Sustainable Urban Policies for Developing Countries by Integrating Center-based Telecommuting with Transit and Road Pricing: A Case Study of Bangkok Metropolitan Region

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Abstract

This study investigates the suitability of integrating telecommuting with transit and road pricing for reducing traffic congestion and air pollution in developing countries. Application of disaggregate modeling to estimate the impacts of transport policies, for instance the reduction of vehicle kilometers of travel (VKT) and air pollution levels, is the principal motivation of this study.

Firstly, a nested logit (NL) model is developed to investigate household travel behavior linked to vehicle ownership, mode choice, and trip sharing attributes. The nest structure consists of two levels; the upper level characterizes car owning, motorcycle owning, and no vehicle owning choices while the lower level represents the household related mode choices. Secondly, the estimated NL model is applied for the purpose of policy analysis considering center-based telecommuting, transit, and road pricing. Several hypothetical satellite offices are considered outside the central business district (CBD) to analyze travel behavior associated with telecommuting. The new locations for the satellite offices are chosen based on travel convenience and compatibility with the current road network. Having center-based telecommuting as a base policy, several policies are investigated by combining the base policy with transit and road pricing. The policy impacts including the reduction of vehicle kilometers of travel and air pollution are estimated using the Bangkok Metropolitan Region as a case study.

Keywords: Integrated policies, developing countries, center-based telecommuting, sustainability, road pricing
INTRODUCTION

Rapid economic development and its related impacts such as increasing mobility and vehicle ownership create a variety of complications in developing countries. In addition, inconsistencies existing between transport and land use have a significant influence on the mobility problem that negatively affects the entire process of development. Although both transport and land use sectors have made many improvements with the growing economic conditions in developing countries, the interrelationship between them has not been well established at the planning and decision making stages. This can be a governing factor for travelers’ motives behind the use of private vehicles. On the other hand, suburban sprawling supports ever growing vehicle usage. Uncontrollable rising land prices in CBD encourage urban dwellers to locate their residences in the suburbs and as a result, suburban sprawling has become more attractive in recent years.

In particular, the outcome of suburban sprawling has disadvantages and is troublesome if a country cannot provide adequate infrastructure and transit facilities to maintain daily transport needs between the suburbs and CBD. It is clear that most developing countries provide inefficient transportation systems and limited highway networks that may not be sufficient to serve the suburbs. Consequently, most households in the suburbs that commute daily to CBD use their own vehicles rather than traveling by the inferior transit modes available. This is likely to cause increasing vehicle ownership. It is clear that increasing vehicle ownership and usage have been receiving more attention in recent years due to their adverse effects on the environment and society. However, urban areas in developing countries are still suffering from environmental problems such as traffic congestion and environmental pollution. Therefore, developing socially and environmentally viable policies are vital for such countries.

The travel decisions among household members in developing countries are interrelated (1) and therefore household travel behavior is explicitly analyzed in this study using the data from the Bangkok Metropolitan Region (BMR). According to figure 1, at least 30% of households in the low-income group, 60% of households in the middle-income group, and 68% of households in the high-income group in Bangkok own either a car or a motorcycle. Since most households in Bangkok own only a single vehicle, the possibility of generating household serving trips is considerably high. Vehicle users in these households, in most cases the commuters, usually take the responsibility of driving for other household members by sharing vehicles for multipurpose trips. By observing person trip data in the BMR, trip sharing can be identified as one of the popular travel attractions for vehicle owning households, for instance car and motorcycle shared trips make up 30% of household trips (1). Therefore, analyzing trip sharing behavior is important. Consequently, major travel decisions concerning vehicle ownership, mode choice, and trip sharing are analyzed in the proposed model.

This research attempts to apply the findings of travel behavior modeling to integrated transport policy analysis in developing countries using the BMR as a case study area. The basic model is developed as a Nested Logit (NL) model with two levels to investigate household travel behavior in connection with vehicle ownership, mode choice, and trip sharing decisions, focusing on two-traveler households. In the nest structure the upper level consists of car owning, motorcycle owning, and no vehicle owning choices and the lower level represents the mode choice combinations for two-traveler households. Since trip sharing is a fairly popular event among the vehicle owning households in the BMR, it is considered as one of the mode choice options in the proposed model. The estimated NL model is
successfully applied for the purpose of policy analysis in regard to center-based telecommuting. In addition, several policies are investigated by combining center-based telecommuting with road pricing and transit fare reductions to understand the combined effect with the integrated policy aspects. Impacts of the policies are explained by congestion reduction and air quality improvements in the BMR. With the proposed policies, vehicle kilometers of travel (VKT) and air pollution can be successfully reduced to improve mobility and air quality within the region.

