ABSTRACT

Title of Document:	ANALYSIS OF ACTIVITY CHOICE: THE ROLE OF ACTIVITY ATTRIBUTES AND INDIVIDUAL SCHEDULES
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Activity-based approaches have taken hold in transportation research over the last several decades. The foundation of the activity-based approach is to view travel as a result of our activity choices and scheduling decisions. Therefore, better understanding of activity choice, planning time horizons, and activity attributes will lead to more accurate demand forecasts. This dissertation extends the current activity choice modeling framework by incorporating the characteristics of the individuals' schedules, planning time horizons and focusing on the salient attributes of the activities.

This study consists of three parts which are linked to one another by their conceptual and empirical findings. The first part identifies the determinants of the planning time horizons - defined as when people decide about performing their activities. Several household and individual characteristics, and activity attributes are

tested for their association with planning times. The activity attributes which have significant impacts on the planning time horizons of the activities are used in the second part for generating new activity groups. The second part clusters activities based on their salient attributes, such as duration, frequency, number of involved people and flexibilities, rather than their functional types (work, leisure, household obligations, etc.) and creates activity groups such as “long, infrequent, personally committed activities”, “quick, spatially fixed, temporally flexible activities” etc. The activity groups generated in this part inform the activity choice modeling structure developed in the third part. The main analytical techniques used in this research are the Principal Components Analysis (PCA) and discrete choice models. PCA is used to define the new activity groups. The analysis of the planning time horizons and activity choice are performed by mixed logit models.

The model results reveal the significant relationships between socio-demographics, temporal characteristics, travel, and characteristics of the schedules on activity choice. The findings of these models could be integrated in the activity choice modules of the existing activity-travel simulation models by either applying the comprehensive model (which may face limitations due to the availability of data) or integrating the findings of the models in the decision rules.

ANALYSIS OF ACTIVITY CHOICE:
THE ROLE OF ACTIVITY ATTRIBUTES AND INDIVIDUAL SCHEDULES

By

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Dedication

This dissertation is dedicated to my mum Oznur Unsal, dad Levent Akar, and my beloved husband Nima Ghalichechian. Without you, I would not be able to accomplish this…

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I would like to thank my advisor Dr. Kelly J. Clifton for her guidance and endless support throughout my doctoral studies. She has guided me in every aspect of this road; technical, personal and professional, preparing me for my future career. Thanks to my committee members Dr. Paul Schonfeld, Dr. Qing Shen, Dr. Ali Haghani and Dr. Cinzia Cirillo. Special thanks to Dr. Cinzia Cirillo for spending time with me on details and passing her knowledge enthusiastically. Without her, it would be difficult to accomplish all these models. Many thanks to Dr. Sean Doherty (Wilfrid Laurier University) for allowing me to use the CHASE dataset, without which it would have been very difficult to carry out this research. I am grateful to David Allen (director of DOTS-UMD) for his kindness and understanding during the time I was working with him. Many thanks to my friends, especially Rahul Nair, Sevgi Erdogan, Carolina Burnier, Aysun Alp, Kaveh Farokhi and Masoud Hamedi. With them, I shared the most fun and also most difficult moments of my Ph.D. years. Finally, I would like to thank the Graduate School for the Ann Wylie Fellowship, which allowed me to focus on my dissertation during my last year.

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1. INTRODUCTION

There are increasing concerns about the high levels of traffic congestion, mobile-source emissions, and the sustainability of our growth patterns and travel. In light of these concerns, many metropolitan areas are shifting towards transportation demand management (TDM) policies, such as: congestion pricing, flexible work hours, and car sharing programs, instead of expanding the existing physical transportation infrastructure. As the way these policies work is by changing the behavior of individuals, they bring certain challenges into travel demand forecasting methods. Individuals adjust their behavior in complex ways motivated by a desire to achieve their activity objectives (Bowman and Ben-Akiva 2001). For example, individuals may tend to schedule their activities at different times and locations to be able to avoid peak hour traffic and congestion tolls if there is any flexibility associated with the time and location of the activities. Estimating the complex nature of responses to these demand management strategies can only be possible with incorporating realistic decision making processes in the demand analysis.

To be able to make informed transportation policy and infrastructure decisions, planners and engineers have to be able to forecast transportation demand under changing household and individual characteristics and different policies. This requires the integration of the complex human decision making process in modeling transport to have realistic representations of individual and household activity and travel decision making.

This need for better understanding of the motivations for travel has led to the emergence of the **activity-based approach** to studying travel behavior. One of the

fundamental principles in transportation research is that travel demand is derived from the need to participate in activities that are spatially and temporally distributed (Bhat and Koppelman 1999; Kitamura et al. 1997; Pas and Harvey 1996). Consequently, understanding travel behavior and predicting travel demand depends on understanding activity participation: how, why, when, how often, where, and with whom the activities are performed.

As the activity-travel schedules of the individuals are at the heart of the activity-based approach, it is very important to understand how people make their activity choices and incorporate these in the modeling. Therefore, **the research aim of this study is to understand how people make their activity choices and develop a new activity choice framework.** More specifically, this study aims to build on the previous research by extending the current activity choice modeling framework by **incorporating the characteristics of the individuals' schedules, planning time horizons and focusing on the salient attributes of the activities.**

Activity-based travel demand analysis was first proposed as an alternative to trip-based modeling (Kitamura 1996; Pas and Harvey 1996). The limitations of trip-based models have been discussed by many authors (Bowman and Ben-Akiva 1996; Kitamura 1988; McNally and Recker 1986). For example, the four-step (trip-based) model of travel demand forecasting has been criticized for lacking a valid representation of underlying behavior. This approach focuses on individual trips, therefore ignores the fundamental principle of travel demand, that travel is a derived demand from the demand for activity participation. As the fundamental units of analysis are trips, that are aggregated at production and attraction ends, the spatial, temporal and interpersonal *links* and

constraints between the trips and activities in individual's activity pattern are not considered. This has important consequences for the ability to capture the dynamics of travel decisions and produce accurate forecasts.

