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An Activity-Based Microsimulation Model of Travel Demand in the Jakarta Metropolitan Area

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Abstract

The goal of the study reported in this paper was to develop a comprehensive activity-based modeling system in the context of developing countries, providing accurate estimates which are expected to serve as better inputs for evaluation of different transportation policy scenarios. The case study is Jakarta, Indonesia as one of the largest metropolitan areas in Asia. The modelling system primarily adopts a tour-based structure in which the tour is used as the unit of modeling travel instead of the trip, preserving a consistency in destination, mode, and time of day choices across trips.

Keywords: Activity-based models, Tour-based models, Microsimulation, Jakarta Metropolitan Area, Developing countries

1 Introduction

1.1 Background

Activity-based modeling of travel demand treats travel as being derived from the demand for activity participation. It has been argued that the activity-based modeling

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approach can offer a rich framework in which travel is analyzed as a daily pattern of behavior related to and derived from differences in lifestyles and activity participation among individuals. As a result, travel needs to be studied in a broader context of activity scheduling.

Despite advances in academic research on activity-based modeling, the majority of the MPOs in the United States are still using conventional regional models based on the four-step modeling paradigm with numerous variations and enhancements. However, a growing number of MPOs either have already developed and applied models of the new type or have at least made a decision to start development of a new model, sometimes in parallel with maintenance and enhancement of the existing four-step model (Vovsha *et al.* 2003a). It seems that activity-based models are more popular in the developed countries than in the developing countries while transportation related problems such as congestion and air quality issues are most serious in the developing world.

The goal of the study is to develop a comprehensive activity-based microsimulation modeling system of which structures and control factors may be significantly different in the context of developing countries, providing accurate estimates which are expected to serve as better inputs for evaluation of different transportation policy scenarios. The study simulates the way individuals schedule their daily activities and travel in an urban region of the developing world. The case study is the Jakarta, Indonesia as one of the largest metropolitan areas in Asia with a population over 21.6 million people and 5.6 million households. The study aims at developing a practical model that can replicate patterns of activity-travel with fully connected choices of time, mode, and location and test different transportation policy scenarios for the Jakarta Metropolitan Area.

The rest of this section describes transportation in the Jakarta Metropolitan Area, including the previous master plan study and descriptions of surveys that have been conducted, current policies under review. The next section, Section 2, describes the framework of the activity-based modeling system used in this study, reviewing definitions and structural aspects in the relevant literature and research. Section 3 describes all the activity-based models in the system, namely, three types of major models (choices of daily activity-travel patterns (Yagi and Mohammadian 2008a), times of day, and mode and destination (Yagi and Mohammadian 2008b)) and two types of sub-models (choices of mode and destination for work-based sub-tours and location of intermediate stops). Section 4 presents the estimation results of the above models and discusses the implications in the context of Jakarta; in addition, several important aspects of activity-based microsimulation modeling is discussed including auto and motorcycle ownership choice, activity rescheduling, joint tour/activity generation (Yagi and Mohammadian 2005), household maintenance tour allocation, model validation (Yagi and Mohammadian 2007b), and policy application (Yagi and Mohammadian 2007a). Section 5 summarizes contributions of the research findings and directions for subsequent research. For further details of some specific model components or aspects of the activity-based microsimulation in this study, please refer to the above-mentioned papers.

1.2 Jakarta Metropolitan Area

Gross regional domestic product (GRDP) of the Jakarta Metropolitan Area is estimated at Rp. 351,000 billion (US$ 39.4 billion) or 22 percent of the national gross domestic product (GDP) (as of 2002), showing that it is strategically the most important region of the nation. While it is a global city, the fact that Indonesia is not as developed as a Western country such as the U.S. leads to large differences in terms of the travel choices made by citizens. Similar to that of other cities in the developing world, Jakarta is tilted away from the private automobile towards transit, motorcycles, taxis (formal or informal) and non-motorized modes of transport. For details, refer to Yagi and Mohammadian (2005).

In the Jakarta Metropolitan Area, a variety of urban transportation management policies are currently being examined, discussed, or implemented. For example, the "3-in-1" scheme, in which only high-occupancy vehicles are allowed to use central arterial roads during peak periods, has recently been more widely and strictly enforced along with the introduction of a new bus rapid transit (BRT) using the centermost lane of the arterial roads as a dedicated "busway." More new policies such as area pricing and license plate restriction are now being discussed for implementation as well as extension of the BRT system. In addition, raising the fuel price is a current controversial issue that is being considered and implemented by the Indonesian government. As such, it is hoped that the proposed new models will contribute to the improvement of the methodology of travel demand forecasting and evaluation of urban transportation policy scenarios in the region. This paper describes the general framework and methodology of activity-based model that has been applied in this study along with the results of model estimation.

1.3 Datasets

In "The Study on Integrated Transportation Master Plan (SITRAMP)" conducted in the Jakarta Metropolitan Area from November 2001 to March 2004 (National Development Planning Agency 2004), detailed transportation surveys such as Household Travel Survey (HTS) and Activity Diary Survey (ADS), and analyses were undertaken to prepare a comprehensive long-term transportation plan. It is worth noting that the activity-based model requires a much richer and more detailed dataset than those required for the conventional travel demand modeling systems. Fortunately, the Jakarta Metropolitan Area has excellent sources of survey data including a regular full-scale household travel survey and an activity diary survey. Both surveys cover activity-travel information of individuals of all generations including children who are 5 years or older (Yagi and Mohammadian 2005). The activity-based modeling system is developed using these two datasets.

The HTS, which is a large scale home interview survey of household daily travel, provides the largest and most comprehensive travel data in the region. The dataset covers as many as 166,000 households equaling three percent of the population and provides daily travel patterns on a weekday and detailed information on household socio-demographic characteristics. Meanwhile, the ADS, which was conducted originally to support the result of the HTS, provides a detailed four-day diary including both weekdays and weekends and covering around 4,000 individuals that were randomly selected from the HTS samples. In other words, respondents of the ADS are represented in the HTS database as well. Both HTS and ADS were conducted in 2002, only a few months apart. Households in the ADS data are linked to the corresponding observation in the HTS dataset by a unique identifier allowing us to use both datasets for analysis (Yagi and Mohammadian 2005). Thus, the large datasets obtained for this study provide a unique opportunity to conduct numerous other research works.

2 Activity-Based Modeling Structure

2.1 Definitions

A "trip" is defined as a travel between two activities representing the trip purpose (Home to Work, Home to School, etc.). The term "purpose" in this study is used to present the activity performed at the trip end. Furthermore, each trip record is coded with travel mode (auto, motorcycle, transit, etc.). A "tour", on the other hand, is defined as a chain of trips which start from a base and return to the same base. One or more activities (i.e. purposes) are involved in the course of a tour. In order to analyze daily activity-travel tour patterns in this study, a tour has been considered a home-based tour if it starts from home and ends at home.

As for out-of-home activities, they are often grouped into the following three commonly categorized activity types (Vovsha *et al.* 2004a):

- Mandatory activities (e.g. work, university, or school),
- Maintenance activities (e.g. shopping, banking, visiting doctor, etc.), and
- Discretionary activities (e.g. social and recreational activities, eating out, etc.).

For this study, mandatory activities are further divided into *work* and *school* purposes because there is essentially a difference between *work* and *school* as to by whom and when such activities are carried out. The last two activity types, *maintenance* and *discretionary* activities, are often treated as one activity type, that is, non-mandatory pattern (Bradley and Vovsha 2005) that can be distinguished from mandatory primary activities such as *work* and *school* patterns. In this study, this classification has been applied to deal with intra-household interactions in the activity-based microsimulation. In addition, it is worth noting that in-home activities (e.g. working at home, shopping online, taking care of a child/old person, being sick, etc.) deserve special consideration though there is not much research done with regard to trade-offs between in-home and out-of-home activities.

Home-based tours, which are defined as the travel from home to one or more activity locations and back home again, are subdivided into "primary" and "secondary" tours based on activity priority (Bowman and Ben-Akiva 2000). Activities are prioritized based on the purpose of the activity, with work activities having the highest priority, followed by work-related, school, and all other purposes. Within a particular purpose, activities with longer durations are assigned higher priorities. The tour of the day with the highest priority activity (i.e. the "primary" activity) is designated as the "primary" tour and others are designated as "secondary" tours.

2.2 Modeling Framework

For this study, the fundamental modeling approach is a discrete choice model based on the random utility maximizing principles. It has been shown that the multinomial logit model is the most popular form of discrete choice model in practical applications (Mohammadian and Doherty 2005). Nested logit model, which has also been utilized in this study, is a model that has been developed in order to overcome the so-called independence of irrelevant alternatives (IIA) limitation in the multinomial model by modifying the choice structure into multiple tiers. Nested logit models are very commonly used for modeling mode choice, permitting covariance in random components among nests of alternatives. Alternatives in a nest exhibit an identical degree of increased sensitivity relative to alternatives in the nest (McFadden 1978). A nested logit model has a logsum or expected maximum utility associated with the lower-tier decision process. The parameter of the logsum determines the correlation in unobserved components among alternatives in the nest (Daganzo and Kusnic 1993). The range of this parameter should be theoretically between 0 and 1 for all nests if the nested logit model is to remain globally consistent with the random utility maximizing principle.