ISSUES ON TRANSPORT AND LAND USE INTERACTION

With advancement in urban planning and policy-making investigations, interactive transport and land use modeling has been receiving great attention. Webster et al. (3) highlighted the importance of integrating transport and land use aspects in urban planning approaches and developed some models and policies taking both aspects into consideration. Ewing et al. (4) investigated land use and accessibility effects on trip generation rates and found that there is no direct relationship between land use and accessibility with trip generation rates. In addition, they mentioned that household trip rates may be affected by land use and accessibility indirectly through their effects on vehicle ownership. More recently, Rujopakarn (5) investigated the validity of the 8th Bangkok transport plan and found that the proposed plan will not be successful due to its incompatibility with the existing land use plans. In Bangkok, many commuters travel daily from the outer suburbs to the city center intensifying the traffic congestion. Therefore, integrated decision making on transport and land use is becoming an urgent issue, especially for developing countries.

Lupa et al. (6) conducted an integrated study of transport and land use for the Northern Illinois region aiming to reduce the vehicle miles traveled (VMT). They proposed transport plans considering land use inputs and found that compacted zones of job and housing tend to decrease VMT regardless of transit enhancements in the area concerned, proving that scattered patterns of housing and jobs are acting as a barrier to controlling VMT. As far as the choices of housing locations are concerned, a trade off between higher commuting times and costs with lower housing charges at locations distant from the work places are important. As reported by Ommeren et al. (7) commuting behavior also depends on the labor markets in addition to the housing markets, and there is also a trade off between higher wages and lower housing charges to maximize the net benefit. This may finally cause excess commuting distances and is often identified as “wasteful commuting”. For several decades many investigations have criticized this topic (8-10). Consequently, redistribution of work and house locations is identified as an appropriate method for improving traffic conditions in CBD areas, thereby assisting travelers to reduce their travel distances. Scott et al. (11) investigated methods for reducing congestion and environmental pollution in North America and found that implementing policies made a positive contribution to improving commuting efficiency. Furthermore, their study mainly investigated the promotion of job-housing balance which showed that the choices of work place and house locations are very important considerations for minimizing commuting distances.

To achieve the target of reducing commuting distances either work place or housing location should be fixed in the analysis. According to Ommeren et al. (7) two kinds of models can be developed: urban equilibrium models with fixed work location, and standard urban equilibrium models with fixed housing location. Cervero and Duncan (12) investigated two land-use strategies, job-housing balance and retail-housing mix, to ascertain which is better in terms of reducing VMT using the San Francisco Bay area as a case study. According to their
findings, job-housing balance can be identified as more effective in terms of reducing motorized travel. The emergence and growth of sub-centers in the Los Angeles region was analyzed by cluster analysis using census journey-to-work data (13). Accordingly, the formation of sub-centers was defined as employment concentration sites.

Wells et al. (14) examined the telecommuting implications for travel behavior in the Minnesota region and two telecommuting schemes were conducted as part of a larger research project. Results of this investigation specify that telecommuting implementation strategies vary within, and between, organizations and those schemes appear to moderate the relationship between telecommuting and complex travel behaviors, such as local task running and trip chaining. Martens and Korver (15) conducted a study on forecasting and assessing the mobility effects of teleservices using telecommuting as a case study. The estimates in their research study were based on realistic and consistent societal scenarios and the use of an operational transport model made it possible to include second-order effects such as induced travel. As Drucker and Khattak (16) mention, working from home is advantageous for both employees and employers, and telecommunications technologies are enabling the new work-at-home phenomena. The effects of socioeconomic, household, location, and accessibility variables on individuals' choices to work from home were estimated with ordered logit, ordered probit, and multinomial logit models incorporating the data from the 1995 Nationwide Personal Transportation Survey. All three models resulted in very similar observations indicating that educational attainment and the presence of small children in the household encourage frequent working from home.

