Incorporating In-Home Activities into an Agent-Based Dynamic Activity Planning and Travel Simulation Model

BY

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THESIS

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This thesis is dedicated to my family, without whom it would never have been accomplished.

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This thesis is dedicated to my mother and the memory of my beloved father, Dr. MirHassan Fassihozaman. As nicely written: “It is your shining example that I try to emulate in all that I do”.

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LIST OF ABBREVIATIONS

AADT	Annual Average Daily Traffic
AAPD	Average Absolute Percent Difference
ACS	American Community Survey
ADAPTS	Agent-based Dynamic Activity Planning and Travel Scheduling
ALBATROSS	A Learning-Based Transportation Oriented Simulation System
ATUS	American Time Use Survey
CHAID	Chi-squared Automatic Influence Detection
CHASE	Computerized Household Activity Schedule Elicitor
CMAP	Chicago Metropolitan Agency for Planning
CPM	Computational Process Model
DTA	Dynamic Traffic Assignment
GPS	Global Positioning System
ICT	Information and Communication Technologies
IID	Independent and Identically Distributed
IPF	Iterative Proportional Fitting
ITS	Intelligent Transportation Systems
LOS	Level-of-Service
LL	Log-Likelihood
MAPE	Mean Absolute Percent Error
MDCEV	Multiple Discrete-Continuous Extreme Value
METSI	Metropolitan Transportation Support Initiative
ML	Mixed Logit
MNL	Multinomial Logit
NTS	National Transportation Statistics
O-D	Origin-Destination
PUMA	Public Use Microdata Area
RMSE	Root Mean Squared Error
SMASH	Simulation Modeling of Activity Scheduling Heuristics
TASHA	Travel Activity Scheduler for Household Agents
TAZ	Traffic Analysis Zone
TRANSIMS	Transportation Analysis and Simulation System
UTRACS	Urban Travel Route and Activity Choice Survey
VMT	Vehicle Miles Travelled

SUMMARY

This thesis addresses one of the important yet neglected areas in Activity-based Travel Demand models: In-home activities. In doing so, it attempts to extend the previously developed activity based framework called Agent-based Dynamic Activity Planning and Scheduling (ADAPTS) by integrating in-home activity models. The models are developed to capture the interdependencies between in-home and out-of-home activities while preserving the main dynamic planning structure of out-of-home activities in ADAPTS. Additionally, the model components are designed so as to make non-transportation demand modeling applications feasible.

This research focuses on generation of individuals' In-home and out-of-home activities as the simulation time runs. Simultaneously, individuals update their schedule based on activities they execute during the day and engage in trips accordingly. The link between in-home and out-of-home activities is implemented through a combination of rule-based and econometric models. Time of day sensitive activity type and duration models are proposed and implemented within the framework with the help of discrete choice, hazard-based and pairwise modeling concepts.

This large-scale package could eventually be used for disaggregate demand forecasting purposes and targeted policies can be tested through relevant scenarios.

CHAPTER 1: INTRODUCTION

According to the U.S. Energy Information Administration, In 2012, the average energy consumption for a US residential utility was approximately 30 KWh per day. The average American family of four uses 400 Gallons of water per day as stated by U.S. Environmental Protection Agency. Approximately 70 percent of which are associated with indoor water use with the most water being consumed in bathrooms of about 27percent.

Considering such facts mentioned above , people's in-home activities affect energy and resource consumption to a great deal so as to focus on modeling people's in-home activities in order to extract the underlied activity pattern, becomes substantial. Based on American Time Use Survey, people spend approximately 75 percent of their time at home. Having said that, associating this great portion of activities to energy matters through agent-based micro-simulation modeling could be the standpoint for testing various energy or resource related policies.

On the other hand, perceiving the associations between in-home and out-of-home activities, could better predict how out-of-home activities are formed. As a result, the two type of activities being modeled in one comprehensive framework can even better justify the incorporation of in-home activities. For example, incorporating in-home activities to an activity based travel demand model which is solely designed to assess out-of-home activities and their corresponding trips, helps to better predict such out-of-home activities not to mention the benefit of testing in-home activity related scenarios

OBJECTIVES

This thesis addresses one of the important yet somewhat neglected areas in agent-based activity models: In-home activities. In doing so, it attempts to extend the previously developed activity based framework called Agent-based Dynamic Activity Planning and Scheduling (ADAPTS) by integrating in-home activity models. The models are developed to capture the interdependencies between in-home and out-of-home activities while preserving the main dynamic planning structure of out-of home activities in ADAPTS. Additionally, significant effort has been put to model in-home activities in great detail so as to make non-transportation research studies more feasible.

This research focuses on generation of individuals' In-home and out-of-home activities as the simulation time runs. Simultaneously, individuals update their schedule based on activities they execute during the day. The link between in-home and out-of-home activities is implemented through a rule-based two-step methodology. The initial step associates in-home activities to out-of-home activities. Time of day sensitive activity type and duration models are proposed and implemented within the framework to determine what type of activities individuals do at home conditional to factors such as their socio-demographic status, what activities they have already done during the day and time of day. The second step attempts to cover the reverse link exploring how in-home activities could affect out-of-home activities leading to out-of-home activity start time and duration models.

Twelve in-home activity type choice models are estimated to find out the major type of In-Home activities; each model representing the activity type choice model for a two-hour period when the start time of the activity falls in. These 12 models are time of day sensitive since the individual's activity choice varies significantly by time of day; yet, the variation settles down within two hour periods. Jointly, 6 hazard-based activity duration models for 6 in-home activity types are estimated to find out the duration of the activity based on the start time and socio-demographic attributes. This provides a sequential in-home activity scheduling by finding the activity type and duration at a specific time when an individual is at home and plans to execute an activity.

Additionally, 6 conditional probabilistic models are presented to further in detail find the categories of in-home activities for activity choice models. Each model can predict the minor categories within the 6 major in-home activity types. For example, if an individual chooses leisure as a major in-home activity, he/she could have several choices as to either socialize, watch TV, read a book, etc. In-home activity models are assumed to be impulsive activities without preplanning assumptions. This assumption, if not in all cases, is a reasonable assumption since people are more impulsive at in-home activities. However, there are some considerations for the in-home activities which require planning in order to make the process more realistic.

As mentioned earlier, other than the in-home activity models, out-of-home activity start time and duration models were also estimated to examine how individuals schedule their preplanned activities on a day considering their previous activities.

Eventually, all of the in-home and out-of-home models are programmed within the ADAPTS C++ framework to present a new agent-based activity framework for comprehensive scheduling including in-home and out-of-home activities. The framework is capable of preplanning, planning and scheduling individual's activities within a one month period considering the heterogeneity between the days of the week.

RELEVANCE/RESEARCH GAPS

So far, there has been minor attention on modeling and specifically micro-simulation of In-Home activities in the field of transportation, or even in other related academic studies. One reason could be associated with the fact that in-home activities do not involve trips. Nonetheless, they could be substituted with out-of-home activities which indirectly affects the trips people make. Therefore, a considerable portion of the previous studies have been focused to develop models leading to in-home versus out-of-home choice of activities. However, there are common similarities in the previous studies involving in-home activities. On one side, these studies are mostly very scattered focusing on very specific activity types or activity attributes; trying to develop or estimate models which are barley applicable in micro-simulation frameworks. Most of the models strive to apply state of the art econometric approaches in order to estimate a sophisticated model without proposing any applicable framework for the prediction or simulation which had been the main purpose of them being developed. As a result, there seems to be a deep gap in proposing micro-simulation frameworks that incorporate applicable in-home activity models. On the other hand, the models are basically designed with a focus on out-of-home activities while considering in-home activities on the side. To better explain, for example, in terms of activity type, detail out-of home activity types compete with minor categories of in-home activities in such models. Sometimes, the focus is on discretionary activities, other times on maintenance type without a comprehensive outlook for the models.

On the other hand, the interdisciplinary nature of science in the 21th century makes us think of research beyond transportation by using what has been learned and experienced in transportation demand modeling. Agent-based frameworks in transportation so called as Activity-based models could potentially be applied in other engineering areas to associate people's activities with the amount of water, gas and electricity they consume with the goal of developing agent-based water/electricity consumption models. Although this research does not explicitly propose any of such models, it provides the basics for moving towards that direction.

THESIS OUTLINE

As mentioned earlier, this thesis presents a new framework for modeling in-home activities in conjunction with out-of home activities. It was explained that a gap exists for simulating in-home activities in a disaggregate level. Following the need, this thesis is organized in a few chapters to pave the way for developing the desired framework. Chapter 2 explores the previous related studies in activity-based models with a focus on in-home activities. This chapter takes a flashback at the related work in various areas in activity planning and scheduling; then, specifically reviews the studies related to in-home activities. Chapter 3 describes the data sources for the models developed in this thesis. A review on the pros and cons of the data source is given and relevant descriptive study of the in-home activities is presented to give sufficient background of the prospective models. Chapter 4 reviews the ADAPTS framework; the framework which was initially developed for the purpose of planning and scheduling out-of-home activities as an environment for activity-based travel demand modeling applications. Furthermore, it explains how the estimated in-home activity models are embedded within the ADAPTS frameworks leading to a new full activity based micro-simulation including in-home and out-of-home activity models. Chapter 5 presents the estimated in-home and out-of-home models from the data. The first part focuses on the in-home activity models developed. Related MNL and hazard-based models for the activity type choice and duration are given and explained in great detail. The probabilistic models for the detail in-home activity type models are provided to further analyze in-home activity type choices. Chapter 6 presents the newly proposed methodology for predicting binary comparison from multinomial choice problems. The chapter then discusses the estimation and implementation of this methodology for solving conflict resolution problem between in-home and out-of-home activities. Chapter 7 presents the simulation environment, platform and the validation results and it proposes suggestions for calibrating the ADAPTS framework. Eventually, the thesis is wrapped up with a conclusion and future work discussion.

CHAPTER 2: LITERATURE REVIEW

Activity Planning is the decision process behind execution of an activity. This decision process could be associated with any aspect of the activity including when the decision/need for the activity is called, when the mode choice, party composition, activity start time and duration are being planned. However, activity scheduling deals with finalizing activity attributes including the start time and duration of the activity within the timeline with regards to other activities of the individual and placing them in the right sequence. Earlier research work has been focused on single attributes of an activity in isolation of other attributes. Models have been developed to predict the focused attributes (1). However, later on, research has been more skewed towards activity modeling frameworks which are capable of taking in to account the interactions between various activity attributes. Those frameworks are not only considerate of the interdependencies among attributes of an activity; but also they could be applied in agent-based micro-simulations (2).

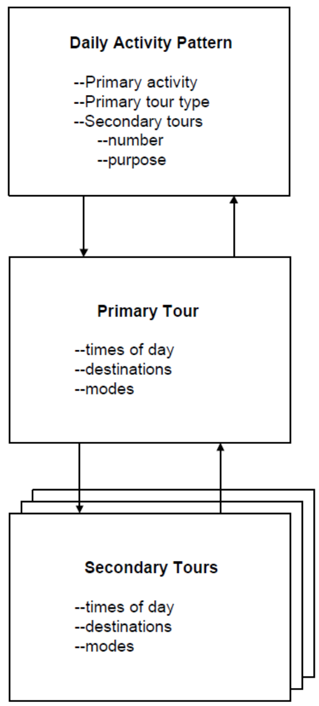
Each activity occurs as the result of multi-criteria decisions conditional to time, location and individual's concerns. To model this complex multi-criteria decision making process, researchers have suggested model components and frameworks, some more complex and realistic than the others. Depending on the timeframe, these frameworks could be daily (3), weekly (4) or even monthly (5). The longer the timeframe, the more flexibility would exist for dynamic planning of the activities since individuals would be able to plan activities as far as a month in advance which could be realistic for some activities such as the ones for medical purposes. Here, the author tries to divide the process of activity decision making in to the constituent criteria and discuss about them separately.

ACTIVITY GENERATION MODELS

Activity generation is the methodology behind how an activity or a sequence of activities is generated based on potential temporal, spatial and individual needs. Such models are estimated as out-of-home activities with associated trips involved. Duration, exact start time and other attributes of the generated activities might not be defined in the activity generation step necessarily (5). However, the core of activity generation structure either in terms of tour-based or trip-based is specified in these models. Furthermore, the purpose of the activity is also defined while other exact activity attributes will be known through other models. Trip-based models are designed to incorporate individual trips with purposes such as Home-based Work, Home-based other and Non-home based. Trips are modeled separately and tours are indirectly formed to relate the separate trips (6). These trips are modeled separately but not independently from each other. On the other hand, tour-based models are based on tours as a combination of potential trips with interdependent linkages (7). The idea of tours comes from the intuitive sense that trips are eventually turned out in to home-based round-trip journeys with primary trips influencing the secondary or less important ones.

Kitamura 1983 came up with a probability based sequencing or chaining of activities (8). Based on the study, they found that the observed trip chaining behavior could be represented through a consistent hierarchical activity order. Later on, they incorporated the time component to the sequencing process. The approach would provide probabilities for fixed sequence of activities in trip chaining. Golob 1986 worked on a similar study on simultaneous decision making in trip chaining through non-linear multivariate analysis (9). Ben-Akiva and Bowman 1995 proposed a daily activity schedule framework more comprehensive than the previous works to be applied in activity-based travel demand models (10). The models were estimated through a nested logit structure to determine an individual's daily activity pattern as primary activity type, primary tour type and secondary tour numbers and purposes. Consequently, the time of day, mode choice and destination choice for primary and secondary tours were modeled. Figure 1 is borrowed from the work to clarify the modeling structure. Other studies attempted to model similar tour-based activity patterns through rule-based structures for limited activity choices (11).

Figure 1. Daily Activity Pattern (Ben Akiva and Bowman 1995)



Later studies are shifted towards need-based activity generation models leaning on the intuition that trips are made as a result of a need for an activity. Instead of models to predict the tours or trips, researchers have tried to focus on the need to generate an activity of a specific type which will cause the tour/trip (12). The idea was presented to bring about a dynamic behavior in activity and tour formation as opposed to the fixed activity sequences before (5). Other activity generation models that have been developed similar to the need-based concept are hazard-based duration ones. They are based on reoccurrence of an activity of a specific type within a timeframe of several days (5). These parametric hazard models are then applied to determine the probability of an activity occurring at any single time. Josh et al 2010 used a bathtub hazard model to better capture the probability of an activity occurring at simulation time steps. Their research had shown that most of the activity types have high initial hazard which decreases significantly with time and gradually increases in probability of occurrence as time passes, leading to bathtub-shaped hazard functions.

TIME ALLOCATION MODELS

Time allocation is the method of allocating time to various tasks or activities based on human behavior. Methods regarding activity time allocation include rule-based, optimization and other choice-based models. Jara Diaz et al 2008 proposed a time allocation model for estimating the value of leisure (13). They have applied a utility-based consumer behavior model to perceive the value people put to leisure activities. Lagrangian Multiplier was utilized to come up with utility maximization and marginal utilities for activities. However, the focus of their study is on leisure activities and how leisure could be valued differently among different communities. Bruzelius 1979 has expanded the value of time definition for various activities (14). Juster and Stafford 1991 analyzed the descriptive patterns of time use by men and women in a variety of countries with various economic development backgrounds , presenting the time use pattern differences between industrialized and developing countries (15). Time use studies have previously focused on labor supply or market hours; however, household activities and non-market hours have been under attention in the last few decades. Jacob Mincer 1962 and Gary Becker 1965 came up with the earliest household production models (16, 17). Household production models which are static are gained through optimization technique and are not dynamic under many circumstances.

Optimization-based Time Allocation models are broadly divided in to two general categories (18):

1. **Budget Constrained Consumer Approach**

Becker initiated the consideration of value of time in the budget of the households. Later on, Deserpa (1971) developed a model for consumption of goods and activities by introducing constraints on minimum activity time allocation (19). In their model, leisure activities are treated differently from non-leisure activities in terms of time value.

DISCRETE CONTINUOUS MODELS

Discrete Continuous Choice models were initially proposed by Hanneman 1984 who presented the consumer demand commodity allocation model based on Random Utility Maximization and Optimization technique (20). Bhat 2005, 2008 introduced Multiple Discrete Continuous Extreme Value Model (MDCEV) which was specifically formulated to target time allocation for various activities within random utility framework. The advantage of random utility models over Budget Constrained Consumer models is the consideration of random variations which is the justification for the more behavioral simulation of time allocation (21, 22).

The MDCEV utility function formulation is constructed as:

$$U = \sum_{j=1}^{k} \Psi(x_j)(t_j + \gamma_j)^{\alpha_j}$$

$$\sum_{j=1}^{k} t_j = T$$

Where:

$\Psi(x_j)$: Baseline utility for time assigned for activity j associated with individual or activity attributes

t_j: Time invested in activity J

γ_j , α_j: Parameters to be Estimate

T : Total time that should be invested in the activities

In order to add the random term to the utility function $\Psi(x_j)$ is defined as:

$$\Psi(x_j) = e^{\beta x_j + \varepsilon_j}$$

Using the Lagrangian multiplier and Kuhn-Tucker conditions to solve the optimization problem and definition of the known utility, we will get to the point that:

$$V_j = \beta x_j + ln\alpha_j + (\alpha_j - 1)\ln(t_j^* + \gamma_j)$$

$V_j + \varepsilon_j = V_1 + \varepsilon_1$ If $t_j^* > 0$ (1 is the activity for which the individual will invest non-zero time)

$V_j + \varepsilon_j < V_1 + \varepsilon_1$ If $t_j^* = 0$

Assuming a standard extreme value distribution for ε_j which are independently and identically distributed, one can gain the probability that only M of the activities are invested non-zero time:

$$P\left(t_2^*, t_3^*, \ldots, t_{M,}^0 0,0, \ldots, 0\right)|\varepsilon_1 = \prod_{i=2}^{M} f(V_1 + \varepsilon_1 - V_i) \times \prod_{l=M+1}^{K} F(V_1 + \varepsilon_1 - V_l)$$

F and f are cumulative distribution function probability density functions respectively.

The closed form below is obtained through further simplification:

$$P\left(t_2^*, t_3^*, \ldots, t_{M,}^0 0,0, \ldots, 0\right) = \left[\prod_{i=1}^{M} c_i\right]\left[\prod_{i=1}^{M} \frac{1}{c_i}\right]\left[\frac{\prod_{i=1}^{M} e^{V_i}}{\left(\sum_{j=1}^{K} e^{V_j}\right)^M}\right](M-1)!$$

Where $c_i = \frac{1-\alpha_i}{t_i^* + \gamma_i}$

This formulation was achieved without considering the correlation structure for the error terms. To account for the possible correlation structure and heteroscedasticity, Mixed MCDEV was proposed to include the correlation between the error terms through accommodating three independent error components.

ACTIVITY DURATION MODELS

Activity duration models are similar to time allocation ones. However, duration models are more focused on one activity type; whereas, time allocation models try to find the optimal time allocations for various activities at the same time as described. Therefore, duration models are more behavioral in terms of taking in to account spatial and temporal factors more realistically. Most of the work done in this area has been accomplished through hazard-based models. As a result, a review on hazard concept is helpful to step forward.

Hazard concept was initially introduced for modeling survival analysis (23). Survival analysis associates the time that passes before an event occurs with correlated causing covariates. Cox 1972 proposed a proportional hazard model that could potentially be used in many applications such as biostatistics, economics, psychology and political science among others (24). Ettema et al. 1995 came up with competing accelerated hazard duration models for major activity types of In-home leisure activities, In-home task activities, work/education, Shopping and Personal business out of home (25). Bhat 1996 proposed a hazard model with non-parametric baseline and non-parametric gamma distribution for unobserved heterogeneity to model shopping activity duration (26). As claimed, the impact of unobserved heterogeneity on the shopping activity duration is significant and a gamma distribution could improve the model. Bhat et al 2005 presented a joint activity and trip simultaneous hazard duration model by considering the correlation between the trip and stop (activity) durations (27). By inserting a correlation term between the activity duration and the corresponding trip, they tried to associate the two hazard models through the unobserved heterogeneity with two correlated log-normal distributions.

Habib et al 2008 developed a discrete-continuous model exploring the relationships between activity party composition, activity start time and duration (28). They tried to model the activity duration part through an accelerated hazard model. In another study, they used multi-level linear model for episode duration with three level random effects for household, individual and daily variations (29). Ferdous 2008 estimated a hazard-based duration model with latent heterogeneity for recreational activity duration (30). The study attempts to examine various hazard functions such as Weibull, Exponential, and Log-logistic on recreational activity duration. The model is claimed to account for the heterogeneity of individuals through gamma distribution and it can predict the recreational activity duration based on socio demographic and temporal attributes such as age, day of the week and information about other activities performed.

ACTIVITY SCHEDULING

Activity scheduling is one of the fundamental steps in activity decisions, forming agenda of individuals; the agenda which is affected by temporal or spatial constraints of travel, individual activity/ travel behavior and many other constraints (31). The early talk comes from psychology studies when the subject of computerized production system as a set of rules for human actions was introduced (32). As quoted directly "Any production whose conditions are matched by elements in working memory becomes a candidate for activation". Therefore these psychology studies state that production systems as a set of condition-action pairs could be the basis for modeling human cognitive architecture and behavior and the way humans learn from the world of information surrounding them.

Garling et al. 1994 developed an operational model called SCHEDULER for household activity scheduling (33). The framework simulated the activity agenda with a long term and short term calendar. A subset of activities with higher priorities was selected from the list of presumed activities in the long term calendar to be placed in the short term one. In the next step, information regarding the short term activities to be executed such as utility, duration, location was retrieved. However, the operational model solved the problem of scheduling activities with simplistic order assumptions to control complexities. SMASH improved the SCHEDULER framework by adding rule-based heuristic scheduling models (34). TASHA was another travel and activity scheduling Framework developed by Miller and Roorda 2003 (35). TASHA simulates people's out of home activities and travel during a weekday. It has a conflict resolution strategy for scheduling conflicting activities based on certain assumptions.

In-Home Activity Modeling

In transportation, there have been some studies regarding In-home activities and their interactions with out of home activities; however, the effort has been scattered without any focus on simulation in micro-simulation frameworks. This part tries to explore those studies that have been at least partly dedicated to model In-home activities.

Bhat and Koppelman 1999 express the necessity for a detailed time-use survey data to perceive the pattern behind how people substitute out-of-home activities for in-home activities (36). In fact, the in-home versus out-of-home choice of the activity affects the generation of trips which is a substantial subject in travel demand models. Doherty and Miller 2000 designed a survey called Computerized Household Activity Scheduling (CHASE) in order to trace household in-home and out-of-home activities during one week (37). A broad set of activity types were defined as in the Table 1 while household and individual schedules were collected based on the activity types in 15 minute intervals. Figure 2 shows the specific scheduling layout of the survey.

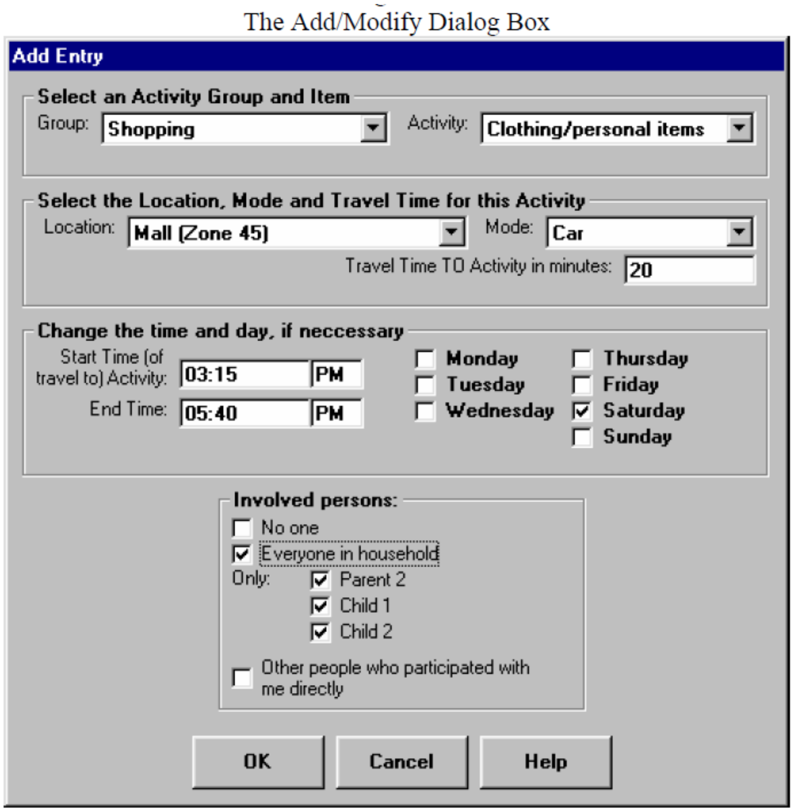
Table 1. ACTIVITY TYPES DEFINED IN CHASE SURVEY (DOHERTY AND MILLER 2000)

Generic Activity Types Used to Define a Household Activity Agenda

BASIC NEEDS	WORK/ SCHOOL	HOUSEHOLD OBLIGATIONS	SERVICES	JUST FOR KIDS
Night sleep	Work	Cleaning/maintenance	Doctor	Tag along with parent
Wash/dress/pack	School	Meal preparation	Dentist	Play, socializing
Home prep meals	Daycare	Chauffeuring	Other professional	Homework
Bagged lunches	Volunteer work	Chauffeuring and passively observing	Personal (Salon, barber, laundry)	With babysitter
Restaurants (family, spouse, alone)	Special training	Attending to children	Banking	Other just for kids
Delivered/picked-up meal	Other work/ school	Pick-up involved person	Video store	
Coffee/snack shops		Other errands	Library	
Other basic needs		Other obligations	Other service	

SHOPPING	RECREATION/ ENTERTAINMENT	SOCIAL	OTHER
Minor groceries (<10 items)	Exercise or active sports (aerobics, fishing, cycling, walking, etc.)	Visiting	Tag along travel
Major groceries (10+ items)	Movies/theatre	Hosting visitors	Pleasure driving
Housewares	Other spectator events	Cultural events	
Clothing/personal items	Playing with kids	Religious events	
Drug Store	Parks, recreation areas	Planned social events	
Mostly browsing	Regular TV programs	Bars, special clubs	
Convenience store	Unspecific TV	Phone/e-mail >10 min	
Pick-up meal	Movie video	Helping others	
Other shopping	Relaxing/pleasure reading/napping	Other Social	
	Hobbies (crafts, gardening, etc.)		
	Other rec/entertainment		

Figure 2. Scheduling layout of CHASE survey(Doherty and Miller 2000)

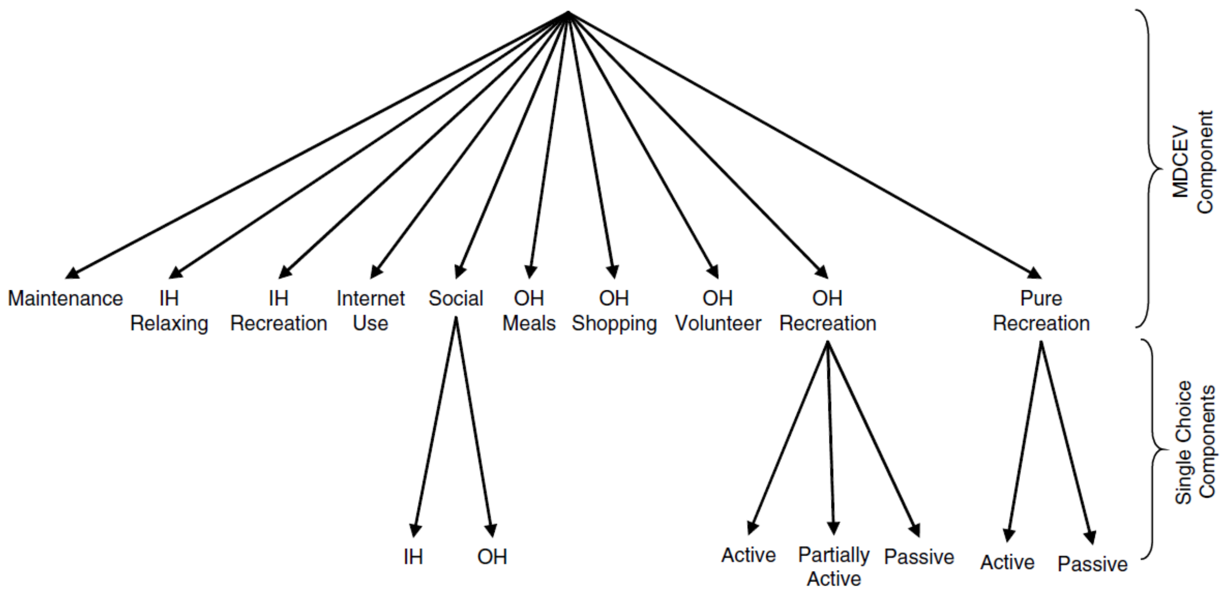


Yamamoto and Kitamura 1999 proposed a time allocation model between in-home and out-of-home discretionary activity type with a doubly censored Tobit model (38). This model can explore how a fixed amount of time is allocated between In-Home and Out-of-home activities either on weekdays or weekends. Doherty 2000 explores the data gathered from CHASE and based on the empirical analysis of the survey reveals the dynamic behavior behind activity scheduling (39). The study also sheds light on some of the facts regarding in-home activities such as sleeping, eating, preparing meals. It is also mentioned that most of the models consider a priority for modeling\sequencing out-of-home activities versus in-home ones.

Srinvasan and Bhat 2005 estimated regression models for the duration of in-home maintenance activities (40). Although the focus of their work is on Joint out-of-home shopping activity participation type and duration model, the in-home activity duration regression models are interesting to explore as well. They have estimated four different models for the following household socio demographic contexts of (1) single-worker households without children, (2) dual worker households without children, (3) single-worker households with one or more children, and (4) dual-worker households with one or more children.

Mohammadian and Doherty 2005 developed Mixed Logit models for planning horizon of activities (41). Although the majority of activities were out of home while several in-home activity types such as night sleep, washing and dressing were excluded from the analysis data, the study implied the impulsive nature of in-home activities. Akar et al 2011 came up with a Mixed Logit model for in-home versus out-of-home discretionary activity type choice (42). They have compared four sequential models each model complementing the previous by adding extra group variables. The group variables in the 4th model, as the most comprehensive one, include individual and household, temporal characteristics, information about people participating in the activity, time spent in other activity types during the day as well as previous and following activity location and type characteristics. Akar et al. 2012 categorized leisure activities in to 8 groups depending on in-home versus out-of-home as well as the plan horizon attributes and developed a Mixed Logit model for the 8-groups choice (43). The observations included in-home and out-of-home leisure activities. The model incorporated covariates related to household and individual, temporal characteristics and a number of other activities in the schedule. Temporal characteristics included evening/morning and weekday/weekend conditions. Bhat and Gosson 2004 proposed a Mixed Multinomial Logit model for weekend recreational activity type choice model (44). The recreational activity type choice set included in-home, out-of-home and pure recreational episodes (recreational trips for the sole purpose of joy from the trip itself such as biking). The study tries to capture the pattern behind weekend recreational activities based on individual and household socio-demographic, land use and episode participation attributes. Additionally, the aspects in the substitution of in-home and out-of-home activities are analyzed. Bhat and Misra 1999 proposed a formulation for allocating a weekly fixed amount of time for discretionary activities between in-home and out-of home and also between weekend and weekday activities (45). The model was estimated to find the time allocations for the alternatives. The methodology was based on utility maximization and the optimal allocation could be obtained through a closed form formulation conditional to simplified assumptions. In another study by Bhat et al 2006, a joint model for the perfect and imperfect substitute goods case is proposed (46). The model is developed for a time use decision application on how much time individuals allocate for maintenance and leisure activities through multiple discrete-continuous extreme value (MDCEV) formulation. The figure below shows the modeling framework for different in-home and out-of-home activity types of their work. The figure below is directly borrowed from the paper. As it shows, the nested structure helps further detail the allocation time for different activity types.

Figure 3. Modeling Activity Time Allocations (Bhat et al 2006)



Doherty 2006 redefined the activity types by the spatial/temporal flexibility component of the activities (47). The redefinition of the activities leads to 8 general categories of in-home and out-of-home activities based on the temporal and spatial flexibility. The four categories of the defined in-home activities are described as (1) Domestic social life (2) Long and frequent basic needs (3) Space-time flexible leisure (4) Long time fixed in-home activities. These groups of activities are fundamentally different in terms of duration, frequency, number of involved persons, temporal/spatial flexibility, and interpersonal flexibility.

Doherty and Oh 2012 proposed Multi-Sensor Monitoring System of Human Psychology and Daily Activities, mainly a GPS and smart phone sensor-based system tracking health and daily activities in order to explore life style impacts on health conditions at a fine temporal/spatial scale (48). The study also provided some general statistics regarding the time people spend at home doing in-home activities as well as out-of home.

CHAPTER 3: DATA

The main source of data for model developments in this thesis is American Time Use Survey (ATUS). Sponsored by the Bureau of Labor Statistics, ATUS is conducted for the goal of measuring how people divide their time among various activities. ATUS provides the most reliable national data about people's time use on a full range of non-market activities. As a result, this survey is an appropriate source for analyzing people's daily activities along with the activity attributes such as when, how long and with whom they perform them. Conducted annually, the last available year 2012, provided a sample size of approximately 12000 individuals. The data was collected for a full schedule within a random day including every single activity an individual performs during the day (even minor activities executed within a few minutes). The accuracy along with fine detailed category type definitions is the basis for the use of this survey in order to model in-home activities.

However, the one-day format of the survey is the main drawback that avoids the weekly or monthly frequency analysis of the activities of an individual. Therefore, the intra-activity associations are bound to one day analysis which is not too unrealistic for the case of in-home activities which are more impulsive as opposed to preplanned. Although some in-home activities could be well-preplanned such as certain socializing gatherings, impulsive or same-day planned activities are more dominant among them.

Having said the pros and cons of ATUS, the data source is considerably suitable for the case of in-home activity analysis. As mentioned earlier, the activity categories are quite detailed in the survey. To better generalize the groups of the in-home activities, all activities were divided in to 6 general fundamentally different categories. The 6 categories initially defined, were: Sleep, Personal Maintenance, Household Maintenance, Leisure/Social, Discretionary-Other and Mandatory activities.

These 6 general categories are analyzed and later modeled with choice modeling methods. For every single category, models will be presented to achieve more detailed category types. It is noteworthy to explain that personal maintenance includes eating/drinking and personal care activities. Household maintenance includes household activities, caring for household members, caring for non-household members. Leisure/social includes a variety of activities like socializing, relaxing, watching TV, reading a book, among others. Discretionary other activities are religious/spiritual, volunteer and telephone calls and eventually, mandatory activities include work or education related tasks.

Before jumping to the models, a descriptive analysis of the in-home activities observed from ATUS data is given as the background of the models to be presented in the following sections.

DESCRIPTIVE STUDY

The study provided here is focused on time of day variations as well as duration distributions for various activities. The graphs are obtained from the ATUS data after applying the corresponding weight factors. Initially, time of activity execution during a day is explored to assess the proportion of people involved in various activities at time of day intervals.

IN-HOME LEISURE TIME OF DAY FREQUENCIES

Figure 4 shows the distribution of In-home leisure activities within time of day intervals for various socio-demographic groups. The intervals are 15 minutes and the Y-axis shows the percentage of people from the corresponding socio-demographic groups who are involved in the activity at the time interval. The socio-demographic groups under consideration are listed as employed either full time or part time, unemployed, retired, adult students and teens. The activity types are generally divided in to 5 groups as socializing and communicating, watching TV, using computer as leisure, sports/exercises and the other leisure category. The other leisure includes activities such as relaxing, reading a book, listening to music or radio, doing art work, playing games or others of the sort.

The graphs show a general pattern common among various socio-demographic groups. Watching TV seems to be the most frequent in-home leisure activity at home. People spend considerable time watching TV or movies as the most popular in-home leisure activity among all socio-demographic groups. The peak of watching TV happens at around 21 pm; around the time, 42 percent of the full time employed, 53 percent of the part time employed, 57 percent of the unemployed and approximately 60 percent of the retired people are watching TV while it is much less like a high peak for adults and teens, more scattered with maximum 35 percent participation at the peak time interval. This could implicitly describe the spontaneity and more flexibility in teens and adult students ‘schedules. The next frequent activity fluctuates between socializing/communicating and other leisure depending on different socio-demographic groups. Adult students keep socializing/communicating a top priority compared to other leisure type;

while, retired people are the exact opposite; with less engagement in in-home socializing/communicating, they are more involved in other leisure types such as reading a book, listening to radio, etc. In case of sports or exercises at home, teens seem to have the highest participation among other socio-demographic groups since adults are more willing to perform such activities in the gyms, recreational centers and outdoor. On the other hand, computer use for leisure has the most participation by adult students and teens typically later the night. In case of adults the peak happens at around 10 pm. To explicitly interpret the data, we could say that approximately 6 percent of adults in the nation are using computer for leisure at the 15 minute interval between 09:52':30" pm to 10:07':30" pm. For teens this peak happens twice during the day either at 3 pm or 9 pm with approximately 5 percent of the teenagers involved within the corresponding 15 minutes intervals.