The following figure, Figure 1 illustrates the basis of the activity-based framework. The individuals' and households' socio-economic characteristics and lifestyles, together with the opportunities and constraints of the external environment (the availability of activity centers, locations) and network travel characteristics affect the activity-travel choices of the individuals. These decisions over time lead to individuals' activity and travel agendas. At the aggregate level, the outcomes of these decisions affect the overall travel demand and this demand, naturally, have implications on the original transportation system characteristics. Consequently, any policy that affects the activity-travel decisions of individuals may cause changes in the overall transportation characteristics. These changes may be through demand management policies (such as congestion pricing, car-sharing, etc.), through increased use of technology (online banking, tele-working, etc.) and changes in the household and individual attributes.

The following sections, Section 1.1 and 1.2 introduce the important factors contributing to the generation of the activity-travel schedules which are of particular interest of this research, including activity attributes, activity groups and planning time horizons. Section 1.3 presents how these factors shape the motivation and specific aims of this study, followed by the conceptual framework for this research, Section 1.4.

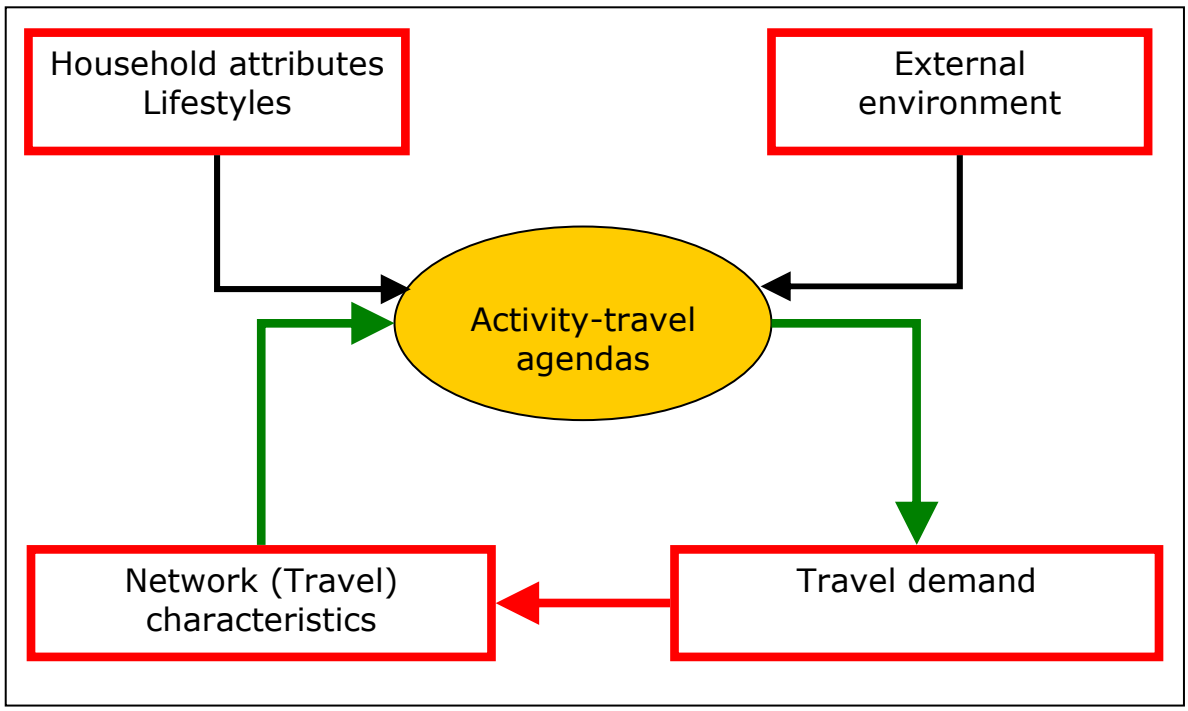

Figure 1: The conceptual framework of activity-based approach

1.1 The Importance of Activity Groups and Attributes

One analytical issue in activity-based analysis is the classification of activities in discrete groups. The basis for these classifications is that the underlying motivations for participation in various types of activities are different and thus have distinct implications for travel demand forecasting. This approach, referred to as the ***traditional approach*** (Doherty 2006), groups the activities based on their ***function (or purpose),*** such as work, leisure, etc. Many researchers studied the activity choice, considering the activities based on the following groupings: mandatory activities (work, school, etc.), household maintenance activities (cleaning, meal preparation, etc.) and leisure (social events, exercising, etc.) activities (Akar et al. 2007; Bhat and Lockwood 2004; Bhat and Gossen

2004; Golob and McNally 1997; Kemperman et al. 2006; Lu and Pas 1999; Yamamoto and Kitamura 1999).

However, recent studies argue that the boundaries between leisure, mandatory, and maintenance activities overlap due to the multi-attribute nature of activities, increasing fragmentation, and multi-tasking (Mokhtarian et al. 2006). In addition to this, activities that have been considered mandatory, such as work, may involve certain discretionary elements, while those classified as discretionary, such as pre-planned social events, may be to some extent mandatory due to prior commitments (Yamamoto and Kitamura 1999). The increased choices brought about by technology have long been the subject of inquiry of researchers interested in the potential substitution and complementary effects of ICT (Information and Communication Technologies) on travel demand (Handy and Yantis 1997; Mokhtarian and Salomon 2002). Activities, which were previously subject to temporal and spatial constraints, now have more flexibility about when, where and with whom they are conducted (Clifton et al. 2007). For example, people may be able to work from home for all or part of their work day; on-line banking eliminates the need to travel to a financial institution during business hours to conduct transactions; and cable television, digital TV, and mail-order movies, combined with home theatre systems, provide more options for in-home entertainment.

Activity choices ultimately have implications for travel demand and thus, it is important to understand the factors associated with them. Consequently, calls have been made to replace these traditional activity groupings with more ***salient attributes of the activities***, including their frequency, duration, travel required, and flexibilities (Doherty 2006). From a transportation standpoint, it is critical to identify the attributes of activities

that make them unique since these attributes may have significant impacts on travel. For instance, the location and duration of the activity, the spatial, temporal and interpersonal flexibilities associated with the activity are some of the key determinants of related transportation patterns.