STUDY AREA AND DATA DESCRIPTION

The empirical analysis is conducted using the data from the BMR in Thailand. The BMR consists of the Bangkok Metropolitan Area (BMA) and five adjacent provinces: 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 km² and the total population was 13.8 million in 2001. The BMR is split into three major zones: CBD, Inner Suburb, and Outer Suburb, and the Inner and the Outer Ring Roads are considered as zone separation cordons.

The total daily person trips in the BMR were about 22 million in 2001; 90% of which were generated within the CBD and the Inner Suburb zones. The BMR is identified as one of the worst metropolitan areas in the world for traffic congestion; especially during the morning and evening commuting hours when the traffic situation is extremely severe. In the BMR, the lowest travel speed occurs in the central area of Bangkok (CBD), and it is about 5~10 km/hr. The travel speed increases as the distance from the city center increases.

The data, which are used in this study, were obtained from the household travel survey that was conducted in the BMR during 1995/96. The UTDM (Urban Transport Database and Model Development) Project was responsible for the survey (2). The survey provides a wide variety of data useful for understanding travel behavior. The data consists of attributes of the trips that were made on the date of the survey as well as information on household members. Although there were a large amount of households in the database, 1205 households were selected for the empirical analysis according to the model requirement of two-traveler households, of the two, one traveler has to be a commuter. In the database trips were indicated using the zones of origin 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 (shared or otherwise), origin and destination zones, transfer zones, travel times, and time of day.

Geographical information of the study region was originally computerized by the MAPINFO Geographical Information System based Arc-view software, which is helpful for easy reference and meaningful comparison as necessary. Furthermore, location-based information such as trip length is measured on the existing road network using the criteria of the shortest distance between origin and destination zones. To help strengthen the overall database, the Bangkok Environmental Improvement (BEIP) Project provided an additional database for the home interview survey (17).

METHODOLOGY

The methodology consists of three main stages: Data preparation for the model, Model development, and Policy analysis. Figure 2 illustrates the activities involved in each stage and the sequence which the activities are linked together to generate the intended outputs in each stage. The details of the stages are explained in the following sections. Firstly, the NL model development and the data preparations for the models are discussed. This is followed by a discussion of the model estimation and the results. Secondly, the application of the NL model for integrated policy analysis is presented.

THE NL MODEL FOR TWO-TRAVELER HOUSEHOLDS

Data Preparation and Model Development

The transportation modes in the BMR at the time of data collection were bus, rail, car, motorcycle, hired motorcycle, taxi, and ferry. The main mode of public transport in Bangkok is bus transportation since the rail facilities currently operate very inefficiently and provide services mostly on an inter-city travel basis. Ferries are functioning along the “Chao Praya” river as well as many canals in Bangkok, even though the accessibility and the serviceability relating to those are rather poor. Since rail and ferry are not accessible modes for many in the BMR, they are excluded from the analysis.

In developing countries, travel decisions of household members are interrelated and therefore, this study is based on two-traveler households in Bangkok. Two-traveler households are selected in order to comprehend the household travel behavior with a feasible modeling approach; using three or more travelers may complicate the modeling process. Among the two-travelers, one of the travelers makes a commuter trip.

The travel purpose of the second traveler in the household can be any type, such as work, shopping, private business, social or recreation. When both travelers share the same vehicle, the commuter has to drop by the destination of the second traveler before reaching his destination. The commuter trip can be home-to-work (work-bound) or work-to-home (homebound). Therefore, detours of both work-bound and homebound trips are explicitly incorporated in the analysis. This approach contrasts with the others, which deal with conventional definition of home-to-home trips with complete cycles.

The nest structure, developed in this study, for the two-traveler households has two levels as shown in figure 3. The upper level characterizes the household choices for car owning, motorcycle owning, and no vehicle owning. The lower level represents the corresponding mode choice combinations for two-traveler households. Altogether it has 17
options to represent household travel patterns. In Figure 3, C, CSH, M, MSH, B, H, and T represent the modes of car, car sharing, motorcycle, motorcycle sharing, bus, hired motorcycle, and taxi, respectively.