Exploring these graphs can obviously represent how in-home activity participations are variant during the day. Coming up with models that can well extract these patterns for application in activity based micro-simulations not only can help simulate in-home participations but also could indirectly adjust the out-home activities, their start times and durations. Clearly, the way out-of-home activities are generated should be compatible with such distributions of in-home activities; and aggregate results of a micro-simulation should preserve these in-home activity type distributions during a day.

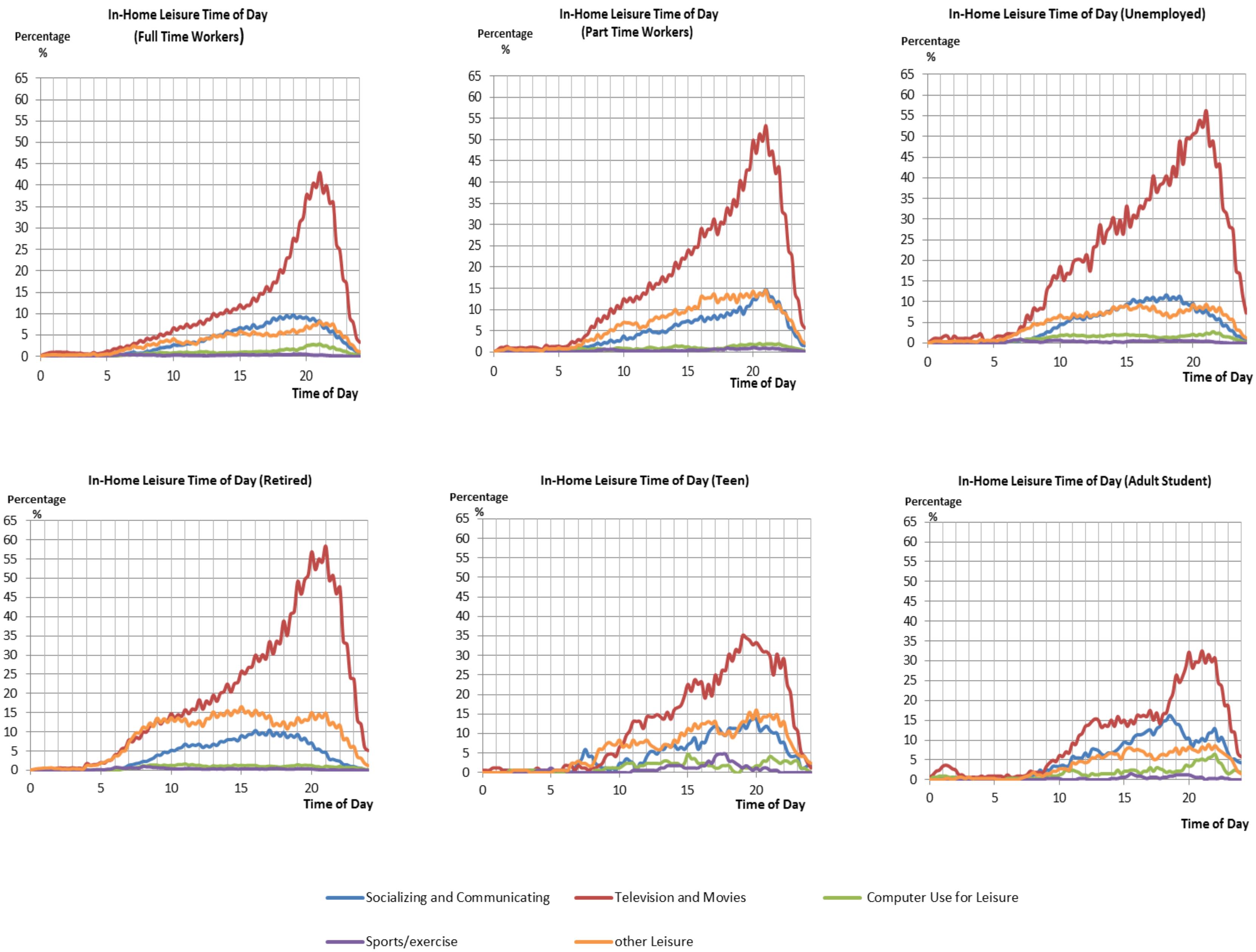


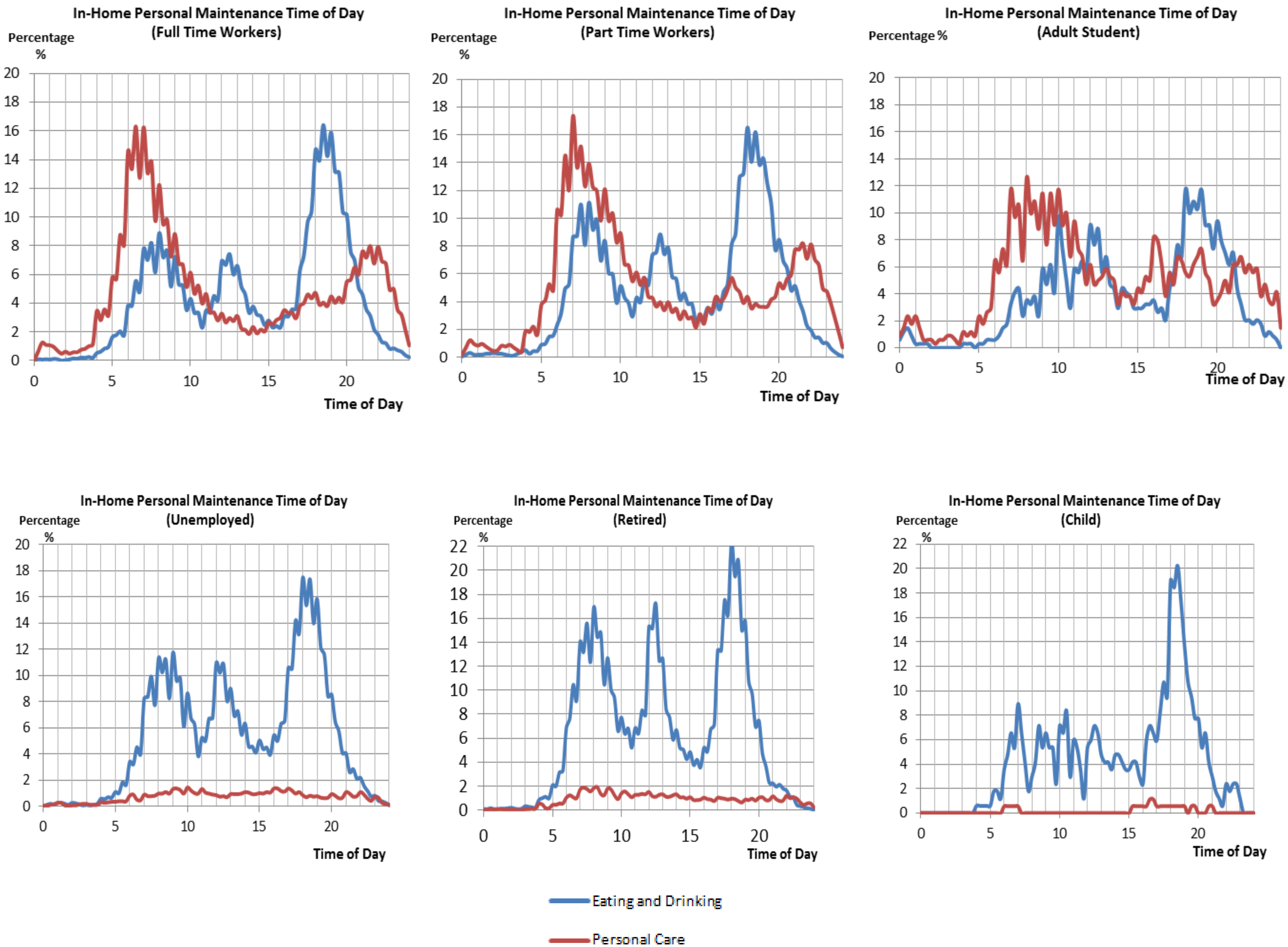
Figure 4. In-Home Leisure Time of Day Frequencies

IN-HOME PERSONAL MAINTENANCE TIME OF DAY FREQUENCIES

Figure 5 represents In-home personal maintenance participation distribution for various socio-demographic groups at 15-minute time of day intervals. In-home personal maintenance includes eating/drinking and personal care. Personal care does not include sleeping as it is analyzed separately. Considering eating/drinking, the common three meals a day are showing the triple peaks during morning, noon and evenings. The peaks are pretty vivid for adults while teens have more scattered eating/drinking schedule. Adult students and teens are more inclined to late morning breakfasts compared to employed, unemployed and retired individuals which is reasonable due to the more flexible schedule they have with less responsibilities. Also, from a psychological point of view, younger people seem to be more spontaneous with the high pulses in the corresponding graphs. Retired people have the highest peak in eating/drinking around 6 pm for dinner with 22 percent of them eating/drinking within the corresponding 15-minute interval which displays the higher inflexibility in their dinner schedule. Surprisingly, teens have similar pattern in their dinner schedule while they are way flexible earlier in the day.

In terms of personal care, employed individuals and adult students have a quite different pattern compared to unemployed, retired and teens. The graphs show that the latter group is much less involved in personal care activities. Personal care activities involve washing, dressing, grooming oneself and personal activities. Employed individuals and adult students seem to spend much more time on personal care due to the more frequent social interactions and obligations. Employed individuals have dual peak personal care graph during the day; one early morning around 7-8 am and the other peak later the night at around 9-10 pm

Figure 5. In-Home Personal Maintenance Time of Day Frequencies



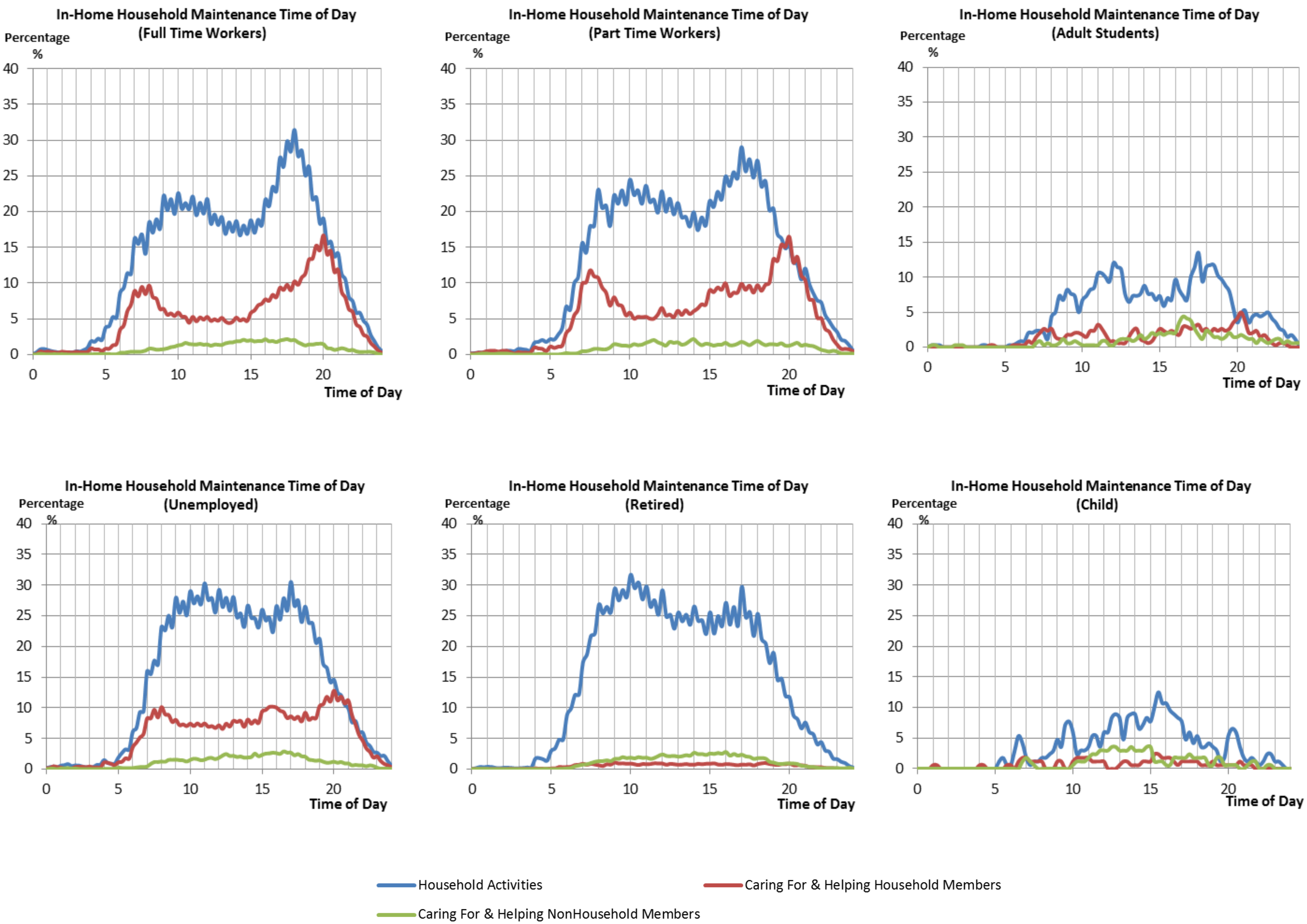
IN-HOME HOUSEHOLD MAINTENANCE TIME OF DAY FREQUENCIES

Figure 6 represents the distribution of household maintenance activities among various socio-demographic groups at time of day intervals. Household maintenance generally includes household activities, caring for household members and caring for non-household members. Household activities involve a variety of household chores such as housework, food and drink preparation, interior/ exterior maintenance and repair among others. As expected, teens and adult students have the minimum share in household maintenance activities with a peak of approximately 10-15 percent involved in the peak 15-minute interval.

Typically, the peak of household activities seems to happen at 6 pm, most possibly after getting home from work for employed people; or the time when people do the preparations for dinner or other household chores. On the other hand, the peak of caring for household members happen at around 8 pm; most possibly after dinner to help household members as by helping children with their education. Caring for non-household members is pretty scattered with high participation during afternoon.

Household activities graphs seem to have dual peaks during the day, one around the morning at around 10 am until noon and the other peak as mentioned at around 6 pm. Retired and Unemployed people are more involved in household activities. However, employed individuals have the most engagement in caring for household members. This is also true for unemployed individuals but the graph is more scattered during the day due to the more flexible schedule. Retired people have the least engagement in caring for household members since they mostly do not have children to take care of during a day. In terms of caring for non-household members, adult students are more involved since many of them live with roommates or friends as non-household members.

Figure 6. In-Home Household Maintenance Time of Day Frequencies



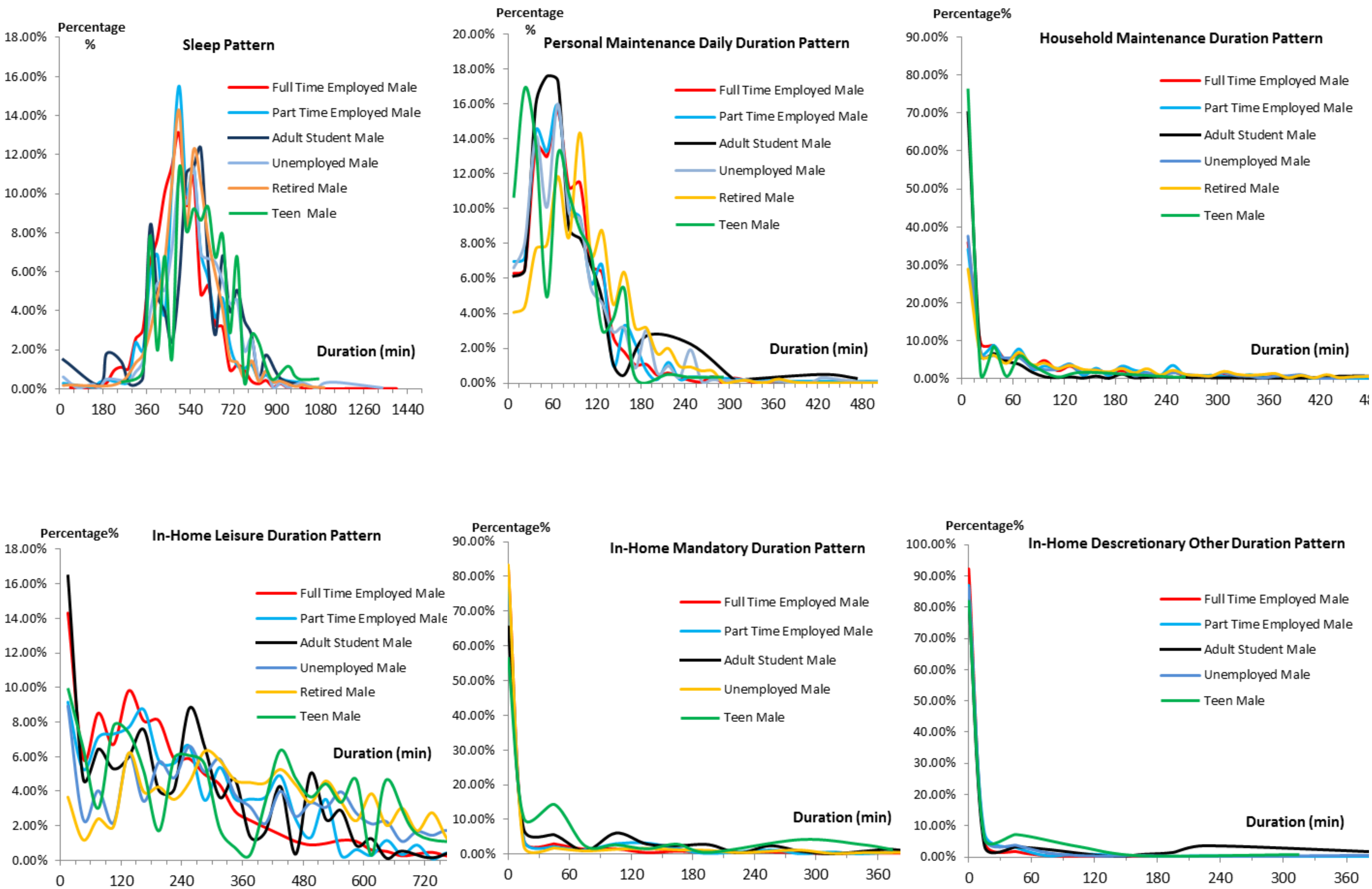
IN-HOME ACTIVITY DURATION FREQUENCIES

This section describes the total daily amount of time individuals allocate to the 6 in-home category types defined earlier. Figure 7 displays the distribution of daily time allocations to various activity types for different socio-economic categories. From the sleep pattern graphs, employed individuals have the least total amount of daily sleep. Full time employed individuals have total average sleep of 490 minutes including the night sleep and the naps during the day while part-time employed individuals spend 30 minutes more on sleeping on average. Retired, adult students, unemployed and teens have respectively more sleep on average with teens 580 minutes sleep on average. In terms of personal maintenance, retired and unemployed individuals allocate the most amount of daily time as 101 and 84 minutes a day on average. Note that the majority of this time is specifically allocated to eating/drinking while personal care was shown as minor activities in figure 6 graphs. Employed individuals and adult students spend an average of 72-74 minutes on personal maintenance activities showing no significant statistical difference. On the other hand, teens spend the minimum amount of time as 66 minutes on personal maintenance activities.

Retired and unemployed individuals spend the most on household maintenance activities with the average of 120 and 101 minutes respectively. Following them, Part time and full time employed spend an average of 90 and 80 minutes respectively. In terms of in-home leisure, retired people spend the most amount of time with an average of 388 minutes on average. Unemployed and teens are respectively the following in-home leisure fans while fulltime employed spend the least amount of time on in-home leisure with 198 minutes daily on average. Teens and adult students are involved in mandatory in-home activities more than others; mostly in education related tasks with an average of approximately an hour a day.

Discretionary other activities are assigned the least amount of time between all other activities with an average of 24 minutes daily as the highest by adult students.

Figure 7.In-Home Daily Activity Time Allocation Frequencies



IN-HOME DAILY ACTIVITY TIME ALLOCATION AND GENDER DIFFERENCES

Figure 8 shows the total daily time allocations to various in-home activities for different socio-demographic groups by gender. The graphs show that women in general are more involved in in-home household maintenance activities. This pattern is more visible for unemployed and part time females whose participation in in-home household maintenance activities surpass the male counterparts.

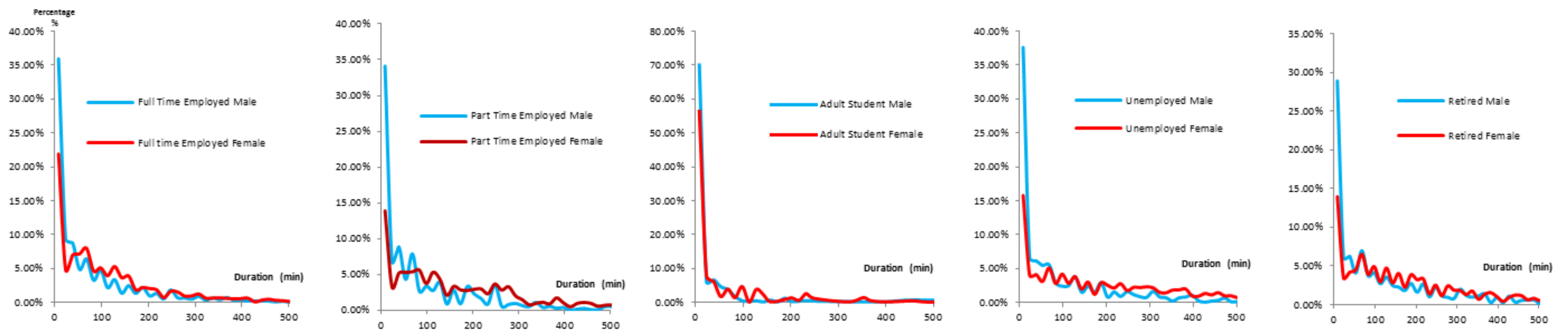
Women are also more engaged in personal maintenance activities which could possibly be due to the more time they put in to personal care . Similar to household maintenance pattern, unemployed, part time and adult student females allocate considerably more time to personal maintenance than the male counterparts. On the other hand, retired males and females are very similar in terms of in-home personal maintenance time allocation.

It is interesting that men spend more time than women in in-home leisure activities. This pattern is specifically evident for unemployed and retired males who spend more time on in-home leisure activities than their female counterparts. Even though this pattern exists among all socio-demographic groups, it is less obvious among full time workers.

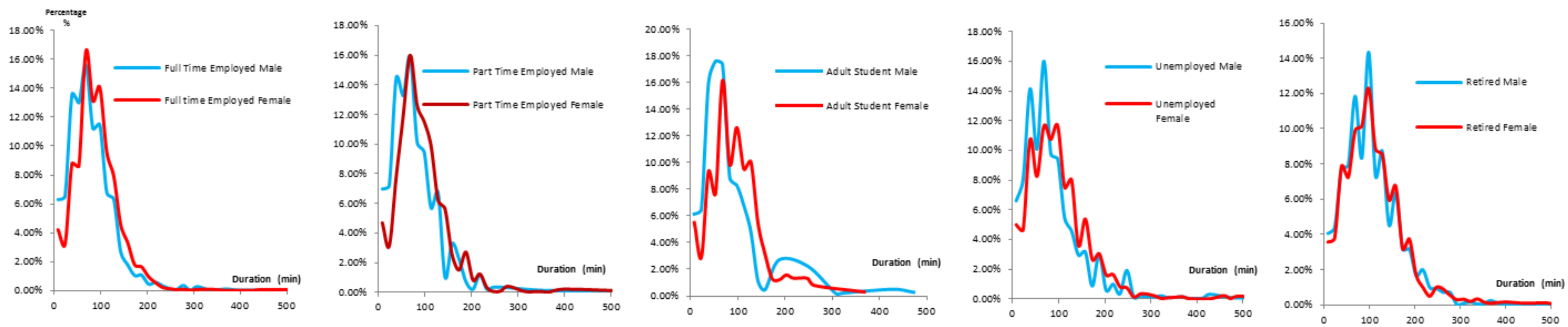
Following the noted points, it could be concluded that women are more involved in in-home household and personal maintenance activities compared to men; while men are more engaged in in-home leisure activities. Therefore, these fundamental gender differences must be considered in activity type choice and duration models

Figure 8. In-Home Activity Duration and Gender Differences

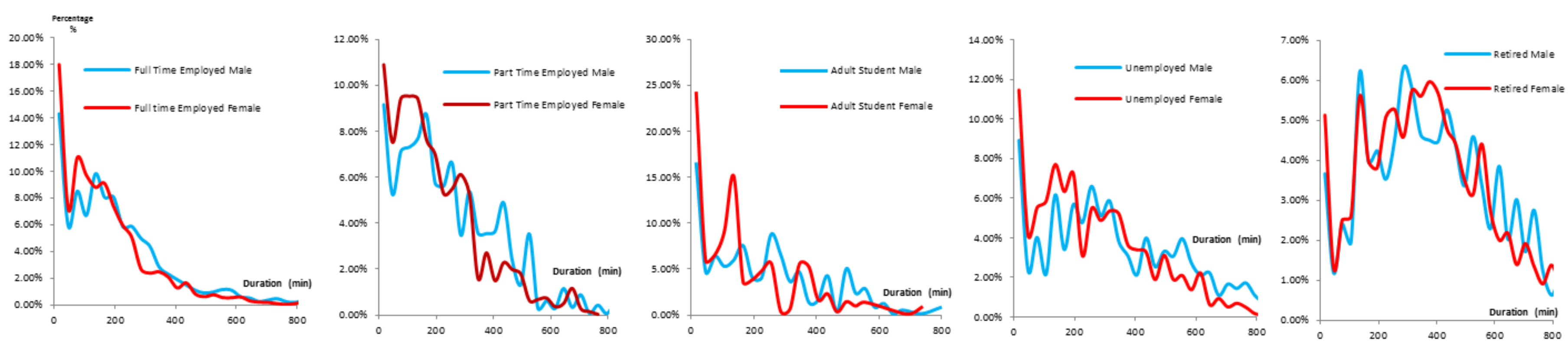
Household Maintenance Male Versus Female



Personal Maintenance Male Versus Female



Leisure Male Versus Female

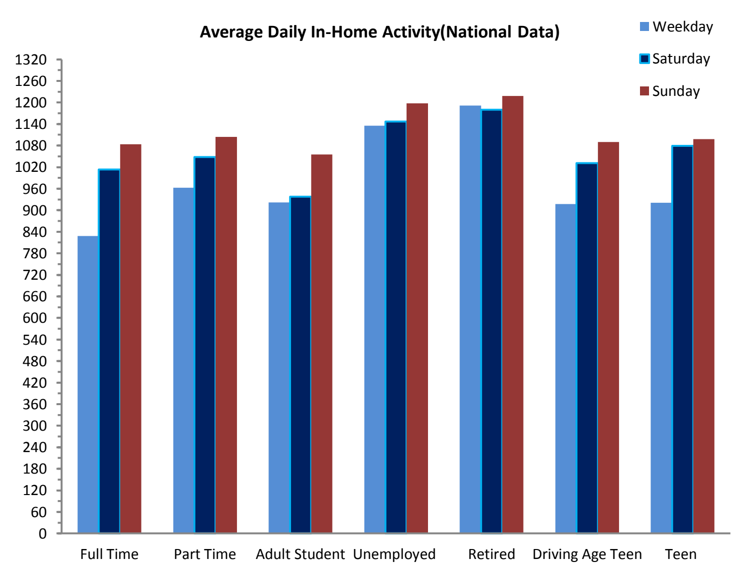


WEEKDAY/WEEKEND IN-HOME ACTIVITY DURATIONS

Figure 9 represents the weekday versus weekend in-home activity time allocations by various socio-demographic groups. Evidently, Sunday is the day when people allocate the most amount of time for in-home activities which is specifically conspicuous for unemployed and retired people. Following Sunday, Saturday is another in-home activity day dominantly by full time and part time workers. While weekends' in-home activity participation is considerably higher compared to weekdays; this pattern is less visible for unemployed, retired and adult students with the retired even spending more in-home time on weekdays as opposed to Saturdays. Adult students spend the least amount of in-home activity time on Sundays compared to the other groups. Among all socio-demographic groups, full time workers, teens and adult students spend the least in-home activity time during the weekdays.

In a nutshell, the data gets along with the intuitive sense that students, teens and workers spend less in-home activity time while unemployed and retired individuals are more inclined to settle in at home.

Figure 9.Weekday/Weekend In-Home Activity Durations



CHAPTER 4: INCORPORATING IN-HOME ACTIVITIES INTO ADAPTS

ADAPTS OUT-OF-HOME ACTIVITIES

Before explaining how in-home activities are being incorporated within ADAPTS, it helps to review this activity planning and scheduling framework. ADAPTS was designed to simulate the process of out-of-home activity planning and scheduling in a dynamic setting so as to capture the spontaneity behind individuals' activity planning. It was shown in the literature that the attributes of activity planning such as time choice, mode choice, party composition along with other attributes are not necessarily planned in a fixed order nor a fixed time. As a result, it was attempted to treat activity planning as a set of discrete activity attribute planning models with flexible and dynamic calling order. The framework can preplan activities as far as one month ahead; however the focus of activity execution and trip assignment is allocated to the last week of the month to analyze individual's trips.

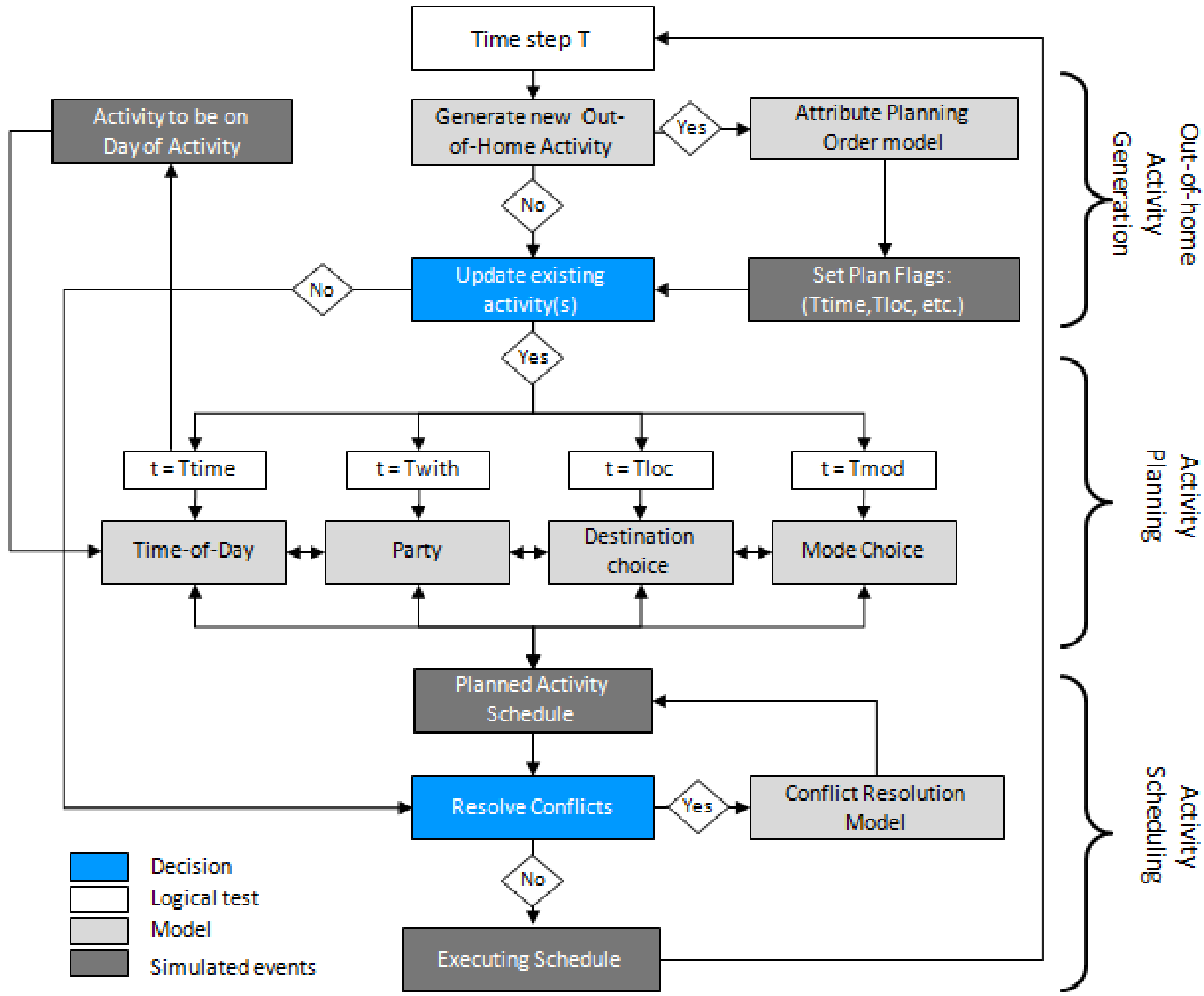
ADAPTS out-of-home activity planning and scheduling conceptually consists of three distinct phases. The first phase is known as activity generation which just demonstrates the need for executing an activity sometime in the future in a one month period. The activity might be scheduled as impulsive, same day, same week or in the following weeks depending on the urgency. Activity generation step is modeled with the use of simultaneous hazard modeling for the 9 defined out-of-home activity types. At each time step, an individual would check out his/her schedule and the probability of an activity to be generated would be calculated based on the time since the previous activity of the same type had been executed. At this phase, all of the activity attributes such as time of execution, mode choice, duration are left unspecified for the next phases. However, the planning horizon of the attributes such as when and in what order the attributes are being planned are specified. Called as “Planning Order Model”, this model of the phase sets the flexibility of the planning attributes and defines when each attribute is supposed to be planned.

The second phase is associated with the activity planning models. The activity attribute values are obtained at the time and the order defined by the Planning Order Model. Models for time of day, duration, mode choice, destination choice and party composition are applied to set these attributes. However, the time of day and duration are defined based on frequency tables for different activity types. As a result, the way time of day and duration for out-of-home activities are defined are highly independent of the individual’s schedule. Therefore, one of the areas which needs improvement in ADAPTS, is the frequency based models. It is quite helpful to remodel these two sub-models to consider individuals’ schedule (either in-home or out-of-home activities) within time of day and duration models.

Eventually, the third phase attempts to resolve the conflicts that occur for the activities that have overlaps. This is quite possible since the time of day and duration models are set independent of the individuals’ other planned activities.

Figure 10 represents the modified ADAPTS out-of-home activity planning and scheduling framework. As mentioned, out-of-home activities need to be scheduled in conjunction with other scheduled or executed activities. Although out-of-home activity generation considers the interrelationship between the activity types through the simultaneous hazard system, the association of in-home activities and their impact on out-of-home activities are neglected in those models. Besides, the activity generation models does not consider such interrelationships for time of day and activity duration settings.

Figure 10.ADAPTS Out-of-home Activity Planning and Scheduling (Josh et al 2010)



As shown in Figure 10, The three phases of activity generation, planning and scheduling are the fundamental parts of out-of-home activity generation. However, out-of-home time of day and duration models are planned to be developed in ADAPTS to associate a new out-of-home activity with the activities already set on the day on which the activity is about to be executed. In other words, new models for out-of-home activity start time and duration are to be planned in order to create the link between out-of-home and in-home activities.