The modeling system in this study primarily adopts a modified version of the frameworks proposed for Boston (Bowman and Ben-Akiva 2000), and Portland (Bowman *et al.* 1998; Bradley *et al.* 1999) to develop an uncomplicated yet credible model which can replicate the patterns of activity and travel in developing world. It has a similar tour-based structure in which the tour is used as the unit of modeling travel instead of the trip, preserving a consistency in destination, mode, and time of day across trips. The overall modeling structure is depicted in Figure 1. All models are for home-based tours unless otherwise specified. It is a system of random utility based disaggregate logit and nested logit models assuming a hierarchy of model components, with three types of major models, namely, choices of daily activity-travel patterns, times of day, and mode and destination in the hierarchy. Lower level choices depend on the decisions at the higher level, and higher level decisions are linked to the lower level choices through the logsum variables reflecting expected maximum composite utility of lower-level choices. Furthermore, two types of additional sub-models are added to this framework in order to determine additional characteristics of tours, that is, mode and destination choice for work-based sub-tours and location choice of intermediate stops. Each model is described in the subsequent sections. This study will show that such a deeply nested structure practically works with all the model components connected to each other through logsum variables within a proper range of 0 and 1 and statistically significant parameters.

As a basic input to the proposed activity-based modeling system, various household and household member information, zone-based socioeconomic and land use data, and highway and transit network-based data are prepared, and the modeling system will generate people's daily activity-travel patterns, tours, and trips that can be integrated into origin-destination (OD) trips by mode and by time of day for full network assignment. The base year is set as 2002 and all the models are estimated based on the input as of 2002. For future years, the population will be updated first to prepare for household and household member information; especially, a household auto/motorcycle ownership choice model is adopted to set the number of autos and motorcycles owned by each household.

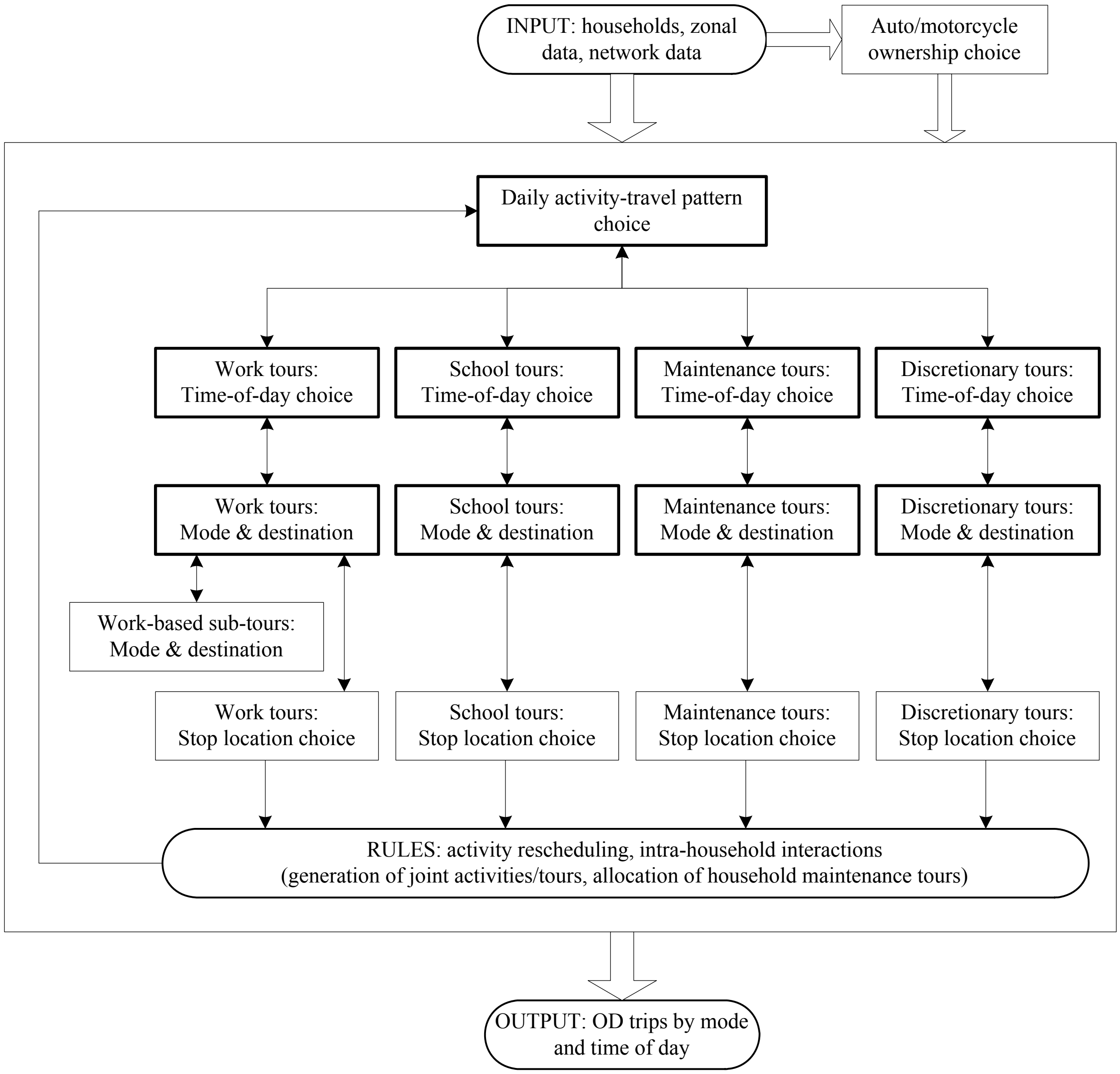


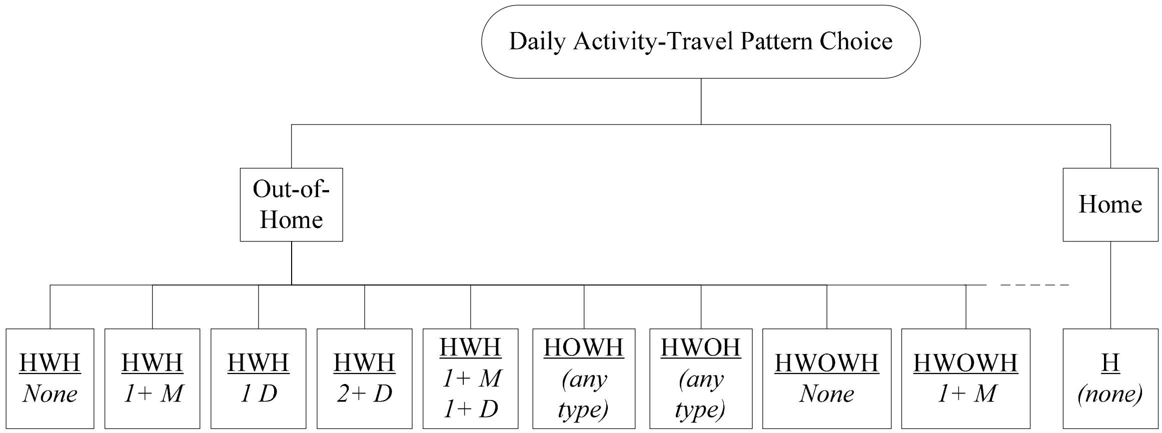
Figure 1. Overall Modeling Structure

3 Model Description

3.1 Daily Activity-Travel Pattern Choice

Daily activity-travel patterns (DAPs) except for *home*, which means staying at home all day, are defined by primary activity, primary tour type, and number and type of secondary tours. Primary activities or purposes are classified as *home* (H), *work* (W), *school* (S), *maintenance* (M), and *discretionary* (D) for the sake of modeling.

Both primary and secondary tours are treated as home-based. Primary tour type is defined by presence and sequences of intermediate stops and presence of (work-based) sub-tours in a tour. The primary tour type classification depends on whether it is a



Note: Primary activities/tours are underlined and secondary tours are in *italics*.

Figure 2. Modeling Structure: Daily Activity-Travel Pattern Choice Model

simple tour from home to a destination and then back to home again with no intermediate stops, or a tour with at least one intermediate stop for another activity on the way from home or on the way back home; and whether it includes at least one sub-tour (for *work* tours only) which is further divided into an intermediate returning-home sub-tour and a sub-tour to somewhere else. As shown in an example of Figure 2, each classification is represented as a string of letters indicating a sequence of activities. Note that an 'H' is included at the beginning and the end of each string to show that it is a home-based tour. For simplicity, activity purpose of intermediate stops and work-based sub-tours (except for intermediate return home) is not considered in this model, and those are represented as an 'O' in the activity sequence.