As a result, investigating the activity attributes more in-depth, from a different perspective, and looking at how these attributes affect the activity choice remain to be studied. Doherty (2006) sets the ground for this and starts challenging the traditional activity groupings; however, no one has performed an activity choice modeling based on these new grouping ideas. Still a wider variety of activity attributes need to be explored and incorporated to modeling efforts.

1.2 The Importance of Planning Time Horizons

Planning time horizons are defined as *the time when the individuals decide about performing their activities* (Doherty 2005). As the observed travel patterns are the results of an underlying activity scheduling process, understanding and modeling these decisions is vital for modeling activity-travel patterns.

Many changes in policy (for instance through TDM strategies) would result in changes in the attributes or distribution of activities on the agenda. This would then invoke a scheduling response and subsequent changes in activity and travel patterns (Bowman and Ben-Akiva 1996). For instance, the implementation of flexible work hours would in the first instance lead to changes in scheduling.

Some of the activities in our schedules are *planned well in advance*, some of them exist in the schedules *as a part of a routine* and some of them are added to the schedule very close to the execution time, *spontaneously*. These timing mechanisms need to be

replicated to be able to develop behaviorally realistic activity scheduling models, as they introduce constraints and opportunities for the subsequent activity-travel choices.

When individuals enter their pre-planned, fixed and routine activities to their schedules, these bring many temporal, spatial and interpersonal constraints into their agenda. In addition, the activities to be chosen (after the pre-planned, fixed and routine activities are added in the schedule) also have certain constraints, routine and variable elements and flexibilities associated with them. As a result, the individuals make their activity decisions subject to the **constraints of the schedule** and the **attributes of the activities**.

The **activity-travel simulation models** attempt to replicate the way individuals make their schedules and execute their activities in order to evaluate the effects of policy changes and forecast travel demand (Arentze and Timmermans 2004; Bowman and Ben-Akiva 1996; Doherty 2005; Ettema et al. 1993). They typically form initial, ***(skeletal)***, schedules from a list of activities to be performed, and then the other activities and travel are added to the schedule subject to the spatial, temporal and personal constraints and opportunities.

In practice, a fixed order of sequencing is assumed based solely on the activity type. While there have been calls to revisit this assumption (Mohammadian and Doherty 2005; Roorda et al. 2007), research on forecasting the planning time horizons with a focus on activity attributes and robust travel measures has been lacking.

This is particularly important as the *attributes of the activities may be subject to change while the function of the activity may be still the same*. For instance, the increasing availability of internet and web services enabled people to conduct their

banking activities online, which may have changed (reduced) the time required for the activity and brought temporal and spatial flexibilities. These attributes may also vary across individuals and households.

As a result , while the existing literature highlights the importance of the replicating the timing decisions (planning time horizons) for achieving behaviorally realistic travel demand models (Doherty 2005; Mohammadian and Doherty 2006; Roorda et al. 2007), the links between the planning time horizons and their association with activity and travel attributes is one of the areas where still many questions remain.

1.3 Conceptual Framework

The motivation for this study stems from the gaps in the existing research. Better understanding of activity choice, planning time horizons, and the activity attributes affecting the choice process will improve the current activity-based models and allow for more realistic demand forecasts. Accordingly, this research aims to build on the previous research by extending the current activity choice modeling framework by incorporating the characteristics of the individuals' schedules, planning time horizons and focusing on the salient attributes of the activities.

The choice to participate in a given activity is a function of various phenomena and is a complex decision. There are several direct, indirect relationships and feedback loops among the determinants of activity choice. The socio-economic characteristics of the individuals and the external environment influence the daily and weekly patterns of activities for individuals and the choice for each activity episode is partly a function of these decisions, the opportunities and constraints introduced by the activity attributes and

the available time window. The constraints introduced by the activity attributes may be in various dimensions, such as: temporal, spatial and interpersonal.

The activities in people's schedules may be ***pre-planned***, planned as a part of a ***routine*** or ***impulsively*** and these activities may have ***fixed*** and ***flexible*** components. The concepts of being flexible or fixed describe the degree to which activities could take place at different times, locations, with other people, for other people and alone. The ***routine*** activities are considered as the activities which take place at the same time and place with similar interpersonal characteristics, such as work related activities. The routine activities generally have ***fixed*** components (time, space, people) associated with them. There are other activities whose location and time can not be changed, therefore have fixed components, such as medical appointments. The ***flexibility*** of an activity indicates that the person has the choice to perform this activity at different locations, different times, with or without other people. For example out-home meals may have these flexibilities and therefore vary in time and place. On the other hand, many activities may have both fixed and flexible components. For example, eating lunch may be temporally fixed for a regular employee; however, the location and the interpersonal characteristics may be flexible.

The choice of one activity subsequently affects future activity patterns, both directly (by the activity performance itself; a person who performs a certain type of activity may choose not to conduct the same activity the next day), and indirectly (through the temporal, spatial and interpersonal constraints and opportunities it brings to the daily and weekly schedule). As these decisions, over a period, are not independent

from one another, it is extremely important to consider the fixed and routine schedules when analyzing activity choice.

Within this framework, the **activity attributes, planning times** and the **scheduling attributes** are of particular interest. In this study, **it is hypothesized that the activity attributes are important determinants of the planning time horizons**. For example, temporally and spatially flexible activities are more likely to be planned closer to the execution time, personally fixed and long activities are planned as a part of a routine, etc.

This research assumes that after individuals plan their routine and pre-planned fixed activities, the schedule is left with time blocks to be filled with other activities and for each available time window, a *decision making* act is performed to choose the activity (type, duration, location, etc.) to be scheduled. This is illustrated in Figure 2. For the sake of simplicity only one day is shown. In Figure 2, the routine activities may be school/ work related activities or exercising and the fixed activity may be a medical appointment or a pre-planned social activity, such as hosting visitors.