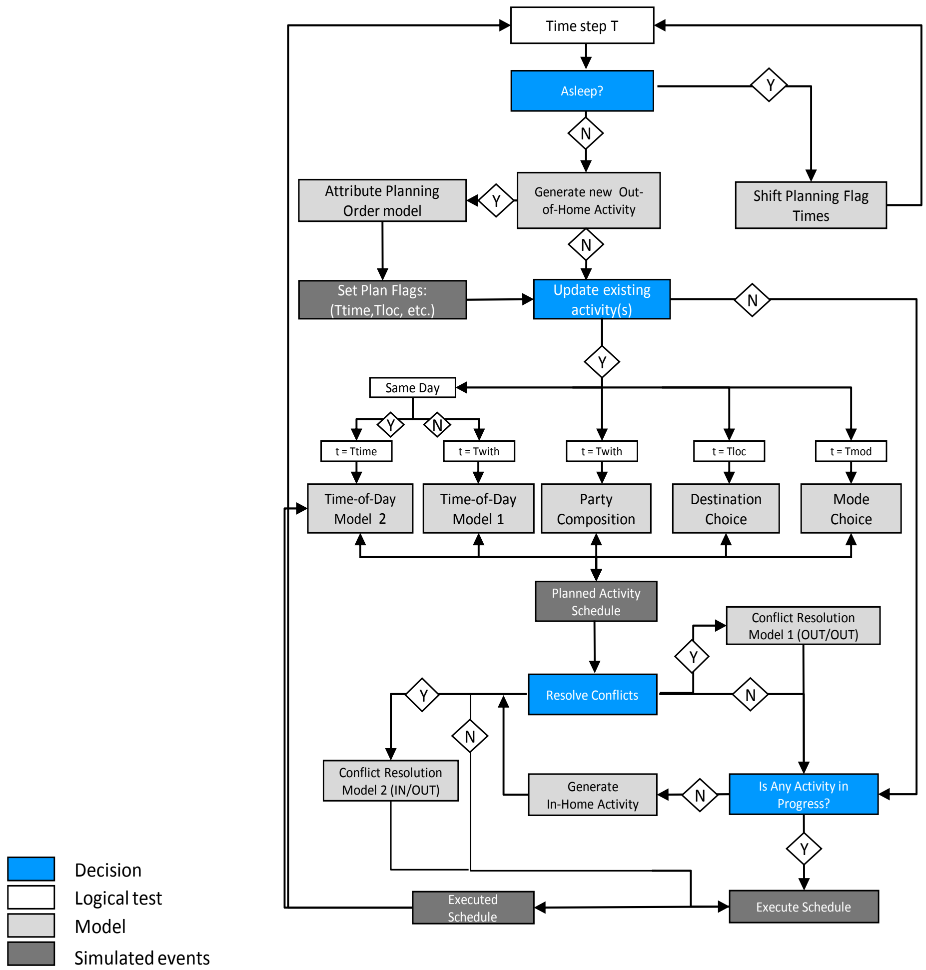
ADAPTS IN-HOME ACTIVITY EXECUTION FRAMEWORK

Figure 11 displays the new ADAPTS framework which is capable of simulating full schedule of individuals including all in-home and out-of-home activity types. This framework generates in-home activities conditional to the executed and planned activities as the simulation time continues and fills the individuals' activity schedule gap with in-home activities interactively. Therefore, individuals might update their out-of-home activities according to their in-home activity engagement and vice versa. The only restricting assumption in this thesis is the bound of in-home and out-of-home activity interactions to one day which is imposed by the models that are developed from the one-day format of ATUS survey. Even though this assumption might be erroneous for preplanned in-home activities, it copes with the fact that most in-home activities occur impulsively or are planned within the same day (Mohammadian and Doherty, 2005).

As shown in Figure 11, at each time step, the simulation starts with a check that the individual is asleep or not. If asleep, the duration of the sleeping has already been defined; thus, all the plan flags that were assigned during the sleep range including the plan time for activity start and duration times and other attributes of activities that conflict with the sleeping time are shifted with a simple rule-based assumption so that the plan flag times will hit when the individual is awake and can decide the activity attributes accordingly. Then, according to the previous ADAPTS framework, the activity generation decision is made for the out-of-home activities according to the competing hazard model mentioned earlier. Following that, the attributes of the existing out-of-home activities are defined in case their plan times fall within this time step interval. At this time, if the start and duration planning time (plan flags) of an out-of-home activity with impulsive or same day plan horizon arrives; then, a module is employed to set these attributes considering their executed as well as the planned schedule. This means the start time and duration of the out-of-home activity would be associated with what the individual has already done during the day and what is already planned for the rest of the day. For instance, if an individual wants to plan when he/she will eat out today, he/she would consider where and when he/she had a meal earlier in the day.

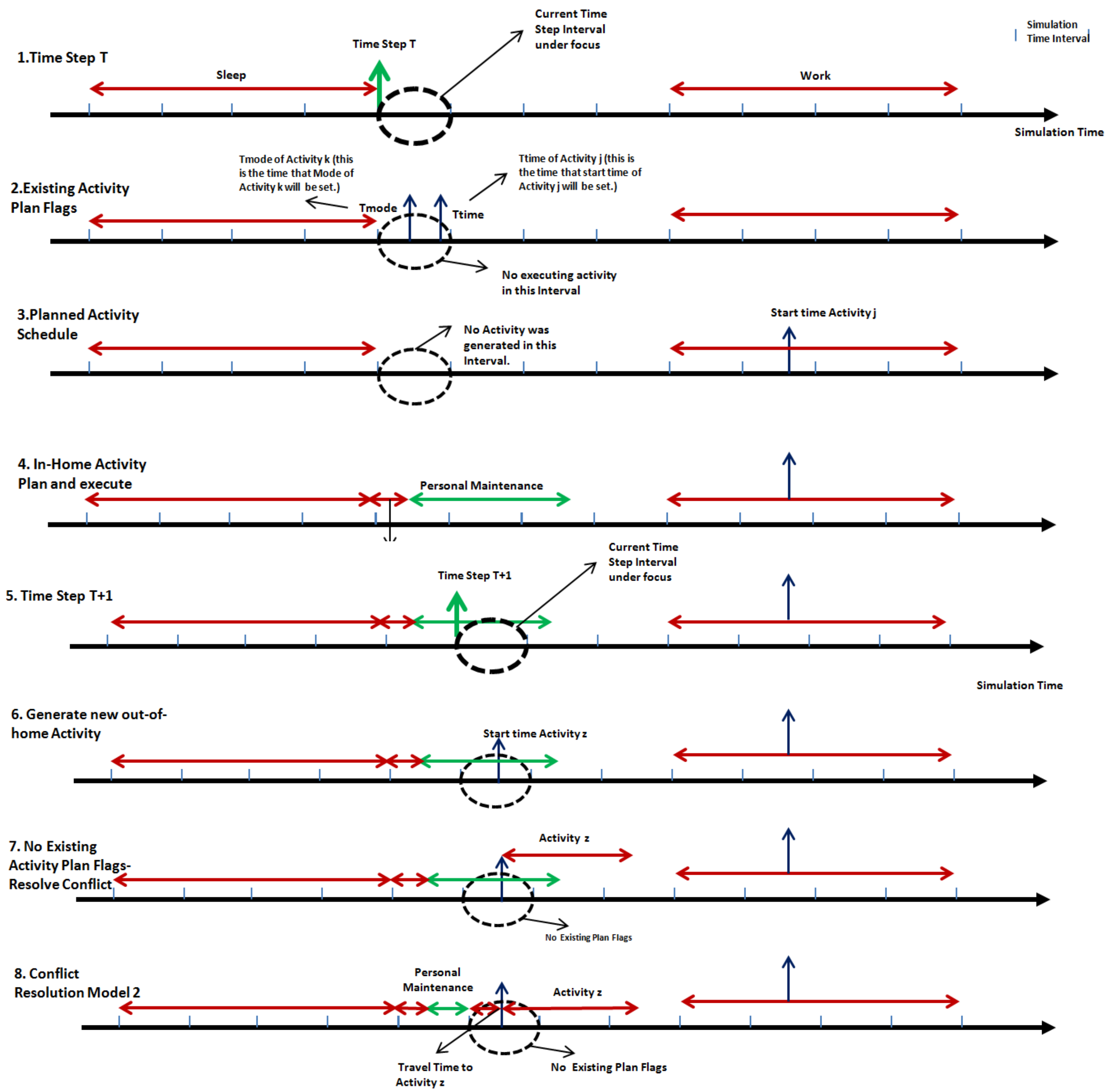
Finally, the activities which are scheduled to be executed at this time step are monitored; if any conflicts occur between the scheduled in-home or out-of-home activities, a two-step conflict resolution model is called to resolve the conflict between out-of-home activites and the conflict between in-home and out-of-home ones. The first conflict resolution model is similar to what is already implemented in ADAPTS to find the conflicts of out-of-home activities. However, the second model resolves the conflict between in-home and out-of-home activity which prioritizes them with a binary probit formula. Once, the conflict is resolved; the model checks if an activity will be executed at this time step or not. If so, an in-home activity type and duration model is run with the condition that the in-home activity must not conflict with the executing activity(s). This means the start time of the in-home activity must be after the end of the executing activity. In case, the individual is doing an out-of-home activity, the travel time between the out-of-home location to home must also be taken in to account for generation of an in-home activity within the time step interval. This conditional in-home activity model might limit the duration of the in-home activity. If the start of the in-home activity could not be fitted within the time step Interval, It will be shifted to the following time steps. In case, there is no activity scheduled for execution during this time step interval, the in-home activity type and duration model is called to fill in the respective gap.

Figure 11.New ADAPTS framework with full activity simulation



This framework can be better described with a relevant example that is provided in Figure 12. This simplified illustrative example of the simulation algorithm starts with time step T and its corresponding interval. In this example, it is assumed that, at time step T, no new out-of-home activity is generated; thus, stage 2 updates the exisiting activities by setting their attributes. As shown, plan times for mode of the exiting activity k and start time of activity j are within this interval and their associated models are called respectively which leads to stage 3, planned activity schedule. Since there is no activity in the executing list of this interval, this implies that an in-home activity is about to occur. Thus, the in-home activity generation model is called to set and execute. The model defines the type and duration of this activity. This whole process is one cycle of the framework which was shown in Figure 11. Stage 5 shows timestep T+1 when the same procedure continues. First, out-of-home activity generation model is run. In this example, a new impulsive out-of-home activity is generated at satge 6. Since it is an impulsive activity, the start time and other attributes of the activity should be planned and executed almost at the same time step. Also, for simplicity, it is assumed that no other activity plan flags are scheduled during this interval. This gets us to stage 7 when a conflict is recognized; The previous personal maintenance activity overlaps with the impulsive out-of-home activity which is about to execute. As a result, in stage 8, conflict resolution model II is called to prioritize between the in-home and out-of-home activity.The result could be a compromise between the two or the deletion of one. In this example, the in-home personal maintenance activity is squeezed to execute the out-of-home activity.

Figure 12. Illustrative example of New ADAPTS Framework



CHAPTER 5: MODEL DEVELOPMENT

SEQUENTIAL IN-HOME ACTIVITY TYPE AND DURATION

In this section, the preliminary models that have been developed for in-home activity prediction are discussed. Earlier in chapter 3, a descriptive study on determinant factors in activity type choice and duration was explored. It was shown that how and with what extent individuals differ in activities they perform at home. In conjunction with what was inferred from those studies, the models developed here take in to account socio-demographic, time of day and scheduling factors in a fine tuned detail. These models fill the schedule gaps with in-home activity types and durations so that individuals' schedules would be fulfilled 24 hours a day. The in-home activity models here are developed based on individuals' schedule, the activities that are carried out either in-home or out-of-home. It is noteworthy to mention that the updated out-of-home activity start time models that associate out-of-home activities to in-home activities are postponed to following sections. These models complement an association link between in-home and out-of-home activities.

The in-home activity models are developed based on a given time of day. Assuming that the ADAPTS framework has already determined that an individual executes an activity in home at a given time based on the impulsive generation of in-home activities in simulation time, the question would be of what type and for what duration the activity is about to be performed. In the previous section, it was described how in-home activity generation models are sequenced to make the ADAPTS in-home activity framework operational.

The diagram in Figure 13 shows the layout of the in-home activity type and duration models. This diagram shows that input data including demographic attributes, start time of the activity and the scheduled activities of an individual define the general type of an in-home activity about to be performed. The in-home activity to be executed is associated with the activities the individual has already performed during the day until the time of the simulation and restricted by the following planned activities. Time of day is the key determinant of activity type. Intuitively, it is evident that this factor would go beyond a simple variable since individuals' activities is highly dependent on time of day. For instance, no matter what socio-demographic group an individual belongs to, he/she would probably have lunch around noon. As a result, activity type choice models are designed as a set of 12 different models for every 2 hour range within 24 hours of a day. If the start time of an activity falls in a specific range, the corresponding model is called for determining the general activity type. Not only time of day is a significant factor beyond a simple variable of a model; but also, different socio-demographic groups would act differently throughout the day. This emphasizes on having different activity type choice models throughout a day and different hours. The data shows that people's activities are pretty consistent within 2 hour ranges. Nonetheless, it is even more accurate to divide down the 2 hour range to less; but, there should be a trade-off between realism and the attempted effort. Going back to the diagram, once the corresponding general activity type choice model results in an activity type; it becomes an input for the duration model to set the activity duration based on activity type, time of day and other socio-demographic attributes. Therefore, 6 hazard-based activity duration models were developed for the 6 general activity types. The choice of 6 different duration models rather than one general duration model is due to the distinction in the nature of activity types. Having one single model dims the significance of attributes other than activity type in the model; therefore, it is more appropriate to distinguish between different activity types by developing different duration models for each. Finally, once the activity type and duration is known, disaggregate (specific) activity type models are employed to set the specific type of the in-home activity. For instance, if the original activity type and duration is Personal Maintenance and 60 minutes; then, this model could set the specific type as Eating/Drinking.

This conditional probability is formulated in equation 1 where the joint probability of a specific activity type such as Eating/Drinking and its duration conditional to its occurrence at home is presented. Since Eating/Drinking is a subset of Personal Maintenance activities, the probability that the individual does this activity with a predefined duration can be decomposed to three terms which are the subject of the sequential model. The first term in the equation, $(C|I)$ **,** is the first component of the sequence which defines the general activity type. These are the 12 choice models for 12 2-hour ranges during a full day. Eating/Drinking is a sub-category of Personal Maintenance. Once, the general category is known, the next conditional term $f(D|C \cap I)$ is the duration model that constitutes 6 hazard-based models for the 6 general activity types. In this example, the duration model for Personal Maintenance is employed. Finally, the last term $f(A|C \cap I \cap D)$ defines the probability of the specific activity type given other attributes. These third group of models are developed based on CHAID tree classification algorithm which are described in the following sections.

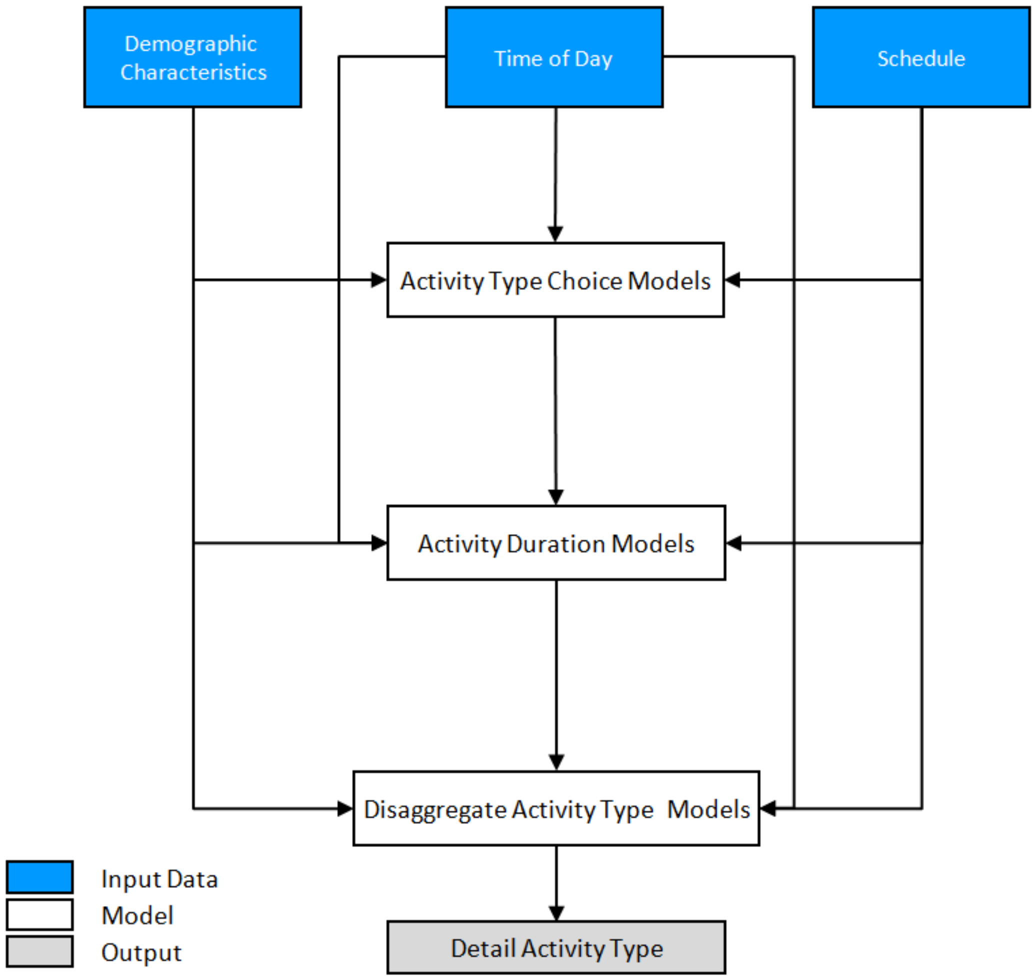
A: Eating/Drinking C:Personal Maintenance D: Duration I:In-Home

1: $f(A \cap D|I) = f(C|I)f(D|C \cap I)f(A|C \cap I \cap D)$Proof.

$$A \in C \rightarrow f(A \cap C \cap I \cap D) = f(A \cap I \cap D)$$

$$f(A|C \cap I \cap D)f(C|I)f(D|C \cap I) = \frac{f(A \cap C \cap I \cap D)}{f(C \cap I \cap D)}\frac{f(C \cap I)}{f(I)}\frac{f(D \cap C \cap I)}{f(C \cap I)} = \frac{f(A \cap I \cap D)}{f(C \cap I \cap D)}\frac{f(C \cap I)}{f(I)}\frac{f(D \cap C \cap I)}{f(C \cap I)} = \frac{f(A \cap I \cap D)}{f(I)} = f(A \cap D|I)$$

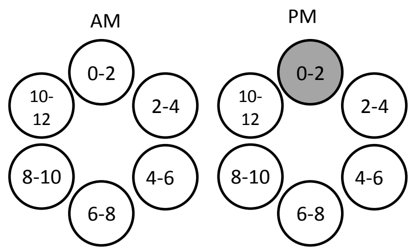
Figure 13.Sequential In-Home Activity Type and Duration Model



IN-HOME ACTIVITY TYPE CHOICE MODELS

As mentioned earlier, 12 activity type choice models are developed based on the start time of the activity. Figure 14 shows the models as two hour circles within a full day. For instance, the gray circle symbolizes the model to define in-home activity type in case the start time of the activity falls between noon to 2 pm in the afternoon.

Figure 14. Time of Day Model Circles



These models are developed with Multinomial Logit (MNL) Formulation. Although MNL is the most basic form of discrete choice modeling, it is still widely used specifically in practical applications. Since MNL provides a clear-cut closed form for the choice probabilities, it is applicable in large scale models such as ADAPTS in which runtime due to numerous calculations accounts as the most important computational factor. The general in-home activity type alternatives are listed in Table 2 as the general activity types.

Table 2. DESCRIPTIVE STUDY OF IN-HOME ACTIVITIES FOR ALL THE WEIGHTED SAMPLE INDIVIDUALS

General Activity Type	Detail Type	Example/ Clarification	Average Duration for each activity episode (min)	Standard Deviation of Duration	Percentage of total number of In-Home activity episodes	Average number of daily episodes For all
SLEEP	-	Naps, night sleeps	246	120	19.4%	2.16
PERSONAL MAINTENANCE	Eating/Drinking		30	22	12.7%	1.41
	Grooming/Washing	Taking a shower, using bathroom, dressing	31	23	11.4%	1.27
	Health-related Self-care	Taking medicine	45	99	0.9%	0.10
	Personal Activities		75	59	0.05%	0.005
HOUSEHOLD MAINTENANCE	Caring	Caring for someone	35	43	7.0%	0.78
	Cleaning	Cleaning the house or kitchen, washing dishes	59	70	5.3%	0.59
	Food/Drink Preparation		32	34	7.3%	0.81
	Household Management	Checking emails, financial management	36	50	2.5%	0.28
	Laundry		51	55	2.0%	0.23
	Other Household Activities	Fixing, Decorating	55	77	4.5%	0.50
LEISURE/ RECREATIONAL/ SOCIAL	Computer Use	Just for leisure	75	66	1.3%	0.14
	Drug Consumption		17	17	0.1%	0.01
	Hobbies/Games		99	81	0.9%	0.11
	Radio/Music		86	80	0.3%	0.03
	Read/Write		70	58	2.7%	0.30
	Relax/Think		97	101	1.5%	0.16
	Social/Communicate		70	76	2.2%	0.24
	Exercise	(at home)	52	49	0.5%	0.06
	Watch TV/Movies		120	99	12.9%	1.44
MANDATORY		Homework, Work	105	99	2.4%	0.24
DISCRETIONARY OTHER		Speaking on the phone, Religious Activity, Volunteer	41	46	2.2%	0.27

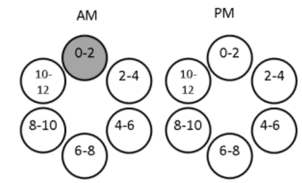
Tables 3-14 represent the corresponding in-home activity type choice models estimated. All the models are tested for their statistical significance with Akaike Information Criterion (AIC) compared to the null and predecessor estimated models. It is noteworthy to mention that the constant estimates of the models play a significant role in activity type choices since the constants are the ultimate time of day representations. For example, if the activity start time is sometime between 10-12 PM or 0-2 AM, then, the probability of sleeping increases as it can be seen from the negative value of the constants for the other alternatives. It is clear how time of day itself can determine people's in-home activities. However, a variety of socio-demographic attributes can also impact activity type choice. Typically, higher number of children and being employed increase the probability of selecting household maintenance activities. Exploring the estimate of the number of children covariate in the models, it is noticeable that the 8-10 PM model has the largest value for household maintenance alternative (Not displayed in this table). This exactly matches the peak of caring for household members in the descriptive study of data.

Employed individuals are also associated with more household maintenance activities except for the time between 6-8 AM. The probability of doing in-home household maintenance slightly decreases in this interval probably in favor of personal maintenance activities before leaving for work. Men are less involved in household maintenance activities that are represented as the negative values in most of the models. This is well emphasized for the activities starting between 10 to 12 PM when men show the least participation in household maintenance activities.

Married individuals perform more household maintenance while doing less personal maintenance activities at home. Household maintenance activities are more intense in the afternoon from 0-2

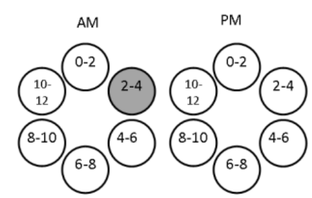
PM as well as in the evening from 6-8 PM. Weekdays are associated with more in-home mandatory activities with a boost at 8-10 AM. The impact of various scheduled activities is also considered in these models in the form of hours the person has been involved in various activities up until the start of the upcoming activity which could potentially affect the choice of the activity. For example, if an individual has been more involved with personal maintenance activities during the day until the start of the upcoming activity, he/she would be more willing to be involved in in-home leisure/social activities; whereas, if an individual is more involved in personal maintenance activities late night, the probability of performing a leisure/social activity at home decreases most probably in favor of sleeping. The models show if an individual is highly involved in in-home leisure/social activities before the start of the new in-home activity episode, the probability of performing a personal maintenance activity drops significantly. On the other hand, if more time is spent on in-home personal maintenance activity, the probability of performing in-home personal maintenance increases for the upcoming activity. Moreover, if an individual is already involved with long hours of out-of-home activity, the probability of in-home activity household maintenance slightly decreases. Eventually, long hours of out-of-home personal maintenance decrease the probability of in-home personal maintenance. This is intuitive since an individual who eats out would possibly put less time for eating/drinking at home.

Table 3. IN-HOME ACTIVITY TYPE CHOICE MODEL FOR ACTIVITY START TIME IN 0-2 AM



Parameter	Sleep	Personal Maintenance	Household Maintenance	Leisure/Social	Discretionary Other	Mandatory
Constant	-	-1.102888 (-13.10)	-2.326805(-15-98)	-1.467578(-15.85)	-3.829285(-21.75)	-4.418723(-18.79)
Constant for Teens	-	-1.208972 (-3.22)	-2.447925(-4.04)	-2.115756(-4.34)	-3.750765(-3.66)	-6.680206(-1.52)
Employed	-	-	0.254468 (1.66)	-	-	-
Number of Children	-	-	0.158562(2.32)	-0.083442(-1.59)	-	-
Male	-	-	-0.58297(-3.81)	-	-	-
Married	-	-	0.744604(4.88)	-	-	-
In-Home Personal Maintenance	-	-	-	-0.135458(-1.52)	-	-
In-Home Leisure	-	-0.09508 (-5.49)	-	-	-	-
		Loglikelihood	-225545			

Table 4. IN-HOME ACTIVITY TYPE CHOICE MODEL FOR ACTIVITY START TIME IN 2-4 AM



Parameter	Sleep	Personal Maintenance	Household Maintenance	Leisure/Social	Discretionary Other	Mandatory
Constant	-	0.182457(1.92)	-0.897038(-6.79)	-0.23632(-2.6)	-2.706147(--15.09)	-2.647451(-15.17)
Constant for Teens	-	-	-	1.361828(2.53)	-	-
Employed	-	-	0.254468 (2.04)	-	-	-
Number of Children	-	-	0.223329(3.55)	-0.203174(-2.48)	-	-
Male	-	0.529114(4.62)	-0.58297(-3.69)	-	-	-
Married	-	-	0.673046(4.93)	-	-	-
In-Home Personal Maintenance	-	-	-	-0.537314(-4.2)	-	-
In-Home Leisure	-	-0.152911 (-8.28)	-	-	-	-
		Loglikelihood	-226611			

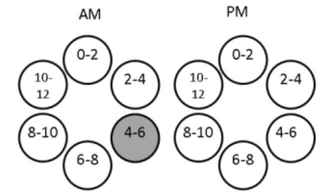


Table 5. IN-HOME ACTIVITY TYPE CHOICE MODEL FOR ACTIVITY START TIME IN 4-6 AM

Parameter	Sleep	Personal Maintenance	Household Maintenance	Leisure/Social	Discretionary Other	Mandatory
Constant	-	0.182457(1.92)	-0.897038(-6.79)	-0.23632(-2.6)	-2.706147(--15.09)	-2.647451 (-15.17)
Constant for Teens	-	-	-	1.361828(2.53)	-	-
Employed	-	-	0.254468 (2.04)	-	-	-
Number of Children	-	-	0.223329(3.55)	-0.203174(-2.48)	-	-
Male	-	0.529114(4.62)	-0.58297(-3.69)	-	-	-
Married	-	-	0.673046(4.93)	-	-	-
In-Home Personal Maintenance	-	-	-	-0.537314(-4.2)	-	-
In-Home Leisure	-	-0.152911 (-8.28)	-	-	-	-
		Loglikelihood	-226611			

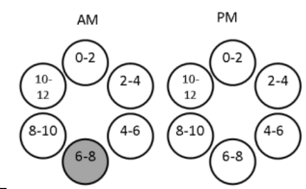
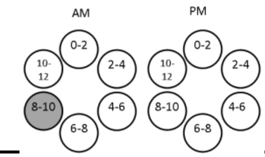


Table 6. IN-HOME ACTIVITY TYPE CHOICE MODEL FOR ACTIVITY START TIME IN 6-8 AM

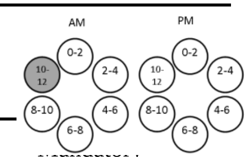
Parameter	Sleep	Personal Maintenance	Household Maintenance	Leisure/Social	Discretionary Other	Mandatory
Constant	-	3.489972(41.8)	3.347262(39.13)	2.242896(27.39)	0.278838(2.9)	0.240643(2.01)
Constant for Teens	-	3.684552(11.25)	2.005033(5.39)	1.472242(3.92)	-1.103057(-1.38)	-
Employed	-	-	-0.102255 (-2.59)	-	-	-
Number of Children	-	-	0.35701(18.04)	-0.144445(-4.56)	-	-
Male	-	-0.107339(-2.17)	-0.625868(-12.31)	-	-	-
Married	-	-0.124563(-2.44)	0.078396(1.51)	-	-	-
Out-of-Home Mandatory	-	-	-0.451483(-4.95)	-0.163746(-1.67)	-	-
In-Home Personal Maintenance	-	2.110652(11.35)	-0.474069(-2.44)	0.832974(4.18)	-	-
In-Home Leisure	-	-1.28315 (-25.96)	-	-	-	-
Weekday						0.386342(3.26)
		Loglikelihood	-217373			

Table 7. IN-HOME ACTIVITY TYPE CHOICE MODEL FOR ACTIVITY START TIME IN 8-10 AM



Parameter	Sleep	Personal Maintenance	Household Maintenance	Leisure/Social	Discretionary Other	Mandatory
Constant	-	3.172975(47.2)	3.014497(45.51)	2.32502(36.37)	0.510617(6.64)	-
Constant for Teens	-	2.847212(11.15)	1.270594(4.04)	1.704569(6.32)	-1.077452(-1.7)	-
Employed	-		0.072561(1.81)			
Adult Student						0.528167(1.95)
Number of Children	-		0.240965(11.64)	-0.102143(-3.47)		
Male	-	-0.100331(-2.01)	-0.591552(-12.08)			
Married	-	-0.07225(-1.43)	0.287015(5.79)			
Out-of-Home Personal Maintenance		-0.581494(-2.40)				
Out-of-Home Mandatory	-		-0.233113(-4.05)	-0.216407(-2.84)		
In-Home Personal Maintenance	-	1.085072(16.67)		0.527129(6.82)		
In-Home Leisure	-	-0.827095(-25.5)				
Weekday						0.896388(10.17)
		Loglikelihood	-220303			

Table 8. IN-HOME ACTIVITY TYPE CHOICE MODEL FOR ACTIVITY START TIME IN 10-12 AM



Parameter	Sleep	Personal Maintenance	Household Maintenance	Leisure/Social	Discretionary Other	Mandatory
Constant	-	2.177223(29.98)	2.636628(37.1)	2.065118(28.47)	0.122564(1.42)	-0.222879(-1.98)
Constant for Teens	-	2.389074	1.568577(5.39)	2.033432(8.14)	-	-
Adult Student	-	-	-	-	-	0.40361(1.43)
Number of Children	-	-	0.192634(7.8)	-0.118504(-3.74)	-	-
Male	-	-	-0.623352(-13.17)	-	-	-
Married	-	-	0.336501(7.15)	-	-	-
Out-of-Home Personal Maintenance	-	-0.297829(-2.11)	-	-	-	-
Out-of-Home Mandatory	-	-	-0.23277(-5.39)	-0.176956(-3.68)	-	-
In-Home Personal Maintenance	-	1.367886(21.45)	-	0.406945(5.61)	-	-
In-Home Leisure	-	-0.327073(-17.11)	-	-	-	-
Weekday	-	-		-	-	0.413372(3.27)
Loglikelihood	-222435					

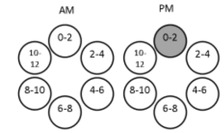


Table 9. In-Home Activity Type Choice Model For Activity Start Time In 0-2 PM

Parameter	Sleep	Personal Maintenance	Household Maintenance	Leisure/Social	Discretionary Other	Mandatory
Constant	-	1.613175(22.91)	1.986436(29.59)	1.652707(26.62)	-0.64621(-8.83)	-0.802068(-8.45)
Constant for Teens	-	2.036521(5.93)	1.604337(4.41)	2.106385(6.28)	-	-
Employed	-	-	-	-	-	-
Adult Student	-	-	-	-	-	0.950427(4.43)
Number of Children	-	-	0.181121(7.63)	-0.112711(-3.87)	-	-
Male	-	-	-0.554462(-10.98)	-	-	-
Married	-	-	0.413646(8.12)	-	-	-
Out-of-Home Personal Maintenance	-	-0.431021(-4.06)	-	-	-	-
Out-of-Home Mandatory	-		-0.086155(-4)	-0.097787(-4.11)	-	-
In-Home Personal Maintenance	-	0.560277(8)	-0.359221(-4.98)	-	-	-
In-Home Leisure	-	-0.263542(-17.20)	-	-	-	-
Weekday	-	-	-	-	-	0.513128(4.60)
		Loglikelihood	-223004			

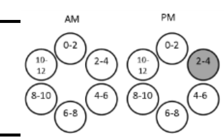


Table 10. In-Home Activity Type Choice Model For Activity Start Time In 2-4 PM

Parameter	Sleep	Personal Maintenance	Household Maintenance	Leisure/Social	Discretionary Other	Mandatory
Constant	-	1.47542(20.31)	1.937444(33.66)	1.805564(32.3)	-0.276963(-3.93)	-0.858146(-8.24)
Constant for Teens	-	1.195994(4.32)	1.046429(3.62)	1.835237(7.15)	-1.031424(-2.25)	0.44041(1.49)
Adult Student	-					1.136483(5.67)
Number of Children	-		0.294132(14.17)			
Male	-	0.168213(2.84)	-0.547595(-11.2)			
Married	-	-0.208284(-3.54)	0.33829(-3.54)			
Out-of-Home Personal Maintenance	-	-0.225224(-2.94)				
Out-of-Home Mandatory	-		-0.01973(-1.66)	-0.045696(-3.58)		
In-Home Personal Maintenance	-	0.628601(12.04)		0.20137(4.26)		
In-Home Leisure	-	-0.227621(-15.21)				
Weekday	-					0.522553(4.47)
Loglikelihood			-222765			

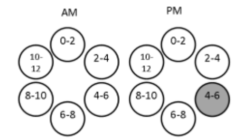


Table 11. In-Home Activity Type Choice Model For Activity Start Time In 4-6 Pm

Parameter	Sleep	Personal Maintenance	Household Maintenance	Leisure/Social	Discretionary Other	Mandatory
Constant	-	2.152119(32.36)	2.893973(43.4)	2.538713(37.71)	0.266718(3.45)	-0.206553(-2.36)
Constant for Teens	-	2.909513(9.35)	2.223465	2.941011(9.36)	-	2.057565(6.18)
Employed	-	-	0.177148(4.4)	-	-	-
Adult Student	-	-	-	-	-	1.508408(7.88)
Number of Children	-	-	0.178954(8.97)	-0.104938(-4.57)	-	-
Male	-	-	-0.599986(-15.87)	-	-	-
Married	-	-	0.240135(6.27)	-	-	-
Out-of-Home Mandatory	-	-	-0.042663(-6.25)	-0.047736(-6.7)	-	-
In-Home Personal Maintenance	-	1.164992(30.6)	-	0.377781(9.37)	-	-
In-Home Leisure	-	-0.119552(-14.27)	-	-	-	-
			Loglikelihood	-219244		

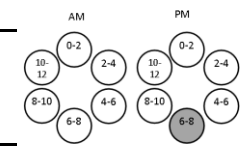


Table 12. In-Home Activity Type Choice Model For Activity Start Time In 6-8 Pm

Parameter	Sleep	Personal Maintenance	Household Maintenance	Leisure/Social	Discretionary Other	Mandatory
Constant	-	2.099542(32.28)	1.949894(29.81)	2.166708(36.54)	-0.161914(-2.62)	-0.669106(-7.14)
Constant for Teens	-	1.72205(8.03)	0.453632(1.71)	1.582584(7.52)	-1.034715(-2.77)	-
Employed	-	-	0.229504(5.82)	-	-	-
Adult Student	-	-	-	-	-	1.080894(5.63)
Number of Children	-	-	0.382389(20.12)	-	-	-
Male	-	-	-0.561307(-14.4)	-	-	-
Married	-	-0.069076(-1.66)	0.26874(6.67)	-	-	-
Out-of-Home Personal Maintenance	-	-0.077079(-2.13)	-	-	-	-
Out-of-Home Mandatory	-	-	-0.006897(-1.26)	-0.011697(-2.15)	-	-
In-Home Personal Maintenance	-	0.505234(10.09)	-	0.269881(5.49)	-	-
In-Home Leisure	-	-0.16074(-20.65)	-	-	-	-
Weekday	-	-	-	-	-	0.341088(3.3)
			Loglikelihood	-217456		

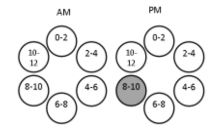


Table 13. In-Home Activity Type Choice Model For Activity Start Time In 8-10 P

Parameter	Sleep	Personal Maintenance	Household Maintenance	Leisure/Social	Discretionary Other	Mandatory
Constant	-	0.097893(1.93)	-0.615145(-5.61)	0.084142(2.59)	-2.091009(-7.58)	-2.573983(-32.3)
Constant for Teens	-	0.277384(2)	-1.21881(-5.61)	-	-2.461514(-7.58)	-1.588521(-7.19)
Employed	-	-	0.250427(5.79)	-	-	-
Adult Student	-	-		-	-	0.94747(4.69)
Number of Children	-	-	0.453408(24.4)	0.113376(6.74)	-	-
Male	-	-0.1049(-2.5)	-0.594469(-13.59)	-	-	-
Married	-	-0.155478(-3.66)	0.110025(2.46)	-	-	-
Out-of-Home Personal Maintenance	-	-0.123125(-3.51)		-	-	-
Out-of-Home Mandatory	-	-		-	-	-
In-Home Personal Maintenance	-	0.161344(4.63)	-0.072694(-2.01)	0.06816(2.33)	-	-
In-Home Leisure	-	-0.122863(15.83)	-	-	-	-
Weekday	-	-	-	-	-	0.153333
		Loglikelihood	-221996			

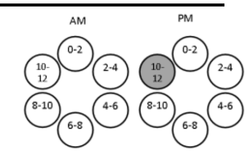


Table 14. In-Home Activity Type Choice Model For Activity Start Time In 10-12 Pm

Parameter	Sleep	Personal Maintenance	Household Maintenance	Leisure/Social	Discretionary Other	Mandatory
Constant	-	-0.808278(-14.74)	-1.854614(-22.24)	-1.038327(-27)	-3.390263(-46.67)	-4.261006 (-27.60)
Constant for Teens	-	-0.938895(-5.24)	-2.323236(-6.88)	-1.188237(-7.04)	-2.909602(-8.37)	-4.041155(-7.74)
Employed	-	-	0.1744(2.26)	-	-	-
Adult Student	-	-	-	-	-	0.868688(2.88)
Number of Children	-	-	0.288105(9.39)	-	-	-
Male	-	-0.117469(-2.05)	-0.703337(-8.77)	-	-	-
Married	-	-0.221615(-3.91)	0.171667(2.15)	-	-	-
In-Home Personal Maintenance	-	-	-0.343369(-5.54)	-0.118917(-3.02)	-	-
In-Home Leisure	-	-	-	-	-	-
Weekday	-	-	-	-	-	0.644893(3.48)
		Loglikelihood	-221996			

IN-HOME ACTIVITY DURATION MODELS

The previous section described how in-home activity type is selected conditional on the known start time of the activity. Here on, this section presents the models for setting the duration of the activity given the activity type known from the previous models. These duration models are designed with the help of hazard-based duration modeling. Hazard approach of duration modeling was pioneered by COX 1972 to be used in survival analysis studies. “Survival analysis examines and models the time it takes for events to occur”(Fox 2002).In other words, the time it takes for an event to occur is typically called the failure time. This failure time could be as broad as the time it takes until a patient recovers or the time it takes for a resident to move out of a rented or an owned property. The method of analysis is either through a parametric or non-parametric approach depending on the stochasticity structure of the event failure. Hazard function at a point of time is specifically defined as the probability of an event occurring in the next time step conditional on the fact that it has not yet occurred until that point of time as shown:

$$h(t) = \lim_{\Delta t \to 0} \frac{\Pr(t+\Delta t \geq T \geq t-\Delta t \mid T \geq t)}{\Delta t} = \frac{f(t)}{1-F(t)} = \frac{f(t)}{S(t)}$$

$f(t)$: Density Function

$F(t)$ Cumulative Density Function

$S(t)$: Survival Function

$h(t)$: Hazard Function

Proportional and Accelerated hazard are two major approaches in hazard modeling. The hazard duration models developed for in-home activity types are estimated based on proportional hazard modeling. In order to better perceive the models developed, a brief description of the two methods is provided in the following paragraph.

