

A COMBINED RP/SP NESTED LOGIT MODEL TO INVESTIGATE HOUSEHOLD DECISIONS ON VEHICLE USAGE, MODE CHOICE AND TRIP-CHAINING IN DEVELOPING COUNTRIES

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Abstract: This study proposes a combined RP/SP Nested Logit (NL) model to investigate travel behavior in developing countries. Combining Revealed Preference (RP) and Stated Preference (SP) data is a prominent tool for expressing complex travel behavior and forecasting travel demand for new transport services. The recent behavioral variations of urban travelers are successfully analyzed using the proposed model. Emphasis is mainly placed on investigating household decisions of vehicle usage, mode choice and trip-chaining aspects together with the travelers' intention on proposed Mass Rapid Transit (MRT) system in Bangkok Metropolitan Region (BMR).

Key Words: Stated preferences, Revealed preferences, Mass rapid transit, Nested Logit, Developing countries.

1. INTRODUCTION

In recent years, travel behavior of developing countries is becoming complicated with increasing mobility and intense vehicle usage. Increasing mobility is strongly supported by rapid economic development and as a result, usage of private vehicles is popular among the urban travelers. Despite of that, insufficient supply and inferior quality of public transportation also encourage travelers to use vehicles. Introduction of rapid transit systems, for instance, subway, light rail transit (LRT) or mass rapid transit (MRT), will be a crucial solution to alleviate the mobility crisis in developing countries.

Inherent vehicle usage has been recently diversified with trip chaining importance, especially for developing country households where the commuter often gets the burden in driving for other household members. Consequently, the direct commuter trip has been dramatically turned into a multipurpose trip-chain with numerous work or non-work intermediate stops and purposes. Although most of the previous approaches have been extensively considered the trip chaining decisions of individuals, comparatively less attention was contributed on household serving trip chains due to the complexity of modeling.

Transport users' revealed preferences (RP) for actual travel behavior is very useful in analyzing the travel demand for existing modes. However, forecasting the travel demand on new transport modes is always accompanied with travelers' stated preferences (SP) since the actual travel data (RP) for such modes are not available. This study aims to propose a combined RP/SP Nested Logit (NL) model to analyze complex household travel behavior on existing modes and to forecast the travel demand on new transport mode, investigating Bangkok Metropolitan Region (BMR) as a case study. Findings of this study postulate some valuable insights, relating to the household travel demand analysis and forecasting, for developing countries by exploiting the advantages of both RP and SP data sources.

2. REVIEW OF RELATED LITERATURE

Among various technological innovations in transport sector, travel demand analysis has been receiving increasing attention in recent years. Transport planners, researchers and practitioners are urgently searching for reasonable solutions to deal with ever-growing travel demand and its related adverse effects, for instance, traffic congestion, air and noise pollution,

In the methodological perspective, disaggregate demand modeling, which describes the behavior of transport user with discrete variables, also called Discrete Choice Analysis (DCA) is very popular in transportation planning (Ben-Akiva and Lerman 1985). In DCA, there are several modeling tools such as Multinomial Logit (MNL) and NL models that are commonly used in travel demand analysis. Estimation of discrete choice models basically relies on RP data for actual travel behavior. However, there is also a substantial interest on SP data, which is based on hypothetical travel scenarios. Although SP techniques have several advantages over more conventional RP techniques, the reliability of the elicited preferences is uncertain (Wardman, 1988; Morikawa, 1989). Abraham & Hunt (1997) estimated a NL model for commuter travel using RP data, and wide range of system attributes was identified as important. There also exists some substantial interest of mode choice modeling with repeated SP observations which can be successfully used to minimize the errors in individual choice response (Fujiwara and Sugie, 1995; Mehndiratta and Hansen, 1997; Hayashi *et al.*, 1998). In recent years, emphasis was made on combining RP and SP data in travel demand modeling (Morikawa, 1989; Ben-Akiva and Morikawa, 1990; Dissanayake and Morikawa, 2000; Polydoropoulou and Ben-Akiva, 2001). The combined analysis with RP and SP data improves the accuracy of parameter estimates by exploiting the advantages of both data sources.