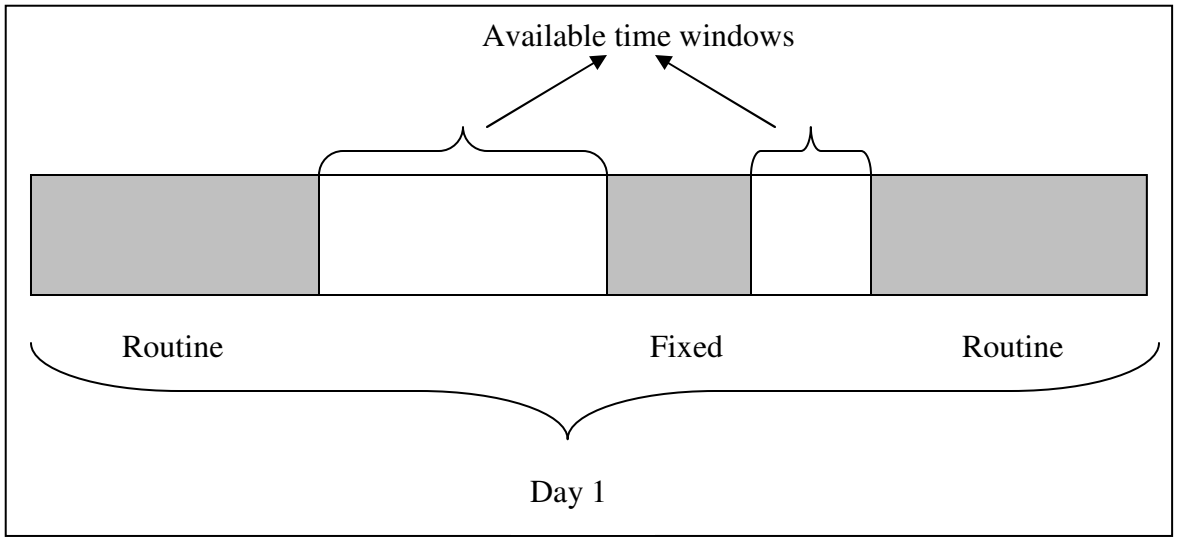

Figure 2: Routine schedule, fixed activities and available time windows

The activity attributes are given the upmost importance while developing the choice model for these available time windows. In this study, the activities are grouped based on their attributes which make them unique (such as duration, frequency, number of people involved and flexibilities), and these groups are taken as the starting point for the choice set. Figure 3 illustrates the approach using the traditional groupings of mandatory, leisure and household obligations, and the approach taken in this study for developing the choice set. The motivation for the approach followed in this study is to improve the behavioral representation of the choice process by incorporating the activity attributes in the analysis and shifting from the approaches that group the activities based solely on their traditional types.