On the other hand, secondary tour type is defined by activity purpose, and it is classified into *maintenance* and *discretionary* activities. Number of secondary tours is counted by activity and classified into 0 and 1 or more secondary *maintenance* tours, and 0, 1, and 2 or more secondary *discretionary* tours. Combination of the primary activity, primary tour type, and number and type of secondary tours brings about a choice set of 121 DAP alternatives, including 1 *home* pattern, 60 primary *work* tour patterns, 20 primary *school* tour patterns, 20 primary *maintenance* tour patterns, and 20 primary *discretionary* tour patterns.

The most notable difference in relative frequency of the DAP alternatives between the HTS and ADS datasets may be the relative frequency of the *home* pattern. In the HTS, the percentage of staying at home all day is as high as 22 percent, while the one derived from the ADS is only about 6 percent. In addition, alternatives of simple primary tour type with no secondary tours have higher frequencies in the HTS. The main cause for such differences may be that relatively short-distance tours, especially those made by non-motorized mode of transport tend to be overlooked in the HTS. Although modeling based on the HTS database could eventually have no major impact on the forecast of longer-distance motorized trips, the ADS database has been selected for model estimation of DAPs.

Efforts were made to include as many DAP alternatives as possible for model estimation. In practice, however, at least 15-20 samples were necessary for each alternative to derive significant estimates from the model. Looking into weekday samples of around 4,000 individuals in the ADS dataset, primary tour types of some alternatives with low frequencies as well as some secondary tour types and numbers have been combined, and 35 alternatives have been included in the model for estimation. Interested readers are referred to Yagi and Mohammadian (2008a) for a detailed discussion of DAP alternatives.

The model for daily activity-travel pattern choice, which is placed at the top of the entire modeling system, has a two-tier nested logit structure, with a choice of whether to go out of home and travel or stay at home all day in the upper tier and a choice of out-of-home DAP alternatives defined by primary tour activity, primary tour type, and number and type of secondary tours in the lower tier under the *out-of-home*. On the other hand, *home* alternative is a degenerate branch with only one stay-home-all-day alternative. The modeling structure of DAPs is depicted in Figure 2. This model is estimated using many variables explaining attributes of the household and the individual. Logsum variables from the lower level, that is, time-of-day choice for primary *work*, *school*, *maintenance*, and *discretionary* tours, and secondary *maintenance* and *discretionary* tours are also included in the model, where applicable.

3.2 Time-of-Day Choice

In order to model the time-of-day (TOD) choice, a day is divided into five time periods, namely, early morning (“EM”, 3:00 – 6:29), a.m. peak (“AM”, 6:30 – 9:59), midday (“MD”, 10:00 – 15:59), p.m. peak (“PM”, 16:00 – 18:59), and night (“NT”, 19:00 – 2:59). These five time periods are distinguished considering not only characteristic hourly traffic volume but also the operation hours of Jakarta’s unique “3-in-1” traffic regulation (i.e. morning operation from 6:30 to 10:00 as of 2002, and evening operation from 16:00 to 19:00 added since 2004). Alternatives are created by combining the time period to leave home to start the tour and the time period to leave the destination of the main activity to start the returning segment of the tour. Frequencies of tours starting early in the morning (EM) are relatively high in Indonesia; according the ADS, over 90 percent of people get up by 6:00 a.m. on weekdays. Observations in both ADS and HTS show that the ratio of overnight tours continuing over 3:00 a.m. on the next day is much less than one percent. Assuming for simplicity that there are no tours that last over night, 15 TOD combinations or alternatives are identified.

As shown in Figure 3, the TOD choice is a multinomial logit model with 15 alternatives, and it is estimated separately for each purpose (i.e. *work*, *school*, *maintenance*, and *discretionary*). Note that students’ TOD choice should be significantly different from that of workers because schools in Indonesia usually have a half-day shift system (i.e. two or three shifts per day). The above four models are to generate logsums that will be passed to the single, upper-level DAP choice model. Since model estimation by purpose needs enough observations for each of the 15 TOD alternatives, samples have been taken from the HTS database. For each purpose, a total of around 25,000 tour samples were used for modeling, and we have ensured that the sample households and individuals that were used for estimation of the DAP choice model are included in the dataset for TOD choice modeling.

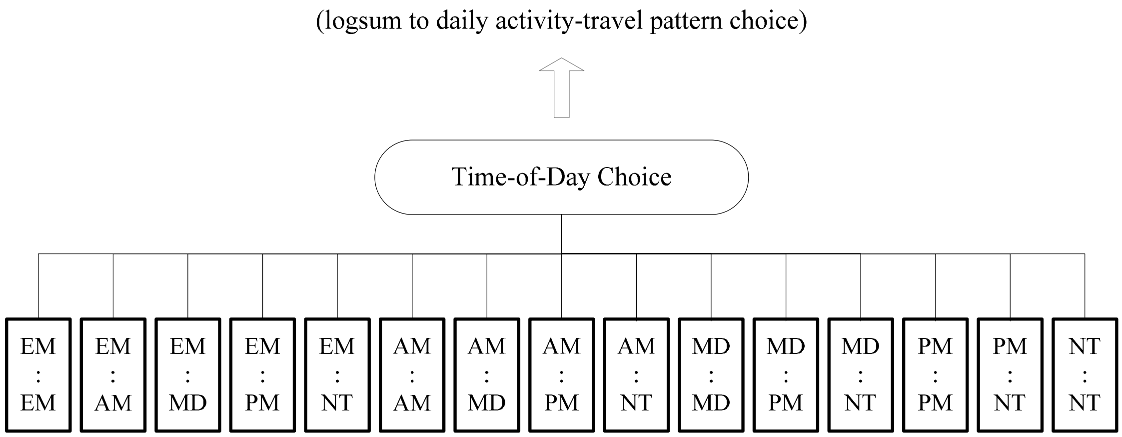


Figure 3. Modeling Structure: Time-of-Day Choice Model

3.3 Mode and Destination Choice

Mode and destination choice is placed at the "bottom" of the hierarchy consisting of the three major models, and is conditional on decisions at the higher levels, that is, choices of DAPs and TODs by purpose. Eight most commonly used combinations of travel modes observed in the region are considered. These include auto drive alone (ATD), auto shared ride (ATS), motorcycle (MTC), taxi (TXA), motorcycle taxi (TXM), transit with motorized access (TRM), transit with non-motorized access (TRN), and non-motorized transport (NMT). Motorcycle taxi is a unique mode of transport but is quite common in urban areas of the developing world. It usually serves relatively shorter-distance trips using any types of roads from alleys to arterials, especially in cases where autos, taxis, or buses are hardly available. Transit has been divided into two, that is, transit with and without motorized access. The former includes park-and-ride or kiss-and-ride access by private auto or motorcycle; however, access by the above-mentioned motorcycle taxi is more common in the Jakarta Metropolitan Area. As for non-motorized transport, walking is a dominant mode though bicycles and pedicabs are also observed in some suburban areas.

As for the destination choice, for parameter estimation purpose, 11 representative destinations are considered for each tour in order to reduce the computational burden. These destinations are sampled from the 336 traffic analysis zones (TAZs) using the stratified importance sampling method, assuming consistency of alternative sampling with nested logit structure. Releasing this assumption for a more efficient estimation of the nested logit model with choice-based sample (Koppelman and Garrow 2005; Garrow *et al.* 2005) as well as to minimize the "cliff effects" of the zonal stratification remains as a future task. In the current model, for each tour purpose, the strata of destinations are constructed based on the distance as well as a size variable which indicates the magnitude of attraction in the destination (Bradley *et al.* 1998). Size variables have been set as total jobs for *work*, total students at school place for *school*, total service industry jobs for *maintenance*, and the sum of service industry jobs and households for *discretionary* activities. As a result, this sampling method leads to higher probabilities of being selected for zones closer to the origin (i.e. home) as well as for zones with larger potential of corresponding attraction.

Actual sampling strata for these 11 representative destination zones are as follows:

- Zone 1, "sampled" from the origin (home) zone;
- Zones 2 and 3, sampled from a distance less than D_1;
- Zones 4 and 5, sampled from a distance between D_1 and D_2 and total jobs smaller than J;
- Zones 6 and 7, sampled from a distance between D_1 and D_2 and total jobs greater than J;
- Zones 8 and 9, sampled from a distance greater than D_2 and total jobs smaller than J;
- Zones 10 and 11, sampled from a distance greater than D_2 and total jobs greater than J,

where:

- D_1 and D_2 are the 20th and 60th percentile distances from the origin zone to all other tour destinations for each purpose, respectively; and
- J is the 50th percentile size variable of all tour destinations for each purpose.

While the value of size variable, J, stays the same regardless of the origin zones, the values of distance, D_1 and D_2, are different depending on the origin zone. Hence, the composition of the above sampling strata for destination choice also differs by the origin zone.