For car owning households, Alternatives 1 through 7 are the possible mode choice combinations: use either car (Alternatives 1~4) or other modes (Alternatives 5~7). In detail, Alternatives 1 through 4 are various car travel patterns in which the commuter (main traveler) travels by car and the second traveler of the same household travels by the available options of car sharing (CSH), bus (B), hired motorcycle (H) or taxi (T). In Alternatives 5 through 7, both travelers who belong to the car-owning group travel by B, H or T. Alternatives 8 through 14 are applicable for the motorcycle owning nest. Among them, Alternatives 8 through 11 are directly related to motorcycle use for commuter travel. For the households with no vehicles, Alternatives 15 through 17 are the mode choice options in which both travelers use B, H or T since they have to manage their travel needs by other available modes in the system.

Attributes, which are obtained from the database, are explicitly incorporated in the analysis. Since this study is based on two-traveler households attributes for both travelers are included appropriately in the model. In each alternative, level-of-service variables such as travel time and travel cost are calculated with explicit consideration of both travelers in a household. For example, travel time for Alternative 2 (commuter uses car and second traveler uses bus) is obtained by adding the commuter’s travel time (car travel) and the second traveler’s travel time (bus travel). Similarly, the travel cost for the alternatives is also calculated. When the household shares the trips, the commuter first drives to the second travelers’ destination (travel distance X) and then, drives to his work place (travel distance Y).

In this study, the shortest route between the destinations is considered. Accordingly, X and Y are kept to within their minimum distances, and the travel time and the travel cost of the shared trips are calculated considering the minimum travel distances X and Y.

**Model Estimation**

The simultaneous estimation (full information maximum likelihood) method is used to estimate the NL model. It is assumed that the scale parameter for the bottom level of the nesting structure (i.e., the level of mode choices) is unity, and the scale parameter for the upper level is estimated. For the Alternatives 7, 14, and 17 in the NL model where both travelers travel by taxi (T), alternative specific constants are considered as zero. In addition, alternative specific constants for the alternatives where both travelers travel by bus (Alternatives 5, 12 and 15) share a common parameter in the corresponding utility functions. Similarly, alternative specific constants for the alternatives where both travelers travel by hired motorcycle (H) for the car owning and the motorcycle owning groups (Alternatives 6 and 13) share the same parameter. However, the constant for Alternative 16 where both travelers travel by hired motorcycle (H) for the no vehicle owning households is kept different from the constant in Alternatives 6 and 13 by considering the variations of choice attitudes for the vehicle owning and the no vehicle owning groups.

**Model Estimation Results and Discussion**

Table 1 illustrates the parameter estimation results for the proposed NL model. According to the estimation results, most of the parameters are significantly estimated with expected signs
providing useful information about travel behavior in developing countries. Alternative specific constants for Alternatives 2, 3, 4, 9, 10, 11, and 16 are significantly positive indicating the household preference for using separate modes rather than forming shared trips. In addition, all households with or without vehicles have a preference for the bus mode (Alternatives 5, 12, and 15) since the common alternative specific constant is positively significant.

Coefficients for the travel time and the travel cost/income are significantly negative as expected. The scale parameter of the upper level is estimated to be 0.49, and it falls in the limit between 0 and 1 to keep the functioning of the nesting behavior of the proposed NL model. A variety of alternative specific dummies are included in the developed NL model to ascertain behavioral realism of developing country households on vehicle ownership, and mode choice as well as trip sharing aspects. The dummies such as distance between travelers’ destinations, individual travel distances, distance shared in the trip chains, time compatibility, CBD travel, trip purpose, household income, number of school children, commuter’s job, gender, and age are selected for the analysis according to the data availability. The distance between the travelers’ destinations is included as a dummy in several utility functions. When the distance between destinations is less than or equal to 15 km, the corresponding dummy in the alternatives of Car sharing (Alternative 1) and Motorcycle sharing (Alternative 8) are positive and significant, expressing the household tendency to make car or motorcycle shared trips for closer destinations. Similarly, when the destinations are far from each other, households prefer separate modes such as Alternative 9 (commuter uses motorcycle and second traveler uses bus).