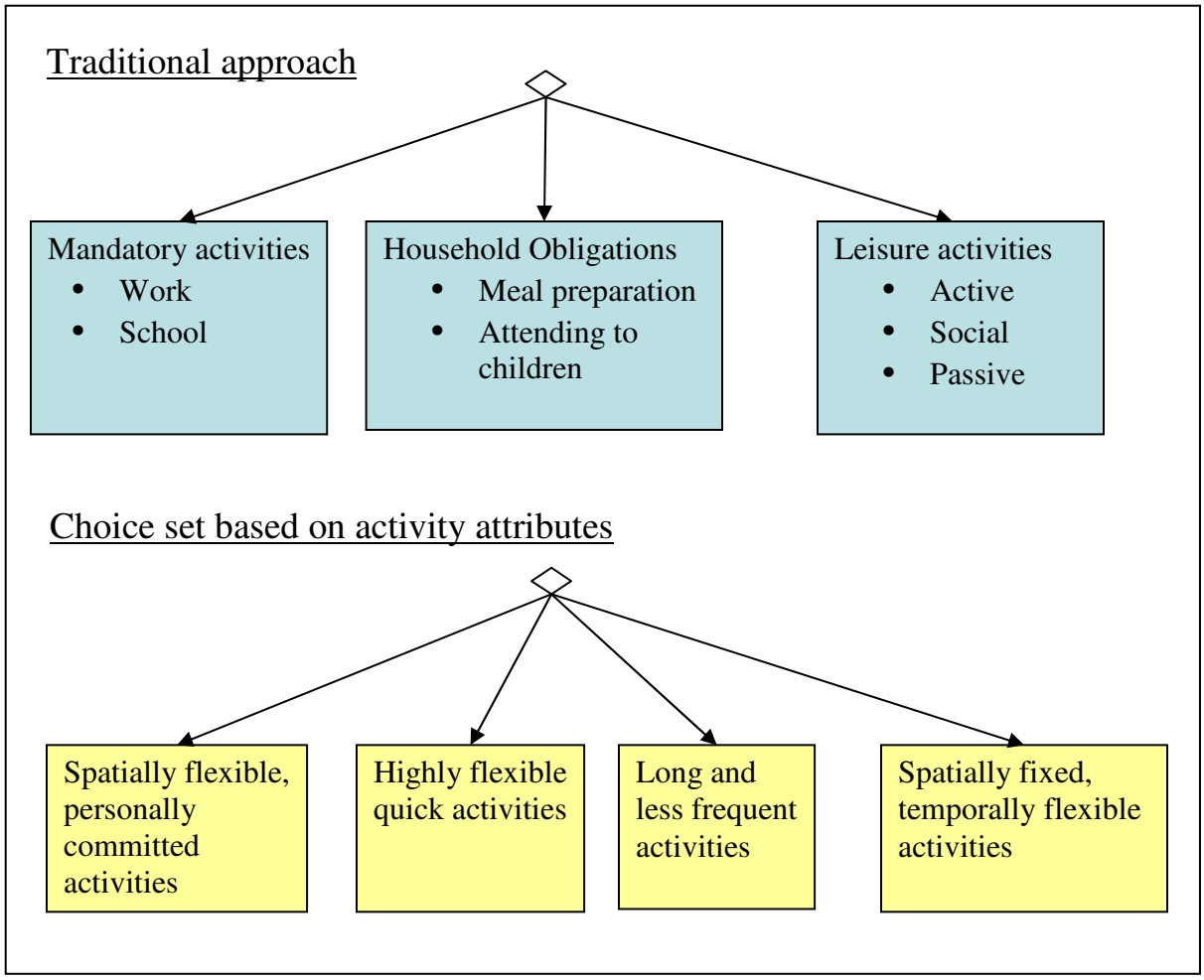

Figure 3: Activity Choice Set: Traditional versus Activity Attributes

1.4 Organization

This dissertation is organized as follows. The next chapter, Chapter 2, discusses the activity-based approaches to travel demand modeling, their applications, planning time horizons and presents the various ways of aggregating activities into groups. This is followed by an overall synthesis of the literature, identifying the gaps and how this study adds to the existing knowledge.

Chapter 3 discusses the methodology used in this research. This study consists of a three stage research design which consists of: *(1)* The analysis of planning time horizons and developing a model predicting the planning sequence, *(2)* Grouping the activities based on the attributes that have significant effects on their planning times and, *(3)* Developing a new activity choice model by structuring the choice set with the findings of the previous stage (the new activity groups). These three stages are linked to one another by their findings. In addition to the research design, the dataset used for the empirical analysis is also introduced in Chapter 3 with a review of its advantages and disadvantages, followed by the econometric approaches employed in this study.

A detailed analysis of planning time horizons based on the empirical data is presented in Chapter 4. Mixed logit models with random coefficients are formulated to analyze the effects of activity attributes, socio-demographics and travel characteristics on the planning time horizons. The activity attributes which have significant effects on the planning time horizons are identified as the attributes which make the activities unique and utilized to generate new activity groups in the next chapter, Chapter 5.

Chapter 5 groups the activities based on their attributes and generates new activity groups such as: temporally flexible and personally committed activities; short, spatially flexible, frequent activities, etc. These groups are then further analyzed in terms of how the activities grouped based on their function (such as household obligations, work, etc.) measure against these new categories. The findings of this chapter reveal that activities which have been categorized in different groups based on their function (leisure, work, etc.) may have similar attributes and therefore belong to the same group based on their attributes.

Chapter 6 presents the new activity choice framework with the activities grouped based on their attributes. The structure of the choice set in this framework is based on the new activity groups created in Chapter 5. The model results reveal the significant relationships between household and individual characteristics, temporal characteristics, travel, and characteristics of the activity-schedule on activity choice.

Chapter 7 discusses the findings of this research in terms of its main contributions. This research contributes to the existing body of knowledge by developing a new activity choice framework, analyzing the planning time horizons of the activities and grouping the activities based on their attributes, instead of their function. The findings of this research reveal the relationships between the household and individual characteristics, activity attributes and schedules. The limitations of this research and future research directions are also discussed in this chapter.

As discussed before, a realistic representation of the choice process is essential for developing sound travel demand models to assess the impacts of TDM policies and changing lifestyles. The findings of this research can be integrated into the activity-choice and sequencing modules of the existing activity-travel simulation models, which are used for this purpose, to improve their resulting forecasts.

2. LITERATURE REVIEW

The factors affecting the activity and travel behavior, such as individuals' schedules, socio-demographic characteristics, activity attributes and spatial, temporal, and interpersonal constraints are studied within the activity-based framework (Ettema and Timmermans 1997; Kitamura 1988; M. Lee-Gosselin et al. 2006; McNally 2000; Pas and Harvey 1996). While several improvements have been achieved in the activity-based analysis, and the models have shifted from the theoretical stages to practice (Bhat and Koppelman 1999; Rossi et al. 2009), still many questions remain on the relationships among the activity attributes and activity groups, planning time horizons and the choice process.

This chapter reviews the activity-based approaches with a focus on activity choice, activity groups and planning time horizons. The review will start with a discussion of the activity-based approaches in general, how they emerged, their differences from the trip based approaches, and their current applications. The discussion continues with the importance of planning time horizons on developing realistic activity-travel agendas and the activity choice process. This is followed by a review of the activity categories (such as work, leisure and household obligations) and the recent calls to replace the existing categories with the ones that are based on the activity attributes. The review will conclude by a discussion of the gaps in the existing literature and how this research aims to fill these gaps.

2.1 Activity-Based Demand Modeling

Activity-based approaches have taken hold in travel behavior research over the last several decades. The development of the activity-based approach to travel demand analysis is characterized by the desire to understand the phenomenon of urban travel. The foundation of the activity-based approach is to view travel demand as derived from the need to participate in activities that are spatially and temporally distributed. (Bhat and Koppelman 1999; Bowman and Ben-Akiva 1996; Kitamura 1988; Kurani and Lee-Gosselin 1996; McNally 2000; Pas and Harvey 1996). Consequently, understanding travel behavior and predicting travel demand depend on understanding activity participation.

As activity-based approach enables us to analyze the scheduling of activities in time and space, the constraints (spatial, temporal and interpersonal) on travel and activity participation, and the interactions between activity and travel choices over the analysis period, a greater understanding of travel demand is achieved with this approach (Pas and Harvey 1996). Several methodologies are employed to analyze various phenomena such as activity choice, time allocation, in-home and out-of-home activity participation, interpersonal dependencies and daily activity patterns (Akar et al. 2007; Bhat and Lockwood 2004; Bhat and Gossen 2004; Bowman and Ben-Akiva 2001; Cirillo and Axhausen 2009; Golob and McNally 1997; Kitamura 1996; Pas and Harvey 1996).

Some of the original ideas of the activity-based approach come from the ideas set forth by geographers (Chapin 1974; Cullen and Godson 1975; Hägerstrand 1970). Hägerstrand (1970) introduced the importance of various spatial and temporal constraints

that affect the activity and travel behavior. Chapin (1974) emphasized the role of personal characteristics, needs, desires and opportunities.