In proportional hazard models, the impact of the covariates is imposed to the hazard function in a multiplicative manner, that means that the hazard ratio for two observations has nothing to do with the time variable (hazard variable).This assumption could be unrealistic in many cases as in medical applications for which, time, itself could change the shape of the hazard function. In other words, the impact of the covariates could be accelerated or decelerated by time. The hazard function in a proportional hazard model would look like:

$$h(t \mid X) = h_0(t) f(\beta_T X)$$

This hazard function does not include the covariate in the baseline hazard which makes it proportional. The ratio of the hazard function for two observations would be as of:

$$\frac{h_1(t \mid X_1)}{h_2(t \mid X_2)} = \frac{h_0(t) f(\beta_T X_1)}{h_0(t) f(\beta_T X_2)} = \frac{f(\beta_T X_1)}{f(\beta_T X_2)}$$

Therefore, the hazard rate would be constant and not conditional on the hazard variable (time). On the other hand, hazard function in Accelerated models impose the covariate to the baseline hazard in order to accelerate or decelerate the life course of an event. As a result, the formulation generally looks like:

$$h(t \mid X) = h_0(tf(\beta_T X)) f(\beta_T X)$$

In this study, we have used proportional hazard model since the issue of covariate acceleration or deceleration impact is less of a concern in activity duration models. The shape of the hazard function is defined with the baseline function and a constant is multiplied to update the rate in accordance with the covariates ‘values.

The type of distribution used in these models is Weibull. Although the hazard function for Weibull distribution is monotonically increasing , it is quite compatible with the intuitive sense that the hazard should increase as the duration of the activity increases since the activity should be over after a certain time. However, it is also interesting to try fitting other non-monotonic hazard distributions such as log-logistic or bathtub hazard with decreasing hazard rate at early times and increasing afterwards. It can be shown that the formulation for a Weibull hazard and survival function would look like as the following formulas:

$$h(t) = \alpha\beta t^{\beta - 1}$$

$$f(t) = \alpha\beta t^{\beta - 1} \exp^{-\alpha t^{\beta}}$$

$$\alpha = \exp^{\sum \hat{\alpha}_i \hat{X}_i}$$

In order to relate the hazard function to the covariates, α is written as a function of socio demographic attributes as well as time of day binary variables. β is specific to the activity type since activity types have totally different duration patterns. 6 different in-home activity types led to 6 different hazard-based duration models. For easier estimation process, log of time was modeled instead of time itself. The likelihood function for each activity type was written as the following and the function was maximized with SAS software for achieving the parameter estimates. The Tables below represent the estimated models for the activity types.

$$L = \prod_{i=1}^{N} f_i(\log(t))$$

The duration model for sleep has the least α_i and β parameters since sleep typically has longer durations and the hazard rate for failure (getting up) has smoother ascending curve. The binary two-hour range variables are based on the start time of the activity. Obviously, the duration of an activity is highly correlated with the start time. For example, the night sleep is much longer than the afternoon sleep; that is the reason why the corresponding night hour estimates are less than the afternoon hours in order to reduce the hazard rate in favor of longer sleep hours. Employed people sleep slightly less than others which is shown by the covariate which increases the hazard rate. Also weekdays and being married are associated with less sleep.

Table 15. SLEEP DURATION HAZARD MODEL

Parameter	Estimate	t-value
Alpha_sleep_22_24	0.001236	18.70
Alpha_sleep_20_22	0.001175	18.26
Alpha_sleep_18_20	0.001233	15.35
Alpha_sleep_16_18	0.002581	13.38
Alpha_sleep_14_16	0.003616	15.77
Alpha_sleep_12_14	0.003158	16.48
Alpha_sleep_10_12	0.002664	13.07
Alpha_sleep_8_10	0.002423	11.85
Alpha_sleep_6_8	0.00208	11.50
Alpha_sleep_4_6	0.002226	12.59
Alpha_sleep_2_4	0.001742	15.22
Alpha_sleep_0_2	0.001359	17.64
Alpha_sleep_Employed	0.000022	1.65
Alpha_sleep_Married	0.000030	1.34
Alpha_sleep_weekday	0.000048	2.17
Beta_sleep	3.680844	134.39
Log Likelihood	-23460	

Personal Maintenance duration model shows an interesting pattern. Table 16 shows that the activities that start late night after 2 AM have the longest durations among all in-home personal maintenance activities. Other factors associated with longer durations include being female versus males, weekends versus weekdays and being adults versus teenagers.

Table 16. IN-HOME PERSONAL MAINTENANCE DURATION HAZARD MODEL

Parameter	Estimate	t Value
Alpha_personalM_22_24	0.00466	27.18
Alpha_personalM_20_22	0.003336	30.50
Alpha_personalM_18_20	0.002463	30.63
Alpha_personalM_16_18	0.002241	29.85
Alpha_personalM_14_16	0.002241	25.73
Alpha_personalM_12_14	0.00236	28.06
Alpha_personalM_10_12	0.002186	28.20
Alpha_personalM_8_10	0.002278	30.52
Alpha_personalM_6_8	0.002269	30.94
Alpha_personalM_4_6	0.001979	25.24
Alpha_personalM_2_4	0.001781	16.05
Alpha_personalM_0_2	0.004677	16.16
beta_personalM	4.752162	243.39
Alpha_PersonalM_male	0.000219	7.22
Alpha_personalM_weekday	0.000366	11.99
Alpha_personalM_Teen	0.000382	3.82
Log Likelihood	-39469	

Table 17 shows the in-home household maintenance estimated duration model. From the model, It can be concluded that in-home household maintenance activities which start at a time between 8 AM and 4 PM have the longest durations. Notably, men even though less frequently involved in household maintenance activities, they put longer durations than women to the activity episodes. Employed individuals and teenagers have also shorter in-home household maintenance activity episodes. Additionally, weekdays are associated with shorter household maintenance episodes.

Table 17. IN-HOME HOUSEHOLD MAINTENANCE DURATION HAZARD MODEL

Parameter	Estimate	t Value
Alpha_householdM_22_24	0.017317	23.56
Alpha_householdM_20_22	0.015448	36.22
Alpha_householdM_18_20	0.01188	37.53
Alpha_householdM_16_18	0.00983	35.42
Alpha_householdM_14_16	0.007846	30.92
Alpha_householdM_12_14	0.007065	29.75
Alpha_householdM_10_12	0.007783	30.78
Alpha_householdM_8_10	0.006917	30.76
Alpha_householdM_6_8	0.010329	34.44
Alpha_householdM_4_6	0.013161	25.93
Alpha_householdM_2_4	0.00926	13.51
Alpha_householdM_0_2	0.016815	12.99
beta_householdM	3.474122	251.98
Alpha_householdM_female	0.001379	11.25
Alpha_householdM_Employed	0.000552	4.72
Alpha_householdM_weekday	0.00212	17.21
Alpha_householdM_child	0.001548	2.14
Log Likelihood	-57553	

Table 18 represents the estimated hazard model for in-home leisure/socialize activities. These activity episodes are typically longer in the morning from 10 AM until afternoon as well as later - in the evening until 8 PM. Furthermore, women, teenagers as well as employed individuals have shorter in-home activity episodes compared to their counterparts. Same as previous models, people spend shorter in-home leisure episodes during weekdays.

Table 18. IN-HOME LEISURE/SOCIALIZE DURATION HAZARD MODEL

Parameter	Estimate	t Value
Alpha_Leisure_22_24	0.00049	22.24
Alpha_Leisure_20_22	0.00033	23.90
Alpha_Leisure_18_20	0.00020	21.90
Alpha_Leisure_16_18	0.00020	21.05
Alpha_Leisure_14_16	0.00021	20.78
Alpha_Leisure_12_14	0.00018	19.88
Alpha_Leisure_10_12	0.00020	19.91
Alpha_Leisure_8_10	0.00024	20.60
Alpha_Leisure_6_8	0.00030	20.44
Alpha_Leisure_4_6	0.00032	15.14
Alpha_Leisure_2_4	0.00021	11.50
Alpha_Leisure_0_2	0.00036	12.58
Beta_Leisure	5.28524	222.38
Alpha_Leisure_female	0.00005	13.54
Alpha_Leisure_Employed	0.00005	12.43
Alpha_Leisure_weekday	0.00005	13.61
Alpha_Leisure_child	0.00006	5.00
Log Likelihood	-38914	

Discretionary other include activities like religious, volunteer or telephone call activities. Typically, these are very short term activities. The longest activity duration seems to occur late night from 2AM to 4AM. However, the average daily time assigned to this type of activity is less than 15 minutes.

Table 19. IN-HOME DISCRETIONARY OTHER DURATION HAZARD MODEL

Parameter	Estimate	t Value
Alpha_DiscOther_22_24	0.013113	9.73
Alpha_DiscOther_20_22	0.011872	11.80
Alpha_DiscOther_18_20	0.010773	11.33
Alpha_DiscOther_16_18	0.012043	11.14
Alpha_DiscOther_14_16	0.010638	10.82
Alpha_DiscOther_12_14	0.010218	10.29
Alpha_DiscOther_10_12	0.012082	10.53
Alpha_DiscOther_8_10	0.012683	11.15
Alpha_DiscOther_6_8	0.011155	10.06
Alpha_DiscOther_4_6	0.010116	7.63
Alpha_DiscOther_2_4	0.006364	4.71
Alpha_DiscOther_0_2	0.012557	5.10
beta_DiscOther	3.438573	71.69
Alpha_DiscOther_Employed	0.000807	1.82
Alpha_DiscOther_weekday	0.001352	3.12
Log Likelihood	-4968	

Finally, in-home mandatory activity duration model is presented in Table 20. Shorter activity episodes are associated with Saturdays as well as employed individuals.

Table 20. IN-HOME MANDATORY DURATION HAZARD MODEL

Parameter	Estimate	t Value
Alpha_Mandat_22_24	0.001105	7.03
Alpha_Mandat_20_22	0.001006	8.20
Alpha_Mandat_18_20	0.000743	7.88
Alpha_Mandat_16_18	0.000796	7.77
Alpha_Mandat_14_16	0.000687	7.71
Alpha_Mandat_12_14	0.000482	7.28
Alpha_Mandat_10_12	0.000608	7.31
Alpha_Mandat_8_10	0.000532	7.33
Alpha_Mandat_6_8	0.000464	6.93
Alpha_Mandat_4_6	0.000527	5.83
Alpha_Mandat_2_4	0.000469	4.49
Alpha_Mandat_0_2	0.000675	3.60
Beta_Mandat	4.786896	66.53
Alpha_Mandat_Employed	0.000040	1.46
Alpha_Mandat_saturday	0.000018	0.58
Log Likelihood	-4397	

The hazard based duration models for various in-home activity types are reliable activity duration estimates that considered time of day and socio-demographic attributes. As a result, these combination of models could be used in the ADAPTS framework to predict in-home activity durations based on a reliable source of data (ATUS).

DISAGGREGATE IN-HOME ACTIVITY TYPE MODELS

Once, the general in-home activity type and duration is obtained through the corresponding models explained in the previous section, the third group of models define the detail activity type. These models are obtained through a random forest decision tree algorithm which is efficient and interpretable for this application. Other than interpretability, decision tree is helpful in this application since the variability in activity type choice mainly arises from a few variables which are highly nonlinear in expressing the dependent variable; for instance, time of day and duration. The models were developed for only three of the general in-home activity types which are considerably more frequent at home as of personal maintenance, household maintenance and leisure activities.

Table 21 represents the detail in-home social/leisure activity type choice decision tree model. There are 18 heterogeneous categories/leaves; each representing a group of in-home leisure activities and the corresponding percentage of detail activity types within each group which is then used for the simulation purpose. For example, 9 percent of in-home leisure activities that have duration less than 6.5 minutes are drug consumptions as split by the CHAID algorithm (category 18). Accordingly, 43% of them are social/communication activities which are the dominant category in this group. All other categories can be interpreted accordingly.

Table 22 displays the household maintenance activity type model which is categorized in to 6 groups including caring (household or non-household members), cleaning, food/drink preparation, household management, laundry and other household activities. The choice of activity types was selected based on two factors: frequency of activities and activities that could affect travel. Activities such as cleaning, cooking and caring could potentially eliminate/replace out-of-home activities. Other household activities at home involve fixing indoor/outdoor, decorating and other maintenance activities. The table shows that for instance, category 13 includes in-home household maintenance activities that are performed by females who have children. The activities happen between noon and 7 pm and their duration is longer than 78 minutes. The dominant specific activity type in this group is caring with 31% frequency. After that, cleaning is the next dominant activity type which is 21%. These categories finely cluster the activity types given the activity and individual attributes.

Finally, Table 23 represents the in-home Personal Maintenance activity type model which is sensitive to four key variables as of start time, duration, age and gender. The CHIAD algorithm splits the leaves in a way that the dominant activity of this type which occurs after 11 AM and before 9 PM and its duration is more than 5.5 minutes (categories 14 and 15) is Eating/Drinking. Grooming/Washing is dominant when the start time is after 9 PM and also earlier in the morning. Health-care related activities are typically more frequent when the duration of the activity is less than 10 minutes or for older individuals.

Table 21. IN-HOME SOCIAL/LEISURE DISAGGREGATE ACTIVITY TYPE DECISION TREE MODEL

Variable	Category 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Start (hour of day)			>=17	9.6< & < 17	9.6< & < 17	9.6< & < 17	< 9.6	< 9.6	< 9.6		>=15 & <20	>=20	<15	>=19	<19 & >=14	<14 & >=9.4	< 9.4	
Duration (min)	>60	20<= & <60	20<= & <60	20<= & <60	20<= & <60	20<= & <60	20<= & <60	50< & <60	20<= & <50	6.5< = & <20	6.5< = & <20	6.5< = & <20	6.5< = & <20	6.5< = & <20	6.5< = & <20	6.5<= & <20	6.5< = & <20	<=6.5
Age		<54	>=54	>=54	>=54	>=54	>=54 & <62	>=62	>=62	<54	<54	<54	<54	<54	<54	<54	<54	
Married										NO	YES	YES	YES					
Race				NOT WHITE	WHITE	WHITE												
Sunday					NO	YES												
Alternative	***Decision Rule***																	
Computer Use	4%	9%	5%	6%	6%	7%	9%	7%	5%	11%	6%	9%	13%	4%	4%	5%	5%	6%
Drug Cons	0%	0%	0%	0%	0%	0%	0%	0%	0%	3%	0%	2%	2%	1%	1%	2%	1%	9%
Hobbies/Games	4%	4%	4%	4%	7%	6%	3%	6%	6%	4%	5%	2%	3%	3%	4%	7%	4%	2%
Radio/Music	1%	2%	2%	2%	1%	1%	1%	1%	2%	2%	0%	1%	1%	1%	1%	0%	2%	1%
Read/Write	8%	11%	21%	14%	25%	26%	24%	35%	42%	7%	6%	21%	11%	18%	15%	23%	36%	7%
Relax/Think	6%	6%	5%	20%	11%	10%	7%	4%	7%	8%	11%	4%	11%	9%	16%	14%	6%	8%
Social/Communicate	6%	12%	10%	11%	12%	23%	6%	3%	6%	17%	45%	27%	21%	13%	28%	19%	5%	43%
Exercise	1%	4%	2%	3%	3%	3%	6%	4%	7%	4%	2%	2%	8%	3%	6%	8%	12%	6%
Watch TV/Movies	70%	52%	51%	40%	35%	24%	44%	40%	24%	44%	25%	32%	30%	47%	25%	22%	29%	18%
Highest Predicted		Watch TV/Movies	Watch TV/Movies	Watch TV/Movies	Watch TV/Movies	Reading/ Writing	Watch TV/Movies	Watch TV/Movies	Reading/ Writing	Watch TV/Movies	Social/ Communicate	Watch TV/Movies	Watch TV/Movies	Watch TV/Movies	Social/ Communicate	Reading/ Writing	Reading/ Writing	Social/ Communicate

Table 22. In-Home Household Maintenance Disaggregate Activity Type Decision Tree Model

	Categories																
Variable	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Number of Children	0	0	0	0	0	0	0	0	0	0	>0	>0	> 0	>0	>0	>0	>0
Start (hour of day)			>=20.1	>=20.1	<20.1	<16	<16	>16 & <18.2	>18.2 & <20.1	>18.2 & <20.1	< 19	< 19	>12 & < 19	<12	<19	<19	>=19
Duration (min)	>82	>82	<82	<82	<12	>42 & <82	>12 & <42	>12 & <82	>12 & <82	>12 & <82	>78	>78	>78	>78	<78	<78	
Age									< 60	>= 60	>37	<=37			>=42	< 42	
Gender	M	F									M	M	F	F			
Household Size			< 3	>=3													
Alternative	*Decision Rule*																
Caring	5%	6%	10%	30%	6%	6%	7%	4%	8%	5%	25%	52%	31%	21%	24%	42%	61%
Cleaning	23%	37%	19%	23%	13%	30%	20%	18%	23%	35%	23%	13%	21%	46%	15%	13%	13%
Food/Drink Preparation	9%	15%	15%	10%	33%	20%	35%	49%	36%	24%	8%	7%	19%	7%	32%	28%	9%
Household Management	9%	8%	22%	14%	16%	11%	12%	9%	8%	13%	3%	2%	4%	4%	8%	5%	6%
Laundry	7%	14%	8%	9%	7%	11%	7%	4%	8%	6%	4%	2%	13%	14%	8%	5%	5%
Other Activities	47%	20%	26%	14%	26%	22%	19%	16%	16%	17%	37%	24%	12%	8%	13%	7%	6%
Highest Predicted	Other Household	Cleaning	Other Household Activities	Caring	Food/Drink Preparation	Cleaning	Food/Drink Preparation	Food/Drink Preparation	Food/Drink Preparation	Cleaning	Other Household	Caring	Caring	Cleaning	Food/Drink Preparation	Caring	Caring

Table 23. IN-HOME PERSONAL MAINTENANCE DISAGGREGATE ACTIVITY TYPE DECISION TREE MODEL

Variable	Categories 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Start (hour of day)	>21	< 6.5	< 4.1	> 4.1 & =< 6.5	> 4.1 & =<6.5	> 4.1 & =<6.5	> 6.5 & =< 11	> 6.5 & =<11	> 6.5 & =<11	> 6.5 & =<11	> 6.5 & =<11	> 6.5 & =<11	>= 11 & <21	>= 11 & <21	>= 11 & <21
Duration (min)		>20	<20	< 7.5	>= 7.5	>= 7.5	> 32	> 32 & < 57	>57	< 5.5	< 5.5	> 5.5 & < 32	<5.5	>=5.5 & <12	>=12
Age					<= 48	> 48				>= 58	< 58				
Gender							F	M	M						
Alternative	***Decision Rule***														
Eating/Drinking	23%	26%	21%	42%	43%	60%	32%	40%	55%	23%	51%	60%	35%	61%	78%
Grooming/Washing	71%	72%	68%	30%	57%	37%	65%	59%	42%	23%	35%	38%	48%	36%	20%
Health-related Self-care	5%	2%	10%	28%	0%	3%	3%	1%	3%	54%	14%	1%	17%	3%	1%
Personal Activities	1%	0%	1%	0%	0%	0%	0%	0%	0%	0%	0%	1%	0%	0%	0%
Highest Predicted	Grooming	Grooming	Grooming	Eating/ Drinking	Grooming	Eating/ Drinking	Grooming	Grooming	Eating/ Drinking	Health-related Self-care	Eating/ Drinking	Eating/ Drinking	Grooming	Eating/ Drinking	Eating/ Drinking

JOINT IN-HOME ACTIVITY TYPE AND DURATION COPULA MODEL

Previous section in model development was devoted to sequential in-home activity type and duration models which are implemented in the ADAPTS microsimulation framework. This section proposes a joint copula model formulation for predicting in-home activity type and duration. Unlike the sequential estimation technique, the discrete-continuous joint formulation takes in to account the correlation between the unobserved factors of in-home activity type and duration. Bhat et al 2009 developed the copula discrete continuous framework in estimating vehicle type choice and miles of travel. Born et al 2013 developed a joint discrete continuous model for estimating activity participation and episode duration with Joe copula formulation. In a similar effort and for the purpose of microsimulation, this section reformulates the joint Frank copula for modeling in-home activity type and episode duration. So far, most joint copula models have been developed to the estimation stage and rarely used in a microsimulation framework.

For describing the copula formulation, initially, one need to get familiar with copula functions; functions that represent an m-variate cumulative density function in the form of a known associated copula function. This function specifies the association between the m variables through a set of parameters; yet the general shape of association is imposed and embedded in the copula function.

MODELING METHODLOGY

This section describes the modeling formulation of the joint discrete continuous copula used in this study. This formulation associates a multinomial logit model with a multiple regression through a Frank copula linkage. In other words, the unobserved factors of the two models are associated through a Frank copula function. However, whether the Frank copula represents an appropriate association for this application is an important subject that should be investigated. In the study by Bhat et al 2009, Frank copula stood out from a list of other functions for modeling vehicle type and miles of travel. This was the reason behind using Frank copula for this problem.

To represent the formulation, we need to remind that the problem was divided into 6 general in-home activity types including sleep, personal maintenance, household maintenance, leisure/recreation, discretionary-other and mandatory activities which were elaborated in the previous sections. For making the estimation procedure feasible, logarithm of activity episode duration is used and modeled instead of the duration itself.

IN-HOME ACTIVITY TYPE CHOICE COMPONENT

The first component of this joint formulation is the in-home activity type model which is based on the basic random utility theory. The random utility for each activity type is written as a function shown in the below equation:

$$\forall i: \{1,2,\dots,6\}\; U_{ni} = \sum_{k=1}^{m} \beta_{ik} x_{nk} + \varepsilon_{ni}$$

Where U_{ni} is the random utility of activity i for individual n and β_{ik} is the k-th attribute individual or activity attribute and eventually, ε_{ni} is common random term expressing the stochasticity of the choice problem due to the unobserved factors. According to the random utility maximization theory, the individual chooses the in-home activity that provides the highest utility which means:

Choose i: $U_{ni} > \max U_{nj} \quad \forall j \in 1,2,..,6\ j \neq i$

$$U_{ni} = \sum_{k=1}^{m} \beta_{ik} x_{nk} + \varepsilon_{ni} > \max U_{nj} \quad EQ \quad \sum_{k=1}^{m} \beta_{ik} x_{nk} > V_{ni} = \max U_{nj} - \varepsilon_{ni}$$

In the formula above, $\sum_{k=1}^{m} \beta_{ik} x_{nk}$ is the deterministic part of the inequality, yet, the right part is the random term. Assuming the distribution for ε_{nj} terms that are independently and identically extreme value type-1 distributed, the V_{ni} would have a logistic distribution.

Table 24. ESTIMATION RESULT FOR THE JOINT IN-HOME ACTIVITY TYPE AND DURATION COPULA

Variable	*MNL* Sleep	*MNL* Personal Maintenance	*MNL* Household Maintenance	*MNL* Leisure /Recreation	*MNL* Discretionary -Other	*MNL* Mandatory	*Regression (log duration)* Sleep	*Regression (log duration)* Personal Maintenance	*Regression (log duration)* Household Maintenance	*Regression (log duration)* Leisure /Recreation	*Regression (log duration)* Discretionary -Other	*Regression (log duration)* Mandatory
Copula Dependency Parameter							-1.83 (-8.8)	-1.49 (-4.7)	-1.15 (-3.9)	-1.31 (-6.6)	-1.26 (-2.1)	-1.28 (-1.9)
TIME OF DAY:												
Activity start between 12 AM -2 AM	-	-1.80 (-2.4)	-2.38 (-7.2)	-2.19 (-3.8)	-3.73 (-13.7)	-4.75 (-21.4)	5.69 (8.7)	2.27 (5.5)	2.39 (9.5)	3.79 (8.7)	3.59 (12.9)	3.69 (7.6)
Activity start between 2 AM - 4 AM	-	-0.28 (-3.5)	-1.02 (-10.4)	-1.03 (-2.8)	-2.76 (-8.5)	-2.90 (-14.8)	5.08 (4.9)	2.84 (5.8)	2.85 (3.8)	4.20 (2.3)	4.32 (1.3)	5.13 (1.9)
Activity start between 4 AM - 6 AM	-	1.72 (-1.7)	0.94 (3.2)	0.28 (3.7)	-0.75 (-13.0)	-1.36 (-4.2)	4.68 (8.8)	3.07 (2.8)	2.67 (7.8)	3.87 (6.3)	2.85 (5.2)	4.07 (1.1)
Activity start between 6 AM - 8 AM	-	2.46 (4.7)	2.16 (5.0)	1.36 (2.9)	-0.03 (-8.7)	-0.21 (-6.2)	4.70 (3.1)	2.98 (1.9)	2.92 (2.3)	3.88 (1.5)	2.83 (1.4)	4.05 (3.2)
Activity start between 8 AM - 10 AM	-	2.04 (5.2)	2.11 (4.2)	1.54 (7.5)	0.25 (6.5)	-	4.52 (2.4)	2.97 (1.7)	3.32 (3.4)	4.10 (2.2)	2.67 (1.8)	4.03 (1.4)
Activity start between 10 AM - 12 PM	-	1.59 (3.5)	1.87 (2.9)	1.42 (1.7)	0.07 (2.9)	-0.32 (-5.8)	4.32 (2.5)	3.00 (4.9)	3.28 (5.0)	4.25 (4.2)	2.71 (1.4)	3.89 (1.7)
Activity start between 12 PM - 2 PM	-	0.88 (5.8)	1.24 (4.7)	0.96 (2.3)	-0.54 (-5.4)	-0.70 (-3.5)	4.14 (5.2)	2.92 (3.2)	3.34 (4.1)	4.36 (6.6)	2.86 (1.2)	4.22 (3.1)
Activity start between 2 PM - 4 PM	-	0.71 (2.7)	1.41 (6.1)	1.26 (8.5)	-0.23 (-3.4)	-0.67 (-2.0)	3.99 (2.2)	2.88 (5.5)	3.31 (6.5)	4.27 (8.8)	2.83	3.86
Activity start between 4 PM - 6 PM	-	1.80 (1.8)	2.04 (7.2)	1.74 (9.2)	0.10 (2.4)	-0.49 (-1.5)	4.30	2.99	3.16	4.27	2.70	3.66
Activity start between 6 PM - 8 PM	-	1.34 (6.7)	1.53 (3.8)	1.61 (5.3)	-0.17 (-3.7)	-0.71 (-2.8)	5.47	2.92	2.99	4.37	2.84	3.80
Activity start between 8 PM - 10PM	-	-0.86 (10.2)	-0.98 (-3.0)	-0.40 (2.7)	-2.01 (-5.4)	-2.66 (-10.7)	5.75	2.63	2.70	4.05	2.76	3.50
Activity start between 10 PM - 12 PM	-	-1.72 (-13.5)	-2.79 (-1.9)	-1.72 (-8.5)	-3.23 (-10.8)	-4.08 (-5.9)	5.81	2.35	2.48	3.67	2.65	3.28
Weekday (Y/N)	-					0.42 (2.4)	-0.05	-0.10	-0.22	-0.18	-0.18	0.09
X1	-	0.58 (5.4)		0.25 (4.7)								
X2	-											
X3	-	-0.18 (-7.5)										
X4	-	-0.10 (-2.7)										
X5	-		-0.01 (-5.6)	-0.01 (-8.4)								

X1: Duration of schedule's in-home personal maintenance activity (hr)
X2: Duration of schedule's in-home household maintenance activity (hr)
X3: Duration of schedule's in-home leisure activity (hr)
X4: Duration of schedule's out-home personal maintenance activity (hr)
X5: Duration of schedule's out-home mandatory activity (hr)

Table 25. ESTIMATION RESULT FOR THE JOINT IN-HOME ACTIVITY TYPE AND DURATION COPULA MODEL (CONTINUED)

Variable	*MNL*						*Regression (log duration)*					
	Sleep	Personal Maintenance	Household Maintenance	Leisure /Recreation	Discretionary -Other	Mandatory	Sleep	Personal Maintenance	Household Maintenance	Leisure /Recreation	Discretionary -Other	Mandatory
SOCIODEMOGRAPHIC:												
Gender (Male :1, Female:0)	-		-0.57 (-3.5)					-0.02 (-1.6)	0.06 (3.8)			
Age < 16 (Y/N)	-	0.39 (2.3)	-0.87 (-4.2)	0.005 (1.9)	-0.40 (-6.5)	0.61 (2.9)	0.13 (8.2)	-0.06 (-5.5)	-0.27 (-13.5)	-0.14 (-1.9)		-0.11 (-5.9)
Adult Student (Y/N)	-			0.12 (5.4)		0.75 (6.5)						
Married (Y/N)	-		0.21 (5.4)									
Employed (Y/N)	-		0.06 (2.8)				-0.02 (-2.9)	0.03 (5.1)	-0.05 (-8.7)	-0.14 (-6.8)		-0.15 (-3.0)
Retired (Y/N)	-			0.17 (3.8)			0.75 (6.0)	0.06 (3.1)	-0.21 (-6.4)	0.02 (4.7)		
Number of Children	-		0.28 (11.2)	-0.05 (-2.5)								
RACE:												
White (Y/N)	-	0.62 (6.9)	0.69 (8.7)	0.58 (16.2)	-0.12 (-1.4)							
Black (Y/N)	-	0.75 (8.8)	0.37 (10.0)	0.53 (12.0)	0.22 (3.8)	-0.63(-7.3)						
Asian (Y/N)	-	0.64 (2.8)	0.67 (5.7)	0.44 (3.4)	0.04 (1.1)	0.49 (5.5)						
Hispanic (Y/N)	-	0.55 (3.0))	0.44 (6.7)	0.38 (5.7)	-0.51(-1.4))	-0.47 (-3.5)						
Scale Parameter:							1.04 (4.7)	1.00 (5.8)	1.15 (6.7)	1.03 (3.3)	1.28 (2.1)	1.32 (3.8)

CHAPTER 6: CONFLICT RESOLUTION

INTRODUCTION

In activity-based travel demand models, the objective is to predict disaggregate travel behavior and choices in microsimulation frameworks so that individual trips would be simulated with a reasonable detail (1). This helps transportation engineers and planners to assess a variety of transportation management policies with the help of a more reliable platform than the previous generation travel demand models. As a result, activities as trip generators are the core of these models (2). However, most activity based models focus on out-of-home activities as the activities that generate trips. Yet, in-home activities that comprise approximately 70 percent of daily activities affect individuals' activity schedule and indirectly impact the trips people make. A reliable activity based model that simulates a cycle of a day, week or a month must take in to account activities that people perform at home. Modeling in-home activities in conjunction with out-of-home activities and therefore the full schedule of individuals can lead to more consistent activity-based models that take in to account the rational activity pattern of individuals. For instance, sleeping is a type of a routine activity that should be simulated so that the integrity of activity scheduling would be preserved accordingly. Therefore, the sleep pattern itself can help integrating people's out-of-home activities. Most people have a regular night sleep with an approximately 6 to 8 hours of sleep. If sleep pattern is carefully predicted then the out-of-home activities following could be better adjusted for a more robust and consistent schedule.

In a specific module of the ADAPTS that models in-home activities, an agent would choose between performing an in-home or an out-of-home activity which is the instance of an activity conflict. This chapter proposes a reverse pairwise modeling technique that models these pair comparisons in a single closed formulation. The idea is to compare different types of out-of-home activities with in-home activities and make a decision accordingly. For instance, an agent/individual might want to decide whether to eat-out or eat at home; eat-out or perform a leisure activity at home ; sleep at home or eat-out and all pairs of in-home vs. out-of-home conflicts. This pairwise comparison arises according to the scheduling algorithm.

This chapter proposes a new modeling methodology for extracting pairwise comparisons from polychotomous choice problems. The closed form and convexity of the likelihood function it proposes, makes its applicability ready and effective. The chapter also contributes to the state of the art activity-based models by full activity microsimulation.

As a result, in line with the previous research effort of modeling in-home activities in ADAPTS microsimulation, this chapter proposes and implements a modeling technique for scheduling in-home and out-of-home activities with a conflict resolution technique. Initially, a review of the latest works in the literature is provided.

DATA

As mentioned, the activity categories are quite detailed in the survey. To better generalize the groups of the in-home activities, all activities were divided in to 6 general fundamentally different categories. The 6 categories initially defined include Sleep, Personal Maintenance, Household Maintenance, Leisure/Social, Mandatory and Discretionary-other. Similarly, out-of-home activities were grouped into the same categories except for Sleep. As a result, all activities were grouped in to 11 different categories. These 11 categories were considered for bi-comparisons. 5 out-of-home and 6 in-home categories provided 30 combinatorial comparisons. Each combination of in-home and out-of-home categories was formulated and modeled in the reverse pairwise modeling. It is noteworthy to mention that the activity classification might be ambiguous for some activity types such as discretionary-other. However, the classifications had to be made to incorporate the assumptions and definitions made in the survey.