If both travelers’ travel distances are long, for example more than 30 km, the corresponding dummy in Alternative 2 is significant and positive in sign. It highlights that the commuter uses a car and the second traveler uses the bus for long distance travel. If the second traveler’s travel distance is more than 5 km, the dummy in Alternative 3 (commuter uses a car and second traveler uses a hired motorcycle) is significantly negative, indicating that a hired motorcycle is not a suitable option for distance traveling. When both travelers of the household share their travel distance by 75% or more, motorcycle sharing is found to be an attractive option for Bangkok travelers.

The dummy variable for time compatibility, which mainly compares both travelers’ activity start and finish times, has a significant positive effect indicating its importance in trip sharing. In other words, when the commuter’s work start time (finish time) is later (earlier) than the second traveler’s activity start time (finish time), car sharing is an attractive alternative.

Traveling in CBD is also tested with several dummies in the estimated model. When both travelers’ trips are in CBD, the travelers’ preference for motorcycle shared trips is negative. When both travelers’ trips are in CBD, traveling by hired motorcycle is not an attractive choice for them since it may not be a safe travel option in highly congested areas such as Bangkok. Also, if the trips of both travelers are in CBD, owning a car is not a preferable option for them. For the trips that touch CBD, Alternative 2 is a suitable travel option. Traveling through the CBD zone, especially in the BMR, is extremely difficult during peak congestion hours, and therefore, the commuter drives alone and has the second traveler use a bus rather than attempting to share the trips in congestion areas.

The commuter’s job is tested as a dummy in Alternative 8 (motorcycle sharing) and the car-owning utility functions. According to the results executive job holding commuters are less likely to share motorcycle trips. When the commuter’s job is either executive or
business, the related dummy in the car-owning utility function has a positive sign indicating the greater propensity to own vehicles. It indirectly highlights the interaction between car owning and the reputation linked with the job. When both travelers’ in the household have jobs in executive or business categories, the dummy in the no vehicle owning utility function yields with a positive significance.

The dummy variable for male commuters, which is included in the alternatives of Car sharing (Alternative 1) and Motorcycle sharing (Alternative 8), significantly yields a positive sign expressing their contribution to household travel responsibilities by sharing trips. The commuter’s age is also tested as a dummy and it is found that commuters over fifty years of age prefer not to own vehicles.

Trip purpose is found to be an important factor in mode selection. Therefore, both travelers’ trip purposes are tested as a dummy in Alternative 8 (motorcycle sharing). When the trip purpose of the second traveler is for commuting or schooling, a motorcycle shared trip is considerably the preferred option for Bangkok travelers.

Household income is also incorporated as a dummy in the No Vehicle-owning utility function. When the household income is less than or equal to 25000 Thai Baht vehicle owning is not a suitable option. When there are school children in the household car owning is the option preferred.

Calculation of the Value of Time (VOT) for the estimated model is important to measure the external validity of the model, and the VOT generally incorporates the coefficients of travel time and travel cost. According to the specification of the proposed NL model, VOT also depends on the household income in addition to the coefficients of travel time and travel cost. Since the data set has a variety of household incomes, different VOT figures exist. Therefore, the average VOT is calculated and is 30 Thai Baht/hr. The VOT obtained is very similar to that of the study conducted in the same region by the UTDM project (2). Therefore, the estimated model is intuitively reasonable to represent the actual circumstances in the study region. The goodness of fit for the model has a high value of 0.41.

MODEL APPLICATION FOR URBAN TRANSPORT POLICIES

Integrated transport and land use policies are becoming an important issue in developing countries due to mounting traffic congestion and air pollution. Therefore, this study applies the developed NL model for urban transport policy analysis considering center-based telecommuting, road pricing, and transit subsidy. A policy of center-based telecommuting is mainly conducted by relocating work places in the suburbs by means of satellite centers aiming to reduce travel distances and to improve the traffic condition in CBD areas. In addition, policies are analyzed by combining telecommuting with road pricing and transit fare reductions to understand the combined effect with the integrated policy issues.