Sobel (1980) made emphasis on travel demand forecasting for individuals and various types of NL structures were incorporated for the mode choice analysis. When the journey consists of multiple modes such as Kiss-and-ride (K & R) and Park-and-ride (P & R), a NL model is considered as an appropriate method to analyze the choice behavior considering similarities of unobserved attributes in particular sub groups (Ortuzar, 1983). Commuting-based mode choices were estimated by two-level NL model by keeping the upper-level for line haul choices and the lower-level for access or egress modes, and extended the analysis for market segmentation approach considering income and work trip sub-groups (Talvitie, 1978). Mannering *et al.* (1994) developed a NL model to investigate individual travel behavior, emphasizing mainly on activity type and activity chaining aspects, where the upper-level represents the activity type choice and the lower-level shows the number of stops in the activity chain. Polydoropoulou and Ben-Akiva (2001) developed a combined RP/SP NL model considering access and main mode choice for new mass transit project in Tel-Aviv metropolitan area.

3. STUDY BACKGROUND

A combined RP/SP NL model is proposed in this study to investigate the overall decision making process relating to travel demand modeling.

The specific areas of concern are as follows:

1. analyze travel demand for existing modes with explicit coverage of household travel decisions on vehicle usage, mode choice and trip chaining.
2. forecast travel demand for proposed Mass Rapid Transit (MRT) Project in Bangkok Metropolitan Region (BMR).

Figure 1 illustrates some important considerations relating to the modeling approach. Accordingly, improvement of transport sector and policy analysis is greatly depending on user preferences on existing modes over vehicle ownership, vehicle usage and mode choice aspects as well as user preference over new modes. The preferences of transport users are generally collected as RP and SP data since those are in latent form.

4. STUDY AREA

In this study, BMR is selected for the empirical analysis (Figure 2). 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 km² and the total population in the study region is 13.8 million in 2001.

As indicated in Figure 2, BMR is split into three major zones: CBD, inner suburb and outer suburb where 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.

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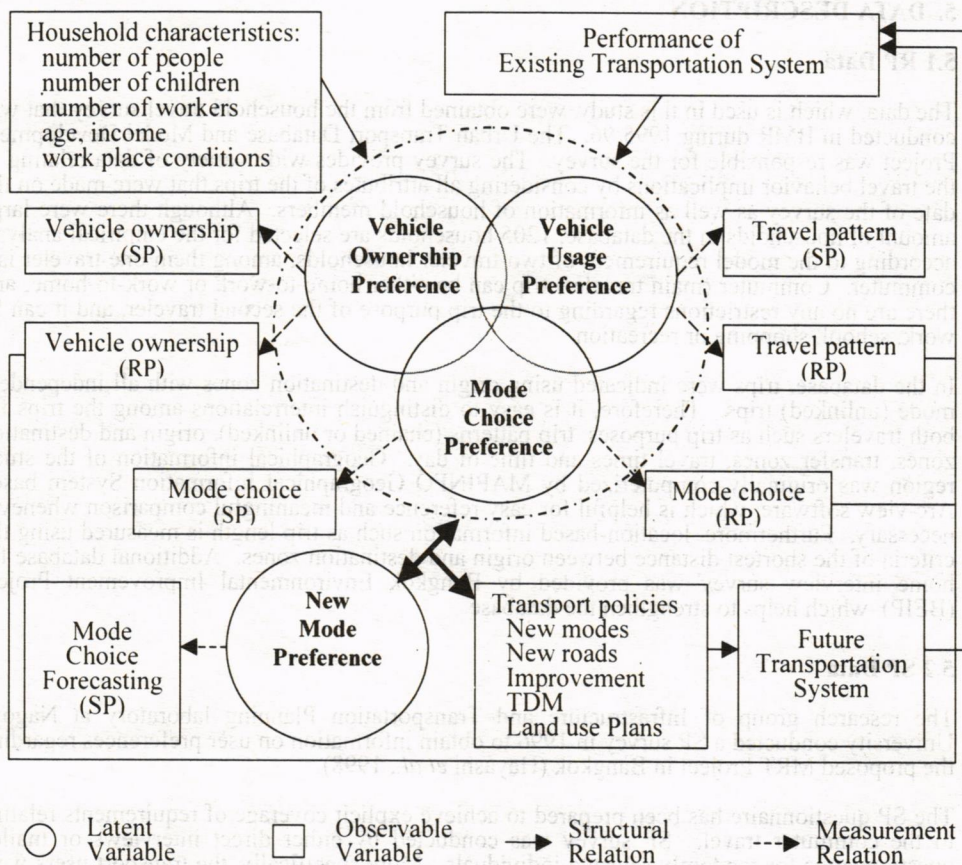