The model has a two-tier nested logit structure. As shown in Figure 4, for each representative zone, auto drive alone, auto shared ride, and motorcycle; and taxi, motorcycle taxi, transit with motorized access, and transit with non-motorized access are each placed in the second tier under different nests while non-motorized transport is placed as a degenerate branch. Although nests are created for each representative destination zone, logsum parameters are set to be common for the nests which involve the same mode group. The model is estimated separately for each purpose (i.e. *work*, *school*, *maintenance*, and *discretionary*). Each of these four models will generate a logsum that will be passed to the TOD choice model of the same purpose. Samples have been taken from the HTS database; in fact, each model contains samples of the same 25,000 tours that were used for modeling TOD choice. That is, this dataset again includes the sample households and individuals that were used for estimation of the DAP choice model.

3.4 Additional Sub-Models

Furthermore, two more sub-models are included in the activity-based modeling system, namely, mode and destination choice for work-based sub-tours (in *work* tours only) and intermediate stop location choice.

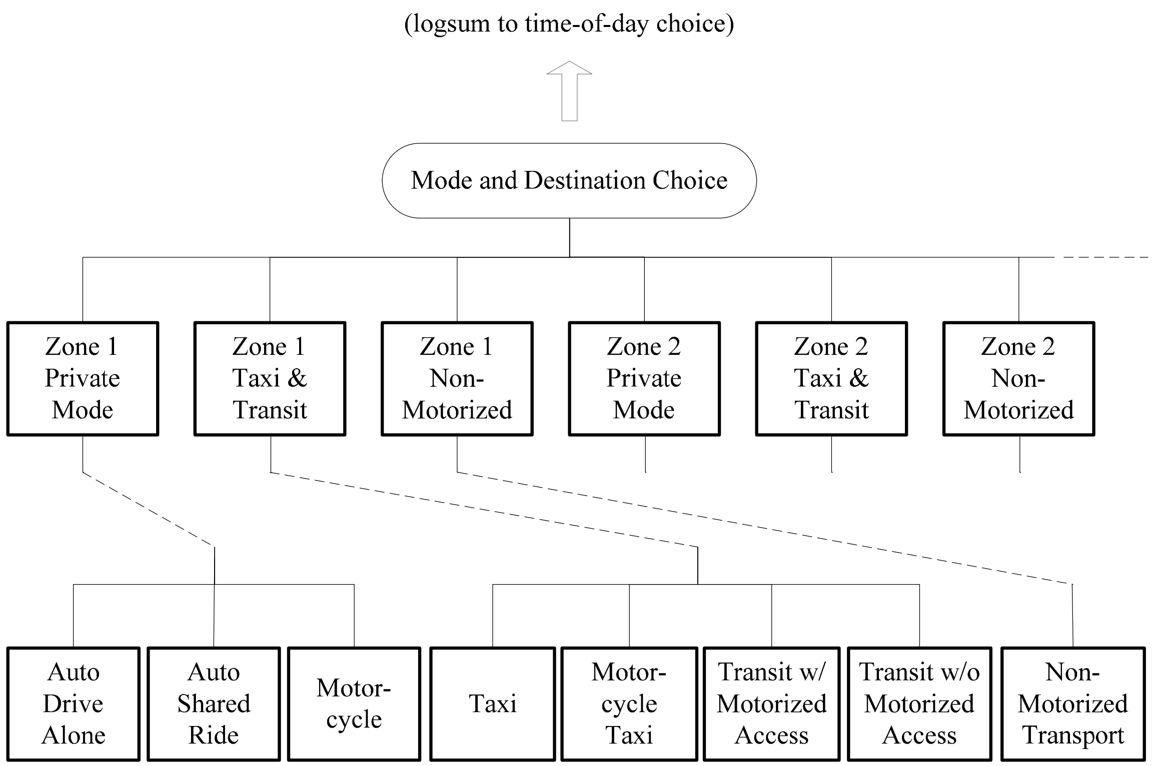


Figure 4. Modeling Structure: Mode and Destination Choice Model

3.4.1 Mode and Destination Choice for Work-Based Sub-Tours

For the work-based sub-tour mode and destination choice, the methodology is similar to that of the above-mentioned home-based tour mode and destination choice. In the same way, the alternatives consist of combinations of eight travel modes and 11 representative sub-tour destinations. The origin zone to set the sampling strata for this model is a zone in which the workplace is located, that is, the destination zone of the corresponding home-based *work* tour. The size variable which determines the strata of sub-tour destinations has been set as total jobs, just like for home-based *work* tours. For simplicity, only one model is estimated regardless of the actual activity conducted for the work-based sub-tour. While, in reality, TOD choice of a work-based sub-tour would depend on its activity, it is determined in the microsimulation by looking up the frequency tables that have been developed based on the statistics of the ADS and HTS.

3.4.2 Intermediate Stop Location Choice

This model determines only the location of intermediate stops made on the way from home or on the way back home. As for the mode, it is fixed to be the same as the mode that was determined in the upper, home-based tour mode and destination choice model, and switching modes before and after the stop is not considered. For intermediate stop location choice, the stratified importance sampling method that was used for the mode and destination choice models is adopted again to set 11 representative zones for stops. However, the methodology has been slightly modified; that is, both home zone and destination zone of the tour are regarded as the origin zone to set the sampling strata for this model. If a zone is classified into different representative zone strata depending on the home and destination zones as the origin, the stratum that is closer to the origin is chosen as a rule.

4 Model Development

4.1 Model Estimation Result

Major characteristic explanatory variables were described under each model. In addition, other socioeconomic variables related to households and household members are introduced to the utility functions, including household composition (i.e. number of members, adults, children, and infants); household income; vehicle ownership (i.e. number of automobiles and motorcycles owned by the household); household location (i.e. central business district (CBD), Jakarta city, and urban/suburban area); status of the individual; income of the individual; school type for student; and gender and age of the individual.

Parameters of the models are actually estimated from lower to upper models in this order to generate and pass logsums to the upper models, while the model estimation results are described first from the top model. For nested logit models, parameters are estimated simultaneously across the two tiers using full information maximum likelihood estimation (FIML) approach.

4.1.1 Daily Activity-Travel Pattern Choice

The adjusted rho-squared value of the estimated nested logit model, as a measure of fit of the model, is 0.50, showing a pretty good model fit. The logsum coefficient capturing the effect of the expected maximum utility from out-of-home activity patterns is estimated as 0.81, and coefficients of the logsums taken externally from the lower time-of-day choice models are estimated as 0.13 - 0.44. These coefficients all fall within the theoretically acceptable range between 0 and 1 in a nested logit structure with significant *t*-values. For detailed model estimation results, refer to Yagi and Mohammadian (2008a).

The DAP model involves choices of activity patterns as a function of individual and household attributes in the Jakarta Metropolitan Area which proved to be different from those observed in the models developed for the U.S. or other parts of the developed world. These unique attributes can be summarized as follows.

- Household size is relatively large in Jakarta and there are a variety of composition patterns of household members. As such, variables associated with household member composition including number of household members, adults, and children are one of the key factors that determine DAPs of each household member, reflecting interactions among household members.
- Household income is another interesting factor that proved significant in the DAP choice model. For example, people in the lower-income household have greater utility of *work* tours. Though further investigation is necessary, this may be because higher-income workers tend to have less time and more flexibility, implying that income levels influence people's activities more directly in the developing country's case.

- Mobility is still limited in Jakarta, and, in this sense, auto availability greatly enhances mobility of people. Household location also has an influence on mobility; for example, households located within Jakarta city limit have greater utility for additional stops or intermediate home returns in the case of *work* tours.
- Differences in gender and/or age seem to be significant factors for DAP choice in Jakarta. Males or male adults have greater opportunity to travel in general, while female adults have less opportunity for *school* tours. Age also has an influence on activity patterns; for example, older people have a greater utility of staying at home all day or having primary *discretionary* or *maintenance* tours.
- Since all household members of age 5 or older are included for modeling, there is a diversity of status of individuals. Variables indicating school types greatly helped to better estimate the DAP choice models.

4.1.2 Time-of-Day Choice

In the estimated multinomial logit model, the adjusted rho-squared value, as a measure of fit of the model, depends on the tour purposes and ranges from 0.30 to 0.57, showing a good model fit. The external logsum coefficients capturing the effect of the expected maximum utility from the lower mode and destination choice models also depend on the tour purposes and are estimated as 0.61 - 0.96. These coefficients all fall within the theoretically acceptable range between 0 and 1 with significant *t*-values. For detailed results of the TOD choice models, interested readers are referred to Yagi and Mohammadian (2006).

Variables indicating tour types have been successfully included in the TOD choice models. They are conditional on DAPs and therefore important to generate utility logsums for the upper DAP choice. Having intermediate stops, especially on the way back home, generally reduces the utilities of choosing late returning departures such as p.m. peak and night. Secondary tours, which exist only in *maintenance* or *discretionary* tours, increase the utilities of rather late tour starts like in the midday or later.

Modeling outcomes, especially in the context of Jakarta, are summarized below.