Analyzing Telecommuting by the Introduction of Satellite Offices in Suburbs

In this study, five hypothetical satellite centers are considered in the outer suburbs in the BMR as shown in figure 4. New locations are decided with explicit consideration of the available transport facilities including the recently implemented Mass Rapid Transit (MRT) system together with current residential locations to provide commuters with easy accessibility.
The commuters’ job and the second travelers’ job as well as the location of the destination are considered as governing factors to understanding the possibility of changing their destinations to the proposed satellite centers in the suburbs. In this policy, housing locations are considered as fixed. For the households who would be able to change their destinations from their current work places to a satellite center new commuting distances to the closest satellite center are re-measured using GIS maps. By using their new travel distances, attributes such as travel times and costs are calculated. Undoubtedly, some jobs are not flexible enough to be carried out in the satellite centers due to occupational obligations, for example, jobs such as salesman, laborer, driver, and technician, and therefore no alterations is made to their commuting distances due to the introduction of satellite centers. In addition, for the households that live in CBD and have their work or activity places in CBD, actual trips are unaffected by the new satellite locations; the attributes of their trips are considered to be the same as the original figures. After reorganizing the attributes with the new locations of work places, the following policies are investigated:

- **Policy 1:** *Center-based Telecommuting*
  Analyzed considering five hypothetical satellite centers in the outer suburbs.

- **Policy 2:** *Center-based Telecommuting and Road pricing*
  Analyzed considering five hypothetical satellite centers in the outer suburbs together with a road-pricing scheme in CBD (car: 80 Baht/day and motorcycle: 30 Baht/day). The charges are only collected from single occupant vehicles that enter CBD. Therefore, trip chains are made as an appreciated mode choice option in the region.

- **Policy 3:** *Centre-based Telecommuting, Road pricing, and Transit subsidy*
  Analyzed considering five hypothetical satellite centers in the outer suburbs together with a road-pricing scheme in CBD (car: 80 Baht/day and motorcycle: 30 Baht/day) and a transit subsidy (bus fares by 25% of actual fares).

Policies 1 through 3 are analyzed using the estimated NL model and the resulting impacts are presented using the reductions of vehicle kilometers of travel (VKT) and air pollution in the region.

**Assessment of Policy Related Impacts**

VKT and pollution emissions are estimated by using household choice probabilities for each alternative included in their choice set of 17 alternatives explained in Equations 1 and 2.

\[
VKT_n(i) = P_n(i)d_n
\]  
\[
T(VKT) = \sum_{n=1}^{N} \left[ \sum_{i=1,8} P_n(i)d_{n,\text{share}} + \sum_{i=1,8} P_n(i)(d_n^1 + d_n^2) \right]
\]

In the above Equations, \(N\) is the total number of households in the database, \(VKT_n(i)\) is VKT by alternative \(i\) for household \(n\), \(T(VKT)\) is the total VKT, \(P_n(i)\) is the probability that alternative \(i\) is chosen by household \(n\), \(d_n\) is the travel distance of household \(n\), \(d_{n,\text{share}}\) is the distance of the shared ride, \(d_n^1\) is the commuters’ travel distance, and \(d_n^2\) is the second travelers’ travel distance.
VKT for the base case (without policy) and the policies 1 through 3 are calculated separately using Equations 1 and 2. The reductions of VKT for car and motorcycle travel with the policies are graphically represented in Figure 5.

According to the results, policy 1 (center-based telecommuting) shows a great effect in reducing private vehicle usage in the area by up to 20%. Although integrated policies 2 and 3 continue to reduce VKT in the area, the resultant effect due to road pricing and transit fare reduction is found to be small.

For the air pollution estimations, country-level emission factors are applied rather than using composite emission factors with a default speed to improve the accuracy of the results. Therefore, emission factors due to mobile source emissions that are used in this study were obtained from the Pollution Control Department in Bangkok. Equation 3 explains the procedure of estimating air pollution where \( E(APE) \) indicates the expected value of emission in milligrams, \( F(AP)_{car} \) and \( F(AP)_{mc} \) are emission factors for car travel and motorcycle travel in mg/km.

\[
E(APE) = \sum_{n=1}^{N} \left[ \left( \frac{P_n(1)}{P_n(11)} \right) \frac{d_{nc}^{share}}{d_{nc}^{share}} + \left( \frac{P_n(2)+P_n(3)}{P_n(11)} \right) \frac{d_n^1}{d_n^1} + \left( \frac{P_n(4)+P_n(7)+P_n(14)+P_n(17)}{P_n(11)} \right) \frac{d_n^2}{d_n^2} \right] \times \begin{cases} F(AP)_{car} \end{cases}
\]