Table 26 is a descriptive study of the mean and standard deviation for the duration of each episode of these activities from the ATUS. It should be noted that the average durations are for each single activity episode and are not daily allocated times. Also, the averages include all the samples in the ATUS including those who might not participate in any of the corresponding activities. The averages are obtained considering the corresponding survey weight for each individual. According to this classification, recorded travel activities are the most frequent by comprising up to 20 percent of total activities. The next frequent are in-home household maintenance, in-home personal maintenance and in-home leisure activities respectively. In terms of episode duration, sleeping has the highest average activity episode duration of about 4 hours. Even though average daily sleeping is about 8 hours, the average duration per episode is 4 hours which is due to the daily naps and also interruption of night sleep by other activities such as personal maintenance that causes the night sleep split into two or more activity episodes. The next longest activities are work episodes with an average duration of approximately 200 minutes. It is important to mention that routine work activities typically involve more than one work episode considering the interruptions made by breaks, social interactions and personal maintenance activities. It is also interesting that household maintenance and travel has the most variability in terms of duration considering the ratio of the mean to the standard duration.

Table 26. DESCRIPTIVE ANALYISIS OF IN-HOME AND OUT-OF-HOME ACTIVITIES

Id	Activity Type*	Example	Average duration for each activity episode (min)	Standard deviation of episode duration	Percentage of total number of activity episodes	Average number of daily episodes
1	SL_IN	Sleeping	246	120	11.67%	2.1
2	PM_IN	Eating, drinking, grooming	31	29	15.02%	2.8
3	HM_IN	Caring, cleaning, preparing food	43	56	17.24%	3.2
4	RL_IN	Watching TV, hobbies, games	102	92	13.41%	2.5
5	DIS_IN	Telephone calls, Spiritual/Volunteer	41	46	1.46%	0.27
6	MAN_IN	Homework, primary work at home	105	99	1.30%	0.24
7	PM_OUT	Eat out, using public bathroom	47	40	3.31%	0.61
8	HM_OUT	Pick up/drop off kids, grocery shopping	35	53	6.81%	1.3
9	RL_OUT	Outdoor recreation, attend social events	90	93	4.20%	0.78
10	DIS_OUT	Telephone calls, Spiritual/Volunteer	83	77	1.25%	0.23
11	MAN_OUT	Work at office	199	135	3.93%	0.73
12	TR_OUT	Travel, waiting associated with travel	19	27	20.42%	3.6

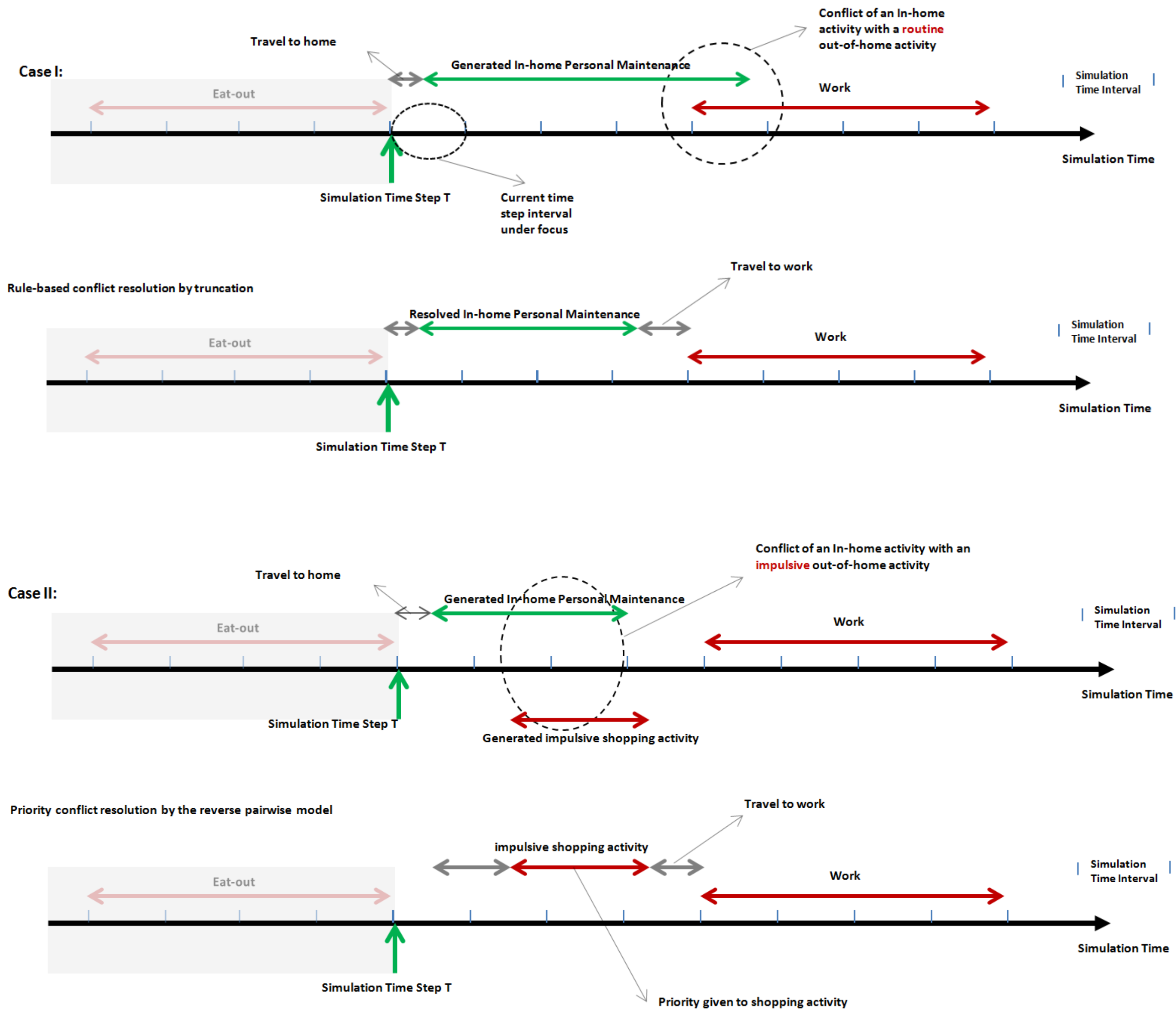
*SL_IN: Sleeping at home
PM_IN: Personal maintenance at home
HM_IN: Household maintenance at home
RL_IN: Recreation/leisure/social interaction at home
DIS_IN: Discretionary-other activity at home
MAN_IN: Mandatory activity at home
PM_OUT: Personal maintenance out-of-home
HM_OUT: Household maintenance out-of-home
RL_OUT: Recreation/leisure/social interaction out-of-home
DIS_OUT: Discretionary-other activity out-of-home
MAN_OUT: Mandatory activity at home out-of-home
TR_OUT: Travel

CONFLICT RESOLUTION PROBLEM

The conflict resolution model resolves the potential conflict between in-home and out-of-home activities. As mentioned earlier, once, duration of the generated in-home activity is set; odds exist that the activity would have a conflict with the preplanned out-of-home activities; or in other cases, impulsive out-of-home activities that are generated will conflict with an on-going in-home activity. In these cases, a conflict resolution model comprising of rule-based and econometric approaches is designed to target the potential conflicts. In case the in-home activity overlaps with a preplanned activity which is planned well in advance of the activity execution, the priority is given to the preplanned out-of-home activity. Therefore, the in-home activity will be truncated accordingly. For the impulsive activity, the priority will be given either to the in-home or out-of-home activity based on the parameterized reverse Pairwise Coupling model which is the subject of this chapter.

Since initial version of ADAPTS was equipped with a conflict resolution model between out-of-home activities, the concern for developing the new framework was to target the interactions of in-home and out-of-home activities. One of these concerns was the potential conflict that could happen between the two types of activities. For better clarification, Figure 15 shows the two general cases of conflict resolution between an in-home and an out-of-home activity. According to this figure, the case I conflict happens between an in-home activity which is about to generate at the simulation time and a preplanned/routine out-of-home activity that must happen on time. For example, an individual need to be at work at 9 AM. In this case, the generated in-home activity needs to be truncated or even deleted if the individual does not have enough time for its execution. Case II which is the subject of this chapter occurs when a conflict arises between an impulsive out-of-activity and a generated in-home activity. In this case, the proposed model must set a priority between the two activities. In the example provided, the shopping activity is prioritized by the individual.

Figure 15. Conflict Resolution Representation



PAIRWISE COUPLING

Pairwise Coupling is a method of pairwise decomposition technique that helps with multi-class classification problems (50). The idea is to transform a K-level problem into $\binom{k}{2}$ binary choice problems, one for each of the class pairs. Similar to Bradley Terry model that predicts the outcome of a multinomial, pairwise coupling is used to predict outcome of a multinomial problem by decomposing the problem in to observed pairwise comparisons(51). Imagine a problem with K classifications (choices). The Bradley Terry model says the probability that choice i would beat choice j is $p_{i/j} = \frac{p_i}{p_i + p_j}$ where p_i represents the probability that choice i would be chosen among all other k alternatives (52). Since the observed data reveals the comparison probabilities, one would hope to solve a system of equations with k variables and $\binom{k}{2}$ equations in addition to the constraint $\sum_{i=1}^{k} p_i = 1$. However, this does not have a solution in general since it is overly-constrained. (51) Therefore, there are approximate methods that minimize the distance between the observed comparison probabilities and the estimated ones.

Bradley Terry model can also be parameterized and estimated through various estimation techniques such as maximum likelihood. For instance, for the case of single parameter per observation and assumption of exponential scoring the formula would be like equation II.

I. $$P(i/j) = \frac{p_i}{p_i + p_j} = \frac{e^{\beta_i}}{e^{\beta_i} + e^{\beta_j}}$$

(i/j): i preferred to j

In another case, odds probably can be formulated through logit as equation III:

II. $$\frac{P(i/j)}{P(j/i)} = \beta_i - \beta_j$$

For parameter estimation, using maximum likelihood the log-likelihood function would be as equation IV.

III. $$\sum_i^n \sum_j^n n_{ij} \ln(p_i) - n_{ij} \ln(p_i + p_j)$$

Where n_{ij} is the observed number of times that choice i has beaten choice j.

The problem with the Bradley Terry model is that the $p_{i/j}$ values are learnt independently of each other. To overcome this limitation, pairwise coupling seeks to better capture the limitations of the previous approach. Pairwise coupling methods try to use all the comparison pairs for estimating classification probabilities. In other words, given an observation x and the class label y, the goal is to estimate $p_i = P(y = i|x)\ \ i = 1,2, \dots, k$ by estimating pairwise probabilities r_{ij} which are estimates of $u_{ij} = P(y = i|y = i\ or\ j\ , x)$.(ref)

One of the approximate methods of pairwise coupling is to average among the pairwise probabilities in order to achieve p_is.

IV. $$p_i = \frac{\sum_{j \neq i} \Pr(i|\{i.j\}) \Pr(\{\mathrm{i,j}\})}{K-1} = \frac{\sum_{j \neq i} p_{i/j}\ (p_i + p_j)}{K-1}$$

The equation IV represents the probability decomposition to pairwise terms. There have been various algorithms to solve this equation. Wu et al 2004 proposed solving the equation as a linear system. Considering P as a the vector of p_is, they rewrote the equation as:

V. QP=P where $p_i \geq 0\ \forall i$, $\sum_{i=1}^{k} p_i = 1$ $$Q_{ij} = \begin{cases} \frac{r_{ij}}{k-1} & if\ i \neq j \\ \sum_{s:s \neq i} \frac{r_{is}}{k-1} & if\ i = j \end{cases}$$

Meanwhile, others have proposed approximate algorithms such as the assumption of $(p_i + p_j) \approx 2/k$ and using it for achieving convergence iteratively. In all pairwise coupling problems, the pairwise comparisons are observed. For example, in a soccer world cup, one might use the results of the friendly matches between the teams to estimate the probability of championship for each of the participating teams. However, what if one wants to solve the reverse problem. The reverse problem's example could be the comparison of two specific brands of shoes, while the observed data are people's shoes' purchases among a list of many alternative brands. Similarly, flashing back to our conflict resolution problem, the observed data are the list of peoples 'activities recorded in ATUS. There are no recorded pairwise activity comparison instances in the data; therefore, coming up with an algorithm to solve a reverse pairwise classification problem could be the answer to our conflict resolution problem. The following section describes how the proposed reverse problem could be formulated and implemented for the conflict resolution problem in ADAPTS.

PROPOSED REVERSE PARAMETERIZED PAIREWISE COUPLING

As mentioned earlier, one of the important conflict instances that can happen is the conflict between an on-going in-home activity and an impulsive or same day out-of-home activity. This is the case when a pairwise comparison is required to choose the activity with higher priority. In case, the out-of-home impulsive activity has higher priority then it will be executed and the individual will stop the in-home activity to engage in the other. For example, if the individual is eating dinner at home or watching TV and at the same time he/she might be thinking of going out for a casual socializing, then, a pairwise comparison is required to estimate which one has more priority for the individual to perform. Having said that, the proposed methodology is reverse pairwise coupling given the observed data. Since the ATUS data has records of activities individuals performed in their diary, there is no observed data on how they compare two activities at a time. In other words, the observed data provides the probability of an activity given the full list of activities individuals can perform. However, we are looking for comparison of two activities for the conflict resolution problem. Given the Bradley Terry probability formulation parameterized through an exponential scoring, one can formulate the comparison probability as:

$$p_{n_{i/j}} = \frac{e^{\sum_{k=1}^{m} \beta_{i/j_k} x_{nk}}}{1 + e^{\sum_{k=1}^{m} \beta_{i/j_k} x_{nk}}} \qquad \forall\, i < j$$

$$p_{n_{j/i}} = \frac{1}{1 + e^{\sum_{k=1}^{m} \beta_{i/j_k} x_{nk}}}$$

Where $p_{n_{i/j}}$ is the probability that individual n would prefer activity type i over activity type j. $\beta_{i/j_k}$is the coefficient that implies the importance of attribute k in preferring activity i over activity j. x_{nk} is the value of attribute k for individual n. It could be either an individual-specific or generic variable such as time of day. Now, consider this formulation within the pairwise coupling probability achieved in the previous section. In this case, instead of finding an estimate for the p_is, the goal is to find a reliable estimate for the parametric$p_{n_{i/j}}$. Therefore, by replacing p_i and $p_j$values on the right side of the equation VII knowing that these values can be estimated given the observed structure of the data, it is possible to provide a convex likelihood function. In this case, the likelihood function is shown in equation VII.

$$p_i = \frac{\sum_{j \neq i} \Pr(i|\{i.j\}) \Pr(\{\mathrm{i,j}\})}{K-1} = \frac{\sum_{j \neq i} p_{i/j} \;\; (p_i + p_j)}{K-1}$$

I. $$L(\beta) = \prod_{n=1}^{N} \frac{\sum_{j \neq i} p_{n_{i/j}} \;\; (\hat{p}_{n_i} + \hat{p}_{n_j})}{K-1} =$$

$$\prod_{n=1}^{N} \frac{\sum_{j<i} \left(\frac{1}{1 + e^{\sum_{k=1}^{m} \beta_{j/i_k} x_{nk}}} \right) (\hat{p}_{n_i} + \hat{p}_{n_j}) + \sum_{j>i} \left(\frac{e^{\sum_{k=1}^{m} \beta_{i/j_k} x_{nk}}}{1 + e^{\sum_{k=1}^{m} \beta_{i/j_k} x_{nk}}} \right) (\hat{p}_{n_i} + \hat{p}_{n_j})}{K-1}$$

Where $p_{n_{i/j}}$ is obtained from the above formulas and $\hat{p}_{n_i}$ as well as $\hat{p}_{n_j}$ are the estimates that are achievable either through the activity choice models estimated in previous efforts or frequency-based estimates from the observed data. In other words, the sum in the parenthesis defines the weight of the comparison probabilities. Respective parametric formulas for the comparison probabilities are embedded in the likelihood function.

As mentioned earlier in the data section, there are 11 categories of in-home and out-of-home activities. However, only pairwise comparisons of in-home and out-of-home activities are in consideration which means 6x5 pairs. Yet, from this 30 pairs only 24 is required for our application since it is assumed that mandatory out-of-home activities could not be impulsive. The travel activity is also omitted from the estimation considering that travel is typically made for the purpose of executing another activity. Comparison probability for all other activity pairs between out-of-home versus out-of-home activity types and in-home versus in-home activity types are estimated with frequency comparison of the data. Therefore, the only parametric terms are comparison probabilities between in-home and out-of-home activity types. Table 27 and 28 show the estimated values for the probabilities that are obtained from the observed frequency. These values will be used in the likelihood function as well as the parameterized comparison probabilities for estimation of the parameters.

Table 27. OBSERVED FREQUENCY CLASSIFICATIONS

Id	Activity Type	probability symbol	probability
1	SL_IN	p1	0.147
2	PM_IN	p2	0.189
3	HM_IN	p3	0.217
4	RL_IN	p4	0.169
5	DIS_IN	p5	0.018
6	MAN_IN	p6	0.016
7	PM_OUT	p7	0.042
8	HM_OUT	p8	0.086
9	RL_OUT	p9	0.053
10	DIS_OUT	p10	0.016
11	MAN_OUT	p11	0.049

Table 28. OBSERVED COMPARISON FREQUENCY CALCULATED

In-Home vs. In-home				Out-of-Home vs. Out-of-home			
Pair*	Comparison probability	Pair	Comparison probability	pair	Comparison probability	pair	Comparison probability
1/2	0.44	2/1	0.56	7/8	0.33	8/7	0.67
1/3	0.40	3/1	0.60	7/9	0.44	9/7	0.56
1/4	0.47	4/1	0.53	7/10	0.73	10/7	0.27
1/5	0.89	5/1	0.11	7/11	0.46	11/7	0.54
1/6	0.90	6/1	0.10	8/9	0.62	9/8	0.38
2/3	0.47	3/2	0.53	8/10	0.85	10/8	0.15
2/4	0.53	4/2	0.47	8/11	0.63	11/8	0.37
2/5	0.91	5/2	0.09	9/10	0.77	10/9	0.23
2/6	0.92	6/2	0.08	9/11	0.52	11/9	0.48
3/4	0.56	4/3	0.44	10/11	0.24	11/10	0.76
3/5	0.92	5/3	0.08				
3/6	0.93	6/3	0.07				
4/5	0.90	5/4	0.10				
4/6	0.91	6/4	0.09				
5/6	0.53	6/5	0.47				

* For example: 1/2 means that Activity type 1 (sleep) beats activity type 2 (personal maintenance at home) 44% of the times.

* Activity type Ids are defined in Table 26 note. by $p_{i/j} = \frac{p_i}{p_i+p_j}$

Ideally, it would have been more realistic to parameterize the comparisons for the pairs along with the others. However, due to the excessive number of pairs $\binom{11}{2}$ and their associated parameters, the calculated values from Table 28 were utilized. The following section shows the results of the estimated models.

MODEL RESULT

The following tables display the result of the comparison parameters for the reverse pairwise model. Each table represents a comparison pair probability model for an in-home activity type versus an out-of-home activity. The mega model comprising of 30 parametric sub models had more than 200 parameters that were to be estimated. The likelihood maximization procedure was implemented with interior point algorithm in SAS statistical software and the most relevant activity comparison attributes were chosen for the final outcome. The overall fit of the model was compared with the null model and the result shows a significant improvement from the log likelihood of the base model -1,432,128 to the optimal of -348,018. The Akaike Information Criterion (AIC) measure was also monitored for constant improvement over the course of parameter selection.

For interpreting the comparison pair models, the result of the sleep v.s. out-of-home personal maintenance activity model is elaborated. This comparison model represents the probability of choosing either activity in case, the activity choice set of the individual includes only these two activities which could be a conflict case in ADAPTS. This probability assigns a priority measure to each activity and the ADAPTS determines the priority by random number generation.

$$p_{n_{1/7}} = \frac{e^{\sum_{k=1}^{m} \beta_{1/7_k} x_{nk}}}{1 + e^{\sum_{k=1}^{m} \beta_{1/7_k} x_{nk}}}$$

According to this formulation and the model results, if the activity start time is sometime between 12 AM to 6 AM, then the individual would most likely prefer sleeping to out-of-home personal maintenance. Similarly, sleep is more dominant from 8 PM to 12 PM. On the opposite, if the start time is anytime between 6AM to 8PM, the individual would prefer out-of-home personal maintenance to sleep. If the activity is supposed to be executed on a weekend, the model shows that sleeping has more priority to out-of-home personal maintenance with a higher weight on Sundays. If the individual's income is higher, sleeping gets a lower weight since higher income people can afford out-of-home personal maintenance activities such as eating out more often than the others. Other variables in favor of sleeping are age, being a student and higher in-home personal maintenance at home before the start of the upcoming activity. Almost all the coefficient signs make intuitive sense and they match with the observed data. Higher personal maintenance at home eliminates the need for out-of-home personal maintenance; therefore, individuals prefer sleeping to out-of-home personal maintenance. On the other hand, being married, employed and higher out-of-home personal maintenance before the start of the upcoming activity correspond to less preference for sleeping.

According to the comparison probability formula, elasticity measures can also be achieved for these comparison probabilities. The change in probability in favor of activity type i versus activity type j with respect to the change of an observed factor would be:

$$\frac{\partial p_{n_{i/j}}}{\partial x_{nk}} = \frac{\partial\left(\frac{e^{V_{n_{i/j}}}}{1+e^{V_{n_{i/j}}}}\right)}{\partial x_{nk}} = \frac{\partial p_{n_{i/j}}}{\partial V_{n_{i/j}}}\frac{\partial V_{n_{i/j}}}{\partial x_{nk}} = \frac{e^{V_{n_{i/j}}}(1+e^{V_{n_{i/j}}}) - (e^{V_{n_{i/j}}})^2}{(1+e^{V_{n_{i/j}}})^2}\frac{\partial V_{n_{i/j}}}{\partial x_{nk}} = p_{n_{i/j}}\,(1-p_{n_{i/j}}\,)\,\beta_{i/j_k}$$

$$V_{n_{i/j}} = e^{\sum_{k=1}^{m}\beta_{i/j_k}x_{nk}}$$

$$E_{i/j\ x_{nk}} = \frac{\partial p_{n_{i/j}}}{\partial x_{nk}}\frac{x_{nk}}{p_{n_{i/j}}} = \beta_{i/j_k}\,x_{nk}\,(1-p_{n_{i/j}}\,)$$

For instance, if an individual earns an annual salary of 75k and the probability of sleeping versus out-of-home personal maintenance for him at the time is 50%, then, the electivity of income variable for the sleep versus out-of-home personal maintenance at the time would be -7.5%. These elasticity measures provide a scale for how in-home and out-of-home activities can replace each other.

Table 29. REVERSE COUPLE MODEL FOR SLEEP VS OUT-OF-HOME PERSONAL MAINTENANCE ACTIVITY

Parameter	Definition	Estimate	t-value
beta17_Hr0_2	If sleep start time is between 12AM-2AM	2.46	35.8
beta17_Hr2_4	If sleep start time is between 2AM-4AM	5.41	43.6
beta17_Hr4_6	If sleep start time is between 4AM-6AM	0.46	20.3
beta17_Hr6_8	If sleep start time is between 6AM-8AM	-2.95	-30.2
beta17_Hr8_10	If sleep start time is between 8AM-10AM	-5.21	-65.6
beta17_Hr10_12	If sleep start time is between 10AM-12PM	-3.84	-32.5
beta17_Hr12_14	If sleep start time is between 12PM-14PM	-2.84	-21.5
beta17_Hr14_16	If sleep start time is between 14PM-16PM	-2.27	-32.5
beta17_Hr16_18	If sleep start time is between 16PM-18PM	-3.83	-24.7
beta17_Hr18_20	If sleep start time is between 18PM-20PM	-2.31	-12.9
beta17_Hr20_22	If sleep start time is between 20PM-22PM	2.80	27.5
beta17_Hr22_24	If sleep start time is between 22PM-24PM	3.70	33.6
beta17_Sunday	If sleep activity is on Sunday	0.51	2.8
beta17_Saturday	If sleep activity is on Saturday	0.10	1.9
beta17_income10k	Income (x10k)	-0.02	-3.5
beta17_married	If individual is married	-0.05	-2.8
beta17_student	If individual is student	0.05	-4.6
beta17_PRTAGE	Age	0.0025	5.8
beta17_HHSIZE	Household Size	0.02	1.6
beta17_PEMLR	If individual is employed	-0.13	13.8
beta17_INHOME_PERSONALM	log duration of Inhome personal maintenance	0.01	6.3
beta17_OUTHOME_PERSONALM	log duration of outhome personal maintenance	-0.02	4.7

Table 30 displays the result of sleep versus out-of-home household maintenance model. Similar to the previous submodel, sleep is dominant from 8PM all the way to 6 AM while the trend is opposite during other hours. It is interesting that from 8 to 10 AM, out-of-home household maintenance is more dominant to sleep than out-of-home personal maintenance; yet, from 10 AM to noon, this is out-of-home personal maintenance which is more dominant to sleep than out-of-home household maintenance. This does make intuitive sense since most eat-outs during the day start from 10 AM to noon. Factors in favor of out-of-home household maintenance are being married, higher income, age, gender being female, higher household size, being employed, and if the day is a Saturday. On the other hand, Sundays, being a student, longer duration of in-home personal maintenance so far, longer duration of in-home leisure activity so far and longer duration of out-of-home personal maintenance so far, being retired are more associated with sleeping than out-of-home household maintenance.

Table 30. REVERSE COUPLE MODEL FOR SLEEP VS OUT-OF-HOME HOUSEHOLD MAINTENANCE ACTIVITY

Parameter	Definition	Estimate	t-value
beta18_Hr0_2	If sleep start time is between 12AM-2AM	2.66	18.5
beta18_Hr2_4	If sleep start time is between 2AM-4AM	5.09	26.3
beta18_Hr4_6	If sleep start time is between 4AM-6AM	0.13	5.3
beta18_Hr6_8	If sleep start time is between 6AM-8AM	-4.07	-8.6
beta18_Hr8_10	If sleep start time is between 8AM-10AM	-5.06	-6.6
beta18_Hr10_12	If sleep start time is between 10AM-12AM	-4.26	-21.6
beta18_Hr12_14	If sleep start time is between 12PM-14PM	-3.32	-13.7
beta18_Hr14_16	If sleep start time is between 14PM-16PM	-3.49	-17.3
beta18_Hr16_18	If sleep start time is between 16PM-18PM	-4.54	-23.5
beta18_Hr18_20	If sleep start time is between 18PM-20PM	-3.41	-9.2
beta18_Hr20_22	If sleep start time is between 20PM-22PM	2.33	36.8
beta18_Hr22_24	If sleep start time is between 22PM-24PM	3.25	40.2
beta18_sunday	If sleep activity is on Sunday	0.19	4.2
beta18_saturday	If sleep activity is on Saturday	-0.12	3.5
beta18_retired	If individual is retired	0.03	1.8
beta18_income10k	Income (x10k)	-0.03	-2.8
beta18_married	If individual is married	-0.09	-7.3
beta18_student	If individual is student	0.16	3.5
beta18_PRTAGE	Age	-0.01	-1.6
beta18_PESEX	Gender	0.21	4.6
beta18_HHSIZE	Household Size	-0.06	-12.5
beta18_PEMLR	If individual is Employed	-0.18	-1.4
beta18_INHOME_PERSONALM	log duration of Inhome personal maintenance	0.005	2.8
beta18_INHOME_LEISURE	log duration of Inhome leisure	0.006	4.1
beta18_OUTHOME_PERSONALM	log duration of outhome personal maintenance	0.004	5.4

Table 31 represents the comparison model between sleep and out-of-home leisure/social activities. Similar to previous models, people prefer sleep to out-of-home leisure from 8PM to 6 AM and they prefer out-of-home social/leisure during other hours of a day. Factors in favor of out-of-home leisure activities are Saturdays, Sundays, higher income, higher household size, , being a student and longer duration of out-of-home personal maintenance activities so far. On the other hand, being married, being retired, longer duration of in-home personal maintenance or leisure/social activity are associated with more preference for sleep.

Table 31. REVERSE COUPLE MODEL FOR SLEEP VS OUT-OF-HOME LEISURE/SOCIAL

Parameter	Definition	Estimate	t-value
beta19_Hr0_2	If sleep start time is between 12AM-2AM	2.65	27.2
beta19_Hr2_4	If sleep start time is between 2AM-4AM	5.34	31.2
beta19_Hr4_6	If sleep start time is between 4AM-6AM	0.27	16.9
beta19_Hr6_8	If sleep start time is between 6AM-8AM	-3.50	-23.5
beta19_Hr8_10	If sleep start time is between 8AM-10AM	-5.12	-34.6
beta19_Hr10_12	If sleep start time is between 10AM-12PM	-4.36	-45.1
beta19_Hr12_14	If sleep start time is between 12PM-14PM	-3.13	-31.5
beta19_Hr14_16	If sleep start time is between 14PM-16PM	-3.24	-12.4
beta19_Hr16_18	If sleep start time is between 16PM-18PM	-4.37	-18.5
beta19_Hr18_20	If sleep start time is between 18PM-20PM	-3.37	-22.0
beta19_Hr20_22	If sleep start time is between 20PM-22PM	1.95	21.5
beta19_Hr22_24	If sleep start time is between 22PM-24PM	3.30	12.0
beta19_Sunday	If sleep activity is on Sunday	-0.03	-7.2
beta19_Saturday	If sleep activity is on Saturday	-0.34	-18.2
beta19_retired	If individual is retired	0.12	4.2
beta19_income10k	Income (x10k)	-0.03	3.7
beta19_married	If individual is married	0.16	2.9
beta19_student	If individual is student	-0.39	-12.3
beta19_HHSIZE	Household Size	-0.02	-2.0
beta19_PEMLR	If individual is Employed	-0.16	-4.1
beta19_INHOME_PERSONALM	log duration of Inhome personal maintenance	0.003	3.3
beta19_INHOME_LEISURE	log duration of Inhome leisure	0.006	8.5
beta19_OUTHOME_PERSONALM	log duration of outhome personal maintenance	-0.003	-2.8

Compared to sleep, out-of-home discretionary-other activities are associated with factors as Sundays, being retired, being married, higher income, being employed, female individuals, higher age while Saturdays and male individuals prefer sleep to out-of-home discretionary activities.

Table 32. REVERSE COUPLE MODEL FOR SLEEP VS OUT-OF-HOME DISCRETIONARY-OTHER ACTIVITY

Parameter	Definition	Estimate	t-value
beta110_Hr0_2	If sleep start time is between 12AM-2AM	2.28	32.3
beta110_Hr2_4	If sleep start time is between 2AM-4AM	6.20	51.0
beta110_Hr4_6	If sleep start time is between 4AM-6AM	3.73	21.2
beta110_Hr6_8	If sleep start time is between 6AM-8AM	-1.83	-12.5
beta110_Hr8_10	If sleep start time is between 8AM-10AM	-5.38	-18.5
beta110_Hr10_12	If sleep start time is between 10AM-12PM	-4.96	-19.4
beta110_Hr12_14	If sleep start time is between 12PM-14PM	-2.68	-8.3
beta110_Hr14_16	If sleep start time is between 14PM-16PM	-2.47	-5.5
beta110_Hr16_18	If sleep start time is between 16PM-18PM	-4.93	-13.9
beta110_Hr18_20	If sleep start time is between 18PM-20PM	-2.55	-2.5
beta110_Hr20_22	If sleep start time is between 20PM-22PM	3.50	23.5
beta110_Hr22_24	If sleep start time is between 22PM-24PM	3.76	30.4
beta110_sunday	If sleep activity is on Sunday	-0.93	-2.4
beta110_saturday	If sleep activity is on Saturday	0.35	-1.7
beta110_retired	If individual is retired	-0.05	-2.6
beta110_income10k	Income (x10k)	-0.04	-1.6
beta110_married	If individual is married	-0.70	-7.0
beta110_student	If individual is student	-0.04	-5.3
beta110_PRTAGE	Age	-0.006	-2.8
beta110_PESEX	Gender	0.26	6.6
beta110_PEMLR	If individual is Employed	-0.05	-3.1

The only out-of-home activity type that has a very different pattern in competing with sleep is mandatory activity. In contrast with others, out-of-home mandatory is dominant to sleep from 4AM to 6PM. This is true since many work activities associated with specific careers start as early as 4 AM in the morning. Factors that are associated with sleep against out-of-home mandatory activity are higher age, being retired, being married, higher in-home personal maintenance and higher in-home out-of-home personal maintenance. Yet, higher out-of-home mandatory, being employed and being a student are more associated with out-of-home mandatory against sleep.

Table 33. REVERSE COUPLE MODEL FOR SLEEP VS OUT-OF-HOME MANDATORY ACTIVITY

Parameter	Definition	Estimate	t-value
beta1_11_Hr0_2	If sleep start time is between 12AM-2AM	2.30	36.8
beta1_11_Hr2_4	If sleep start time is between 2AM-4AM	4.63	32.4
beta1_11_Hr4_6	If sleep start time is between 4AM-6AM	-0.31	-15.3
beta1_11_Hr6_8	If sleep start time is between 6AM-8AM	-3.21	-12.5
beta1_11_Hr8_10	If sleep start time is between 8AM-10AM	-4.27	-26.0
beta1_11_Hr10_12	If sleep start time is between 10AM-12PM	-3.18	-13.1
beta1_11_Hr12_14	If sleep start time is between 12PM-14PM	-1.74	-12.1
beta1_11_Hr14_16	If sleep start time is between 14PM-16PM	-1.92	-17.8
beta1_11_Hr16_18	If sleep start time is between 16PM-18PM	-2.83	-20.0
beta1_11_Hr18_20	If sleep start time is between 18PM-20PM	0.44	14.3
beta1_11_Hr20_22	If sleep start time is between 20PM-22PM	3.95	35.9
beta1_11_Hr22_24	If sleep start time is between 22PM-24PM	3.79	46.3
beta1_11_sunday	If sleep activity is on Sunday	1.52	12.4
beta1_11_saturday	If sleep activity is on Saturday	0.99	10.8
beta1_11_retired	If individual is retired	0.52	2.3
beta1_11_income10k	Income (x10k)	0.01	4.7
beta1_11_married	If individual is married	0.02	5.2
beta1_11_student	If individual is student	-0.12	-4.1
beta1_11_PRTAGE	Age	0.02	1.9
beta1_11_PEMLR	If individual is Employed	-0.69	-11.0
beta1_11_INHOME_PERSONALM	log duration of Inhome personal maintenance	0.02	5.5
beta1_11_OUTHOME_PERSONALM	log duration of outhome personal maintenance	0.02	3.0
beta1_11_OUTHOME_MANDAT	log duration of outhome mandatory	-0.01	-2.5

Table 34 displays the comparison model between in-home personal maintenance versus out-of-home personal maintenance. The model shows that in-home personal maintenance is preferred to out-of-home personal maintenance from 4 PM to 10AM which does make sense since people are usually at home during the time. Sundays and Saturdays are associated with in-home personal maintenance since those days are off days; therefore, people must execute personal maintenance activities at home more frequently. In addition, being student, higher household size and longer duration of in-home personal maintenance so far increase the odds of preferring in-home personal maintenance to out-of-home. Being retired, higher income, being married, being employed and longer duration of out-of-home personal maintenance are all associated with preferring out-of-home personal maintenance to in-home personal maintenance. It is noteworthy to mention that out-of-personal maintenance activities are mostly eat-outs.

Table 34. REVERSE COUPLE MODEL FOR INHOME PERSONAL MAINTENANCE VS OUT-OF-HOME PERSONAL MAINTENACE ACTIVITY

Parameter	Definition	Estimate	t-value
beta27_Hr0_2	If inhome activity start time is between 12AM-2AM	0.10	5.8
beta27_Hr2_4	If inhome activity start time is between 2AM-4AM	0.40	8.9
beta27_Hr4_6	If inhome activity start time is between 4AM-6AM	2.81	13.6
beta27_Hr6_8	If inhome activity start time is between 6AM-8AM	2.87	11.4
beta27_Hr8_10	If inhome activity start time is between 8AM-10AM	1.41	12.1
beta27_Hr10_12	If inhome activity start time is between 10AM-12PM	-1.12	-3.0
beta27_Hr12_14	If inhome activity start time is between 12PM-14PM	-1.49	-5.3
beta27_Hr14_16	If inhome activity start time is between 14PM-16PM	-0.91	-3.2
beta27_Hr16_18	If inhome activity start time is between 16PM-18PM	0.13	1.9
beta27_Hr18_20	If inhome activity start time is between 18PM-20PM	0.31	2.1
beta27_Hr20_22	If inhome activity start time is between 20PM-22PM	1.18	6.2
beta27_Hr22_24	If inhome activity start time is between 22PM-24PM	1.64	2.8
beta27_Sunday	If inhome activity activity is on Sunday	0.54	5.0
beta27_Saturday	If inhome activity activity is on Saturday	0.13	4.3
beta27_retired	If individual is retired	-0.03	-2.5
beta27_income10k	Income (x10k)	-0.01	-5.1
beta27_married	If individual is married	-0.07	-1.9
beta27_student	If individual is student	0.50	2.4
beta27_PESEX	Gender	-0.03	-1.7
beta27_HHSIZE	Household Size	0.08	3.7
beta27_PEMLR	If individual is Employed	-0.15	-8.9
beta27_INHOME_PERSONALM	log duration of inhome personal maintenance	0.04	2.9
beta27_OUTHOME_PERSONALM	log duration of outhome personal maintenance	-0.04	-2.0

Comparing in-home personal maintenance to out-of-home household maintenance reveals that from 6 PM to 10 AM, in-home personal maintenance is preferred more frequently. This is in line with the fact that people mostly perform in-home activities during those hours. The submodel also shows that people prefer to do personal maintenance at home than household maintenance outside on Sundays and the pattern is reverse on Saturdays. Factors contributing to in-home personal maintenance against out-of-home household maintenance include being a student, male individuals and higher age and longer duration of in-home personal maintenance before the start of the upcoming activity.