Chapin (1974) argued that activities result from individuals' basic desires such as physical needs, social needs, etc. He stated that in addition to this, the *"opportunities"* (provision of services and facilities and their qualities) are important to understand activity patterns. The availability of activity centers, their attractiveness and their accessibility would affect the frequency, timing and duration of the activities associated with these centers. This idea, provided by Chapin in early 70s, is one of the theoretical underpinnings of urban land use planning, linking activity patterns to urban land use patterns (Ettema and Timmermans 1997).

Hägerstrand (1974) also argued that activities are performed because of basic needs. His work proposed that activity patterns are realized in particular spatio-temporal settings. He defined time and space as determinants of daily activity patterns and stated that the sequence of activities define a *path in space* and *time*. His contribution to this field was introducing the *prism* concept. The *prism* defines all possible time-space paths, given various constraints, individuals may choose to perform their activities.

Cullen and Godson (1975) introduced an approach which brings these two approaches together; they suggest that an individual's agenda is structured both by the motivational and psychological factors, and the time and space constraints.

Ettema and Timmermans (1997) state that Hägerstrand's time space prisms led to several models (such as CARLA, STARCHILD) which aim to identify feasible activity schedules as a function of these constraints. Hägerstrand's contribution to this field is his approach of analyzing the constraints imposed on an individual to determine how they

limit possible behavior alternatives, which is different from the traditional view where behavior was represented with observed actions (McNally 2000).

McNally (2000) discusses several characteristics of the activity-based approach that distinguish it from the trip-based models. These could be listed as:

- Travel is viewed as a demand derived from the demand for activity participation.
- The analysis is based on the sequences and patterns of behavior, not only trips. This enables the analyst consider the full array of *activities and travel behavior*.
- The influence of household and individual characteristics on travel and activity behavior is taken into account.
- The spatial, temporal and interpersonal factors that constrain activity and travel behavior are also considered.

With the increasing knowledge of technical information and data collection efforts, activity-based approaches achieved extensive progress and evolved from the theoretical stage to applications for purposes of forecasting and policy analysis (Bhat and Koppelman 1999; Bowman and Ben-Akiva 1996; Kitamura 1996; Pas 1996; Rossi et al. 2009). Many urban areas and regional agencies around the world are in the process of, or are considering the initiation of transitioning to new activity-based travel demand models.

The theoretical underpinnings of the activity-based approach are transferred into practice by activity-travel simulation models to perform policy analysis and forecasts. Some of the well-known examples of these models can be listed as: STARCHILD (*developed by Recker, McNally and Root*), AMOS (*developed by RDC Inc.*), SMASH (*developed by Ettema, Borgers and Timmermans in Netherlands*), FAMOS (*developed by*

Pendyala in Florida), TASHA (*developed by Roorda and Miller in Toronto*) and TRANSIMS (*developed by Los Alamos National Laboratory, supported by Federal Highways Administration*).

The detailed information on these models are well documented (Ettema et al. 1993; Ettema and Timmermans 1997; Kitamura 1996; McNally 2000; Pas 1996; RDC Inc. 1995; Recker et al. 1986a; Recker et al. 1986b; Roorda et al. 2008). While these activity-based models share some features in terms of their purposes and processes, they also differ from one another in certain ways. These models consist of several modules to replicate human behavior and predict choices. Several assumptions are taken as inputs in these modules; for instance, the sequence in which the activities are added to individuals' schedules are assumed to be based solely on activity types, the work location is generally taken as fixed, etc. The success of these models depend on the extent these assumptions are behaviorally realistic, nevertheless, several of these assumptions are being challenged by researchers and many aspects of activity choice are still under question.

Consequently, while these models prove that activity-based approaches have shifted from the theoretical stages to practice, they rely on several assumptions regarding the activity patterns. Confirming the validity of these assumptions and/or shedding light on the questions regarding these assumptions, including the relationships between the planning time horizons, activity groups and activity choice, will improve these models. The rest of this chapter presents a review of the literature with a specific emphasis on the areas where still many questions remain, more specifically, activity choice, planning time horizons and activity categories.

2.2 Activity Choice, Schedules and Planning Time Horizons

Activity analysis examines the activity participation, time use and the resulting travel patterns of individuals, by exploring the choice, frequency, location, duration and several other attributes of the activities. These decisions, with their planning over time, define the **scheduling** process (Doherty et al. 2002; Miller and Roorda 2003). The findings of the existing studies reveal that there are significant relationships between the ***activity attributes*** and ***activity schedules*** due to the fact that they both bring opportunities and constraints for ***activity choice*** (Doherty 2005; Doherty et al. 2002; Miller and Roorda 2003; Mohammadian and Doherty 2006; Mohammadian and Doherty 2005; Roorda et al. 2007).

While activity choice have been a subject for many studies (Bhat and Lockwood 2004; Bhat and Gossen 2004; Bhat et al. 2006; Golob and McNally 1997; Kemperman et al. 2006; Lu and Pas 1999), the focus of attention has mainly been on the methodological advances in modeling, while the nature and inherent characteristics of the activities including people involved in the activity, the flexibilities and constraints associated with the activity, the scheduling constraints, activity history, etc., have been lacking attention.

For instance, Bhat and Gossen (2004) formulated a mixed multinomial logit model for the type of recreational activity episodes that the individuals participate during the weekend using the 2000 San Francisco Bay Area Travel Survey. The recreational activities are categorized into three groups as in-home, out-of-home and purely recreational. While they examined the effects of household and individual socio-economics, land-use mix and density variables, the only activity attributes they included in the analysis were the temporal characteristics of the activities (the month and whether

the activity is performed in the morning, afternoon or evening). They did not include the variables related to activity duration, incurred travel and involved people in the activity.