- Some variables reflecting interactions among household members are also included in the TOD choice. Those with children or infants in the household have a greater utility for relatively shorter-duration TOD combinations during the daytime. In particular, they are more likely to have *maintenance* tours earlier in the day. In general, not only *work* or *school* tours but also *maintenance* and *discretionary* tours starting in early morning are quite common in Jakarta.
- Income has a great influence also on the TOD choice. For *work* tours, personal income which is more directly related to a worker’s job type also has a great influence as well, and the modeling results imply that lower-income people tend to have *work* tours which either start early in the morning or return home in the night time. For *school* tours, those of higher-income households are more likely to have longer-duration *school* tours. For *maintenance* and *discretionary* tours, TODs for those activities seem to be different depending on the household income; lower-income

people have greater utilities of these activities earlier in the day while higher-income people have greater utilities later in the day.

- Variables regarding gender and age are again playing significant roles in the TOD choice. Males increase the utilities for *work* tours of longer duration while older people increase the utilities for *work* tours of shorter duration. As for *maintenance* and *discretionary* tours, males or younger people are more likely to choose combinations of TODs toward the night time.
- Some variables indicating job or workplace types have proved to be significant in the TOD choice for *work* tours, such as commercial occupations/workplaces that increase the utilities of early starts or late returns, and agricultural occupations/workplaces that increase the utilities of early starts and midday returns.
- As for *school* tours, relatively a variety of TOD combinations have been observed. This may be because of the shift system (two or three shifts per day) adopted for elementary and high schools in Indonesia.

4.1.3 Mode and Destination Choice

The home-based mode and destination choice model by purpose shows a good fit with the adjusted rho-squared value ranging from 0.38 to 0.62. The log-sum parameters from the lower branches range from 0.66 to 0.79 for private modes and from 0.50 to 0.76 for taxi and transit modes, staying within a reasonable range. The external logsum coefficient capturing the effect of the expected maximum utility from the lower work-based sub-tour mode and destination choice model has been estimated as 0.10 in the *work* tour model. Coefficients of the external logsums from the lower intermediate stop choice models depend on the tour purposes and are estimated as 0.04 - 0.09. These coefficients all fall within the theoretically acceptable range between 0 and 1 with significant *t*-values. For detailed results of the home-based mode and destination choice model, please refer to Yagi and Mohammadian (2008b).

As a whole, the models have captured the key significant variables, including not only the above-mentioned trip and zone attributes, but also tour or activity-related variables such as presence of intermediate stops, distinction of primary or secondary tours, and start times of the tour or returning segment of the tour. To put it briefly, presence of intermediate stops in a tour increases the utilities of private modes including taxis that are more convenient for making stops. Secondary tours increase the utilities of motorcycles and non-motorized transport instead of transit or taxis, implying that travel distance is generally shorter in secondary tours. Tours with a home return in the night time increase the utilities of private modes including taxis, probably because of convenience and security.

Furthermore, various socioeconomic attributes of both households and individuals also play significant roles in the models. Focusing on comparison with similar studies conducted for the U.S. cases (Bradley *et al.* 1999), the modeling results give the following characteristic implications in the context of Jakarta.

- Car competition between household members, which often has an influence on mode choice in the U.S., is not an “issue” in the case of Jakarta. The auto ownership ratio is still low in Jakarta, and whether the household owns an auto or motorcycle is more significant for mode choice rather than actual number of vehicles owned (except for *school* tours).

- In Jakarta, auto shared ride more often indicates those who do not actually drive but have chauffeurs. Carpools or vanpools do exist in Jakarta, but those are more commercially operated and treated as unofficial transit. As a result, auto shared ride is characterized rather as a mode for high-income people.
- Income has a greater influence on mode choice. Generally, utilities of auto and taxi increase as the income becomes higher, while utilities of motorcycle, transit (with non-motorized access), and non-motorized transport increase as the income becomes lower.
- Gender and age also play more active and distinct roles in the models. That is, males have greater utilities of private modes, while females have greater utilities of taxi and transit. In addition, older people have greater utilities of private modes including taxis rather than non-motorized transport or transit (except for *school* tours).
- Some variables indicating the status of individuals directly increase the utilities of certain travel modes. For example, homemakers have greater utilities of non-motorized transport for *maintenance* and *discretionary* tours. Full-time workers have greater utilities of autos or motorcycles for *discretionary* tours.
- A variety of commuting allowances are commonly provided by the employer in the case of the Jakarta. As such, availability of such allowance mainly increases utilities of private modes in *work* tours.

4.1.4 Additional Sub-Models

4.1.4.1 Mode and Destination Choice for Work-Based Sub-Tours

The estimated work-based sub-tour mode and destination model is presented in Table 1. The adjusted rho-squared value, as a measure of fit of the model, is 0.72, showing a very good model fit. The log-sum parameters from the lower branches are estimated as 0.90 and 0.98 for private modes and taxi and transit modes respectively, staying within a reasonable range with significant *t*-values. Modeling outcomes are summarized and discussed below.

In this model, generalized travel time proved to work best among several types of cost and time-related variables. The coefficient estimated as generic across the travel modes, however, has a smaller magnitude compared to those in the home-based tour mode and destination choice. This may imply that selection of a sub-tour destination does not depend on the cost or time as much as the destination choice for home-based tours. On the other hand, the origin zone dummy has a very high *t*-value in this model, increasing the utility for intra-zonal tours. Other zone-related variables included in the model are the urban area zone dummy, the service job density, and the fraction of land for business use.

For mode choice, a dummy variable indicating whether the same mode was used to commute between home and workplace has been included in the model with highly significant *t*-values except for non-motorized transport. As such, the mode choice for work-based sub-tours is closely related to the main tour travel mode. As for other variables, tour-related variables such as start times of the tour or returning segment of the tour as well as socioeconomic variables such as individual attributes have been

Table 1. Work-Based Sub-Tour Mode/Destination Choice Model

Observations = 10,755, Parameters = 51, $L(0)$ -39,288, $L(\hat{\beta})$=-10,869

$-2\left[L(0)-L(\hat{\beta})\right]$=56,837, $\rho_0^2=$0.723, AIC = 21,841

Alternative / Variable	**coeff.**	**(*t-stat*)**
Logsums		
Private mode logsums	0.903	(*38.2*)
Taxi/transit mode logsums	0.982	(*25.3*)
Generalized Travel Time (hr)		
Generalized travel time (hr)	-0.414	(*-3.4*)
Destination Land Use		
Dummy: origin (workplace) zone	4.411	(*39.6*)
Dummy: zone in urban area	1.185	(*4.9*)
Service job density (/ha) in the zone	-0.002	(*-2.3*)
Percentage of land used for business use	0.005	(*1.6*)
Log of relevant size variable in the zone	1.000	*constr.*
Auto Drive Alone		
Dummy: returning trip starts in night	1.250	(*2.4*)
Dummy: same mode chosen for home-based tour	0.781	(*6.2*)
Dummy: male	0.949	(*4.5*)
Log of monthly ind. income (mil. Rp.)	1.422	(*17.8*)
Dummy: chauffeur	2.662	(*7.6*)
Dummy: work in a government office	-0.613	(*-3.1*)
Dummy: work in a private company	-0.329	(*-2.3*)
Auto Shared Ride		
Alternative-specific constant	0.334	(*1.5*)
Dummy: sub-tour starts in early morning	1.818	(*3.6*)
Dummy: same mode chosen for home-based tour	1.216	(*11.1*)
Log of monthly ind. income (mil. Rp.)	1.422	(*17.8*)
Dummy: chauffeur	2.225	(*13.9*)
Dummy: work in a government office	0.509	(*3.9*)
Dummy: work in a private company	0.650	(*6.6*)
Motorcycle		
Alternative-specific constant	2.679	(*4.0*)
Dummy: same mode chosen for home-based tour	1.602	(*15.1*)
Log of monthly hhd income (mil. Rp.)	-0.121	(*-1.6*)
Log of age of the individual	-0.679	(*-3.9*)
Dummy: male	1.169	(*5.7*)
Dummy: merchant	0.291	(*1.9*)

Alternative / Variable	**coeff.**	**(*t-stat*)**
Taxi		
Alternative-specific constant	-2.519	(*-4.0*)
Log of travel (network) distance (km)	-0.545	(*3.2*)
Dummy: same mode chosen for home-based tour	1.532	(*3.2*)
Dummy: male	-1.364	(*-5.7*)
Log of monthly ind. income (mil. Rp.)	1.219	(*7.1*)
Dummy: work in a private company	0.683	(*2.8*)
Motorcycle Taxi		
Alternative-specific constant	-2.572	(*-4.0*)
Dummy: same mode chosen for home-based tour	2.335	(*6.9*)
Dummy: male	-0.930	(*-3.3*)
Transit with Motorized Access		
Alternative-specific constant	-3.757	(*-5.7*)
Dummy: sub-tour starts in a.m. peak	0.795	(*2.2*)
Dummy: same mode chosen for home-based tour	1.897	(*5.1*)
Dummy: male	-0.567	(*-4.6*)
Transit with Non-Motorized Access		
Alternative-specific constant	-0.111	(*-0.2*)
Transit walk time (hr)	-1.783	(*-3.9*)
Dummy: same mode chosen for home-based tour	0.728	(*8.8*)
Dummy: male	-0.567	(*-4.6*)
Non-Motorized Transport		
Alternative-specific constant	3.944	(*6.9*)
Travel time (hr) × hhd income (mil. Rp.)	-0.402	(*-8.1*)
Dummy: sub-tour starts in a.m. peak	-3.130	(*-23.6*)
Dummy: one-member household	-0.400	(*-3.0*)
Log of age of the individual	-0.497	(*-4.8*)
Dummy: male	-0.371	(*-3.9*)
Dummy: merchant	-0.589	(*-5.5*)
Dummy: work in a government office	-0.174	(*-2.9*)
Dummy: work in a private company	-0.247	(*-2.9*)

included in the model. For example, gender plays active and distinct roles in the model, increasing the utilities of private modes for males and increasing the utilities of taxi and transit for females. In addition, some variables indicating job or workplace types have proved to be significant in the model. However, few variables that indicate household attributes including income have been used in the model. This may be because effects from those variables have been already captured indirectly by including the above-mentioned dummy that shows whether the same mode was used for the home-based main tour (Bradley *et al.* 1998).

