 1 (commuter's work start time is later than others activity start time, or commuter's work finish time is earlier than others activity finish time)	6.66	3.3
travel distance for both travelers > 20km, Alt. 5	-0.78	-1.5
distance between destinations ≤ 15km, Alt 1,5	1.48	2.7
distance between destinations ≥ 15km, Alt. 6	0.50	1.2
car driving license, car-using	15.20	2.0
mc driving license, mc-using	24.80	2.1
no vehicle and no driving license, No Vehicle-using	13.74	1.8
trips within CBD, Vehicle-using	-2.93	-1.8
commuter's job(executive or business), Vehicle-using	3.94	1.9
commuter's job(executive), Alt. 5	-1.41	-5.3
Number of observations	1205	
$L(\hat{\beta})$	-850.1	
$L(c)$	-2858.4	
VOT (Baht/hr)	28	

Using the estimated values of the scale parameters, parameter for log-sum variables can be calculated. Therefore, parameters for log-sum variables for car-using, mc-using, vehicle-using and no vehicle-using nests are 0.36, 0.30, 0.97 and 0.98 respectively. Parameters for log-sum variables are in the theoretically acceptable range from 0 to 1, and the values for vehicle-using and no vehicle-using nests are very close to 1 implying that the upper level of the NL model has been closely characterized with simple MNL model.

Most of the dummy variables explicitly highlight the behavioral trend on vehicle usage, mode choice and trip chains for the households in developing countries. Dummy variable for male commuters, which is included in the alternative 1 (1,2 car-chain/shared ride) and the alternative 5 (1,2 mc-chain/shared ride), significantly yields with positive sign expressing their contribution for household travel responsibilities by making trip chains. The dummy variable for time compatibility, which mainly compares both travelers' activity start and finish times, is positively significant indicating the realistic behavior of forming car- chains. In other words, when the work start time (finish time) of the commuter is later (earlier) than the activity start time (finish time) of the second travelers, car chain is found to be an attractive alternative.

If the travel distance of each traveler is more than 20km, motorcycle chain is less attractive. When the distance between destinations is less than or equal to 15km, related dummy variable is positively significant highlighting the household tendency to make car chains or mc chains. There exists very high positive significance for the dummy of commuter's driving license with car-using and mc-using alternatives proving the basic requirement of vehicle use. "No vehicle and no driving license" dummy is tested in the alternative of no vehicle-using household that yields a parameter with expected sign.

For the trips that touch the CBD zone, alternative 2 (1 car, 2 bus) is a suitable mode selection. In other words, traveling through CBD zone, especially in BMR, is extremely difficult during peak congestion hours, and therefore, the commuter drives alone by allowing the second traveler to use a bus rather than making trip chains in the congested areas. If both travelers' trips are in CBD, vehicle-using option is not attractive for them. Commuter's job condition is also analyzed by introducing dummy variables into the alternatives of vehicle-using as well as mc-chain. When the commuter's job is either executive or business, the related dummy variable estimates with positive sign indicating the preference to own a vehicle. It indirectly highlights the interaction between the vehicle usage and the reputation linking with the job condition. Also, executive job oriented commuter shows negative tendency to create mc-chains since the related dummy is significantly negative.

$L(c)$ is obtained by incorporating the estimated values of the scale parameters while keeping all the other parameters to be zero. Value of time (VOT) is calculated using the estimated coefficients of the travel time and the travel cost/income, and it is obtained as 28 Baht/hr. The obtained value of VOT is very similar to the study that was conducted in the same region by UTDM project and therefore, the estimated model is intuitively sensitive to behave with the actual circumstances in the area concerned.

6. MODEL APPLICATION FOR TRANSPORT POLICIES

6.1 Traffic Situation Prevalent in BMR

Regarding the traffic congestion, BMR is identified as one of the worst metropolitan areas in the world. Especially during morning and evening commute hours, traffic situation there is extremely severe. In BMR, the lowest travel speed exists in the central area of Bangkok (CBD), and the travel speed increases as the distance from the city center increases. For the year 1998, variation of travel speeds in the study area is shown in Figure 3.

Figure 3. Variation of Travel Speeds in BMR
(Source: Hayashi *et al.*, 1998)

6.2 Policy Based Scenarios

Policy analysis is mainly searching for solutions to alleviate traffic congestion and environmental degradation due to intense vehicle usage in developing countries. Estimated NL model is successfully applied to investigate several policy scenarios. Especially, emphasis is made on restraining vehicle usage in and around CBD.