On another study, Bhat et. al. (2006) extend Bhat's multiple discrete continuous extreme value model (MDCEV) to model the perfect and imperfect substitutes case from the econometric literature. In their research, they define the imperfect substitutes as the activities which serve different functional needs, such as social activities, maintenance activities, etc. The activities which serve the same functional need (for instance, recreation) are defined as perfect substitutes, such as physically passive recreation (i.e. going to movies) or physically active recreation (i.e. exercising). While these studies make important contributions on the methodological advances, they do not consider the scheduling constraints and activity attributes in their choice framework, and therefore lack the representation of the conceptual relations.

The understanding of activity schedules and how they are formed are essential to integrate these constraints and opportunities in the analysis and develop realistic activity-travel models. This leads to the need for examining these timing mechanisms; ***planning time horizons*** of the activities in detail.

There are many complicating factors in the analysis of the planning horizons, as different attributes of an activity are often planned at varying time horizons (Doherty 2005). For instance, a person may decide that she will do shopping over the weekend; however, she may decide about the location or with whom to do the shopping just prior to the activity. This level of detail remains to be a limitation on the analysis of planning time horizons due to lack of data collected for these details.

The literature suggests that people add highly routine and fixed activities first in their schedules (Doherty et al. 2002; Miller and Roorda 2003; Roorda et al. 2007). The ***routine*** activities are considered to be the activities that take place at the same time and place with similar interpersonal characteristics. The routine activities tend to have ***fixed*** components (time, space, people) associated with them. In addition to routine activities, there are other activities which have fixed components, such as medical appointments. This collection of routine activities form the ***skeletal structure*** of an individual's activity agenda (Doherty et al. 2002).

In practice, the activity scheduling models such as ALBATROSS and TASHA make simple assumptions about the types of activities that form the "skeletal" schedule. ALBATROSS assumes that the skeletal structure consists of all work, drop-off/pick-up of people or goods, medical visits, personal business, sleep and eat activities (Arentze and Timmermans 2004). TASHA assumes that skeletal schedule includes work and school activities. In both cases, the skeletal schedule is assumed to be a deterministic function of only the traditional activity type (Roorda et al. 2008).

Recent research in this field reveal that activity type is not the only determinant on activity scheduling decisions (Doherty 2005; Doherty et al. 2002; Miller and Roorda 2003; Mohammadian and Doherty 2005; Roorda et al. 2007). The individual and household characteristics and the activity attributes (such as the flexibilities involved, duration, location, and involved people) play an important role. The incorporation of these attributes in the activity simulation models will enable these models to better capture the dynamics of the human behavior, and predict the changes in the activity and

travel patterns due to the changes in the household and individual characteristics and activity attributes.

Mohammadian and Doherty (2005) developed a mixed logit model to predict the choice of activity scheduling time horizon using the CHASE (Computerized Household Activity Scheduling Elicitor) data. They look at the effects of various activity and household attributes on the planning time horizon. Some of their findings could be summarized as household obligations, shopping, entertainment, eating and social activities tend to be planned closer to the execution time, the longer duration activities are less likely to be performed impulsively, rather planned ahead, out-home activities are planned ahead, weekend activities are more likely to be impulsive activities. This study examined the links between the activity attributes and the planning time horizons rather than defining the planning time horizon solely based upon the traditional activity types. Their analysis could be improved by segmenting the model by activity types and incorporating the travel attributes in the analysis to reveal the links between the planning time horizons and travel. While they include the travel time as reported by the individuals in their model, using a more robust measure of accessibility could improve the model.

The extensive research conducted by Doherty et. al. (2002) reviews the activity scheduling process and presents a conceptual model for the weekly household activity-travel scheduling process based on the empirical evidence from the 2003 CHASE survey data, collected from 354 individuals residing in the Toronto metropolitan area. The qualitative model establishes a set of *routine activities* and a *skeletal schedule* for the week, based upon the self reports of the respondents. The authors argue that the decisions made before the week commences (on the first Sunday) tend to be highly routine, making

the decision about their exact timing and location a relatively straightforward task because they are usually fixed in time and space. Then the scheduling decisions follow, on different planning horizons; days before, the same day, impulsive, etc.

According to Doherty et. al. (2002) the scheduling decisions are determined by the "*priorities*" of the activities on the agenda. The priority of an activity is a function of the activity attributes and the dynamic aspects of the schedule at that moment. For instance, whether the duration of the activity is feasible to fit in the time window, whether the activity is spatially feasible, activity history (number of activities of the same basic type performed recently), activity future (number of occasions the activity is scheduled in the future), etc. The "priority" of an activity is dynamic and changes as the dynamic aspects of the schedule, temporal, and spatial dimensions change. According to this framework, first an activity is chosen for scheduling, and then a feasible time window is chosen. At the time the priorities of the activities are determined, the choice of activity to schedule is made based on the decision rule. This rule could be either scheduling the activity with the highest priority or scheduling all activities over a threshold value randomly. Doherty et. al (2002) emphasize that the key to the success of this model will be considering the salient attributes of the activities rather than the traditional grouping (work, leisure, shopping, etc.). The authors conclude that the exact form of the priority model and its estimation will require considerable efforts.

As indicated in the above paragraph, one of the factors considered to be important in constructing activity schedules in Doherty et. al.'s conceptual framework is the *activity history* of the individual. This factor is incorporated in the activity-scheduling models developed by Cirillo and Axhausen (2009). They incorporated the past activity

involvement in their analysis in order to extend the static activity-choice models to dynamic ones. Using the 1999 Mobidrive survey (a six-week travel diary collected in Germany -Karlsruhe and Halle- from 317 individuals), they studied the choice of activity-type and scheduling. Several variables related to the present and past activity involvement are considered. The trips are grouped into tours and two types of key activities are defined to distinguish the daily patterns: the main activity (work/school activities for working days) and principal activity (the longest out-of-home activity for non-working days). Different activity-travel patterns are identified based on the timing such as morning pattern, midday pattern, and evening pattern dependent on the primary activity. The developed model has 38 alternatives, which are never available at the same time. A very interesting and unique approach for creating the activity duration for the non-chosen alternatives is utilized. The activity duration for the non-chosen alternatives is randomly drawn from the vector of the same purpose activity durations reported by the same individual. The results of their study reveal that a greater portion of the explanatory power of their models is provided by the variables which describe the dynamics of the day. This finding confirms the significant contribution of incorporating the constraints of the schedules and activity history in the models.