4.1.4.2 Intermediate Stop Location Choice

Results of the estimated multinomial logit models are presented in Table 2. Four different models have been estimated for *work*, *school*, *maintenance*, and *discretionary* main tour purposes. The number of observations available for sampling differs by purpose; however, each model shows a fairly good fit with the adjusted rho-squared value ranging from 0.21 to 0.38. Modeling outcomes are summarized and discussed below.

As a variable related to the cost and time of tours with an intermediate stop, extra generalized travel time to make the stop as compared to making no stop has been included. In this way stops are more likely to be made in zones involving a shorter 'detour' in terms of generalized travel time. This coefficient has been estimated as generic across the travel modes, and it has proved to be significant in all the four models. Furthermore, variables indicating TOD in which a stop is made have been included in the models except for *school* tours. Particularly in *work* tours, these variables imply that tours starting early in the morning reduce the utility of making a stop in the same zone as home or destination while tours with the second half (returning-home) departure in the night time increase the utility of making a stop in the same zone as home or destination.

For the intermediate stop location choice, some unique variables have been adopted in the models. Variables indicating the geographical relationship between origin (home) and destination zones of the tour are among such variables. In general, if a destination zone was selected from the zone group further from the origin in the home-based tour mode and destination choice model, it increases the utility of making a stop in a zone of the zone group further from both the origin and the destination, and vice versa. Variables indicating the travel mode of the tour have also been included in the models, implying that most of the motorized travel modes except for motorcycle taxi are likely to increase the utilities of choosing zones further from the origin and destination zones. To the contrary, motorcycle taxi and non-motorized transport are likely to increase the utilities of choosing a zone that is the same as the origin or the destination.

Among the zone-related variables included in the models, a dummy variable indicating whether the zone is inside the CBD which is designated as the area for the "3-in-1" regulation has been newly included in the models except for *discretionary* tours. This variable reduces the utilities of the CBD zones for stop location. Some household-related variables have proved to be significant in the models; for example, people with children or infants in the household are more likely to make stops in the zones that are the same as the origin or destination (except for *school* tours) while higher-income people are more likely to make stops in the zones further from both the origin and the destination. As for variables regarding individuals' attributes, male adults tend to choose stops further from the origin and destination except for *school*

Table 2. Home-Based Tour Stop Location Choice Model

Main Tour Type	**Work**		**School**		**Maintenance**		**Discretionary**	
Observations =	17,346		8,461		8,752		2,175	
Parameters =	39		31		32		33	
$L(0)$ =	-43,103		-21,025		-21,748		-5,405	
$L(\hat{\beta})$ =	-33,934		-14,597		-13,965		-3,357	
$-2\left[L(0)-L(\hat{\beta})\right]$ =	18,338		12,856		15,566		40,95	
ρ_0^2 =	0.213		0.306		0.358		0.378	
AIC =	67,946		29,255		27,994		6,781	
Alternative / Variable	**coeff.**	**(*t-stat*)**	**coeff.**	**(*t-stat*)**	**coeff.**	**(*t-stat*)**	**coeff.**	**(*t-stat*)**
***Generalized Travel Time** (hr)*								
Additional generalized travel time	-1.048	(*-61.3*)	-1.432	(*-42.3*)	-1.296	(*-37.4*)	-0.956	(*-16.6*)
Stop in Home Zone								
Dummy: stop on the way from home	0.168	(*3.5*)	-	-	-	-	0.609	(*4.2*)
Dummy: stop in the early morning period	-0.388	(*-5.3*)	-	-	-	-	-	-
Dummy: stop in the midday period	-	-	-	-	-	-	-0.671	(*-5.3*)
Dummy: stop in the late night period	0.322	(*2.9*)	-	-	-	-	-	-
Dummy: main tour OD zones are the same	-	-	-	-	0.353	(*4.7*)	0.420	(*2.9*)
Dummy: main tour mode is drive alone	-0.217	(*-2.2*)	-	-	-	-	-	-
Dummy: main tour mode is motorcycle	-	-	-0.151	(*-1.9*)	-	-	-	-
Dummy: main tour mode is taxi	-0.493	(*-2.6*)	-0.767	(*-2.4*)	-	-	-	-
Dummy: main tour mode is motorcycle taxi	0.536	(*4.0*)	0.358	(*1.6*)	0.473	(*3.8*)	-	-
Dummy: main tour mode is non-motorized	0.809	(*11.4*)	0.747	(*7.0*)	1.243	(*15.3*)	1.139	(*6.5*)
Dummy: infant (age < 5) in household	-	-	-	-	0.202	(*2.3*)	-	-
Dummy: child (5 £ age < 17) in household	0.135	(*3.5*)	-	-	0.206	(*3.8*)	0.284	(*2.5*)
Dummy: one-member household	-	-	-2.212	(*-2.1*)	-	-	-	-
Log of monthly household income (million Rp.)	-	-	-	-	-	-	-0.155	(*-1.9*)
Dummy: male adult (age ³ 17)	-	-	-	-	-	-	-0.237	(*-2.0*)
Log of age of the individual	0.133	(*2.1*)	-	-	-	-	-	-
Dummy: full-time worker	0.129	(*2.6*)	-	-	-	-	-	-
Dummy: elementary student	-	-	0.705	(*6.3*)	-	-	-	-
Dummy: senior high school student	-	-	-0.374	(*-5.0*)	-	-	-	-
Dummy: university/academy student	-	-	-0.452	(*-5.6*)	-	-	-	-
Stop-in-Tour-Destination-Zone								
Alternative-specific constant	0.481	(*2.1*)	-0.165	(*-4.9*)	-0.023	(*-0.7*)	-0.105	(*-0.9*)
Dummy: stop in the early morning period	-0.388	(*-5.3*)	-	-	-	-	-	-
Dummy: stop in the a.m. peak period	-	-	-	-	-	-	0.322	(*2.1*)
Dummy: stop in the midday period	-	-	-	-	-0.104	(*-2.2*)	-0.679	(*-5.1*)
Dummy: stop in the late night period	0.322	(*2.9*)	-	-	-	-	-	-
Dummy: main tour OD zones are the same	-	-	-	-	0.353	(*4.7*)	0.420	(*2.9*)
Dummy: main tour mode is drive alone	-0.447	(*-4.4*)	-	-	-	-	-	-
Dummy: main tour mode is motorcycle	-	-	-0.151	(*-1.9*)	-	-	-	-
Dummy: main tour mode is taxi	-0.493	(*-2.6*)	-0.767	(*-2.4*)	-	-	-	-
Dummy: main tour mode is motorcycle taxi	0.478	(*3.4*)	0.358	(*1.6*)	-	-	-	-
Dummy: main tour mode is non-motorized	0.934	(*13.1*)	0.885	(*8.3*)	1.243	(*15.3*)	1.312	(*7.5*)
Dummy: infant (age < 5) in household	-	-	-	-	0.202	(*2.3*)	-	-
Dummy: child (5 £ age < 17) in household	-	-	-	-	0.206	(*3.8*)	0.284	(*2.5*)
Dummy: male adult (age ³ 17)	-	-	-	-	-	-	-0.237	(*-2.0*)
Dummy: age over 65	-	-	-	-	-	-	0.795	(*2.6*)
Dummy: elementary student	-	-	0.705	(*6.3*)	-	-	-	-
Dummy: senior high school student	-	-	-0.374	(*-5.0*)	-	-	-	-
Dummy: university/academy student	-	-	-0.452	(*-5.6*)	-	-	-	-

Table 2. Home-Based Tour Stop Location Choice Model (*cont'd*)