Although subsidization of public transportation system is widely used in transport sector improvements, it has been observed that the resulting effect is inadequate. Therefore, searching effective policies are very important. Several policy scenarios are suggested in this study by considering "push and pull" strategy where road pricing systems are tested for car and motor cycle usage in and around the CBD, together with subsidizing the public transportation system, especially by reducing transit fares. Policy scenarios are mainly in two folds: fixed vehicle charges throughout the day and different vehicle charges for different time spans of a day emphasizing peak congestion periods. By considering the existing transport fares in the region, car and mc charges are decided in this study. Accordingly, maximum charges for car and mc are taken as 80 Baht/day and 30 Baht/day respectively.

In contrast, scenarios can be explained as follows:

Scenario 1: For CBD travel, car (80 Baht/day) and mc (30 Baht/day) charges are applied throughout the day with bus fare reductions of 50% (case 1a), 25% (case 1b) and actual fares (case 1c).

Scenario 2: Road pricing system indicated in Table 2 is applied for traveling in CBD with simultaneous reductions of bus fares by 50% (case 2a), 25% (case 2b) and actual fares (case 2c). In this scenario, various charges are considered according to the time of entering to the CBD, and the three basic time periods are taken as restricted, partly restricted and free entry for car and mc users.

Table 2. Road Pricing System for CBD Travel

	Free Entry Before 7.30AM	Restricted (7.30-9.30)AM	Partly Restricted 9.30AM-15.30PM	Restricted (15.30-17.30)PM	Free Entry After 17.30PM
car tax: CBD	No charge	80 Baht	40 Baht	80 Baht	No charge
mc tax: CBD	No charge	30 Baht	15 Baht	30 Baht	No charge

Scenario 3: Charges for CBD travel, car (80 Baht/day) and mc (30 Baht/day); and charges for traveling in the inner suburb zone, car (40 Baht/day) and mc (15 Baht/day) are applied throughout the day with bus fare reductions of 50% (case 3a), 25% (case 3b) and actual fares (case 3c).

Scenario 4: Road pricing system indicated in Table 3 is applied for CBD and inner suburb zones with simultaneous reductions of bus fares by 50% (case 4a), 25% (case 4b) and actual fares (case 4c). Similar to the Scenario 2, various tax systems are explicitly considered for restricted, partly restricted and free entry time spans of a day.

Table 3. Road Pricing System for CBD and Inner Suburb Zones

	Free Entry Before 7.30AM	Restricted (7.30-9.30)AM	Partly Restricted 9.30AM-15.30PM	Restricted (15.30-17.30)PM	Free Entry After 17.30PM
car tax:					
CBD	No charge	80 Baht	40 Baht	80 Baht	No charge
Inner suburb	No charge	40 Baht	20 Baht	40 Baht	No charge
mc tax:					
CBD	No charge	30 Baht	15 Baht	30 Baht	No charge
Inner suburb	No charge	15 Baht	7.5 Baht	15 Baht	No charge

Above scenarios are tested by using the estimated NL model and the results are discussed with the corresponding reductions of car and motor cycle travel, vehicle kilometers of travel and air pollution levels in the study region.

7 POLICY BASED RESULTS AND DISCUSSION

7.1 Reduction of Vehicle Travel

According to the proposed NL model, modal shares relating to bus alternative (37.26%) is comparatively higher than the other alternatives and therefore, bus is found to be the most attractive alternative for households in BMR. Preferences for the private vehicle usage such as car (26.1%) and mc (33%) are also considerably higher compared to hired motor cycle and taxi alternatives.

By using the estimated NL model, the Policy Scenarios 1~4 are analyzed. The following reductions of car and motor cycle travel are observed from the policy analysis (Figure 4). Each policy scenario is considered with three cases: a, b and c that are applicable for bus fare reductions of 50%, 25% and 0% (actual fares) as described in section 6.2.