Figure 1. Framework for the Modeling Approach

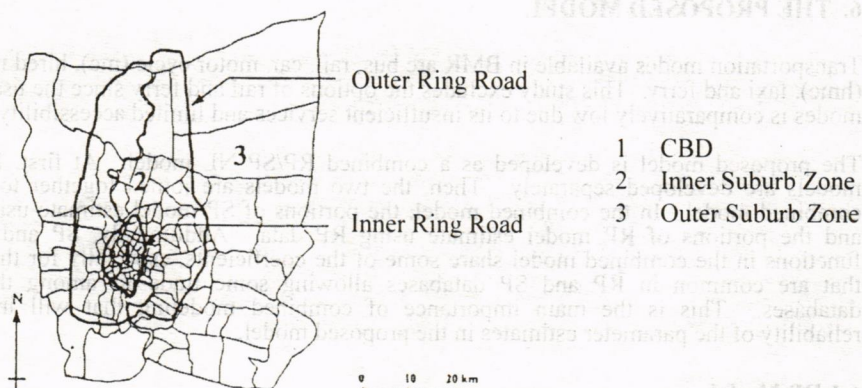


Figure 2. Area Map of the Bangkok Metropolitan Region (Source: Hayashi *et al.*, 1998)

5. DATA DESCRIPTION

5.1 RP Data

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. Commuter (main traveler) trip can be either home-to-work or work-to-home, and there are no any restrictions regarding to the trip purpose of the second traveler, and it can be work, school, shopping or recreation.

In the database, trips were indicated using origin and destination zones 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.

5.2 SP Data

The research group of Infrastructure and Transportation Planning laboratory at Nagoya University conducted a SP survey in 1996 to obtain information on user preferences regarding the proposed MRT Project in Bangkok (Hayashi *et al.*, 1998).

The SP questionnaire has been prepared to achieve explicit coverage of requirements relating to the commuter travel. SP survey was conducted by either direct interviews or mailed questionnaires for randomly selected individuals. More specifically, the transport users were asked to select the choices, which are best suited for their travel requirements, among the hypothetically created travel scenarios. Also, attributes for the choices were explicitly described in the SP questionnaires such as travel time, travel cost, travel speed, reliability (minimum delays), safety, comfort, service frequency, accessibility of intra-model transfers and access/egress time.

6. THE PROPOSED MODEL

Transportation modes available in BMR are bus, rail, car, motor cycle (mc), hired motor cycle (hmc), taxi and ferry. This study excludes the options of rail and ferry since the usage of such modes is comparatively low due to its insufficient services and limited accessibility.

The proposed model is developed as a combined RP/SP NL model. At first, RP and SP models are developed separately. Then, the two models are joined together to develop a combined model. In the combined model, the portions of SP model estimate using SP data and the portions of RP model estimate using RP data. Additionally, SP and RP utility functions in the combined model share some of the coefficients, especially for the attributes that are common in RP and SP databases allowing some trade-off among the separate databases. This is the main importance of combined modeling that will improve the reliability of the parameter estimates in the proposed model.