Main Tour Type	**Work**		**School**		**Maintenance**		**Discretionary**	
Alternative / Variable	**coeff.**	**(*t-stat*)**	**coeff.**	**(*t-stat*)**	**coeff.**	**(*t-stat*)**	**coeff.**	**(*t-stat*)**
Stop in "Inner" Zone (< 20th Percentile Distance)								
Alternative-specific constant	-0.889	(*-3.8*)	-1.542	(*-18.8*)	-0.931	(*-9.4*)	-0.392	(*-0.5*)
Dummy: main tour OD distance is in 0-20 percentile	0.209	(*2.3*)	-	-	0.373	(*2.4*)	-	-
Dummy: main tour OD distance is in 20-60 percentile	0.389	(*6.0*)	-	-	0.335	(*3.2*)	-	-
Dummy: main tour mode is drive alone	-	-	-	-	-	-	1.370	(*2.6*)
Dummy: main tour mode is shared ride	-	-	-	-	0.411	(*2.8*)	0.920	(*2.7*)
Dummy: main tour mode is transit w/ motor. access	-	-	-	-	-	-	0.543	(*1.9*)
Dummy: stop in CBD	-0.145	(*-4.9*)	-0.247	(*-5.2*)	-0.246	(*-5.0*)	-	-
Log of monthly household income (million Rp.)	0.382	(*8.2*)	-	-	0.144	(*2.0*)	-	-
Dummy: male adult (age ≥ 17)	0.146	(*2.2*)	-	-	-	-	-	-
Log of age of the individual	-	-	-	-	-	-	-0.569	(*-2.4*)
Dummy: homemaker	-	-	-	-	-0.328	(*-3.6*)	-	-
Stop in "Middle" Zone (20-60th Percentile Distance)								
Alternative-specific constant (low size var.)	-0.009	(*0.0*)	-0.954	(*-11.5*)	-0.141	(*-1.4*)	0.272	(*0.5*)
Alternative-specific constant (high size var.)	-0.789	(*-3.5*)	-1.237	(*-14.7*)	-0.953	(*-9.5*)	0.053	(*0.1*)
Dummy: main tour OD distance is in 20-60 percentile	0.385	(*8.0*)	-	-	0.176	(*1.9*)	-	-
Dummy: main tour OD distance is in 60-100 percentile	0.480	(*10.1*)	0.170	(*2.7*)	0.462	(*5.2*)	-	-
Dummy: main tour mode is drive alone	-	-	0.590	(*2.7*)	-	-	-	-
Dummy: main tour mode is shared ride	0.279	(*4.0*)	0.607	(*4.4*)	0.551	(*5.1*)	0.534	(*2.3*)
Dummy: main tour mode is taxi	-	-	-	-	-	-	0.637	(*1.9*)
Dummy: main tour mode is transit w/ motor. access	-	-	0.187	(*1.5*)	-	-	0.543	(*1.9*)
Dummy: stop in CBD	-0.145	(*-4.9*)	-0.247	(*-5.2*)	-0.246	(*-5.0*)	-	-
Log of monthly household income (million Rp.)	0.341	(*9.9*)	0.138	(*2.9*)	0.260	(*5.0*)	-	-
Dummy: male adult (age ≥ 17)	0.112	(*2.4*)	-	-	-	-	-	-
Log of age of the individual	-	-	-	-	-	-	-0.507	(*-3.5*)
Dummy: part-time worker	-	-	-	-	-	-	0.518	(*2.1*)
Dummy: homemaker	-	-	-	-	-0.288	(*-4.3*)	-	-
Stop in "Outer" Zone (> 60th Percentile Distance)								
Alternative-specific constant (low size var.)	1.645	(*7.1*)	1.266	(*11.7*)	1.914	(*14.4*)	0.620	(*2.8*)
Alternative-specific constant (high size var.)	0.383	(*1.7*)	0.277	(*2.6*)	0.462	(*3.6*)	-0.365	(*-1.8*)
Dummy: main tour mode is drive alone	0.368	(*4.6*)	0.741	(*3.2*)	-	-	-	-
Dummy: main tour mode is shared ride	0.338	(*4.6*)	0.562	(*3.5*)	0.954	(*7.7*)	0.565	(*2.5*)
Dummy: main tour mode is taxi	-	-	-	-	-	-	0.637	(*1.9*)
Dummy: main tour mode is transit w/ motor. access	0.200	(*2.2*)	0.414	(*3.1*)	0.502	(*2.9*)	-	-
Dummy: stop in CBD	-0.145	(*-4.9*)	-0.247	(*-5.2*)	-0.246	(*-5.0*)	-	-
Log of monthly household income (million Rp.)	0.456	(*12.1*)	0.152	(*2.7*)	0.235	(*3.6*)	-	-
Dummy: male adult (age $\geq$ 17)	0.633	(*11.6*)	-	-	0.215	(*2.0*)	-	-
Dummy: full-time worker	-0.097	(*-1.8*)	-	-	-	-	0.373	(*1.9*)
Dummy: part-time worker	-	-	-	-	-	-	0.760	(*3.1*)
Dummy: university/academy student	-	-	0.138	(*1.7*)	-	-	0.671	(*2.3*)
Dummy: homemaker	-	-	-	-	-0.634	(*-5.5*)	-0.400	(*-1.9*)
Stop Location Land Use								
Dummy: urban area	-	-	0.303	(*2.8*)	-	-	-	-
Job density (/ha) in the zone	-0.002	(*-12.4*)	-	-	-0.003	(*-9.7*)	-	-
Service job density (/ha) in the zone	-	-	0.002	(*8.1*)	-	-	-	-
Fraction of land for business & commercial use	-0.002	(*-2.9*)	-	-	-0.003	(*-2.2*)	-	-
Fraction of land for recreational use	-	-	0.015	(*5.2*)	-	-	0.019	(*3.2*)
Log of relevant size variable in the zone	1.000	*constr.*	1.000	*constr.*	1.000	*constr.*	1.000	*constr.*

tours. Some variables indicating the status of individuals have also been included in the models, such as full-time workers (in *work* and *discretionary* tours), university students (in *school* and *discretionary* tours), and homemakers (in *maintenance* and *discretionary* tours).

4.2 Application to a Microsimulation Model

All the models that have been estimated and described in this paper are used as the bases for a microsimulation model that generates activities/tours with full information including purpose, time of day, origin and destination zones, travel mode, and presence and details of sub-tours and intermediate stops for each household and individual based on the Monte Carlo simulation. For details of operational procedures in the microsimulation, refer to Yagi and Mohammadian (2007a). Those attributes of tours generated by the microsimulation are detailed enough to create OD trip tables by mode and by time of day. In order to make the microsimulation more realistic, several important aspects of activity-based modeling should also be considered such as auto and motorcycle ownership choice, activity rescheduling, joint tour/activity generation, and household maintenance tour allocation.

4.2.1 Auto/Motorcycle Ownership Choice

Microsimulation for future years needs input about the number of autos and motorcycles owned by each household of different attributes. In the Jakarta Metropolitan Area, 56 percent of households own neither autos nor motorcycles; meanwhile, 34 percent own motorcycle(s), and 17 percent own auto(s). A household auto/motorcycle ownership model has been estimated with major combinations of numbers of autos and motorcycles owned by the household as choice alternatives. It is a simple multinomial logit model, and the results are shown in Table 3. Zone-related variables identifying the urban area and household density, variables indicating household composition, and a variable showing household income have proved to influence the auto/motorcycle ownership. It is predicted that these variables, especially zone attributes and income information, will change over time, increasing the number of auto/motorcycle-owning households.

4.2.2 Activity Rescheduling

Though both primary and secondary tours are simultaneously generated for each individual in the microsimulation, it is the primary tour that should have priority in the TOD choice. Secondary tour(s) should then select the TODs for start of the tour and start of the returning segment of the tour from the remaining time windows of the day. The TOD choice models developed in this study include variables indicating whether the tour is a secondary tour and especially whether it is attached to a *work* primary tour so that a combination of TODs would be most likely selected from the available time windows for the secondary tour. However, it is not assured that the primary and secondary tours have no time conflict. Therefore, if such a conflict has occurred, TODs of a secondary tour should be selected again based on a random draw to clear the conflict. It should be noted that a "conflict" here means a full overlap of tours over an entire TOD. Although five time periods have been defined in this microsimulation model, higher TOD resolution would make activity rescheduling more accurate.

Table 3. Household Auto/Motorcycle Ownership Model

Household Auto Ownership Model

Observations = 162,358	Parameters = 25	$L(0)$ = -180,727	$L(\hat{\beta})$=-153,007
$-2\left[L(0)-L(\hat{\beta})\right]$= 55,440	$\rho_0^2 =$ 0.474	$\rho_C^2 =$ 0.4153	AIC = 306,063

Alternative [a]	0 A, 0 M		0 A, 1 M		0 A, 2+ M		1 A, 0 M		1 A, 1+ M		2+ A	
Variable	**coeff.**	**(*t-stat*)**	**coeff.**	**(*t-stat*)**	**coeff.**	**(*t-stat*)**	**coeff.**	**(*t-stat*)**	**coeff.**	**(*t-stat*)**	**coeff.**	**(*t-stat*)**
Alternative-specific constant	-	-	-1.144	(*-83.9*)	-5.483	(*-95.1*)	-3.478	(*-115.6*)	-4.486	(*-84.4*)	-6.783	(*-72.3*)
Dummy: household in urban area	-	-	0.622	(*39.6*)	1.094	(*21.2*)	0.958	(*27.5*)	1.225	(*28.4*)	1.450	(*19.0*)
Household density (/ha) in the home zone	0.009	(*16.5*)	0.005	(*9.2*)	0.005	(*9.2*)	-	-	-	-	-	-
Dummy: infant (age < 5) in household	-	-	0.248	(*15.8*)	-	-	-	-	-	-	-	-
Dummy: child (5 ≤ age < 17) in household	-	-	0.235	(*20.2*)	-	-	-	-	0.308	(*11.1*)	-	-
Dummy: only one adult in household	0.655	(*25.0*)	-	-	-	-	0.722	(*14.4*)	-	-	-	-
Number of adults (age ≥ 17)	-	-	-	-	0.460	(*38.3*)	-	-	0.079	(*7.0*)	0.063	(*3.9*)
Log of monthly household income (mil. Rp.)	-	-	1.052	(*82.0*)	1.830	(*59.3*)	2.759	(*130.7*)	2.856	(*118.8*)	4.192	(*110.5*)

Note: A is auto and M is motorcycle.