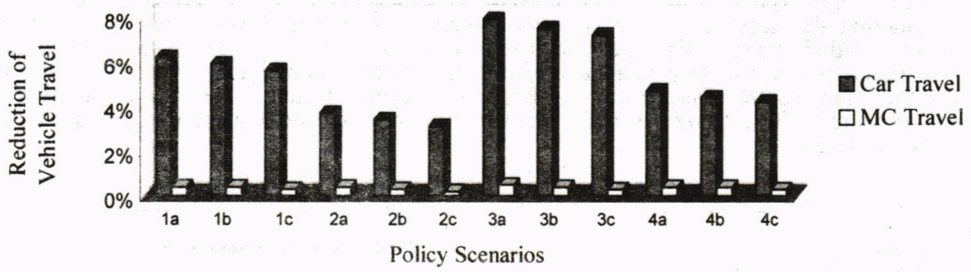

Figure 4. The Reduction of Car and Motor cycle Travel

Resultant reductions of car and mc travel indicate that there is a positive effect of restraining private vehicle usage in the BMR. Among the Scenarios 1~4, Scenario 3 is found to be the most effective policy where 8% of car-travel can be reduced. Therefore, Scenario 3 is further analyzed to estimate the respective reductions of vehicle kilometers and air pollution in the study region.

7.2 Reduction of Vehicle Kilometers of Travel (VKT)

Vehicle kilometers of travel for the base case and Scenario 3 are obtained with explicit consideration of household choice probabilities for each travel alternative. The method of obtaining VKT for each alternative and the total VKT for the entire household travel are described in Equations (1) and (2), respectively. Related results are represented in Figure 5.

$$VKT_n(i) = P_n(i)d_n \tag{1}$$

$$T(VKT) = \sum_{n=1}^{N}\left[\sum_{i=1,5} P_n(i)d_n^{chain} + \sum_{i\neq 1,5} P_n(i)\left(d_n^1 + d_n^2\right)\right] \tag{2}$$

where,

N	total number of households in the data sample
i	travel alternatives as described in Figure 2
$VKT_n(i)$	VKT by alternative i for household n
$T(VKT)$	total vehicle kilometers traveled
$P_n(i)$	probability that alternative i is chosen by household n
d_n	travel distance of household n
d_n^{chain}	trip chain or shared ride distance
d_n^1	commuters travel distance
d_n^2	second travelers travel distance

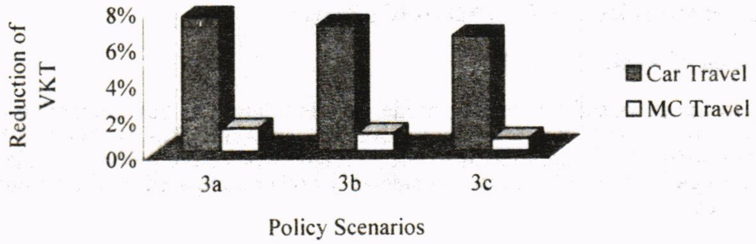

Figure 5. The Reduction of Vehicle Kilometers of Travel

7.3 Reduction of Air Pollution

Pollution emissions from mobile sources are basically depending on vehicle speed. By considering the accuracy of air pollution calculations, country-level emission factors are incorporated in this analysis rather than using a composite emission factor with default speed. The mobile source emission data that are collected from the study region, were obtained from the Pollution Control Department in Bangkok. Figures 6 and 7 shows the variation of emissions for different kinds of pollutants with respect to the vehicle speed of car and motor cycle, in BMR.

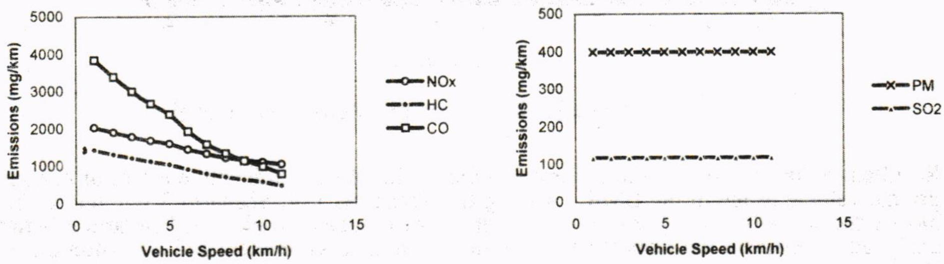

Figure 6. Variation of Mobile Source Emissions with Vehicle Speed for Car Travel

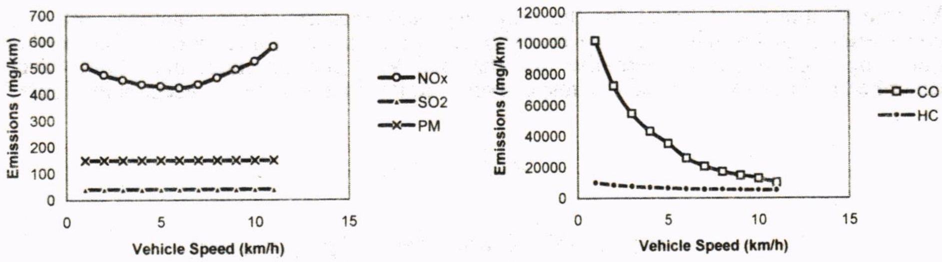

Figure 7. Variation of Mobile Source Emissions with Vehicle Speed for Motor cycle Travel