6.1 RP Model

RP data include complete information of household travel, and two-traveler households are analyzed in this study. Since the household travel consists with multiple modes, a NL model is selected as a suitable analyzing method for RP data.

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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 Independence from irrelevant alternatives (IIA) in the MNL Model. In the NL model, alternatives in the same nest share a common component of random utility. In addition, each alternative has an alternative specific random utility component.

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, in each nest that can be obtained by taking log-sum of the nested utilities for all alternatives belonging to 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. Figure 3 shows the developed nesting structure for the RP model.

As shown in Figure 3, 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 that are relating to car-using and mc-using households. Alternatives 1~4 are applicable for 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. As described earlier, 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 the commuter and the second traveler use bus, hmc or taxi depending on their modal preferences.

According to the data, which was obtained by 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 bus alternative has the highest travel demand (37%) followed by the mc-chain (16%) and the car-chain (13%).

Mode choice representation:

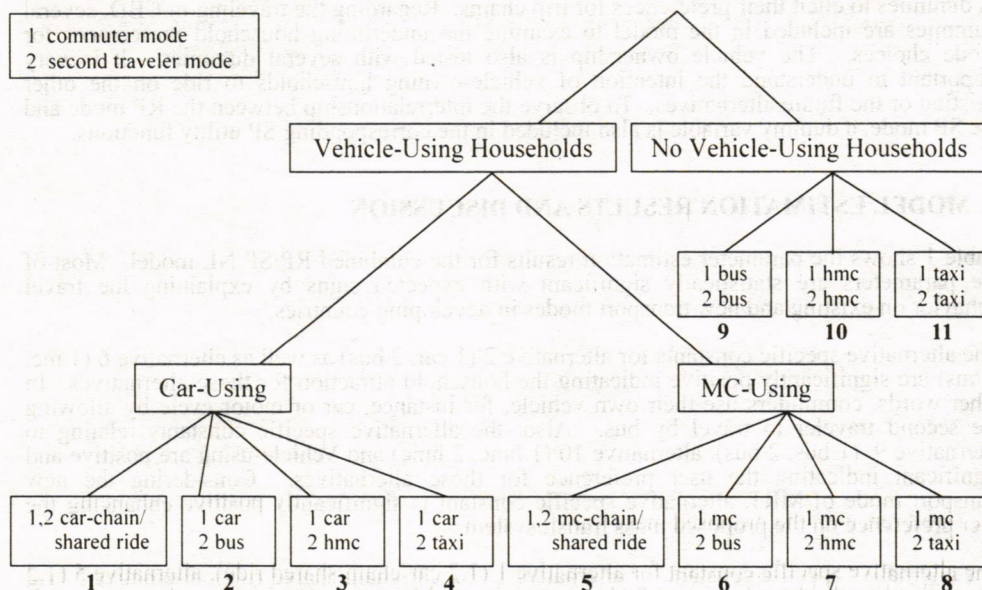


Figure 3. The NL Structure for RP Model

6.2 SP Model

The SP data, which incorporates in this study, provide information on individual commuter trips. Therefore, SP model is developed as a MNL model considering transport user preferences on MRT, bus and car. The SP database consists of 1240 individual trips.

6.3 Combined RP/SP NL Model

Combined RP/SP model is then developed by sharing coefficients of some common attributes in RP and SP models. Especially in this study, the coefficients of the travel-time and the travel-cost/income are shared for all RP and SP based utility functions. In addition, alternative specific constants for bus alternative are also shared with a common parameter in RP and SP utility functions. To observe the relative level of randomness in the RP and SP data sources, a scale parameter is included in the SP utility functions.