Moreover, sometimes a case occurs in which two or more secondary tours have been generated for an individual with a time conflict between them. Secondary tours are classified into either *maintenance* or *discretionary* tours, and *maintenance* tours should be given priority in the TOD choice. As such, secondary *discretionary* tours should be rescheduled if a time conflict occurs between these two activity purposes. In the case of a conflict between secondary tours of the same purpose, one of the tours is given priority on a random basis and the other is rescheduled.

4.2.3 Joint Tour/Activity Generation

Intra-household interactions and decisions and its effect on daily activity-travel patterns should also be considered. For microsimulation development, several important rules have been adopted to generate joint tours/activities. First, one of the basic findings, which has been replicated in several U.S. metropolitan areas, is that if a child stays home sick, this decreases the probability that adult household members will conduct their 'typical' mandatory travel for that day (Vovsha *et al.* 2004b). As such, the following rule has been made.

- If at least one of the school children of pre-driving age has a *home* (i.e. no travel) pattern, it is likely that at least one of the household adults has a *home* pattern to take care of the child. In this case, each non-worker, part-time worker, full-time worker, or university student in the household has a different chance of having a *home* pattern at a certain probability depending on the status. These probabilities should be applied to each household member having a mandatory activity.

Second, it was shown that contrary to what has been observed in the U.S. that travel for mandatory activities is assumed to have an individual character and usually joint mandatory activities are not included in activity scheduling models, mandatory activities in Jakarta have significantly higher joint tour ratio due to joint business and school activities (Yagi and Mohammadian 2005). Hence, the following two rules that are unique to Jakarta have been created in order to generate joint *work* and *school* tours, respectively.

- If more than one workers in the household have the same job category and their primary activity is a *work* tour, it is likely that they work and travel together. The probability that they have a joint primary *work* tour depends on the job category. Different values of joint *work* tour probabilities should be applied to each case based on the job category.
- If more than one school children belong to the same school type (elementary school, junior high school, senior high school, or university) and have a primary *school* tour, it is likely that they go to school and return home together. The probability that they have a joint primary *school* tour depends on the school type. Different values of joint *school* tour probabilities should be applied to each case based on the school type.

Third, models developed for Atlanta and mid-Ohio explicitly model joint travel, which cannot be accounted for in conventional models (Scott and Kanaroglou 2002; Vovsha *et al.* 2003b). Among others, the following two rules have been adopted into our microsimulation modeling system.

- If at least one of the school children of pre-driving age has a non-mandatory (i.e. *maintenance* or *discretionary*) primary tour, it is often associated with visiting a doctor, family event, and so on. In this case, each non-worker, part-time worker, full-time worker, or university student in the household has a chance of escorting the child and having the same primary non-mandatory tour at a certain probability depending on the status. Adults having a higher chance of escorting the child are non-workers, part-time workers, full-time workers, and university students, in this order, and each adult household member should be tested with the probability derived from the observations.
- If a full-time worker or a university student in the household does not have a primary *work* or *school* tour (i.e. having a day off) and chooses a non-mandatory (i.e. *maintenance* or *discretionary*) primary tour, it is often associated with major shopping, family event, vacation, and so on. In this sense, it is likely that he or she is accompanied by at least one of the other adult household members. In this case, each non-worker, part-time worker, full-time worker, or university student in the household has a chance of accompanying the worker/student and having the same primary non-mandatory tour at a certain probability depending on the status. Accompanying adults are likely to be non-workers, part-time workers, full-time workers, and university students, in this order, and each adult household member should be tested with the probability derived from the observations.

4.2.4 Household Maintenance Tour Allocation

In the context of activity-based modeling, household *maintenance* activities, such as grocery shopping and escorting children, should be properly modeled at the household, rather than the individual level and then those should be allocated among household members (Vovsha *et al.* 2004a; Srinivasan and Bhat 2004). Though all activities are first generated at the individual level in the modeling system developed in this study, the following rule has been applied to the microsimulation to take the above concept into consideration.

- Maximum number of *maintenance* tours per household for each household size is determined through the lookup table based on the 95th percentile values of the observed data. If the number of simulated *maintenance* tours exceeds this maximum, *maintenance* tours are deleted from workers, students, homemakers, and others, whoever has exceeding number of *maintenance* tours.

4.2.5 Model Validation and Policy Application

The activity-based microsimulation model developed in this study was calibrated using the base year transportation survey data and was validated both internally and externally (Yagi and Mohammadian 2007a; Yagi and Mohammadian 2007b). The internal validation involves comparison with the expanded survey data including the activity diary survey and household travel survey data and comparison of trip length frequencies. The external validation involves comparison with the observed traffic counts surveyed on two major screen lines in the region.

The microsimulation model was also applied to evaluate future transportation policy scenarios including several area pricing schemes. Direct and secondary results of the policy analyses simulations are discussed in details in Yagi and Mohammadian (2007a; 2007b) including emission estimates as well as emerging effects caused by each policy scenario. Overall, it became clear that the activity-based microsimulation model presented in this study provides accurate travel estimates which are expected to serve as better inputs for evaluation of different transportation policy scenarios.

5 Summary

This paper described a comprehensive multi-tier activity-based modeling system for Jakarta, consisting of random utility based disaggregate logit and nested logit models. While the majority of explanatory variables have been directly derived from the ADS and HTS data, some other trip and zone-related data have also been defined such as generalized travel time computed from the highway and transit network, and land use composition in each TAZ computed from the GIS database. Thus, a number of types of significant variables are included in the modeling system consisting of choices of daily activity-travel pattern, times of day, mode and destination, and intermediate stop location. Interpretation of the effects of these explanatory variables in the developed models resulted in several interesting insights. Furthermore, it has been shown that, in the Jakarta Metropolitan Area or in the context of developing countries, some aspects of the modeling system including structure of the model, choice alternatives, and key variables are significantly different from those observed in the developed world.

With regard to the modeling structure, realization of full connectivity between the models may be worth mentioning. In fact, this type of tour-based structure of random utility based disaggregate logit and nested logit models tends to be more complicated than conventional trip-based models, and this could cause some difficulties in estimation, particularly in cases of hierarchical models with proper logsum linkages

(Bradley *et al.* 1999). In this study, all the activity-based models within a system were connected to each other through logsum variables within a proper range of 0 and 1 and statistically significant parameters. Thus, the study has verified that such a deeply nested and fully connected modeling structure works not only theoretically but also practically.

For application of the estimated models to a microsimulation, further important aspects of activity-based modeling such as auto and motorcycle ownership choice, activity rescheduling, joint tour/activity generation, and household maintenance tour allocation have been considered. Results from this activity-based microsimulation modeling system will be fed into a link-based transportation network assignment program in the form of OD trips by mode, and time of day. Outputs from the network assignment model representing vehicle miles/hours of travel and average travel times can be used to evaluate various policy scenarios or economic impacts of different alternatives. Additionally, outputs by link such as volumes, average speeds, and average congestion levels will be used as part of the input data to the emission model.

The study aimed at developing a comprehensive activity-based modeling system in the context of developing countries to provide accurate travel demand estimates which are expected to serve as better inputs for policy analysis; whereas, the modeling system recognizes the structures and control factors that may well be significantly different from those observed in developed world. Moreover, the study aims at developing a practical microsimulation model that can replicate patterns of individuals' activity-travel and test different transportation policy scenarios for the Jakarta Metropolitan Area. It was a grand goal of the study to introduce a new method of modeling travel demand and evaluating policies to metropolitan regions of the developing world; in this sense, it is hoped that a series of procedures from activity-based modeling to policy analysis will be regarded as good practice for that purpose.

Like many other metropolitan areas in developing countries, Jakarta is facing a transition from conventional infrastructure and highway construction to lower-cost but environment-friendly urban transportation management. It is hoped that the new models developed in this study will contribute to a better understanding of urban travel behavior and improvement of the methodology of travel demand forecasting. It is also hoped that the study will provide a powerful decision-making tool that can be used to better analyze and evaluate urban transportation policy scenarios not only in the Jakarta Metropolitan Area but also in other urban areas of developing countries.

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