In this study, the travel speed is assumed to be unchanged with the policy implementation. The reductions of air pollution levels for \( \text{NO}_x \), \( \text{SO}_x \), \( \text{CO} \), \( \text{PM} \), and \( \text{HC} \) are presented graphically in figure 5. Accordingly, all the pollutants are reasonably reduced with the policies analyzed in this study and reductions are in the range 18% to 26%.

**ADAPTATION OF THE METHODOLOGY OVER LONG-TERM ASPECTS**

Since societal values and concerns with respect to urban systems vary over time, transport planning can be considered as a continuous dynamic process. Given the challenges of long-term sustainability, both the proposed model and policy analysis need to be constantly upgraded by robust information and regional needs. Accordingly, the data management and institutional engagements become the top priorities in the long-run. In order to make transport more sustainable in developing countries, the necessity of institutional and policy reforms has been recently emphasized (18).
Especially in developing countries, travelers’ attitudes and behaviors in regard to transport systems are subject to change over time due to economic development, urbanization, and motorization. Therefore, the proposed NL model has to be re-estimated at different points in time by taking an improved information base (latest household travel databases) into account. Additionally, land use patterns in developing metropolitan areas gradually vary over time due to urban sprawl and new developments, and as a result, improved spatial coverage, for instance updated GIS maps, have to be used in the analysis. Regarding the policies, it is important to incorporate the latest information on traffic related emissions including the country-level emission factors for motor vehicles as used in this research. Until recently, transport planners in developing countries were dependent on past experiences or personal judgment when taking policy decisions partly due to lack of data resources (1, 19). Therefore the data management systems should receive particular attention in such countries if they intend to employ advanced modeling methods in their decision making processes.

Institutional engagements, generally political by nature in the context of developing countries, are highly important in enabling development, supporting on-going research, developing improved methodologies for questionnaire design, data collection, database management, and finally in setting up policy guidelines. However, in developing countries institutional involvement on policy making and decision support has been happening at a slower pace than in that of developed countries. The transport authorities in the BMR, in particular the Department of Highways in Bangkok, are currently in the process of searching for the best policies for regional development. The next step of this research is to present this study to the relevant urban authorities in Bangkok to ascertain whether the policies proposed are appropriate and are in line with their upcoming policy enforcements.

The developed GAUSS computer program, which is used to estimate the NL model and to analyze integrated policies in this study, can be exploited to model the new databases and to estimate the model parameters over long-term practice.

CONCLUSIONS

A methodology is developed to analyze integrated transport policies for the BMR having center-based telecommuting, road pricing and transit subsidy as policy tools in this research. The NL model is found to be a suitable technique to model the basic domain of household mobility over vehicle ownership, mode choice, and trip sharing decisions that is later applied to investigate the policies. Center-based telecommuting is analyzed as the basic policy in this study by relocating work places. To investigate the policy on center-based telecommuting, five hypothetical satellite centers are located in the outer suburbs of Bangkok CBD. New work locations (locations of satellite centers) are decided with explicit consideration of the available transport facilities together with current residential locations, thereby providing commuters with easy accessibility. Consequently, several policies are investigated by integrating center-based telecommuting with road-pricing policy in CBD and transit fare reductions.

Related impacts of the policies are estimated with corresponding reductions of VKT and emissions in the region. To estimate VKT and traffic related emissions, household choice probabilities for each travel option are explicitly incorporated. In addition, to improve the level of accuracy of the pollution estimates, country-level emission factors are used in the analysis. The resultant reductions of VKT and emissions are found to be reasonable and therefore, regional mobility can be significantly improved with the proposed policies.
Furthermore, most of the previous studies relied on aggregate data in determining emission levels that may lead to inaccurate research findings. This research investigates the possibility of applying disaggregate modeling using household travel data directly for the estimation of VKT and emission levels, thereby attempting to improve the reliability of the analysis.