Simultaneous estimation (full information maximum likelihood) method is used to estimate the combined RP/SP NL model. 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 RP and SP databases, are explicitly incorporated in the model estimation to contrast the behavioral realism on mode choice and associated effects on trip chaining for household travel. This study is based on two-traveler households and therefore, attributes for both travelers are incorporated for the model estimation. For example, travel time for alternative 2 (1 car, 2 bus) is obtained by adding the travel time of the commuter (car travel) and the travel time of the second traveler (bus travel).

In the combined RP/SP model, dummies are appropriately included to examine the household travel behavior in developing countries. Furthermore, dummies are very useful to make the model behaving with actual travel conditions in the study region. Therefore, the dummies are selected to reveal the hidden preferences of the commuter and the second traveler belonging to their mode choices together with trip chaining attractions. By considering the trip chaining aspects, the most important consideration is found as the time compatibility among the household members regarding their traveling. Therefore, the dummy for the time compatibility in this model considers the conditions such as work or activity start/finish time and time of day for each trip that is made by the households to examine the possibility of trip-chaining. In addition, commuter's gender, job as well as both travelers' travel distances, distance between the destinations, travel purposes and fraction of distance-share are analyzed as dummies to elicit their preferences for trip chains. Regarding the traveling in CBD, several dummies are included in the model to examine the underlining household preferences for mode choices. The vehicle ownership is also tested with several dummies. It is very important to understand the intention of vehicle-owning households to ride on the other existing or the future alternatives. To observe the interrelationship between the RP mode and the SP mode, a dummy variable is also included in the corresponding SP utility functions.

7. MODEL ESTIMATION RESULTS AND DISCUSSION

Table 1 shows the parameter estimation results for the combined RP/SP NL model. Most of the parameters are statistically significant with expected signs by explaining the travel behavior on existing and new transport modes 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 vehicle, for instance, car or motor cycle by allowing the second traveler to travel by bus. Also, the alternative specific constants relating to alternative 9 (1 bus, 2 bus), alternative 10 (1 hmc, 2 hmc) and Vehicle-using are positive and significant indicating the user preference for those alternatives. Considering the new transport mode of MRT, alternative specific constant is significantly positive enhancing the user preference on the proposed mass transit system.

The alternative specific constant for alternative 1 (1,2 car-chain/shared ride), alternative 5 (1,2 mc-chain/shared ride), alternative 8 (1 mc, 2 taxi) and MC-using are significantly negative. It indicates that, the households have negative intention for those alternatives if all other attributes remain the same.