Air pollution quantities are estimated by incorporating the household choice probabilities for each alternative. Equation (3) explains the calculation procedure.

$$E(AP)=\sum_{n=1}^{N}\left\{\begin{bmatrix} P_n(1)d_n^{chain} + \\ [P_n(2)+P_n(3)]d_n^1 + \\ P_n(8)d_n^2 + \\ [P_n(4)+P_n(11)](d_n^1+d_n^2) \end{bmatrix} * F(AP)_{car} + \begin{bmatrix} P_n(5)d_n^{chain} + \\ [P_n(6)+P_n(8)]d_n^1 + \\ P_n(3)d_n^2 + \\ [P_n(7)+P_n(10)](d_n^1+d_n^2) \end{bmatrix} * F(AP)_{mc}\right\} \quad (3)$$

In Equation (3), $E(AP)$ is the expected value of air pollution emission in milligrams and $F(AP)_{car}$ and $F(AP)_{mc}$ are air pollution emission factors relating to car travel (Figure 6) and motor cycle travel (Figure 7) in BMR.

After implementing the policies, travel condition in the region will be improved and therefore, travel speeds will increase. For the air pollution estimations, variation of travel speeds due to the policy implementation is explicitly encountered. Following assumption is taken into consideration to find the new travel speeds in the study area.

$$T(VKT)^{policy} \Big/ T(VKT)^{base} = (V/C)^{policy} \Big/ (V/C)^{base} \tag{4}$$

In Equation (4), $T(VKT)^{base}$ and $T(VKT)^{policy}$ are total vehicle kilometers traveled regarding to the base case and the policy. Similarly, $(V/C)^{base}$ and $(V/C)^{policy}$ are volume to capacity ratios in the study region before and after the policy implementation. Initially, VKT for each vehicle type is calculated by Equation (1) and obtained values are then modified with the corresponding values of passenger car unit (PCU) for the estimation of $T(VKT)$ by using Equation (5). This study uses PCU for car, mc and bus as 1, 0.4 and 2.

$$T(VKT)=\sum_{n=1}^{N}\left\{\left[(VKT)_n^{car}+(VKT)_n^{taxi}\right]*PCU^{car}+\left[(VKT)_n^{mc}+(VKT)_n^{hmc}\right]*PCU^{mc}+\left[(VKT)_n^{bus}\right]*PCU^{bus}\right\} \tag{5}$$

$(V/C)^{base}$ for CBD, Inner Suburb and Outer Suburb zones are 0.94, 0.81 and 0.48 considering the base year as 1997 (Rujopakarn, 2000). Equation (4) is then used to calculate $(V/C)^{policy}$ for CBD, Inner Suburb and Outer Suburb zones.

Figure 8 represents the variation of travel speeds with respect to V/C ratios for CBD, Inner Suburb and Outer Suburb zones in BMR (Rujopakarn, 2000).

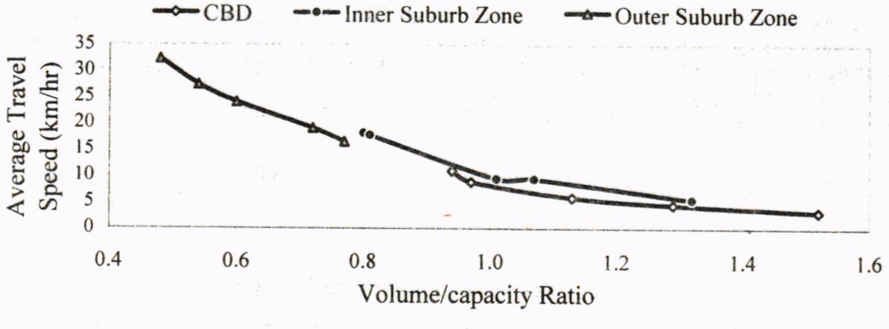

Figure 8. Variation of Average Travel Speed with Volume/capacity Ratios in BMR

By using the calculated values of $(V/C)^{policy}$ and volume/capacity graphs in Figure 8, average travel speeds for policy scenarios: 3a, 3b and 3c can be obtained (Table 4).