Table 35. REVERSE COUPLE MODEL FOR INHOME PERSONAL MAINTENANCE VS OUT-OF-HOME HOUSEHOLD MAINTENACE ACTIVITY

Parameter	Definition	Estimate	t-value
beta28_Hr0_2	If inhome activity start time is between 12AM-2AM	0.23	9.4
beta28_Hr2_4	If in-home activity start time is between 2AM-4AM	1.31	11.2
beta28_Hr4_6	If in-home activity start time is between 4AM-6AM	3.06	6.5
beta28_Hr6_8	If in-home activity start time is between 6AM-8AM	2.46	6.8
beta28_Hr8_10	If in-home activity start time is between 8AM-10AM	1.06	18.0
beta28_Hr10_12	If in-home activity start time is between 10AM-12PM	-1.02	-4.6
beta28_Hr12_14	If in-home activity start time is between 12PM-14PM	-1.59	-5.4
beta28_Hr14_16	If in-home activity start time is between 14PM-16PM	-2.50	-3.4
beta28_Hr16_18	If in-home activity start time is between 16PM-18PM	-1.04	-4.5
beta28_Hr18_20	If in-home activity start time is between 18PM-20PM	0.06	1.8
beta28_Hr20_22	If in-home activity start time is between 20PM-22PM	0.59	12.3
beta28_Hr22_24	If in-home activity start time is between 22PM-24PM	1.16	19.4
beta28_Sunday	If in-home activity is on Sunday	0.44	4.0
beta28_Saturday	If in-home activity activity is on Saturday	-0.18	-5.2
beta28_retired	If individual is retired	-0.05	-7.4
beta28_income10k	Income (x10k)	-0.03	-1.5
beta28_married	If individual is married	-0.23	-1.9
beta28_student	If individual is student	0.80	3.4
beta28_PESEX	Gender	0.32	6.7
beta28_HHSIZE	Household Size	-0.04	-5.4
beta28_PEMLR	If individual is Employed	-0.29	-6.4
beta28_INHOME_PERSONALM	log duration of Inhome personal maintenance	0.04	5.9
beta28_OUTHOME_PERSONALM	log duration of outhome personal maintenance	-0.01	-3.5

Out-of-home leisure/social activity dominates in-home personal maintenance from 10 AM to 10 PM. This is mostly associated with the fact that during those hours people are usually outside and they might frequently have social interactions at work or leisure activities. Factors that motivate out-of-home leisure/social activity are Saturdays, higher income, being a student, being employed and longer duration of out-of-home personal maintenance up until the current time. On the other hand, being retired, being married, higher age, higher in-home personal maintenance, higher household size are all associated with higher preference for in-home personal maintenance activities to out-of-home leisure/social.

Table 36. REVERSE COUPLE MODEL FOR INHOME PERSONAL MAINTENANCE VS OUT-OF-HOME LEISURE ACTIVITY

Parameter	Definition	Estimate	t-value
beta29_Hr0_2	If inhome activity start time is between 12AM-2AM	0.06	1.7
beta29_Hr2_4	If in-home activity start time is between 2AM-4AM	0.65	2.4
beta29_Hr4_6	If in-home activity start time is between 4AM-6AM	2.55	7.5
beta29_Hr6_8	If in-home activity start time is between 6AM-8AM	2.88	6.0
beta29_Hr8_10	If in-home activity start time is between 8AM-10AM	1.45	2.6
beta29_Hr10_12	If in-home activity start time is between 10AM-12PM	-0.15	-1.7
beta29_Hr12_14	If in-home activity start time is between 12PM-14PM	-1.21	-4.5
beta29_Hr14_16	If in-home activity start time is between 14PM-16PM	-2.09	-3.4
beta29_Hr16_18	If in-home activity start time is between 16PM-18PM	-0.48	-2.7
beta29_Hr18_20	If in-home activity start time is between 18PM-20PM	-0.46	-1.9
beta29_Hr20_22	If in-home activity start time is between 20PM-22PM	-0.20	-6.1
beta29_Hr22_24	If in-home activity start time is between 22PM-24PM	0.47	3.8
beta29_Sunday	If in-home activity is on Sunday	0.02	1.6
beta29_Saturday	If in-home activity is on Saturday	-0.34	-5.3
beta29_retired	If individual is retired	0.07	4.6
beta29_income10k	Income (x10k)	-0.01	-2.4
beta29_married	If individual is married	0.30	6.1
beta29_student	If individual is student	-0.25	-7.6
beta29_PRTAGE	Age	0.01	1.7
beta29_HHSIZE	Household Size	0.06	2.6
beta29_PEMLR	If individual is Employed	-0.13	-4.8
beta29_INHOME_PERSONALM	log duration of Inhome personal maintenance	0.03	3.1
beta29_OUTHOME_PERSONALM	log duration of outhome personal maintenance	-0.02	-5.00

The comparison model between in-home personal maintenance and discretionary-other is mainly in favor of in-home personal maintenance except for a few factors such as if the activity is being performed on Sundays or if the individual is retired or married. It is harder to perceive the reasons since discretionary-other activities include a variety of non-related activities such as religious activities, telephone calls and volunteer activities. However, Sundays as the main day of religious activities is interestingly observed in the model.

Table 37. REVERSE COUPLE MODEL FOR INHOME PERSONAL MAINTENANCE VS OUT-OF-HOME DISCRETIONARY-OTHER ACTIVITY

Parameter	Definition	Estimate	t-value
beta210_Hr0_2	If inhome activity start time is between 12AM-2AM	1.31	18.7
beta210_Hr2_4	If in-home activity start time is between 2AM-4AM	0.23	10.4
beta210_Hr4_6	If in-home activity start time is between 4AM-6AM	3.09	23.6
beta210_Hr6_8	If in-home activity start time is between 6AM-8AM	3.38	45.1
beta210_Hr8_10	If in-home activity start time is between 8AM-10AM	-0.05	-1.4
beta210_Hr10_12	If in-home activity start time is between 10AM-12PM	-1.10	-3.4
beta210_Hr12_14	If in-home activity start time is between 12PM-14PM	0.05	1.2
beta210_Hr14_16	If in-home activity start time is between 14PM-16PM	-0.52	2.7
beta210_Hr16_18	If in-home activity start time is between 16PM-18PM	-0.20	-1.5
beta210_Hr18_20	If in-home activity start time is between 18PM-20PM	0.31	3.4
beta210_Hr20_22	If in-home activity start time is between 20PM-22PM	1.63	4.1
beta210_Hr22_24	If in-home activity start time is between 22PM-24PM	0.97	7.8
beta210_Sunday	If in-home activity activity is on Sunday	-1.23	-11.8
beta210_Saturday	If in-home activity activity is on Saturday	1.01	6.8
beta210_retired	If individual is retired	-0.13	-2.8
beta210_income10k	Income (x10k)	0.03	1.8
beta210_married	If individual is married	-0.33	-4.1
beta210_student	If individual is student	0.76	5.9
beta210_PRTAGE	Age	0.02	2.0
beta210_PESEX	Gender	0.63	3.1
beta210_HHSIZE	Household Size	0.20	6.7
beta210_PEMLR	If individual is Employed	0.52	1.8
beta210_INHOME_PERSONALM	log duration of Inhome personal maintenance	0.03	2.5

Table 38 represents the submodel for comparison of in-home personal maintenance with out-of-home mandatory model. Even though this model was not used in the microsimulation since mandatory out-of-home activities are assumed to be routine activities, the submodel was estimated for intuitive understanding of individuals' schedule pattern. The result shows that out-of-home mandatory activity is dominant between 8AM to 10AM as well as form noon to 4PM when people start another work episode after having lunch. Sunday and Saturdays are clearly in favor of in-home personal maintenance. Also, being a student, retired and higher household size are all in favor of in-home personal maintenance. Longer durations of various in-home activities until the start of the upcoming activity also add the weight to stay at home for personal maintenance.

Table 38. REVERSE COUPLE MODEL FOR INHOME PERSONAL MAINTENANCE VS OUT-OF-HOME MANDATORY ACTIVITY

Parameter	Definition	Estimate	t-value
beta211_Hr0_2	If inhome activity start time is between 12AM-2AM	0.09	2.7
beta211_Hr2_4	If in-home activity start time is between 2AM-4AM	-0.84	-3.5
beta211_Hr4_6	If in-home activity start time is between 4AM-6AM	1.44	4.6
beta211_Hr6_8	If in-home activity start time is between 6AM-8AM	0.44	6.7
beta211_Hr8_10	If in-home activity start time is between 8AM-10AM	-0.09	-5.5
beta211_Hr10_12	If in-home activity start time is between 10AM-12PM	0.09	4.5
beta211_Hr12_14	If in-home activity start time is between 12PM-14PM	-0.39	-6.4
beta211_Hr14_16	If in-home activity start time is between 14PM-16PM	-0.42	-1.9
beta211_Hr16_18	If in-home activity start time is between 16PM-18PM	2.35	2.7
beta211_Hr18_20	If in-home activity start time is between 18PM-20PM	3.18	3.0
beta211_Hr20_22	If in-home activity start time is between 20PM-22PM	2.60	2.1
beta211_Hr22_24	If in-home activity start time is between 22PM-24PM	1.27	1.9
beta211_Sunday	If in-home activity is on Sunday	1.84	3.5
beta211_Saturday	If in-home activity is on Saturday	1.17	1.8
beta211_retired	If individual is retired	0.49	3.8
beta211_married	If individual is married	-0.01	1.9
beta211_student	If individual is student	0.18	3.7
beta211_HHSIZE	Household Size	0.07	1.7
beta211_PEMLR	If individual is Employed	-0.71	-8.9
beta211_INHOME_PERSONALM	log duration of In-home personal maintenance	0.04	4.8
beta211_INHOME_HOUSEHOLDM	log duration of In-home household maintenance	0.01	3.5
beta211_INHOME_LEISURE	log duration of In-home leisure	0.01	2.4
beta211_OUTHOME_MANDAT	log duration of outhome mandatory	-0.01	-3.7

After explaining the competitions between in-home personal maintenance with out-of-home activities, it is the turn of exploring how household maintenance activities at home replace activities out-of-home. The following submodel shows that in-home household maintenance dominates out-of-home personal maintenance from 4 to 10AM and then again from 2 PM to midnight. Also, Saturdays are more associated with out-of-home personal maintenance than in-home household maintenance while Sundays are the exact opposite. Being retired, being married, higher age, higher household size and longer duration of in-home household and personal maintenance activities until the start of upcoming activity are associated with preference for in-home household maintenance. This is true while being a student, being employed and longer duration of out-of-home personal maintenance so far adds to the weight of preferring out-of-home personal maintenance to in-home household maintenance.

Table 39. REVERSE COUPLE MODEL FOR INHOME HOUSEHOLD MAINTENANCE VS OUT-OF-HOME PERSONAL MAINTENANCE ACTIVITY

Parameter	Definition	Estimate	t-value
beta37_Hr0_2	If inhome activity start time is between 12AM-2AM	-0.08	-28.3
beta37_Hr2_4	If in-home activity start time is between 2AM-4AM	-0.09	-21.5
beta37_Hr4_6	If in-home activity start time is between 4AM-6AM	1.92	19.8
beta37_Hr6_8	If in-home activity start time is between 6AM-8AM	2.45	38.5
beta37_Hr8_10	If in-home activity start time is between 8AM-10AM	1.03	31.5
beta37_Hr10_12	If in-home activity start time is between 10AM-12PM	-0.87	-11.5
beta37_Hr12_14	If in-home activity start time is between 12PM-14PM	-1.23	-10.5
beta37_Hr14_16	If in-home activity start time is between 14PM-16PM	0.01	1.3
beta37_Hr16_18	If in-home activity start time is between 16PM-18PM	0.53	2.7
beta37_Hr18_20	If in-home activity start time is between 18PM-20PM	0.44	32.4
beta37_Hr20_22	If in-home activity start time is between 20PM-22PM	0.77	26.4
beta37_Hr22_24	If in-home activity start time is between 22PM-24PM	0.66	8.7
beta37_Sunday	If in-home activity activity is on Sunday	0.36	2.8
beta37_Saturday	If in-home activity activity is on Saturday	-0.05	-3.9
beta37_retired	If individual is retired	0.04	1.8
beta37_married	If individual is married	0.34	8.8
beta37_student	If individual is student	-1.04	-7.0
beta37_PRTAGE	Age	0.01	2.5
beta37_PESEX	Gender	-0.81	-7.4
beta37_HHSIZE	Household Size	0.08	3.2
beta37_PEMLR	If individual is employed	-0.16	-6.1
beta37_INHOME_PERSONALM	log duration of Inhome personal maintenance	0.01	4.0
beta37_INHOME_HOUSEHOLDM	log duration of Inhome household maintenance	0.02	5.8
beta37_OUTHOME_PERSONALM	log duration of outhome personal maintenance	-0.04	3.1

Table 40 represents in-home household maintenance pairwise model versus out-of-home household maintenance. From midnight to 10 AM in-home household maintenance is dominant. From 10 AM to 6 PM, out-of-home household maintenance. From 6 PM to 8 PM, in-home household maintenance is preferable. From 8 PM to midnight, out-of-home household maintenance is dominant. On Saturdays out-of-home and on Sundays in-home household maintenance is preferable. Higher income, being retired, being a student, male individuals, higher household size, being employed and longer duration of out-of-home personal maintenance are all associated with preferring out-of-home household maintenance to in-home household maintenance.

Table 40. REVERSE COUPLE MODEL FOR INHOME HOUSEHOLD MAINTENANCE VS OUT-OF-HOME HOUSEHOLD MAINTENANCE ACTIVITY

Parameter	Definition	Estimate	t-value
beta38_Hr0_2	If inhome activity start time is between 12AM-2AM	0.37	1.3
beta38_Hr2_4	If in-home activity start time is between 2AM-4AM	0.61	8.7
beta38_Hr4_6	If in-home activity start time is between 4AM-6AM	2.25	9.5
beta38_Hr6_8	If in-home activity start time is between 6AM-8AM	2.01	5.4
beta38_Hr8_10	If in-home activity start time is between 8AM-10AM	0.64	2.7
beta38_Hr10_12	If in-home activity start time is between 10AM-12PM	-0.61	-3.4
beta38_Hr12_14	If in-home activity start time is between 12PM-14PM	-1.17	-2.4
beta38_Hr14_16	If in-home activity start time is between 14PM-16PM	-1.24	-1.7
beta38_Hr16_18	If in-home activity start time is between 16PM-18PM	-0.58	-5.4
beta38_Hr18_20	If in-home activity start time is between 18PM-20PM	0.03	1.8
beta38_Hr20_22	If in-home activity start time is between 20PM-22PM	-0.07	-2.4
beta38_Hr22_24	If in-home activity start time is between 22PM-24PM	-0.54	-3.2
beta38_Sunday	If in-home activity activity is on Sunday	0.25	4.8
beta38_Saturday	If in-home activity activity is on Saturday	-0.42	-5.0
beta38_retired	If individual is retired	-0.11	-2.7
beta38_income10k	Income (x10k)	-0.02	-4.7
beta38_married	If individual is married	0.25	10.2
beta38_student	If individual is student	-1.27	-3.8
beta38_PESEX	Gender	-0.67	-6.0
beta38_HHSIZE	Household Size	-0.01	-3.4
beta38_PEMLR	If individual is Employed	-0.30	-7.2
beta38_INHOME_PERSONALM	log duration of Inhome personal maintenance	0.01	2.1
beta38_INHOME_HOUSEHOLDM	log duration of Inhome household maintenance	0.02	3.7
beta38_OUTHOME_PERSONALM	log duration of outhome personal maintenance	-0.01	-3.2

From the following table, one can perceive that out-of-home leisure/social activities have priority to in-home household maintenance from 10 AM in the morning all the way to 4 AM after midnight. Sundays and Saturdays also increase the weight of out-of-home leisure/social comparing to in-home household maintenance. Being a student, being employed, male individuals, longer duration of out-of-home personal maintenance are all associated with preferring out-of-home leisure/social to in-home household maintenance.

Table 41. REVERSE COUPLE MODEL FOR INHOME HOUSEHOLD MAINTENANCE VS OUT-OF-HOME LEISURE/SOCIAL ACTIVITY

Parameter	Definition	Estimate	t-value
beta39_Hr0_2	If inhome activity start time is between 12AM-2AM	-0.35	-8.7
beta39_Hr2_4	If in-home activity start time is between 2AM-4AM	-0.01	-1.9
beta39_Hr4_6	If in-home activity start time is between 4AM-6AM	1.53	4.8
beta39_Hr6_8	If in-home activity start time is between 6AM-8AM	2.40	6.2
beta39_Hr8_10	If in-home activity start time is between 8AM-10AM	0.80	2.5
beta39_Hr10_12	If in-home activity start time is between 10AM-12PM	-0.003	-4.8
beta39_Hr12_14	If in-home activity start time is between 12PM-14PM	-0.85	-3.8
beta39_Hr14_16	If in-home activity start time is between 14PM-16PM	-0.87	-2.4
beta39_Hr16_18	If in-home activity start time is between 16PM-18PM	-0.09	-5.8
beta39_Hr18_20	If in-home activity start time is between 18PM-20PM	-0.38	-1.9
beta39_Hr20_22	If in-home activity start time is between 20PM-22PM	-0.52	-3.0
beta39_Hr22_24	If in-home activity start time is between 22PM-24PM	-0.91	-2.9
beta39_Sunday	If in-home activity activity is on Sunday	-0.14	-7.4
beta39_Saturday	If in-home activity activity is on Saturday	-0.48	-9.2
beta39_retired	If individual is retired	0.08	3.6
beta39_income10k	Income (x10k)	-0.003	-4.5
beta39_married	If individual is married	0.71	3.9
beta39_student	If individual is student	-1.79	-10.5
beta39_PRTAGE	Age	0.01	3.8
beta39_PESEX	Gender	-1.10	-4.6
beta39_HHSIZE	Household size	0.06	5.7
beta39_PEMLR	If individual is employed	-0.13	-3.5
beta39_INHOME_HOUSEHOLDM	log duration of Inhome household maintenance	0.02	7.8
beta39_OUTHOME_PERSONALM	log duration of outhome personal maintenance	-0.02	-3.7

In-home household maintenance is mostly dominant over out-of-home discretionary-other activities except for 8 AM to noon. Also, Sundays, being retired, being a student enhance the probability of preferring out-of-home discretionary-other to in-home personal maintenance.

Table 42. REVERSE COUPLE MODEL FOR INHOME HOUSEHOLD MAINTENANCE VS OUT-OF-HOME DISCRETIONRY-OTHERACTIVITY

Parameter	Definition	Estimate	t-value
beta310_Hr0_2	If inhome activity start time is between 12AM-2AM	2.21	12.7
beta310_Hr2_4	If in-home activity start time is between 2AM-4AM	1.11	8.5
beta310_Hr4_6	If in-home activity start time is between 4AM-6AM	2.24	13.8
beta310_Hr6_8	If in-home activity start time is between 6AM-8AM	3.12	7.8
beta310_Hr8_10	If in-home activity start time is between 8AM-10AM	-0.46	-1.8
beta310_Hr10_12	If in-home activity start time is between 10AM-12PM	-0.77	-2.3
beta310_Hr12_14	If in-home activity start time is between 12PM-14PM	0.25	3.5
beta310_Hr14_16	If in-home activity start time is between 14PM-16PM	0.36	4.7
beta310_Hr16_18	If in-home activity start time is between 16PM-18PM	0.04	1.2
beta310_Hr18_20	If in-home activity start time is between 18PM-20PM	0.27	1.6
beta310_Hr20_22	If in-home activity start time is between 20PM-22PM	1.30	5.0
beta310_Hr22_24	If in-home activity start time is between 22PM-24PM	0.74	4.2
beta310_Sunday	If in-home activity activity is on Sunday	-1.51	-1.7
beta310_Saturday	If in-home activity activity is on Saturday	0.74	2.9
beta310_retired	If individual is retired	-0.12	-2.1
beta310_married	If individual is married	0.12	8.5
beta310_student	If individual is student	-0.74	-2.0
beta310_PRTAGE	Age	0.01	2.5
beta310_HHSIZE	Household Size	0.16	3.5
beta310_PEMLR	If individual is employed	0.39	8.5
beta310_INHOME_HOUSEHOLDM	log duration of Inhome household maintenance	0.02	7.4
beta310_INHOME_LEISURE	log duration of Inhome leisure	0.01	5.1

Similarly, out-of-home mandatory activities beat in-home personal maintenance from 8 to 10AM as well as from noon to 2PM which is most possibly attributed to work activity start time. Sundays and Saturdays are clearly associated with in-home household maintenance. In addition, being retired, being married, higher household size, higher age, female individuals and longer duration of in-home household and personal maintenance until the start of the upcoming activity increase the weight of in-home household maintenance preference to out-of-home mandatory.

Table 43. REVERSE COUPLE MODEL FOR INHOME HOUSEHOLD MAINTENANCE VS OUT-OF-HOME MANDATORYACTIVITY

Parameter	Definition	Estimate	t-value
beta311_Hr0_2	If inhome activity start time is between 12AM-2AM	0.10	3.5
beta311_Hr2_4	If in-home activity start time is between 2AM-4AM	-1.48	-1.9
beta311_Hr4_6	If in-home activity start time is between 4AM-6AM	0.48	3.8
beta311_Hr6_8	If in-home activity start time is between 6AM-8AM	0.22	1.9
beta311_Hr8_10	If in-home activity start time is between 8AM-10AM	-0.10	-2.6
beta311_Hr10_12	If in-home activity start time is between 10AM-12PM	0.37	3.9
beta311_Hr12_14	If in-home activity start time is between 12PM-14PM	-0.16	-4.5
beta311_Hr14_16	If in-home activity start time is between 14PM-16PM	0.33	6.1
beta311_Hr16_18	If in-home activity start time is between 16PM-18PM	2.29	10.2
beta311_Hr18_20	If in-home activity start time is between 18PM-20PM	2.72	13.5
beta311_Hr20_22	If in-home activity start time is between 20PM-22PM	1.98	15.0
beta311_Hr22_24	If in-home activity start time is between 22PM-24PM	0.30	7.0
beta311_Sunday	If in-home activity activity is on Sunday	1.49	3.6
beta311_Saturday	If in-home activity activity is on Saturday	0.89	4.0
beta311_retired	If individual is retired	0.41	12.1
beta311_married	If individual is married	0.39	17.1
beta311_student	If individual is student	-1.25	-14.4
beta311_PRTAGE	Age	0.02	10.4
beta311_PESEX	Gender	-0.77	-8.8
beta311_HHSIZE	Household Size	0.10	12.4
beta311_PEMLR	If individual is Employed	-0.63	-7.2
beta311_INHOME_PERSONALM	log duration of Inhome personal maintenance	0.01	3.8
beta311_INHOME_HOUSEHOLDM	log duration of Inhome household maintenance	0.02	4.9
beta311_OUTHOME_MANDAT	log duration of outhome mandatory	-0.02	-3.0

In-home leisure/social dominates out-of-home personal maintenance activities most hours except from 10 AM to 6 PM when people are mostly out of home. On Sundays, people prefer to stay at home doing leisure/social activities than going out for personal maintenance. Factors associated with preferring out-of-home personal maintenance are being employed, earning higher income and spending more out-of-home personal maintenance activities before the start of the upcoming activity. On the other hand, being married, being a student, longer duration of in-home activities before the start of the upcoming activity are all related to in-home leisure/social preference.

Table 44. REVERSE COUPLE MODEL FOR INHOME LEISURE VS OUT-OF-HOME PERSONAL MAINTENANCEACTIVITY

Parameter	Definition	Estimate	t-value
beta47_Hr0_2	If inhome activity start time is between 12AM-2AM	0.28	6.0
beta47_Hr2_4	If in-home activity start time is between 2AM-4AM	-0.13	-2.3
beta47_Hr4_6	If in-home activity start time is between 4AM-6AM	0.66	8.9
beta47_Hr6_8	If in-home activity start time is between 6AM-8AM	0.85	10.1
beta47_Hr8_10	If in-home activity start time is between 8AM-10AM	0.06	1.5
beta47_Hr10_12	If in-home activity start time is between 10AM-12PM	-1.15	-7.2
beta47_Hr12_14	If in-home activity start time is between 12PM-14PM	-1.35	-10.8
beta47_Hr14_16	If in-home activity start time is between 14PM-16PM	-0.15	-4.4
beta47_Hr16_18	If in-home activity start time is between 16PM-18PM	-0.14	-2.9
beta47_Hr18_20	If in-home activity start time is between 18PM-20PM	0.16	3.5
beta47_Hr20_22	If in-home activity start time is between 20PM-22PM	1.31	5.2
beta47_Hr22_24	If in-home activity start time is between 22PM-24PM	1.39	10.1
beta47_sunday	If in-home activity is on Sunday	0.45	5.8
beta47_income10k	Income (x10k)	-0.01	-3.8
beta47_married	If individual is married	0.09	1.4
beta47_student	If individual is student	0.15	5.5
beta47_PEMLR	If individual is Employed	-0.48	-2.9
beta47_INHOME_PERSONALM	log duration of Inhome personal maintenance	0.02	3.2
beta47_INHOME_HOUSEHOLDM	log duration of Inhome household maintenance	0.01	11.2
beta47_INHOME_LEISURE	log duration of Inhome leisure	0.02	7.3
beta47_OUTHOME_PERSONALM	log duration of outhome personal maintenance	-0.03	3.0

It is interesting that the model suggests that individuals prefer out-of-home household maintenance to in-home leisure/social activities from 8 AM to 8 PM. Individuals prefer to stay at home and do leisure/social activities on Sundays. On the contrary, Saturdays are more associated with out-of-home household maintenance than in-home leisure/social. Factors affiliated with preferring out-of-home household maintenance are being married, higher household size, higher income, being employed while male individuals, longer duration of in-home activities and being a student are related to in-home leisure/social activities.

Table 45. REVERSE COUPLE MODEL FOR INHOME LEISURE VS OUT-OF-HOME HOUSEHOLD MAINTENANCE ACTIVITY

Parameter	Definition	Estimate	t-value
beta48_Hr0_2	If inhome activity start time is between 12AM-2AM	0.04	-1.2
beta48_Hr2_4	If in-home activity start time is between 2AM-4AM	0.48	2.4
beta48_Hr4_6	If in-home activity start time is between 4AM-6AM	0.81	5.0
beta48_Hr6_8	If in-home activity start time is between 6AM-8AM	0.07	8.0
beta48_Hr8_10	If in-home activity start time is between 8AM-10AM	-0.30	-1.7
beta48_Hr10_12	If in-home activity start time is between 10AM-12PM	-1.02	-3.5
beta48_Hr12_14	If in-home activity start time is between 12PM-14PM	-1.32	-2.8
beta48_Hr14_16	If in-home activity start time is between 14PM-16PM	-1.30	-5.2
beta48_Hr16_18	If in-home activity start time is between 16PM-18PM	-1.30	-5.3
beta48_Hr18_20	If in-home activity start time is between 18PM-20PM	-0.25	-2.8
beta48_Hr20_22	If in-home activity start time is between 20PM-22PM	0.68	1.9
beta48_Hr22_24	If in-home activity start time is between 22PM-24PM	0.67	2.2
beta48_sunday	If in-home activity is on Sunday	0.27	3.5
beta48_saturday	If in-home activity is on Saturday	-0.29	-3.8
beta48_income10k	Income (x10k)	-0.04	-5.4
beta48_married	If individual is married	-0.16	9.5
beta48_student	If individual is student	0.27	6.3
beta48_PESEX	Gender	0.19	2.6
beta48_HHSIZE	Household Size	-0.16	4.3
beta48_PEMLR	If individual is Employed	-0.70	-2.2
beta48_INHOME_PERSONALM	log duration of Inhome personal maintenance	0.01	3.2
beta48_INHOME_LEISURE	log duration of Inhome leisure	0.02	5.5

The following table represents the competition between in-home and out-of-home leisure/social activities. Preferring to have leisure/social activity out-of-home than in-home starts from 8 AM to 8 PM. Saturdays and Sundays, both increase the weight of having out-of-home leisure/social activities. Being retired, being married and longer in-home activity duration up until the start of the upcoming activity increase the preference of in-home leisure/social. On the contrary, being employed, higher income and longer duration of in-home leisure/social until the start of the upcoming activity increase the chance performing an out-of-home leisure/social activity.

Table 46. REVERSE COUPLE MODEL FOR INHOME LEISURE VS OUT-OF-HOME LEISURE ACTIVITY

Parameter	Definition	Estimate	t-value
beta49_Hr0_2	If in-home activity start time is between 12AM-2AM	0.03	2.5
beta49_Hr2_4	If in-home activity start time is between 2AM-4AM	0.12	3.2
beta49_Hr4_6	If in-home activity start time is between 4AM-6AM	0.44	4.1
beta49_Hr6_8	If in-home activity start time is between 6AM-8AM	0.82	3.8
beta49_Hr8_10	If in-home activity start time is between 8AM-10AM	-0.26	-3.4
beta49_Hr10_12	If in-home activity start time is between 10AM-12PM	-0.69	-5.5
beta49_Hr12_14	If in-home activity start time is between 12PM-14PM	-1.05	-2.4
beta49_Hr14_16	If in-home activity start time is between 14PM-16PM	-0.93	-7.1
beta49_Hr16_18	If in-home activity start time is between 16PM-18PM	-0.83	-2
beta49_Hr18_20	If in-home activity start time is between 18PM-20PM	-0.47	-3.6
beta49_Hr20_22	If in-home activity start time is between 20PM-22PM	0.35	8.3
beta49_Hr22_24	If in-home activity start time is between 22PM-24PM	0.35	10.8
beta49_sunday	If in-home activity activity is on Sunday	-0.08	-18.2
beta49_saturday	If in-home activity activity is on Saturday	-0.46	-13.4
beta49_retired	If individual is retired	0.04	3.1
beta49_income10k	Income (x10k)	-0.03	-6.2
beta49_married	If individual is married	0.27	4.4
beta49_student	If individual is student	-0.57	-5
beta49_PESEX	Gender	-0.27	-3.1
beta49_PEMLR	If individual is Employed	-0.61	-8.1
beta49_INHOME_PERSONALM	log duration of Inhome personal maintenance	0.01	3.2
beta49_INHOME_LEISURE	log duration of Inhome leisure	0.02	4.1
beta49_OUTHOME_PERSONALM	log duration of outhome personal maintenance	-0.01	-3.3

Except from 8 AM to 2 PM, in-home leisure/social activity is dominant to discretionary-other activities. As mentioned earlier, discretionary-other activities include telephone calls, religious or volunteer activities. Sundays increase the chance of out-of-home discretionary-other most possibly due to the religious activities. All other factors are in favor of in-home leisure/social except for being employed.

Table 47. Reverse Couple Model For Inhome Leisure Vs Out-Of-Home Discretionary-Other Activity

Parameter	Definition	Estimate	t-value
beta410_Hr0_2	If inhome activity start time is between 12AM-2AM	1.57	21.4
beta410_Hr2_4	If in-home activity start time is between 2AM-4AM	1.16	18.3
beta410_Hr4_6	If in-home activity start time is between 4AM-6AM	0.98	7.8
beta410_Hr6_8	If in-home activity start time is between 6AM-8AM	1.55	4.6
beta410_Hr8_10	If in-home activity start time is between 8AM-10AM	-1.08	-16.4
beta410_Hr10_12	If in-home activity start time is between 10AM-12PM	-1.27	-23.9
beta410_Hr12_14	If in-home activity start time is between 12PM-14PM	-0.35	-8.2
beta410_Hr14_16	If in-home activity start time is between 14PM-16PM	0.13	3.7
beta410_Hr16_18	If in-home activity start time is between 16PM-18PM	-0.65	-3.1
beta410_Hr18_20	If in-home activity start time is between 18PM-20PM	0.08	1.1
beta410_Hr20_22	If in-home activity start time is between 20PM-22PM	1.52	3
beta410_Hr22_24	If in-home activity start time is between 22PM-24PM	1.14	8.8
beta410_sunday	If in-home activity activity is on Sunday	-1.24	-2.4
beta410_saturday	If in-home activity activity is on Saturday	0.41	3.3
beta410_student	If individual is student	0.33	5.5
beta410_PESEX	Gender	0.45	6.5
beta410_PEMLR	If individual is Employed	-0.15	-1.9
beta410_INHOME_PERSONALM	log duration of Inhome personal maintenance	0.01	2.4
beta410_INHOME_HOUSEHOLDM	log duration of Inhome household maintenance	0.01	2
beta410_INHOME_LEISURE	log duration of Inhome leisure	0.02	5.80

The last comparison submodel for in-home leisure/social is against out-of-home mandatory activities. Interestingly, from 2 AM to 2 PM, the odds are in favor of out-of-home mandatory activities. On Sundays and Saturdays, individuals prefer in-home leisure/social to out-of-home mandatory. Being retired, married and longer duration of in-home activities increase the weight of choosing in-home leisure/social.

Table 48. REVERSE COUPLE MODEL FOR INHOME LEISURE VS OUT-OF-HOME MANDATORY ACTIVITY

Parameter	Definition	Estimate	t-value
beta411_Hr0_2	If inhome activity start time is between 12AM-2AM	0.45	5.5
beta411_Hr2_4	If in-home activity start time is between 2AM-4AM	-1.03	-3.4
beta411_Hr4_6	If in-home activity start time is between 4AM-6AM	-0.09	-4.8
beta411_Hr6_8	If in-home activity start time is between 6AM-8AM	-0.65	-3.0
beta411_Hr8_10	If in-home activity start time is between 8AM-10AM	-0.65	-4.2
beta411_Hr10_12	If in-home activity start time is between 10AM-12PM	-0.23	-3.2
beta411_Hr12_14	If in-home activity start time is between 12PM-14PM	-0.51	-1.5
beta411_Hr14_16	If in-home activity start time is between 14PM-16PM	0.14	1.8
beta411_Hr16_18	If in-home activity start time is between 16PM-18PM	1.60	4.8
beta411_Hr18_20	If in-home activity start time is between 18PM-20PM	2.15	8.5
beta411_Hr20_22	If in-home activity start time is between 20PM-22PM	2.35	6.3
beta411_Hr22_24	If in-home activity start time is between 22PM-24PM	1.18	10.5
beta411_sunday	If in-home activity activity is on Sunday	1.30	12.5
beta411_saturday	If in-home activity activity is on Saturday	0.84	8.7
beta411_retired	If individual is retired	0.55	4.2
beta411_married	If individual is married	0.16	2.1
beta411_student	If individual is student	-0.17	-1.2
beta411_PESEX	Gender	-0.10	2.6
beta411_PEMLR	If individual is Employed	-0.93	10.0
beta411_INHOME_PERSONALM	log duration of Inhome personal maintenance	0.02	3.5
beta411_INHOME_HOUSEHOLDM	log duration of Inhome household maintenance	0.01	1.8
beta411_INHOME_LEISURE	log duration of Inhome leisure	0.02	3
beta411_OUTHOME_PERSONALM	log duration of outhome personal maintenance	0.02	4.2
beta411_OUTHOME_MANDAT	log duration of outhome mandatory	-0.01	-3.5

Table 49 explains the comparison submodel between in-home discretionary-other and out-of-home personal maintenance activities. The model shows that out-of-home personal maintenance is dominant from 10AM to 2 PM. Being employed, retired, married and longer duration of out-of-home personal maintenance contribute to the chance of out-of-home personal maintenance. It is noteworthy to mention that the models for discretionary other activities are less reliable than the others since these activities comprise a smaller portion of samples in the survey. Yet, the model acceptable for our purpose.