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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) : <i>RP</i>	-4.32	-3.6
Alt. 2 – (1 car, 2 bus) : <i>RP</i>	1.49	3.2
Alt. 4 – (1 car, 2 taxi) : <i>RP</i>	-1.22	-1.7
Alt. 5 – (1.2 mc-chain/shared ride) : <i>RP</i>	-1.62	-2.8
Alt. 6 – (1 mc, 2 bus) : <i>RP</i>	1.12	5.1
Alt. 8 – (1 mc, 2 taxi) : <i>RP</i>	-1.79	-2.9
MC-using : <i>RP</i>	-5.45	-3.5
Alt. 9 – (1 bus, 2 bus) : <i>RP/SP</i>	0.77	2.8
Alt.10 – (1 hmc, 2 hmc) : <i>RP</i>	0.80	2.2
Vehicle-using : <i>RP</i>	1.81	2.6
MRT (mrt) : <i>SP</i>	1.43	3.1
Level-of-service variables		
travel time (hrs) : <i>RP/SP</i>	-0.61	-4.2
travel cost/income/10 ² : <i>RP/SP</i>	-2.31	-5.1
Scale parameters		
$\mu^{car/mc}$	0.78	4.0
$\mu^{vehicle/no\ vehicle}$	0.68	4.9
scale (<i>RP:SP</i>)	1.47	3.6
Alternative specific dummies		
male commuter, Alt 1.5: <i>RP</i>	1.28	4.1
time compatibility, Alt. 1: <i>RP</i>	5.02	4.5
(commuter's work start time is later than the others activity start time, or commuter's work finish time is earlier than the others activity finish time)		
travel distance for both travelers > 30km, Alt. 2: <i>RP</i>	1.85	2.5
travel distance for both travelers > 25km, Alt. 5: <i>RP</i>	-1.85	-2.7
distance between destinations \geq 10km, Alt. 6: <i>RP</i>	0.68	2.4
distance between destinations \leq 15km, Alt. 1.5: <i>RP</i>	0.95	2.4
second travelers travel distance > 5km, Alt. 3: <i>RP</i>	-1.96	-2.4
commuter's job(executive or business), Vehicle-using: <i>RP</i>	1.31	2.7
commuter's job(executive), Alt. 5: <i>RP</i>	-1.35	-4.8
mc ownership, MC-using: <i>RP</i>	8.90	4.1
car ownership, Car: <i>SP</i>	1.37	3.0
car ownership, MRT: <i>SP</i>	0.41	2.2
no vehicle and no driving license, No vehicle-using: <i>RP</i>	11.21	4.2
trips touching CBD, Alt. 2: <i>RP</i>	0.67	2.4
trips within CBD, Vehicle-using: <i>RP</i>	-1.16	-2.4
trips within CBD, Alt. 10: <i>RP</i>	-2.07	-3.8
RP mode, Car & Bus: <i>SP</i>	0.90	3.2
low income class, Alt. 9: <i>RP</i>	1.29	3.2
distance sharing fraction of both travelers > 75%, Alt. 5: <i>RP</i>	1.47	5.6
household travel purpose is commuting (work-work), Alt. 5: <i>RP</i>	0.90	3.1
household travel purpose is work-work or work-school, Alt. 9: <i>RP</i>	0.61	1.3
Number of observations		2445
$L(\hat{\beta})$		-1903.3
$L(c)$		-4225.6
VOT (Baht/hr)		82

Coefficients for the travel time and the travel cost/income are significantly negative as expected. Initially, scale parameter for the mc nest is taken as 1 and estimated the model. After several estimations, it is found that the scale parameters for the car nest and the no vehicle-using nest are very close to 1 (i. e. 0.99). Therefore, scale parameters are considered

to be 1 for all nests of car-using, mc-using and no vehicle-using at its mode choice level, and the model is estimated again. According to the results, scale parameters for other levels are found to be significant and values are within the specified limits between 0 and 1. And also, magnitude of those decreases when the level of the nesting structure increases. Using the estimated values for the scale parameters, parameters for log-sum variables can be calculated and those are for car-using, mc-using, vehicle-using and no vehicle-using nests are 0.78, 0.78, 0.87 and 0.68 respectively. The calculated values are in the theoretically acceptable range between 0 to 1 as expected. The scale parameter (RP:SP) significantly estimates as 1.47, implying that the RP data contain more random noise than SP data.

The dummy variables are included in the model to capture the real insight of the behavioral aspects in developing countries. Dummy variable for male commuters, which is included in alternative 1 (1.2 car-chain/shared ride) and 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 significantly positive indicating its importance on forming car-chains. In other words, when the commuter's work start time (finish time) is later (earlier) than the second travelers' activity start time (finish time), car-chain is an attractive alternative for the households in developing countries.

When the travelers travel distance are more than or equal to 30 km, related dummy variable in alternative 2 (1 car, 2 bus) is positive and significant. It indicates that the household tendency to use different travel modes, for instance, commuter use car and the second travel use bus for longer trip lengths. Similarly, when the travelers travel distance is more than or equal to 25 km, related dummy variable in alternative 5 (1.2 mc-chain/shared ride) is negatively significant showing the difficulty of making mc-chains for long distance travel considering both travelers into account. When the distance between destinations is greater than or equal to 10 km, the corresponding dummy variable in alternative 6 (1 mc, 2 bus) is positively significant. It explains that the household attraction to use separate modes where commuter use mc by allowing the second traveler in the same household to use bus when the destinations are far from each other. And also, when the distance between destinations is less than or equal to 15km, related dummy variable is estimated with positive significance highlighting the household tendency to make car-chains or mc-chains. If the second travelers travel distance is more than 5 km, alternative 3 (1 car, 2 hmc) is not a household selection indicating that the hired motor cycle is not a suitable mode for distance traveling.