Table 4. V/C Ratios and Average Travel Speed with Policy Application

	V/C				AverageTravel Speed (km/hr)			
	Base Case (In 1997)	With Policy (Scenario 3) 3a	3b	3c	Base Case (In 1997)	With Policy (Scenario 3) 3a	3b	3c
CBD	0.94	0.88	0.89	0.90	*	12.5	12.1	11.8
Inner Suburb Zone	0.81	0.76	0.77	0.78	*	19.7	19.4	19.0
Outer Suburb Zone	0.48	0.45	0.46	0.46	*	36.0	35.0	35.0

Remarks: * represents that actual vehicle speed for each trip from data.

Average travel speeds in Table 4 is successfully incorporated to estimate the reduction of pollution emissions from car and motor cycle travel (Figure 9).

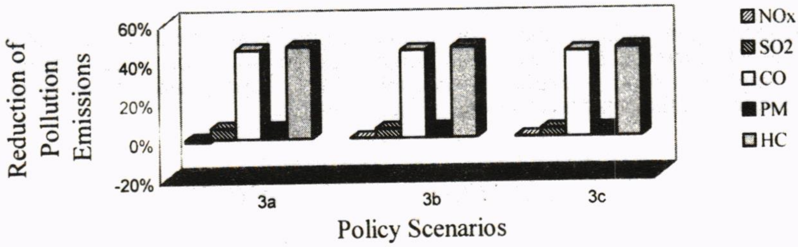

Figure 9. Reduction of Pollution Emissions from Car and Motor cycle Travel

In Figure 9, it has been observed that NO_x emission increases with the Policy Scenario 3a. According to the Figure 7, it can be observed that the NO_x emission factor for motor cycle travel is increasing with travel speed, especially when the speeds are greater than 7km/hr. In this method, increase in travel speed is explicitly considered and therefore, increase in NO_x concentration levels can be expected with the policy application.

7.4 Estimations of Tax Revenues and Funds for Transit Fare Reductions with Policies

Since this study is investigating transport policies with "push and pull" strategy, it is very important to estimate the following:

1. Tax revenues that are collected from private vehicle users for their travel in CBD and in inner suburb zones and
2. Funds that are necessary to reduce transit fares.

For the estimations of tax revenues and funds for fare reductions, household choice probabilities for the Policy Scenario 3a, 3b and 3c are explicitly taken into consideration. According to the results, it is found that tax revenues are higher than the funds that are necessary to reduce the transit fares. Excess Tax Revenues are calculated as Equation (6) and the estimation results for the excess tax revenues are shown in Table 5.

$$Excess\ Tax\ Revenue = \left(1 - {Funds\ for\ Transit\ Fare\ reduction}\Big/{Tax\ Revenue}\right) * 100 \qquad (6)$$

Table 5. Excess Tax Revenues with the Policy Scenarios

Transport Policies	Excess Tax Revenue (%)
Scenario 3a (50% fare reduction)	63%
Scenario 3b (25% fare reduction)	82%
Scenario 3c (actual fares)	100%

8. CONCLUDING REMARKS

This study attempts to investigate congestion reduction strategies for developing countries with explicit consideration of household travel behavior for commuter travel. The NL model is found to be a suitable technique to model the basic domain of the household mobility. Congestion reduction policies are analyzed using the estimated NL model to restrain vehicle usage in metropolitan areas. Several policy scenarios are investigated by considering different road pricing systems, especially for the usage of car and motor cycle in CBD and inner suburb zones, in addition to subsidizing the public transportation system. Policy scenarios are mainly in two folds: fixed tax throughout the day and variable taxes for different time periods of a day considering the peak congestion hours. The most influential policy is obtained by treating CBD and inner suburb zones separately by different vehicle tax systems where private vehicle usage in those zones is considerably declined as a result.

Results of the policies are expressed with the reductions of vehicle kilometers of travel and air pollution quantities. Country-level emission factors are explicitly incorporated for the analysis to improve the level of accuracy of the pollution estimates. Reductions of air pollution estimates due to car and motor cycle travel are discussed with explicit consideration of the speed variations due to the respective policies. Finally, tax revenues from the road pricing system and funds requirement for public transport fare reduction are estimated for the proposed transport policies. According to the results, it is found that the government revenue can be considerably increased with the policy implementation since the tax revenues are higher then the funds requirement for transit subsidy. Finding of this study can be effectively applied to improve the traffic congestion and environmental pollution in BMR.

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