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<td>6, 13 Hired Motorcycle &amp; Hired Motorcycle</td>
<td>0.25</td>
<td>0.3</td>
</tr>
<tr>
<td>8 Motorcycle (shared ride)</td>
<td>1.26</td>
<td>1.3</td>
</tr>
<tr>
<td>9 Motorcycle &amp; Bus</td>
<td>5.02</td>
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<tr>
<td>10 Motorcycle &amp; Hired Motorcycle</td>
<td>4.00</td>
<td>7.5</td>
</tr>
<tr>
<td>11 Hired Motorcycle &amp; Taxi</td>
<td>2.13</td>
<td>2.8</td>
</tr>
<tr>
<td>16 Hired Motorcycle &amp; Hired Motorcycle</td>
<td>1.01</td>
<td>2.3</td>
</tr>
<tr>
<td>Motorcycle-owning</td>
<td>1.53</td>
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</tr>
<tr>
<td>No Vehicle-owning</td>
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<td>2.7</td>
</tr>
<tr>
<td>7, 14, 17 Taxi &amp; Taxi</td>
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<tr>
<td><strong>Level-of-service variables</strong></td>
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<tr>
<td>Travel time (hrs)</td>
<td>-0.42</td>
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<tr>
<td>Travel cost/income/10^2</td>
<td>-2.34</td>
<td>-5.3</td>
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<tr>
<td><strong>Scale parameters</strong></td>
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<td></td>
</tr>
<tr>
<td>( \mu_{\text{car owning/motorcycle owning/no vehicle owning}} )</td>
<td>0.49</td>
<td>5.0</td>
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<tr>
<td><strong>Alternative specific dummies</strong></td>
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<tr>
<td>Distance between destinations ≤ 15km, Alternatives 1, 8</td>
<td>1.05</td>
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<tr>
<td>Distance between destinations ≥ 10km, Alternative 9</td>
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<td>Travel distance for each traveler &gt; 30km Alternative 2</td>
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<td>Second travelers’ travel distance &gt; 5km, Alternative 3</td>
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<td>Distance shared in the trip chain ≥ 75%, Alternative 8</td>
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<td>Time compatibility, Alternative 1</td>
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<td>Trips within CBD, Alternative 8</td>
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<td>Trips within CBD, Alternative 16</td>
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<td>Trips touching CBD, Alternative 2</td>
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<td>Commuter’s job(executive), Alternative 8</td>
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<td>Both travelers jobs not executive, No Vehicle-owning</td>
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<td>Commuter’s age &gt; 50 yrs, No Vehicle-owning</td>
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<td>Trip purpose work-work, work-school, Alternative 8</td>
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<td>School children in household ≥ 1, Car-owning</td>
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<tr>
<td>( L(\hat{\beta}) )</td>
<td>-1937.0</td>
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<tr>
<td>( L(c) )</td>
<td>-3278.1</td>
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<tr>
<td>( \rho^2 )</td>
<td>0.41</td>
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<tr>
<td>( VOT ) (Thai Baht/hr)</td>
<td>30</td>
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</tbody>
</table>

0 in “Parameter” column indicates that the constant term set to zero.
Bold figures are significant at 95%.
FIGURE 1 Household distribution by income and vehicle ownership in the BMR in 1996. Developed using the data from UTDM (2)
FIGURE 2 Model development and integrated policy analysis process.
FIGURE 3 NL model of vehicle ownership, mode choice and trip sharing.

<table>
<thead>
<tr>
<th>Alt.</th>
<th>Household mode choices</th>
<th>Alt.</th>
<th>Household mode choices</th>
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<tr>
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<td>Commodity</td>
<td>Second traveler</td>
<td>Commodity</td>
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<tr>
<td>1</td>
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<td>Car sharing (CSH)</td>
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<tr>
<td>2</td>
<td>Car (C)</td>
<td>Bus (B)</td>
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<td>3</td>
<td>Car (C)</td>
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<tr>
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<td>5,12,15</td>
<td>Bus (B)</td>
<td>Bus (B)</td>
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<td>6,13,16</td>
<td>Hired motorcycle (H)</td>
<td>Hired motorcycle (H)</td>
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</table>
FIGURE 4 Proposed locations of the satellite offices in the BMR.
FIGURE 5 Impacts of the policy proposals.