Commuter's job condition is also analyzed by introducing dummy variables into the alternatives of vehicle-using as well as alternative 5 (1.2 mc-chain/shared ride). When the commuter's job is executive or business oriented, the related dummy variable in vehicle-using alternative is significantly positive 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.

Motorcycle ownership is tested as a dummy in the mc-using alternative and the respective parameter is significantly positive by showing the relation between owning and using motor cycles. Car ownership is also tested as dummies in SP based utility functions of Car and MRT, and the related parameters are positive and significant. "No vehicle and no driving license" dummy is introduced in the alternative of no vehicle-using households that yields a parameter with expected sign.

Traveling in CBD is tested with several dummies. For the trips that touch the CBD zone, alternative 2 (1 car, 2 bus) is found as an attractive mode selection for developing country households. 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 indicating the household preference to use separate modes for traveling in CBD. Dummy variable for CBD trips that is included in vehicle-using alternative is significantly negative indicating the difficulty of using vehicles in CBD zone. If both travelers' trips are in CBD, using hired motor cycles is not a suitable mode choice for them.

RP mode is also tested in SP utility functions of Car and Bus, and the coefficients for those dummies are significantly positive indicating the users' hidden preference to continue their RP modes. When the household income belongs to the lower income group, both travelers in the household prefer to travel by bus. When the travel distance of both travelers shares more

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than 75%. mc-chain is found as a suitable option. Travelers trip purpose is also tested with dummies. If the household travel is for commuting (work/work), mc-chain is a suitable choice option for them.

$L(c)$ is obtained by incorporating the estimated values of the scale parameters while keeping all the other parameters to be zero.

The value of time (VOT) is a measure that represents the external validity of the estimated model, and it is generally calculated by using the coefficients of the travel time and the travel cost. According to the specification of the proposed model, the VOT also depends on household income in addition to the coefficients of the travel time and the travel cost. Since the data set has variety of household incomes, there exist different VOT figures corresponding to each household. Therefore, average VOT is calculated according to the equation (1).

$$VOT = \left(\frac{\text{Coeff. of Travel Time}}{\text{Coeff. of Travel Cost}} \right) * \left(\frac{\text{Average Income}}{\text{Income}/10^2} \right) \quad (1)$$

For the proposed NL model, VOT is calculated using the estimated coefficients of the travel time and the travel cost/income with the average income of the database, and it is obtained as 82 Baht/hr.

8. CONCLUSIONS

A NL model is developed to investigate household travel behavior in developing countries with explicit consideration of recent behavioral variations. The proposed model uses RP and SP data to analyze the travel behavior on existing modes and also to forecast the user intention on proposed MRT system in BMR. The findings of this study provides further evidence that transport users' stated preferences can be profoundly used as an accurate guide to represent the actual underlining preferences. It has been clearly observed that the combined estimation of RP and SP data in travel demand modeling is an effective technique for expressing complex travel behavior and forecasting the travel demand for new transport services.

Considering the households in developing countries, trip chain is very popular mode selection, and considered it as one of the mode-choice options in the proposed NL model. Male commuters attract highly to form trip chains indicating their contribution for household responsibilities. Time compatibility, CBD travel, long distance travel and distance between the destinations are also found to be important for households to get their decisions on trip chaining. According to the estimation results, hired motor cycle is not a suitable travel option for CBD travel as well as long distance travel. When the trips for both travelers are in CBD, they prefer to use separate modes rather than forming trip chains in congested areas. The results obtained from this study is realistic and it can be effectively used for decision-making activities related to the transportation sector in developing countries. Further investigations on the proposed model will be focused on policy related analysis.

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