Table 49. REVERSE COUPLE MODEL FOR INHOME DISCRETIONARY-OTHER VS OUT-OF-HOME PERSONAL MAINTENANCE ACTIVITY

Parameter	Definition	Estimate	t-value
beta57_Hr0_2	If inhome activity start time is between 12AM-2AM	0.08	1.4
beta57_Hr2_4	If in-home activity start time is between 2AM-4AM	-0.24	-2.4
beta57_Hr4_6	If in-home activity start time is between 4AM-6AM	0.16	3.8
beta57_Hr6_8	If in-home activity start time is between 6AM-8AM	0.32	2.1
beta57_Hr8_10	If in-home activity start time is between 8AM-10AM	0.28	1.8
beta57_Hr10_12	If in-home activity start time is between 10AM-12PM	-0.21	-2.1
beta57_Hr12_14	If in-home activity start time is between 12PM-14PM	-0.50	-2.2
beta57_Hr18_20	If in-home activity start time is between 18PM-20PM	0.33	1.9
beta57_Hr20_22	If in-home activity start time is between 20PM-22PM	1.33	3.2
beta57_Hr22_24	If in-home activity start time is between 22PM-24PM	0.42	1.5
beta57_retired	If individual is retired	-1.74	-2.3
beta57_married	If individual is married	-0.09	-1.7
beta57_student	If individual is student	0.21	3.1
beta57_PRTAGE	Age	0.03	2.1
beta57_PESEX	Gender	-0.65	-1.2
beta57_PEMLR	If individual is Employed	-0.34	-3.8
beta57_INHOME_PERSONALM	log duration of Inhome personal maintenance	0.03	2.1
beta57_INHOME_HOUSEHOLDM	log duration of Inhome household maintenance	0.01	3.3
beta57_INHOME_LEISURE	log duration of Inhome leisure	0.01	6.1
beta57_OUTHOME_PERSONALM	log duration of outhome personal maintenance	-0.09	-2.5

The following table shows that in-home discretionary-other is preferable to out-of-home household maintenance from 6 PM to 6 AM. Saturdays are associated with out-of-home household maintenance. On the contrary, Sundays are assigned for in-home discretionary-other rather than out-of-home household maintenance. Being married, employed and higher household size add to the odds of choosing out-of-home household maintenance to discretionary-other activities.

Table 50. REVERSE COUPLE MODEL FOR INHOME DISCRETIONARY-OTHER VS OUT-OF-HOME HOUSEHOLD MAINTENANCE ACTIVITY

Parameter	Definition	Estimate	t-value
beta58_Hr2_4	If in-home activity start time is between 2AM-4AM	0.42	2.2
beta58_Hr4_6	If in-home activity start time is between 4AM-6AM	0.55	1.8
beta58_Hr8_10	If in-home activity start time is between 8AM-10AM	-0.14	-1.3
beta58_Hr10_12	If in-home activity start time is between 10AM-12PM	-0.91	-3.3
beta58_Hr12_14	If in-home activity start time is between 12PM-14PM	-1.18	-2.0
beta58_Hr14_16	If in-home activity start time is between 14PM-16PM	-0.86	-6.2
beta58_Hr16_18	If in-home activity start time is between 16PM-18PM	-0.80	-4.2
beta58_Hr18_20	If in-home activity start time is between 18PM-20PM	0.36	1.8
beta58_Hr20_22	If in-home activity start time is between 20PM-22PM	1.57	3.8
beta58_Hr22_24	If in-home activity start time is between 22PM-24PM	1.21	2.8
beta58_sunday	If in-home activity is on Sunday	0.30	1.8
beta58_saturday	If in-home activity is on Saturday	-0.49	-2.8
beta58_married	If individual is married	-0.65	-1.9
beta58_HHSIZE	Household Size	-0.29	-5.3
beta58_PEMLR	If individual is Employed	-0.84	-3.9
beta58_INHOME_PERSONALM	log duration of Inhome personal maintenance	0.02	3.2

From 10AM to 8PM out-of-home leisure has priority over in-home discretionary-other activities. Sundays and Saturdays both are in favor of out-of-home leisure/social activities with higher probability on Saturdays. Other factors that increase the odds of out-of-home leisure versus in-home discretionary-other are higher income, being employed, longer out-of-home personal maintenance before the start of the upcoming activity.

Table 51. Reverse Couple Model For Inhome Discretionary-Other Vs Out-Of-Home Leisure Activity

Parameter	Definition	Estimate	t-value
beta59_Hr0_2	If inhome activity start time is between 12AM-2AM	0.14	2.5
beta59_Hr2_4	If in-home activity start time is between 2AM-4AM	-0.36	-3.8
beta59_Hr4_6	If in-home activity start time is between 4AM-6AM	0.33	2.0
beta59_Hr6_8	If in-home activity start time is between 6AM-8AM	0.51	1.6
beta59_Hr8_10	If in-home activity start time is between 8AM-10AM	0.13	1.2
beta59_Hr10_12	If in-home activity start time is between 10AM-12PM	-0.27	-2.6
beta59_Hr12_14	If in-home activity start time is between 12PM-14PM	-0.61	-2.8
beta59_Hr14_16	If in-home activity start time is between 14PM-16PM	-0.32	-3.2
beta59_Hr16_18	If in-home activity start time is between 16PM-18PM	-0.37	-4.2
beta59_Hr18_20	If in-home activity start time is between 18PM-20PM	-0.10	-5.3
beta59_Hr20_22	If in-home activity start time is between 20PM-22PM	0.97	1.6
beta59_Hr22_24	If in-home activity start time is between 22PM-24PM	0.61	3.6
beta59_sunday	If in-home activity activity is on Sunday	-0.12	-2.4
beta59_saturday	If in-home activity activity is on Saturday	-0.72	-2.3
beta59_retired	If individual is retired	0.46	4.3
beta59_income10k	Income (x10k)	-0.03	-5.3
beta59_student	If individual is student	0.17	2.5
beta59_PESEX	Gender	-1.69	-1.7
beta59_PEMLR	If individual is Employed	-0.81	-3.9
beta59_INHOME_PERSONALM	log duration of Inhome personal maintenance	0.01	1.5
beta59_INHOME_HOUSEHOLDM	log duration of Inhome household maintenance	0.01	2.4
beta59_OUTHOME_PERSONALM	log duration of outhome personal maintenance	-0.03	-3.0

Comparing in-home and out-of-home discretionary-other activities, one can see from the table that from 10AM to 10 PM, out-of-home discretionary-other seems more dominant. Sundays and Saturdays similar to previous models motivate people to perform activities out-of-home. Being a student or retired and longer duration of in-home activities increase the weight of in-home discretionary-other activities. On the contrary, being married, employed, higher household size are associated with preferring out-of-home discretionary-other activities.

Table 52. REVERSE COUPLE MODEL FOR INHOME DISCRETIONARY-OTHER VS OUT-OF-HOME DISCRETIONARY-OTHER ACTIVITY

Parameter	Definition	Estimate	t-value
beta510_Hr0_2	If inhome activity start time is between 12AM-2AM	0.66	1.7
beta510_Hr2_4	If in-home activity start time is between 2AM-4AM	-1.51	-2.5
beta510_Hr4_6	If in-home activity start time is between 4AM-6AM	2.44	5.7
beta510_Hr6_8	If in-home activity start time is between 6AM-8AM	0.79	4.2
beta510_Hr8_10	If in-home activity start time is between 8AM-10AM	0.22	3.6
beta510_Hr10_12	If in-home activity start time is between 10AM-12PM	-0.18	-2.2
beta510_Hr12_14	If in-home activity start time is between 12PM-14PM	-0.53	-1.5
beta510_Hr14_16	If in-home activity start time is between 14PM-16PM	-0.51	-2.3
beta510_Hr16_18	If in-home activity start time is between 16PM-18PM	0.27	4.5
beta510_Hr18_20	If in-home activity start time is between 18PM-20PM	-0.71	-1.6
beta510_Hr20_22	If in-home activity start time is between 20PM-22PM	-0.25	-2.5
beta510_Hr22_24	If in-home activity start time is between 22PM-24PM	2.32	6.1
beta510_sunday	If in-home activity activity is on Sunday	-1.08	-2.3
beta510_saturday	If in-home activity activity is on Saturday	-1.06	-3.3
beta510_retired	If individual is retired	0.99	1.4
beta510_married	If individual is married	-0.99	-2.4
beta510_student	If individual is student	0.09	6.6
beta510_PESEX	Gender	-0.60	-4.2
beta510_HHSIZE	Household Size	-0.23	-3.3
beta510_PEMLR	If individual is Employed	-0.18	-4.2
beta510_INHOME_PERSONALM	log duration of Inhome personal maintenance	0.02	3.2
beta510_INHOME_HOUSEHOLDM	log duration of Inhome household maintenance	0.01	2.4
beta510_INHOME_LEISURE	log duration of Inhome leisure	0.01	2.00

Next table shows the comparison sub model between in-home discretionary-other activities versus out-of-home mandatory. The submodel is in favor of out-of-home mandatory activities from 2AM to 2 PM. Weekends are associated with discretionary-other activities at home. All other variables except for duration of in-home personal maintenance before the start of the activity, are in favor of out-home mandatory activities since they are more frequent activities compared to in-home discretionary-other.

Table 53. REVERSE COUPLE MODEL FOR INHOME DISCRETIONARY-OTHER VS OUT-OF-HOME MANDATORY ACTIVITY

Parameter	Definition	Estimate	t-value
beta511_Hr0_2	If inhome activity start time is between 12AM-2AM	0.34	1.5
beta511_Hr2_4	If in-home activity start time is between 2AM-4AM	-0.68	-2.8
beta511_Hr6_8	If in-home activity start time is between 6AM-8AM	-0.07	-1.9
beta511_Hr12_14	If in-home activity start time is between 12PM-14PM	-0.09	-3.5
beta511_Hr14_16	If in-home activity start time is between 14PM-16PM	0.18	1.6
beta511_Hr16_18	If in-home activity start time is between 16PM-18PM	0.60	2.3
beta511_Hr18_20	If in-home activity start time is between 18PM-20PM	1.14	3.5
beta511_Hr20_22	If in-home activity start time is between 20PM-22PM	1.77	1.9
beta511_Hr22_24	If in-home activity start time is between 22PM-24PM	0.34	2.5
beta511_sunday	If in-home activity activity is on Sunday	1.15	2.6
beta511_saturday	If in-home activity activity is on Saturday	0.70	4.5
beta511_married	If individual is married	-0.22	-2.2
beta511_student	If individual is student	-0.03	-3.5
beta511_HHSIZE	Household Size	-0.07	-3.0
beta511_PEMLR	If individual is Employed	-1.81	-18.5
beta511_INHOME_PERSONALM	log duration of Inhome personal maintenance	0.02	1.6
beta511_OUTHOME_MANDAT	log duration of outhome mandatory	-0.02	-2.5

The following table starts comparing in-home mandatory such as work or educational activities to the first out-of-home activity, personal maintenance. The model shows that people prefer in-home mandatory to out-of-home personal maintenance from 2 PM to midnight. On Sundays, individuals prefer to do mandatory activity at home while the trend is opposite on Saturday. Married individuals prefer to have personal maintenance activity out-of-home such as eating out whole students prefer to stay at home and focus on mandatory activities which are mainly related to their education. Employed individuals prefer staying at home to do work-related activities. As repeatedly experienced in previous models, longer duration of in-home activities up until the start of this activity increase the probability of choosing the in-home mandatory activities. From all the previous submodels, one can infer that individuals tend to keep their status location constant; if they have spent most of their day at home; they tend to stay at home and vice versa.

Table 54. REVERSE COUPLE MODEL FOR INHOME MANDATORY VS OUT-OF-HOME PERSONAL MAINTENANCE ACTIVITY

Parameter	Definition	Estimate	t-value
beta67_Hr0_2	If in-home activity start time is between 12AM-2AM	-0.92	-2.1
beta67_Hr2_4	If in-home activity start time is between 2AM-4AM	-0.22	-1.2
beta67_Hr4_6	If in-home activity start time is between 4AM-6AM	0.12	1.8
beta67_Hr6_8	If in-home activity start time is between 6AM-8AM	0.45	2.2
beta67_Hr8_10	If in-home activity start time is between 8AM-10AM	0.24	3.0
beta67_Hr10_12	If in-home activity start time is between 10AM-12PM	-0.46	-2.5
beta67_Hr12_14	If in-home activity start time is between 12PM-14PM	-0.54	-3.6
beta67_Hr14_16	If in-home activity start time is between 14PM-16PM	0.33	4.5
beta67_Hr16_18	If in-home activity start time is between 16PM-18PM	0.26	3.3
beta67_Hr18_20	If in-home activity start time is between 18PM-20PM	0.48	4.7
beta67_Hr20_22	If in-home activity start time is between 20PM-22PM	0.89	2.2
beta67_Hr22_24	If in-home activity start time is between 22PM-24PM	0.29	2.8
beta67_sunday	If in-home activity is on Sunday	0.11	1.8
beta67_saturday	If in-home activity is on Saturday	-0.20	-5.4
beta67_married	If individual is married	-0.05	-1.8
beta67_student	If individual is student	0.52	5.9
beta67_PRTAGE	Age	-0.01	-5.2
beta67_PEMLR	If individual is Employed	0.78	2.4
beta67_INHOME_PERSONALM	log duration of Inhome personal maintenance	0.03	3.4
beta67_OUTHOME_PERSONALM	log duration of outhome personal maintenance	-0.10	-6.5

The next table shows that out-of-home household maintenance is more probable to be executed than in-home mandatory from 10AM to 6 PM. Furthermore, weekends increase the weight of out-of-home household maintenance against in-home mandatory. Other factors that enhance the chance of preferring out-of-home household maintenance against in-home mandatory are being married, higher household size, being older and longer duration of in-home household maintenance. The model reveals that being engaged in in-home household maintenance increases the odds of getting engaged in out-of-home household maintenance against in-home mandatory activities. This can be translated as housewives who are in charge of both in-home and out-of-home household maintenance activities. Also, men are more involved in in-home mandatory activities than household maintenance ones.

Table 55. REVERSE COUPLE MODEL FOR INHOME MANDATORY VS OUT-OF-HOME HOUSEHOLD MAINTENANCE ACTIVITY

Parameter	Definition	Estimate	t-value
beta68_Hr0_2	If in-home activity start time is between 12AM-2AM	-0.41	-3.5
beta68_Hr2_4	If in-home activity start time is between 2AM-4AM	0.22	2.1
beta68_Hr8_10	If in-home activity start time is between 8AM-10AM	-0.36	-4.5
beta68_Hr10_12	If in-home activity start time is between 10AM-12PM	-1.07	-3.2
beta68_Hr12_14	If in-home activity start time is between 12PM-14PM	-0.78	-2.4
beta68_Hr14_16	If in-home activity start time is between 14PM-16PM	-0.88	-4.2
beta68_Hr16_18	If in-home activity start time is between 16PM-18PM	-1.19	-8.5
beta68_Hr20_22	If in-home activity start time is between 20PM-22PM	1.11	2.1
beta68_Hr22_24	If in-home activity start time is between 22PM-24PM	0.54	3.0
beta68_sunday	If in-home activity activity is on Sunday	-0.38	-3.5
beta68_saturday	If in-home activity activity is on Saturday	-1.13	-4.0
beta68_married	If individual is married	-0.27	-5.7
beta68_student	If individual is student	1.35	5.4
beta68_PRTAGE	Age	-0.02	4.7
beta68_PESEX	Gender	0.66	6.1
beta68_HHSIZE	Household Size	-0.04	-2.4
beta68_PEMLR	If individual is Employed	0.45	3.5
beta68_INHOME_PERSONALM	log duration of Inhome personal maintenance	0.02	2.0
beta68_INHOME_HOUSEHOLDM	log duration of Inhome household maintenance	-0.01	-7.1
beta68_OUTHOME_PERSONALM	log duration of outhome personal maintenance	-0.01	-2.8

The following table represents the competition between in-home mandatory activity and out-of-home leisure/social activity. The model shows that out-of-home leisure/social is dominant from 8 AM to 8PM and then again from 12AM-4AM. Saturdays and Sundays are both associated with preferring out-of-home leisure activity to in-home mandatory. In addition, older people as well as retired individuals prefer out-of-home leisure. On the contrary, students, the employed and married individuals give more weight to in-home mandatory activities. In terms of individuals' schedule, people who are engaged in in-home leisure and out-of-home personal maintenance more are willing to spend time for out-of-home leisure/social activities over in-home mandatory tasks.

Table 56. REVERSE COUPLE MODEL FOR INHOME MANDATORY VS OUT-OF-HOME LEISURE ACTIVITY

Parameter	Definition	Estimate	t-value
beta69_Hr0_2	If inhome activity start time is between 12AM-2AM	-0.54	-3.5
beta69_Hr2_4	If in-home activity start time is between 2AM-4AM	-0.26	-1.8
beta69_Hr4_6	If in-home activity start time is between 4AM-6AM	0.10	1.5
beta69_Hr6_8	If in-home activity start time is between 6AM-8AM	0.64	2.2
beta69_Hr8_10	If in-home activity start time is between 8AM-10AM	-0.07	-1.3
beta69_Hr10_12	If in-home activity start time is between 10AM-12PM	-0.53	-2.8
beta69_Hr12_14	If in-home activity start time is between 12PM-14PM	-0.39	-1.7
beta69_Hr14_16	If in-home activity start time is between 14PM-16PM	-0.35	-1.9
beta69_Hr16_18	If in-home activity start time is between 16PM-18PM	-0.46	-1.7
beta69_Hr18_20	If in-home activity start time is between 18PM-20PM	-0.06	-1.5
beta69_Hr20_22	If in-home activity start time is between 20PM-22PM	0.72	3.0
beta69_Hr22_24	If in-home activity start time is between 22PM-24PM	0.25	5.2
beta69_sunday	If in-home activity is on Sunday	-0.77	-7.2
beta69_saturday	If in-home activity is on Saturday	-1.24	-8.0
beta69_retired	If individual is retired	-1.30	-13.1
beta69_married	If individual is married	0.36	1.9
beta69_student	If individual is student	0.59	5.8
beta69_PRTAGE	Age	-0.02	-3.5
beta69_PEMLR	If individual is Employed	0.91	4.0
beta69_INHOME_PERSONALM	log duration of Inhome personal maintenance	0.02	3.9
beta69_INHOME_LEISURE	log duration of Inhome leisure	-0.01	-3.5
beta69_OUTHOME_PERSONALM	log duration of outhome personal maintenance	-0.03	-6.2

Comparison between in-home mandatory and out-of-home discretionary-other activities reveals that in-home mandatory activities are preferred most daily hours except from noon to 2 PM and also from 6 PM to 8 PM. Interestingly, these hours are mostly related to lunch and dinner time which might be associated to volunteering within discretionary-other activities. Retired, married and older individuals prefer out-of-home discretionary-other to in-home mandatory activities while employed and higher income people prefer the opposite. In terms of schedule, longer duration of out-of-home mandatory activities before the start of this activity will increase the odds of choosing in-home mandatory. In addition, longer duration of in-home personal maintenance within the daily schedule of an individual will enhance the chance of selecting in-home mandatory over out-of-home discretionary-other activity.

Table 57. REVERSE COUPLE MODEL FOR INHOME MANDATORY VS OUT-OF-HOME DISCRETIONARY-OTHER ACTIVITY

Parameter	Definition	Estimate	t-value
beta610_Hr0_2	If in-home activity start time is between 12AM-2AM	1.91	2.8
beta610_Hr6_8	If in-home activity start time is between 6AM-8AM	0.59	4.1
beta610_Hr8_10	If in-home activity start time is between 8AM-10AM	0.62	1.9
beta610_Hr10_12	If in-home activity start time is between 10AM-12PM	0.25	3.5
beta610_Hr12_14	If in-home activity start time is between 12PM-14PM	-0.11	-2.2
beta610_Hr16_18	If in-home activity start time is between 16PM-18PM	0.49	3.5
beta610_Hr18_20	If in-home activity start time is between 18PM-20PM	-0.56	-6.5
beta610_Hr22_24	If in-home activity start time is between 22PM-24PM	1.59	3.2
beta610_sunday	If in-home activity is on Sunday	-0.66	-5.2
beta610_saturday	If in-home activity is on Saturday	-1.03	-3.0
beta610_retired	If individual is retired	-0.80	-3.5
beta610_income10k	Income (x10k)	0.20	7.1
beta610_married	If individual is married	-0.95	-1.6
beta610_PRTAGE	Age	-0.05	-2.7
beta610_PESEX	Gender	0.17	3.5
beta610_PEMLR	If individual is Employed	1.69	6.3
beta610_INHOME_PERSONALM	log duration of Inhome personal maintenance	0.02	3.8
beta610_OUTHOME_MANDAT	log duration of outhome mandatory	0.01	2.4

Finally, the last submodel of the pairwise comparison conflict resolution problem is between in-home mandatory and out-of-home mandatory activities. The following table shows that from 6 AM to 2 PM, out-of-home mandatory dominates since most people's workhours start in the morning. Factors associated with preferring out-of-home mandatory activities are being employed, being male, being married and longer duration of out-of-home activity so far in the day before the start of this activity. On the other hand, students, the retired tend to choose in-home over out-of-home mandatory activities. Also, Sunday and Saturdays increase the weight of in-home mandatory activities.

Table 58. REVERSE COUPLE MODEL FOR INHOME MANDATORY VS OUT-OF-HOME MANDATORY ACTIVITY

Parameter	Definition	Estimate	t-value
beta611_Hr2_4	If in-home activity start time is between 2AM-4AM	-0.63	-3.5
beta611_Hr4_6	If in-home activity start time is between 4AM-6AM	0.78	1.9
beta611_Hr6_8	If in-home activity start time is between 6AM-8AM	-0.52	-14.8
beta611_Hr8_10	If in-home activity start time is between 8AM-10AM	-0.38	-18.2
beta611_Hr10_12	If in-home activity start time is between 10AM-12PM	-0.09	-8.2
beta611_Hr12_14	If in-home activity start time is between 12PM-14PM	-0.30	-7.1
beta611_Hr14_16	If in-home activity start time is between 14PM-16PM	0.37	2.0
beta611_Hr16_18	If in-home activity start time is between 16PM-18PM	0.71	1.8
beta611_Hr18_20	If in-home activity start time is between 18PM-20PM	1.45	3.1
beta611_Hr20_22	If in-home activity start time is between 20PM-22PM	1.62	4.0
beta611_Hr22_24	If in-home activity start time is between 22PM-24PM	0.06	3.8
beta611_sunday	If in-home activity activity is on Sunday	0.57	6.2
beta611_saturday	If in-home activity activity is on Saturday	0.23	10.1
beta611_retired	If individual is retired	0.71	2.8
beta611_married	If individual is married	-0.14	-4.3
beta611_student	If individual is student	0.41	5.8
beta611_PESEX	Gender	-0.06	-3.4
beta611_PEMLR	If individual is Employed	-0.52	-20.2
beta611_INHOME_PERSONALM	log duration of Inhome personal maintenance	0.04	4.8
beta611_INHOME_HOUSEHOLDM	log duration of Inhome household maintenance	0.03	6.0
beta611_INHOME_LEISURE	log duration of Inhome leisure	0.03	1.9
beta611_OUTHOME_MANDAT	log duration of outhome mandatory	-0.01	-5.4

Considering the data limitations on activity planning and scheduling behavior, specifically interactions of in-home and out-of-home activities, this paper extracted information about such interactions through an econometric approach. This approach that we call it reverse pairwise modeling explores how in-home and out-of-home activities replace each other, in what circumstances, people prefer to stay at home and get engaged in an activity instead of going out and generating a new trip. Even though this approach might have some limitations such as approximations in probability calculations and the unknown activity plan horizon of the observed data, it provides comparison sub-models that make intuitive sense; they are considerably applicable and provide formulated sensitivity analysis. This approach can be used in various applications where the observed data is a multi-classification problem, but the goal is paiwise comparisons.

The estimated models provide a tool for solving in-home versus out-of-home activity conflict scenarios in the activity-based model ADAPTS. These models make the framework a full activity-based model incorporating in-home activities. Agents, on frequent occasions, need to decide if they prefer to stay at home or go out. The models used for this purpose make the ADAPTS smarter on how people make such decisions and avoid over/under-generation of trips/activities. All these efforts will make us closer to the future activity-based models with higher reliability and domain of applications.

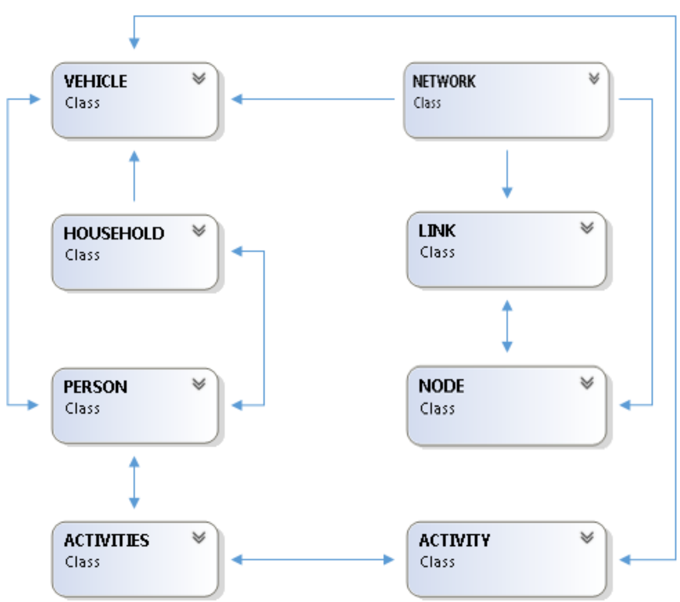
For future, a pairwise activity comparison survey will help us to find out how accurate the estimated models are. Until then, these models provide reliable comparison decisions. Also, the result of these models will be compared with observed comparison ratios from the Bradley-Terry comparison method.

CHAPTER 7: SIMULATION

SIMULATION PLATFORM

The revised ADAPTS is an object oriented simulation framework that is written in C++ visual studio environment. The framework that now incorporates full activity and travel behavior of individuals is composed of more than 50 Classes that instantiate objects as elements of the activity-based model. Within Classes, methods are defined that govern the objects' behavior and status in the simulation. Figure 16 represents the main class entities that constitute the dynamic and static elements of the simulated metropolitan area. The main classes that drive the dynamism are Household, Person and Vehicle classes that are shown with class diagrams in Table 59. A household object has household related properties such as race, income, household size, number of vehicles that describe the household object and a person vector property containing all the persons within the household. Also, it contains methods mostly as Getter and Setters of household related properties to be called within the simulation framework.

Figure 16. ADAPTS Entity Classes



The Household class has association with Person as well as the Vehicle classes. The Person class has a direct link with Activities class which records list of activities an individual does within the planning horizon by various definitions. These lists include a vector of unscheduled, scheduled and recorded activities. It also stores some relevant measures and indexes regarding activity frequencies and rates. Activity class incorporates fields and methods that define a single activity attributes such as plan horizon, activity plan times, start time, mode choice, activity location and type among others. Subsequently, the Activity class has a link with the Vehicle class which means that activity might require travel with a household vehicle in case the activity location is different from the individual's previous activity location. The Vehicle Class has properties such as person and activity which associates its object with Person and Activity objects. It has methods that set the objects' path from origin to destination and remove the links of the path as vehicle reaches path nodes. In a nutshell, household, person and vehicle objects are the main dynamic players in the activity-based model.

Other important entity classes that are in essence static include Network, Link and Node Classes which are displayed in Table 60. Network class includes all the information about transportation network and its current traffic status. The network contains a list of all the links and nodes that it is formed of. Additionally, it has vector attributes containing all the new and existing vehicles at each time step. It also keeps track of some general network statistics such as the total number of vehicles generated as well as the total number of vehicles on the network at each time step. A variety of methods govern the movement of vehicles such as FindDepartingVehicles which basically assigns vehicles to the individuals whose trips are about to depart within the time step or MoveVehicles which is in charge of network vehicle movements within the corresponding time step.

Table 59. ADAPTS DYNAMIC ENTITY CLASSES

HOUSEHOLD
Class

Fields
- _familyType
- _hhWeight
- _house
- _houseTenure
- _houseType
- _id
- _income
- _maxHHSize
- _numChild
- _numVeh
- _numWorkers
- _size
- _strTAZ
- _threadID
- _vpMembers

Methods
- ~HOUSEHOLD
- GetFamilyType
- GetHHID
- GetHouse
- GetHouseTAZ
- GetHouseType
- GetIncome
- GetLocation
- GetMaxHHSize
- GetNumChild
- GetNumVehicle
- GetSize
- GetThreadID
- HOUSEHOLD (+ 1 overload)
- SetFamilyType
- SetHouse
- SetHouseType
- SetIncome
- SetNumChild
- SetNumVehicle
- SetSize
- SetThreadID

Nested Types

PERSON
Class

Fields
- _Activities
- _demographics
- _hhRelation
- _id
- _ignore
- _isEngagedinActivity
- _isTraveling
- _pHousehold
- _pLocation
- _pSchoolLocation
- _pWorkLocation
- _race
- _stats
- _vehicle
- _workMode

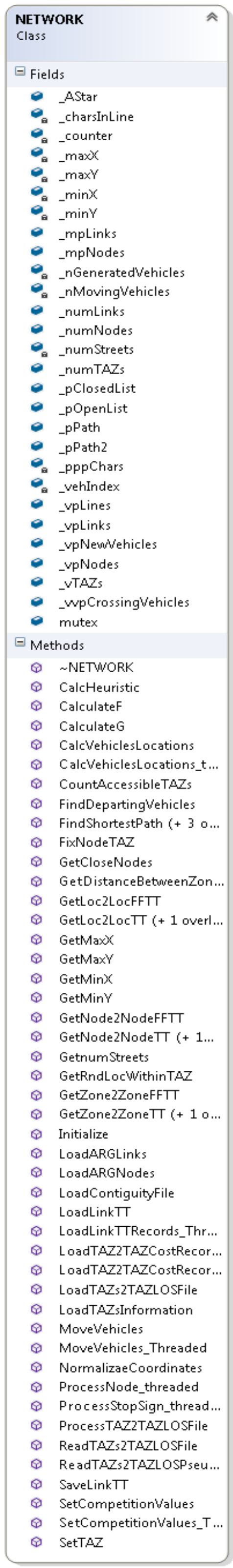
Methods
- ~PERSON
- DoesStartTravel
- FinishCurrentTrip
- GenerateNewTrip
- GetAge
- GetCurrentLocation
- GetHH
- GetHomeLocation
- GetID
- GetIncome
- GetIndustry
- GetRace
- GetSchoolLocation
- GetThreadID
- GetVehicle
- GetWorkLocation
- GetWorkMode
- Is_Adult
- Is_Child
- Is_Employed
- Is_Engaged_in_Activity
- Is_Student
- Is_Traveling
- PERSON
- Set_Engaged_in_Activity
- Set_Traveling
- SetAge
- SetCurrentLocation
- SetHomeLocation
- SetSchoolLocation (+ 1 overload)
- SetWorkLocation (+ 1 overload)
- SetWorkMode
- ShouldbeIngored (+ 1 overload)

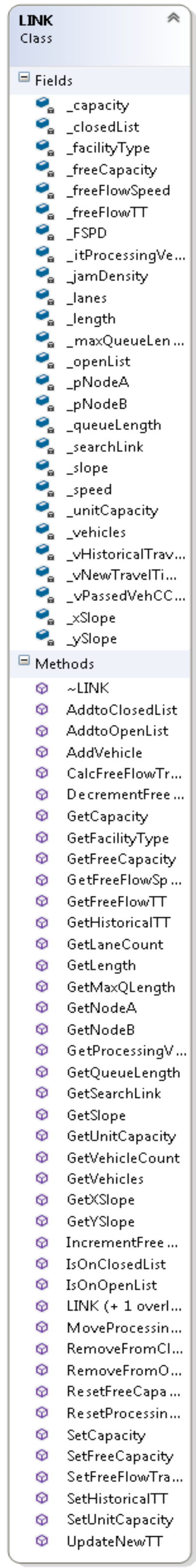
VEHICLE
Class

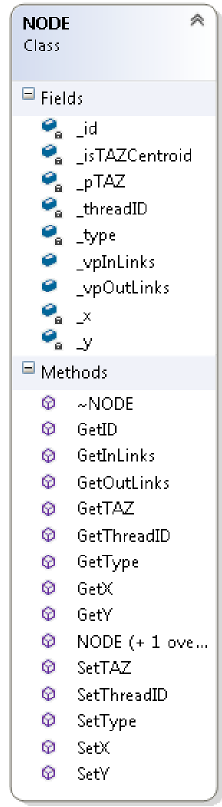
Fields
- _activityID
- _isTravelling
- _offset
- _pAct
- _pDestination
- _pOrigin
- _pPath
- _pPerson
- _processed
- _reachedQueue
- _startTimeOfTrip
- _timeEnteredLink
- _timeReachesEndofLink
- _x
- _y

Methods
- ~VEHICLE
- GetActivity
- GetDestination
- GetFirstLink
- GetOffset
- GetOrigin
- GetPath
- GetReachedQueue
- GetTimeEnteredLink
- GetTimeReachesEndofLink
- GetTripStart
- IsTraveling
- operator!=
- operator<
- operator<=
- operator==
- operator>
- operator>=
- ReduceOffset
- RemoveFirstLink
- Reset
- SetActivity
- SetDestination
- SetOffset
- SetOrigin
- SetPath
- SetReachedQueue
- SetTimeEnteredLink
- SetTimeReachesEndofLink
- SetTraveling
- SetX
- SetXY
- SetY
- Update
- UpdateXY
- VEHICLE

Table 60. ADAPTS STATIC ENTITY CLASSES



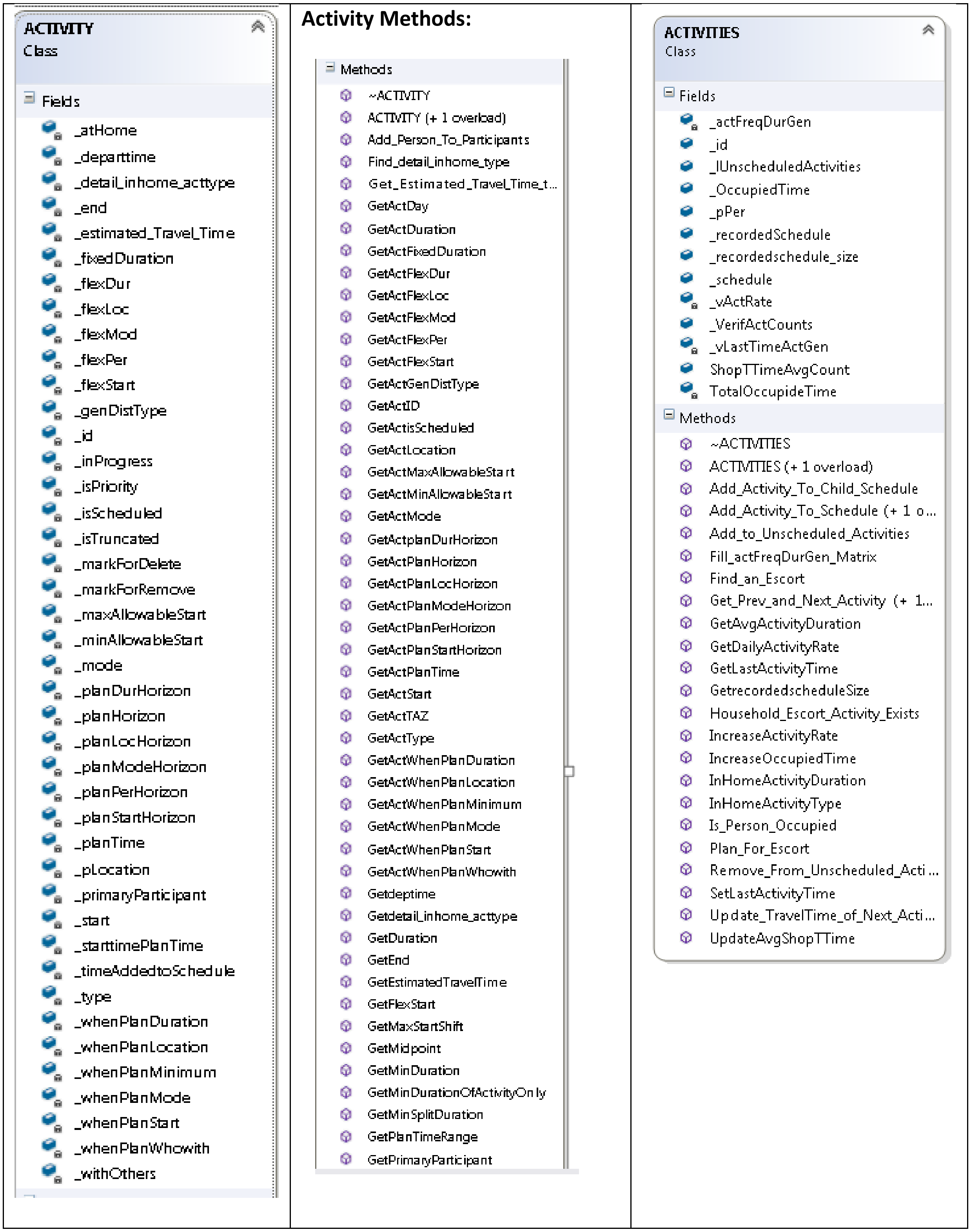




The Link class defines the attributes and methods associated with every link. From the two nodes forming the link to the detailed link properties such as length, speed limit, number of lanes, capacity, free flow speed, jam capacity are all recorded as field attributes. Several Setter methods process the current link density, speed and number of vehicles. Vehicles in a link are listed in a Queue data structure where vehicles are added to the end and eliminated from the front of the queue object. The link object records its historical travel time to be used for a dynamic traffic assignment. The Node class as shown in Table 60 is more static and basically contains the geographic as well as link information. An object of this class represents a road intersection/ junction with properties such as in which TAZ it is located and what links flow into and out of the node.

Activity and Activities are the essential classes that determine the Person and Household objects' behaviors. Single Activity objects are generated for each individual person and they are stored and processed in the fields of an Activities' object. An Activities object itself is an attribute of a Person object representing the activities the individual plans and sets in the schedule. The classes are displayed in Figure 17. The Activity class fields and methods are separated in the figure since Activity has many methods. Also, some of its methods are eliminated from the figure for brevity. As shown, activity properties include various time and location based attributes. These attributes are either related to the planning and scheduling of the activity or they define the current status of the activity. On the other hand, Activities class has methods that are mostly associated with a group of activities. Methods and fields regarding in-home activities such in-home activity type, detail in-home activity type among others are ingested in these two classes.

Figure 17. Activity and Activities Classes:



SIMULATION SETTINGS

The general version of this sequential in-home activity modeling is coded in ADAPTS. For testing the performance and validation of the in-home activity microsimulation, a small sample of 10,000 households including 28,468 individuals from the Chicago Metropolitan area synthetic population were microsimulated for one month of activity planning, scheduling and trip making with a dynamic traffic assignment module. The machine running the framework is an AMD Opteron(TM) Processor 2.3 GHz with 256 GB RAM. Individuals and vehicles' locations were tracked every 30s and their activity schedules were recorded for analysis. One week of simulation results was used for average daily statistical calculations. In addition, the observed in-home activity statistics of the ATUS survey from the Illinois State were utilized for a comparison standpoint. Even though the statistics of ATUS are weighted from IL State and should not be directly compared with a random sample form the Chicago metropolitan, they could be used as standpoint statistics to compare the simulation results with. The following table represents an example of a recorded day of an individual. The example shows that person 0 from household number 18 executed a household maintenance activity for about half an hour before sleeping on day 21. The simulated individual then sleeps for about 5 hours before going to work. This typical example shows that the sleep activity must have been interrupted by the routine primary work activity. This can remind us of the priority given to the routine and pre-simulation activities which has made this person rush to work immediately after waking up. In other frequent occasions, the gap between wake-up and work start time provides sufficient time for executing personal maintenance activities such as having breakfast. However, since previous ADAPTS does not necessarily separate primary-work with eating/drinking at work, one can assume that this individual might have had a meal or other personal maintenance activities at work. The individual departed to work at 5:26 AM and arrived at 5:40 AM. He/she left work at about 1:38 PM and arrived back home at approximately 1:44 PM.

Then, She prepared food/drink for more than an hour. After preparing food/drink, she watched TV for about three hours. At 6:21 PM, she had dinner until 7 PM. Then, she executed a cleaning activity until 7:43 PM. From 7:43 to 8:43 PM she did caring for household members (probably caring for her children). After caring, she used her computer for a leisure activity until 10:07 PM Getting closer to the end of the day, she executed a grooming/bathroom activity until 11:01 PM and eventually, she ended the day with watching TV until past midnight. As this example shows, every single activity of the individual is recorded after execution so that the final schedule of the simulated sample could be analyzed.

VALIDATION

ACTIVITY FREQUENCY AND DURATION

The ADAPTS framework incorporating in-home activities was run for the 10,000 household sample and its simulation results was examined in a validation procedure.

Figure 18 shows the daily frequency and average in-home activity episode durations for the simulation and the ATUS means. In terms of activity counts per day, the ADAPTS seems to over-generate most in-home activities except for sleep and household maintenance at home. However, the most significant difference between the simulated data and the observed national average is for personal maintenance activities. The simulated data over-generates approximately one extra in-home personal maintenance activity per person compared to the ATUS data. Even though, a considerable portion of differences might arise from the sampling error, this overate could have other predictable causes. One cause could be a result of under-generation of out-of-home activities. For investigating this case, the next graph shows the daily activity counts for the out-of-home activities. This time the data for comparison comes from CMAP as it had been recorded in Josh et al 2010. The ADAPTS output for the 10,000 household sample shows a clear underestimation for all out-of-home activity types except for the Errands activity.

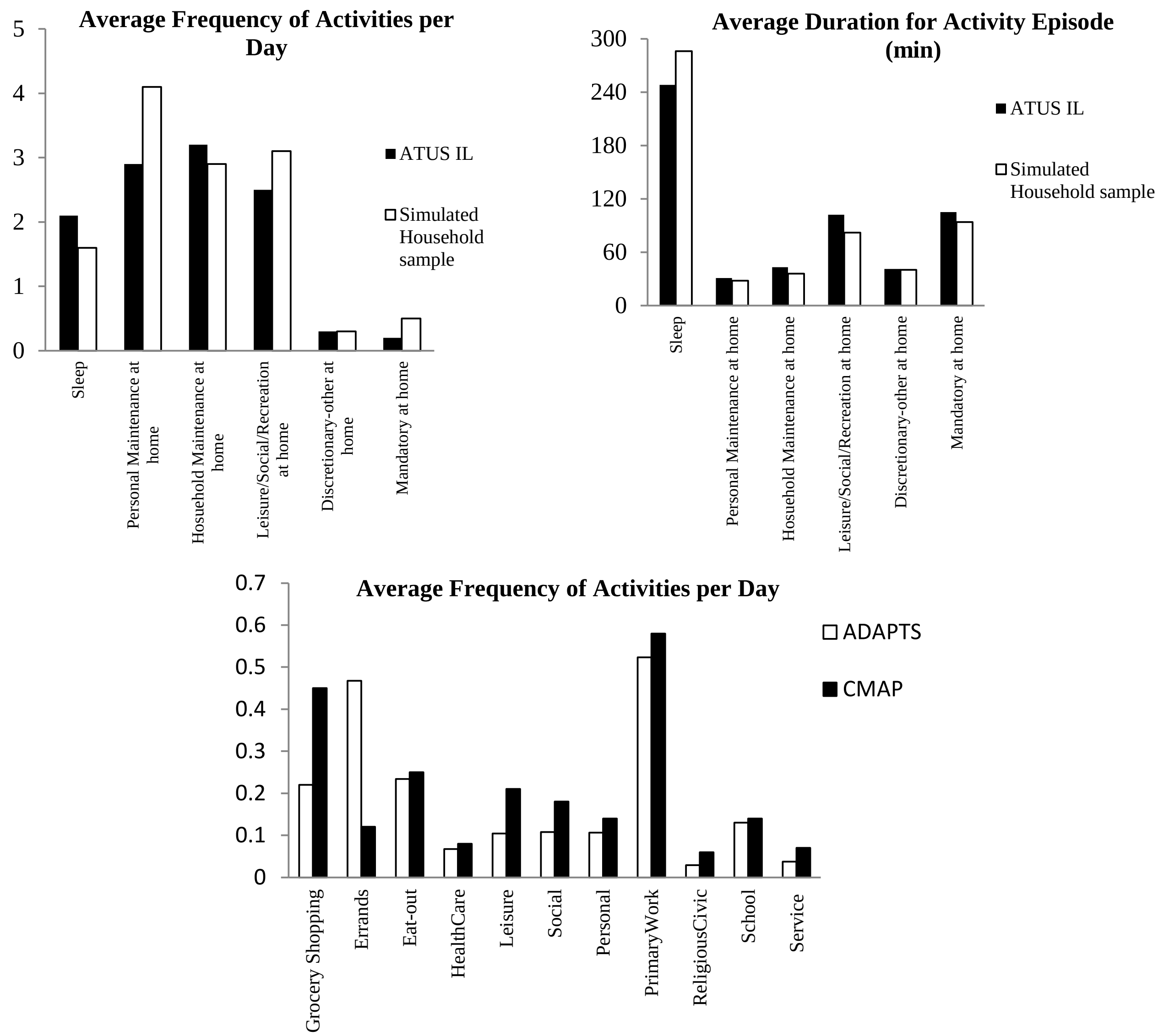
Table 61. ADAPTS ONE-DAY RECORDED ACTIVITY OUTPUT FOR AN INDIVIDUAL

HHID	PerID	ActID	Day	Start	End	Start (time of day)	End (time of day)	Act Type	Detail Activity Type	Order
18	0	88	21	21.0041	21.0236	12:05:54 AM	12:33:59 AM	33_homehousehold maintenance	Caring for hh member	1
18	0	90	21	21.0236	21.1961	12:33:59 AM	4:42:23 AM	31_sleep	-	2
18	0	92	21	21.1961	21.2268	4:42:23 AM	5:26:36 AM	31_sleep	-	3
18	0	-	21	21.2268	21.2363	5:26:36 AM	5:40:16 AM	0-Travel	-	4
18	0	0	21	21.2363	21.568	5:40:16 AM	1:37:55 PM	3_PrimaryWork	-	5
18	0	-	21	21.2268	21.2363	1:37:55 PM	1:43:41 PM	0-Travel	-	4
18	0	93	21	21.572	21.6298	1:43:41 PM	3:06:55 PM	33_homehousehold maintenance	Food/Drink Preparation	6
18	0	94	21	21.6298	21.765	3:06:55 PM	6:21:36 PM	34_leisurehome	Watching TV	7
18	0	95	21	21.765	21.7917	6:21:36 PM	7:00:03 PM	32_homePersonal Maintenance	Eating/Drinking	8
18	0	96	21	21.7917	21.8219	7:00:03 PM	7:43:32 PM	33_homehousehold maintenance	Cleaning	9
18	0	98	21	21.8219	21.8636	7:43:32 PM	8:43:35 PM	33_homehousehold maintenance	Caring for hh member	10
18	0	100	21	21.8636	21.9217	8:43:35 PM	10:07:15 PM	34_leisurehome	ComputerUse	11
18	0	101	21	21.9217	21.9592	10:07:15 PM	11:01:15 PM	32_homePersonal Maintenance	Grooming/bathroom	12
18	0	102	21	21.9592	22.0577	11:01:15 PM	1:23:05 AM	34_leisurehome	Watching TV	13

Since most out-of-home generation models are coming from hazard duration formulations that are extracted from a small survey (UTRACS), there is a possibility that out-of-home activity generations are being underestimated. The other cause of out-of-home activity underestimate might be a result of false updates of times since previous out-of-home activities of the type that had occurred based on the hazard concept. This might occasionally happen when certain pre-planned out-of-home activities are deleted in the ADAPTS conflict resolution module and the time since previous activities are not updated accordingly. On the other hand, Errands activity is largely overestimated. This must come from activity naming misinterpretations since the data for CMAP extracted from Joshua et al 2010 shows a very high level of grocery shopping activities. This value seems to be more correct for all shopping activities rather than just grocery shopping. Therefore, it seems that the errand activity that is generated by ADAPTS also include shopping activities other than grocery shopping. In other words, the sum of errands and grocery shopping should be considered as the basis for comparison.

In terms of activity duration, the ADAPTS seems to underestimate the ATUS average. Except for sleeping, other in-home activities have shorter durations assigned per episode. This might be simply interpreted for the fact that higher frequency assigned to activities will lead to shorter episode durations since days are constrained to 24 hours. In other words, it seems that the total daily duration per activity for the simulated sample is considerably similar to that from the ATUS data.

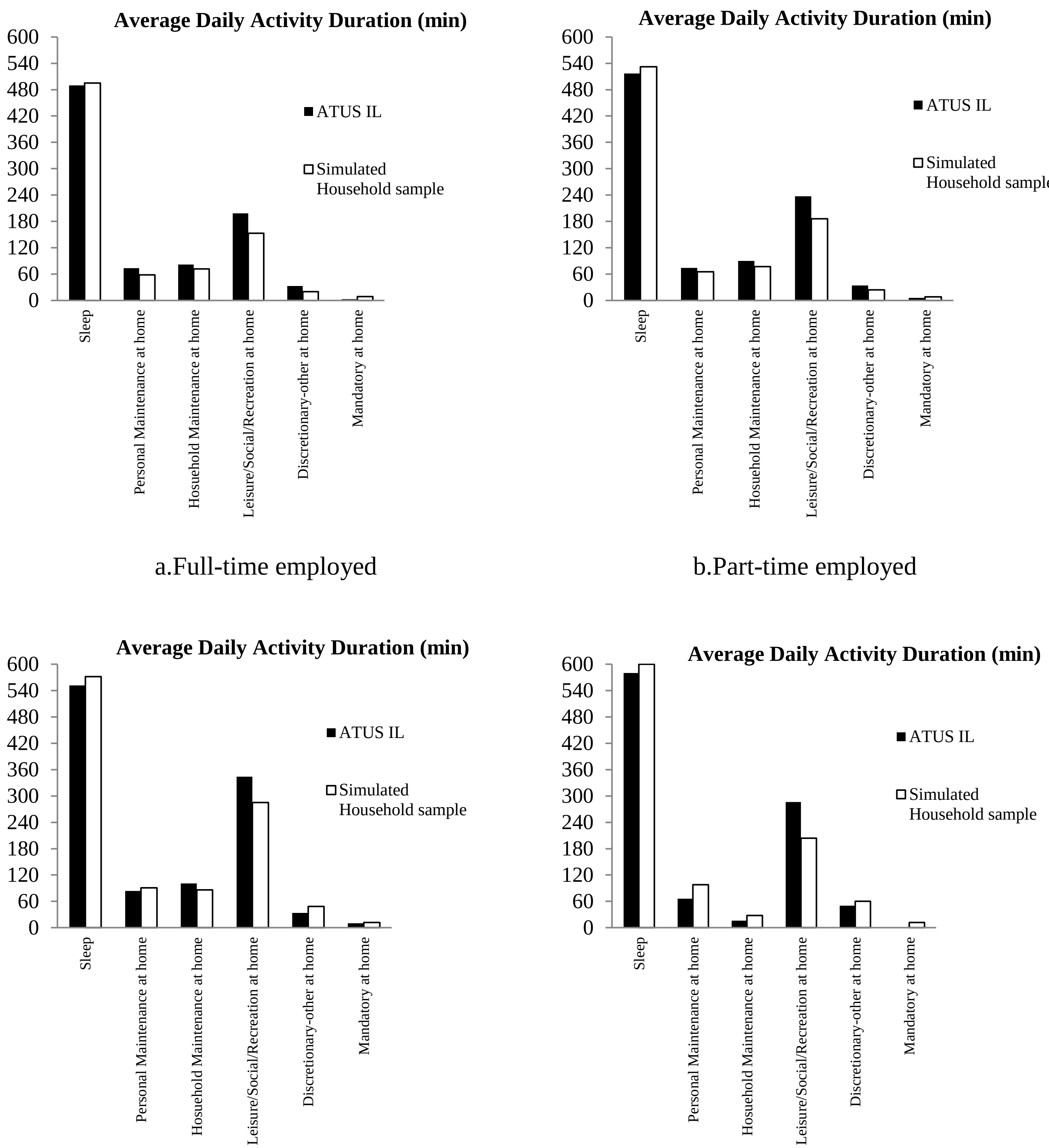
Figure 18. In-home Activity Count and Duration



ACTIVITY PATTERN BY SOCIODEMOGRAPHICS

After examining the simulation results by activity count and episode duration, it is time to see how various sociodemographics are simulated. For validating the heterogeneity of individuals in terms of their activity diaries, four important sociodemographics' aggregate recorded schedules are compared. The simulated results show the right hierarchy of daily activity durations by different sociodemographics. The sleep pattern is consistent with the ATUS average as it shows a descending duration from children, unemployed, parttime and fulltime employed respectively. This pattern was earlier observed in the ATUS data. The simulation also replicates a consistent pattern for household maintenance. The unemployed and parttime employed engage in household maintenance activities the most as is approved by ATUS. One common point among all figures is the duration underestimate for most in-home activities. Whether this underestimate comes from the sampling variations or it is statistically significant requires more investigation. However, the overall relative pattern of in-home daily activity durations seems acceptable. Also, one reason of underestimate might come from activity disconnections within 15 minutes. To avoid these disconnections, the recorded data must be post-processed so that the consistency of the schedule would be preserved. These all require extensive refinement of the software architecture that can be implemented overtime.

Figure 19. Activity Duration by Sociodemographic Categories



a.Full-time employed

b.Part-time employed

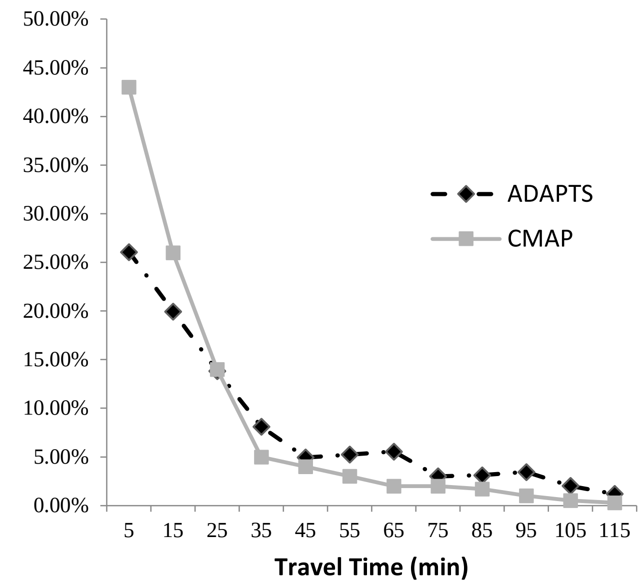
c.Unemployed

d.Children

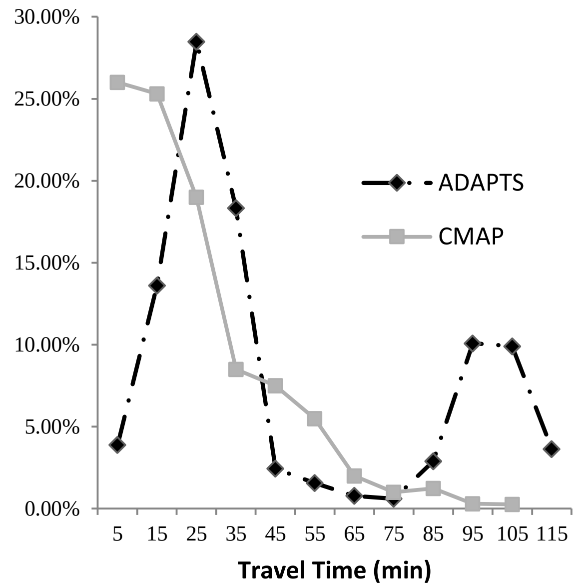
SIMULATED TRAVEL PATTERN STATISTICS

In addition to activity frequency and duration metrics, travel related measures for the auto/passenger mode were also investigated for examining simulation performance. Initially, travel time frequency statistics were recorded from the sample simulation in ADAPTS. For a comparison standpoint the CMAP travel time frequency measures were plotted. Even though it is expected that the CMAP average travel time is higher than the ADAPTS due to embedding traffic impacts, the simulation results show the opposite. This might have a number of causes that requires extensive investigation. First, it might occur from the stop-sign based traffic flow simulation in ADAPTS versus actual traffic light simulation. Second, the location choice model might not have a reliable performance and individuals are typically assigned to farther locations. Third and foremost, this might be due to a biased sample which does not represent the Chicago metropolitan. The 10,000 household sample mostly includes individuals from the suburban area. The simulated results are also plotted by trip purposes. From Figure 20, it can be understood that the most anomaly in the data is captured in work trips. The figure shows that in observed data from CMAP, more than 50 percent of work trips take as long as fifteen minutes, while in the simulated results less than 20 percent of the sample drive as long as fifteen minutes which means that the data includes more commute trips. Almost similar pattern is observed for the shopping and leisure trips which mostly implies either a fundamental difference between the sample and the CMAP data or an erroneous location choice model. However, the general pattern between the rip purposes is preserved according to the CMPA data. It seems that recreational trips are the longest ones both in the simulation and the observed CMAP data.

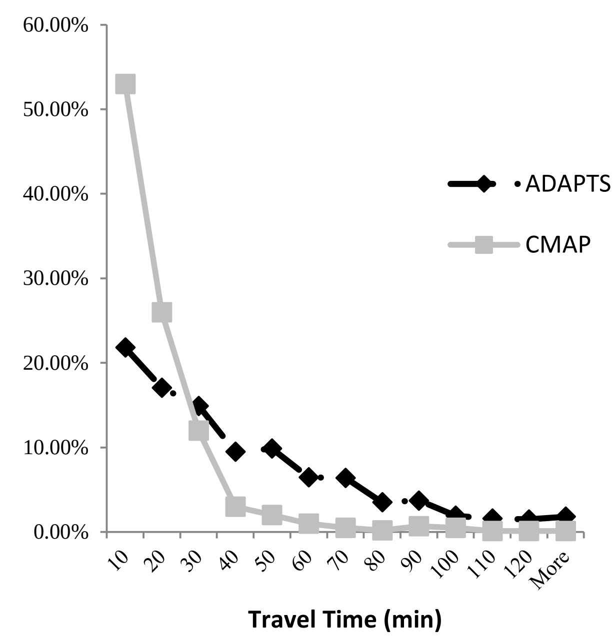
Figure 20. Auto/passenger Travel Time Frequency



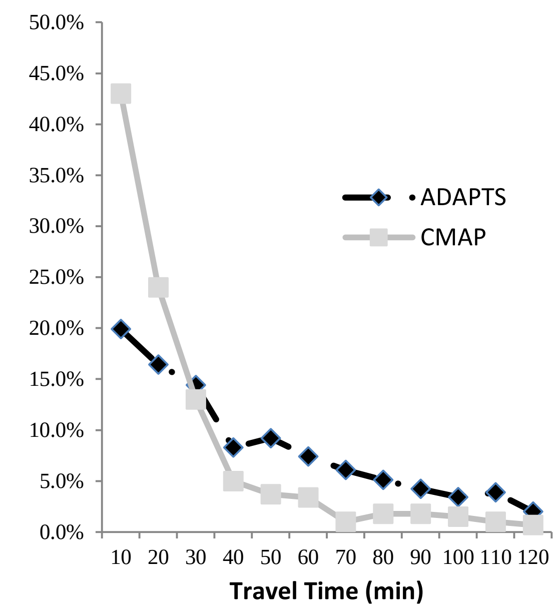
a) All Trips



b) Work Trips



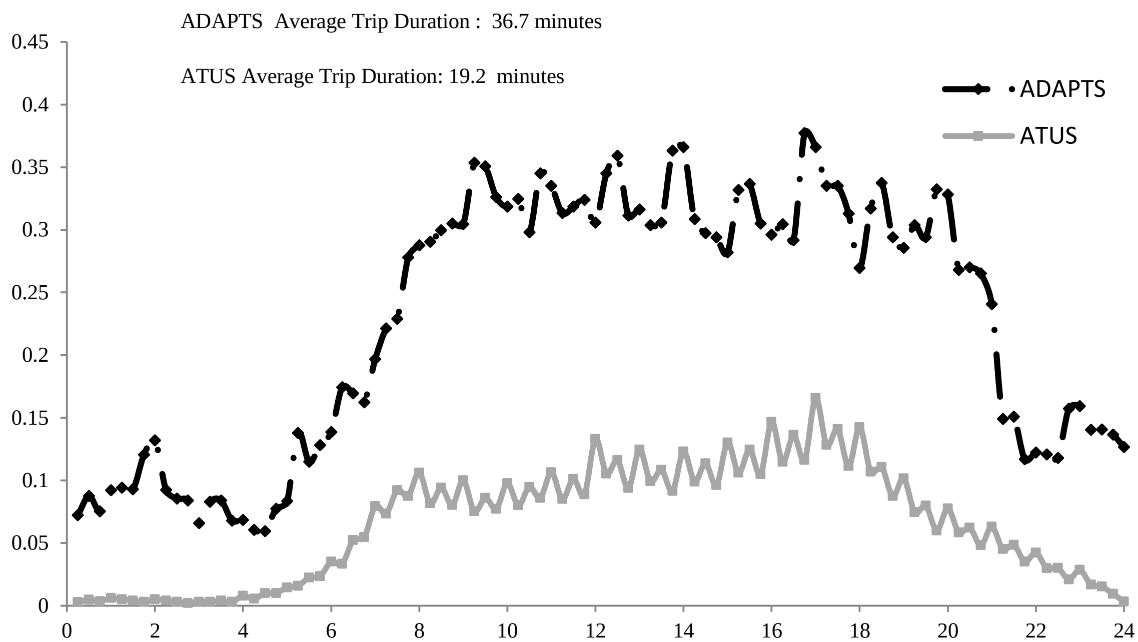
c) Shopping Trips



d) Leisure/Recreational Trips

The next graph represents the time of day travel engagement for the simulated model versus the CMAP data. This graph shows the frequency of people engaged in travel in 15 minute intervals. There is a significant difference between the two graphs that shows that at any given 15 minute interval, there are at least 2 to 3 times more people engaged in travel in the ADAPTS simulated sample than the ATUS observed data. This basically comes from the previous lead where we noticed that the average travel time in the ADAPTS is approximately 2 to 3 times higher than the CMAP data. Therefore, all these aggregate results show that we require a calibration process for the overall ADAPTS modules including the location choice model as well as the traffic assignment. Certainly, any part of the overall framework could cause these variations.

Figure 21. Time of Day Frequency of Auto Travel Engagement



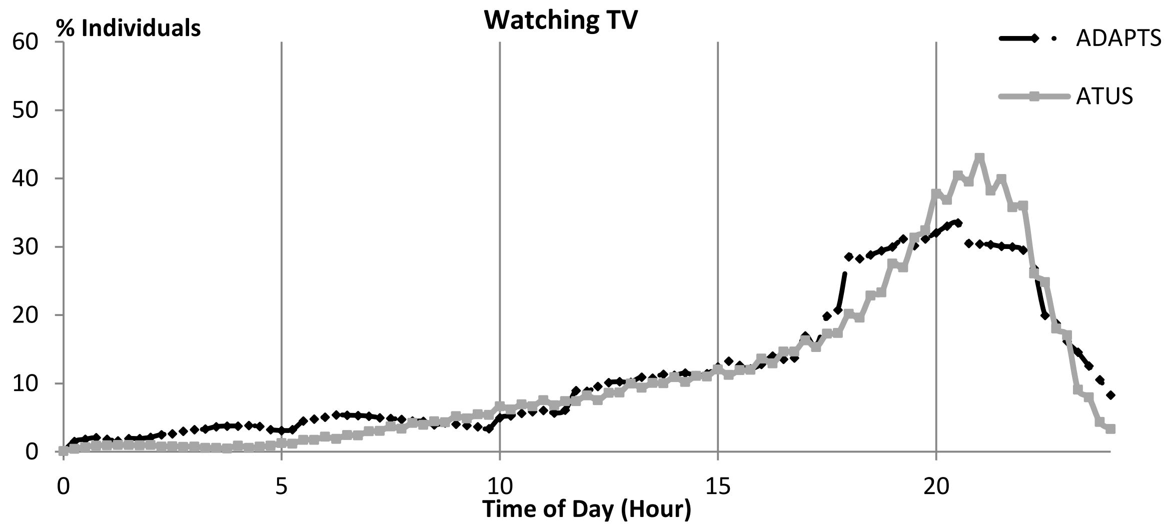
DISAGGREGATE IN-HOME ACTIVITY FREQUENCY

As mentioned, ADAPTS captures the prediction of detail in-home activity types. Among the simulation results, detail in-home activity measures are interesting to look at. Table below shows the average daily frequency of detail in-home activity types over a week of 10,000 household activity microsimulation. These detail in-home activity models are of decision tree format as discussed in the previous chapters which are embedded in the microsimulation. The aggregate result of the microsimulation shows that individuals have 2.04 eating/drinking activity episodes per day at home compared to the ATUS 1.41 episodes. Since fewer out-of-home activities are being generated, the frequency of in-home activities are being overestimated. However, this simulation could lead to better results after embedding the pairwise in-home and out-of-home comparison models. Grooming/Washing activities are also overestimated by 0.63 episodes per day. In general, personal maintenance and leisure activities are overestimated while household maintenance activities are being underestimated. Figure 22 shows the time of day frequency estimates of Watching TV for the employed and unemployed individuals in the ADAPTS versus the ATUS observed data. In general, the simulation seems to shift the peak watching TV hour to about half an hour earlier than the observed ATUS. In the simulated results the peak of watching TV is approximately past 8 PM while the ATUS data shows it at about 9PM. However, the simulated data shows the heterogeneity between employed and unemployed individuals. From the graphs, it is clear that more unemployed individuals are engaged in watching TV than the full time employed which is preserved in the simulated sample.

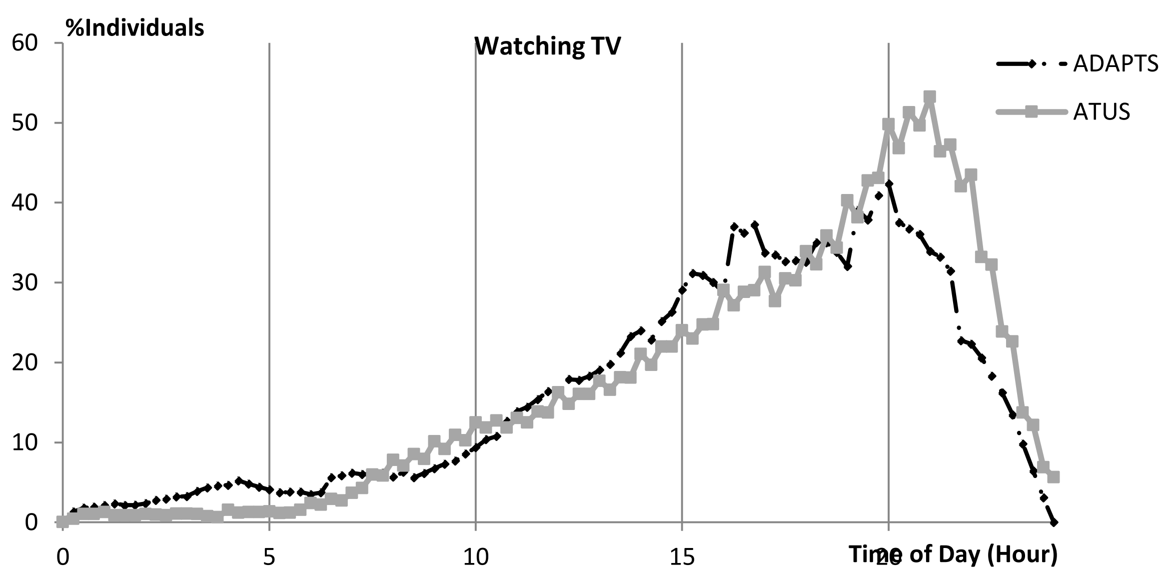
Table 62. DETAIL IN-HOME ACTIVITY DAILY FREQUENCY SIMULATION RESULT

General Activity Type	Detail Type	Example/Clarification	Average number of daily episodes IL	Average number of daily episodes ADAPTS
PERSONAL MAINTENANCE	Eating/Drinking		1.41	2.04
	Grooming/Washing	Taking a shower, using bathroom, dressing	1.27	1.9
	Health-related Self-care	Taking medicine	0.1	0.15
	Personal Activities		0.005	0.01
HOUSEHOLD MAINTENANCE	Caring	Caring for someone	0.78	0.68
	Cleaning	Cleaning the house or kitchen, washing dishes	0.59	0.48
	Food/Drink Preparation		0.81	0.66
	Household Management	Checking emails, financial management	0.28	0.25
	Laundry		0.23	0.25
	Other Household Activities	Fixing, Decorating	0.5	0.40
LEISURE/ RECREATIONAL/ SOCIAL	Computer Use	Just for leisure	0.14	0.19
	Drug Consumption		0.01	0.01
	Hobbies/Games		0.11	0.14
	Radio/Music		0.03	0.04
	Read/Write		0.3	0.43
	Relax/Think		0.16	0.22
	Social/Communicate		0.24	0.2
	Exercise	(at home)	0.06	0.05
	Watch TV/Movies		1.44	1.67

Figure 22. Time of Day Frequency for Watching TV



a. Full time employed



b. Unemployed

Chapter 8: Conclusion and Future Work

A literature review of the travel demand modeling reveals that less effort has been assigned to capturing the associations between in-home and out-of-home activities in the way trips are formed. This dissertation was dedicated to develop an activity-based modeling platform that not only examines the activities that directly lead to travel, but also an overall picture of all daily activities individuals are engaged in. It was mentioned that frequently, activities such as in-home engagements change the way individuals make trips. It was emphasized that most activity-based models focus on out-of-home activities for travel demand modeling while many in-home activities directly or indirectly induce or mitigate the need for travel. Therefore, there is a necessity to develop activity-based models with a broader activity perspective to target these associations. As a result, this thesis contributes to both the theoretical modeling and the implementation platform for incorporating in-home activities into activity-based models. The vision for this effort is to generalize activity-based demand modeling to various applications such as electricity and water consumption that are tightly associated with activity engagements at home.

One of the important concerns for embarking this study was data availability. Since activity planning and scheduling process is less observed in the surveys certainly for the case of in-home activities, the models developed in this framework mostly rely on observed activity instances rather than planning process behind them. Yet, once the models were developed, they were integrated consistently with the previous models developed in the ADAPTS so that the dynamic planning process would be preserved with minimal conflicting assumptions. The main source of data for the explanatory analysis and model development is the American Time Use Survey which is conducted annually in a national scale. The data provided the most reliable in-home activity information in detail format and was used in all the model developments.

The explanatory analysis of ATUS data reveals the factors that cause time use variations, among those the significant factors include sociodemographic segments, gender, time of day and day of week. Socidemographic segments included full time employed, parttime employed, unemployed, retired, children and adult students for which various in-home activity type time use pattern was explored and insights where used for the modeling effort.

Subsequently, ADAPTS overall framework was redesigned to incorporate in-home activities. A revised ADAPTS framework allowed to visit the interaction of in-home and out-of-home activities with a general assumption that preplanned out-of-home activities have priority to conflicting in-home activities. The interaction of in-home and out-of-home activities was limited to a competition between impulsive out-of-home activities that interfered with on-going in-home activities for which Revise Pairwise modeling framework was proposed. In-home activities were generated in an impulsive manner and out-of-home activities were dynamically planned and scheduled with the simulation time.

The theoretical contribution this thesis offers is the development of three types of modeling frameworks. First, a sequential in-home activity type, duration and detail type framework that incorporates a wide range of constituent models within the ADAPTS framework were developed. This type of conditional sequential modeling, at each time step, predicts which general in-home activity type an individual engages in and for how long, then, it determines which detail activity type it is. A set of joint MNL, hazard-based and decision tree cluster-based models define the sequence of predictions.

Second, the thesis offers a Reverse Pairwise modeling framework to be used for conflict resolution instances between in-home and out-of-home activities. This type of modeling provides a general solution for binary comparison problem while the observed data is multinomial. The formulation was achieved and a convex closed-form likelihood function was offered for these types of problems. After theoretical formulation, it was then applied to solve the conflict resolution problem in ADAPTS. The comprehensive set of models can then determine how individuals compare detail in-home activity types with out-of-home ones and which one they select to engage in at any given time. The next type of models developed are joint copula model of in-home activity type and duration. These joint models take into account the correlation between the activity type and duration error terms. Even though these models were not used in the implementation, they can potentially replace the sequential modeling framework.

Eventually, a great effort was put to implement the sequential modeling framework within the ADAPTS software. For output validation, the ADAPTS was given a random 10,000 household population and activity results were extracted and aggregate statistics were recorded to be compared with the ATUS data. The result showed the potential areas of improvement.

In the future, the estimated Reverse pairwise models need to be implemented which are suspected to adjust the activity frequencies. Furthermore, all ADAPTS out-of-home activity models including activity location choice models as well as the traffic assignment modules must be calibrated. The result of the model shows higher travel times than expected which emphasizes the importance of validation and calibration in future efforts.

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