The studies discussed above confirm the importance of planning time horizons and the effects of the existing schedules on the activity choice. While the existing studies (Bhat 1998; Bhat and Gossen 2004; Bhat and Koppelman 1999; Cirillo and Axhausen 2009; Doherty 2005; Doherty et al. 2002; Kitamura 1996; Mohammadian and Doherty 2006; Mohammadian and Doherty 2005; Roorda et al. 2007) point to the important links between the planning time horizons, activity attributes and activity choice, a

comprehensive approach, looking at all these aspects in an integrated manner has been lacking. In addition to these, the way the activities are grouped also has significant implications on activity choice, as it affects the structure of the choice framework directly. The following section discusses the existing work and the gaps in the area of activity categories.

2.3 Review of the Activity Categories

Many researchers studied activity choice, considering the activities based on their traditional groupings, such as mandatory activities (work, school, etc.), household maintenance activities (cleaning, meal preparation, etc.) and leisure activities (social events, exercising, etc.). These researchers are interested in several research questions such as: the choice of in-home versus out-of-home discretionary activities (Akar et al. 2007; Bhat and Misra 1999; Yamamoto and Kitamura 1999), the travel and time allocation relationships among in-home and out-of-home subsistence, maintenance and recreation activities (Lu and Pas 1999), recreational activity choice (Bhat and Lockwood 2004; Bhat and Gossen 2004; Bhat and Misra 1999; Kemperman et al. 2006), the household heads interaction and its impacts on time allocation for maintenance, discretionary and work activities (Golob and McNally 1997).

In travel demand literature, the mandatory, household sustaining and discretionary activities are typically treated as distinct groups of activities. Among these three activity groups, other sub-aggregations have been proposed mainly within groupings of *leisure* activities. These sub-groups are generally based upon the nature of the activity, type of outcome, level of physical or mental exertion and location (Bhat and Lockwood 2004;

Bhat and Gossen 2004; Bhat and Misra 1999; Bhat et al. 2006; Kemperman et al. 2006; Passmore and French 2001).

Passmore and French (2001) suggest a simple classification of three groups for leisure activities: 1) achievement leisure (playing sports, hobbies, creative and performance arts); 2) social leisure (activities for the purpose of being in the company of others); and 3) time-out leisure (listening to music, watching TV, contemplation). Bhat and Lockwood (2004) group the recreational episodes into four categories; physically active travel; physically active activity; physically passive travel; and physically passive activity. Several of these classifications and more are reviewed in Mokhtarian et al. (2004). The descriptive findings of a recent study focusing on social commitments indicate that social activities differ widely in terms of their duration, their timing across times of day and days of the week, associated travel, and their degree of flexibility in time and space (Kemperman et al. 2006). While this study provides valuable insights on the context of social activities, the conclusions are limited as only social activities are studied and the full array of activities is not considered.

Although there is literature analyzing leisure activity choice, these studies focus on more specific research questions, such as methodological advancements and most of the time do not address the differences in the activity attributes and their implications on participation rates and travel demand.

Discretionary activities by definition are often considered to have the most flexibility in terms of their participation, timing, location, duration, etc. (Handy and Yantis 1997; Mokhtarian et al. 2004). However, the related literature regarding activity

groups explain that there is some controversy about which activities are considered discretionary and the variation in their level of obligation.

Doherty (2006) argues that the salient attributes of the activities may explain travel behavior better than the activity types based on their function. His study focuses on the measures of spatial, temporal, interpersonal flexibilities, and the other attributes (frequency, duration, involved people, travel time and location) of activities to create new activity groups. Two principal components analysis (PCA) are conducted to identify the new activity clusters sharing similar attributes - one for in-home activities and one for out-of-home activities. Surprisingly, the results demonstrate that, many activities that were traditionally categorized in different groups share the same attributes. For example, in-home activities which are low in weekly frequency, have high number of people involved and low interpersonal flexibility are categorized as "domestic social life" which include social activities (hosting visitors) and household obligations (attending to children). Out-of-home activities which have long durations, high travel times and high frequency are categorized as "long and frequent committed acts" and include work and school activities as well as some social (visiting, planned social events, cultural events) and spectator activities.

To sum up, while there are studies focusing on activity attributes and challenging the activity groups based solely on their functions, investigating the activity attributes more in-depth, from a different perspective, and looking at how these attributes affect the activity choice remain to be studied.

2.4 Discussions of the Existing Literature

While activity-based demand modeling has advanced substantially, and activity-simulation models have been used in practice for demand estimation and policy analysis, many aspects of the fundamentals of behavior regarding the activity patterns remain to be explored. For example, the links between the activities attributes and schedule characteristics, which attributes make the activities unique in terms of their participation and travel characteristics, the effects of time and space constraints, and the planning horizon of activities still remain to be explored further in detail.

As discussed in Section 2.1, the activity-simulation models attempt to replicate human behavior to forecast the activity-travel patterns in the future and under different policy scenarios and they operate several modules to replicate human behavior and predict choices. Several assumptions are taken as inputs in these modules and the success of these models depend on the extent these assumptions are behaviorally realistic, nevertheless, several of these assumptions are being challenged by researchers and many aspects of activity choice are still under question. Consequently, these models can be improved by shedding light on the existing questions of the activity-travel decision processes and incorporating these findings in the model assumptions.

Several of these questions are related to the activity attributes, planning time horizons, scheduling constraints and activity choice. While there is a rich literature documenting the relations among these, and there are calls for improvements on these aspects (Cirillo and Axhausen 2009; Doherty 2006; Doherty et al. 2002; Mohammadian and Doherty 2005; Mokhtarian et al. 2006), an integrated approach analyzing these concepts together have been lacking.

Within these considerations in mind, this study focuses on the two aspects of activity choice where several research questions remain: (1) the planning time horizons and, (2) the inherent characteristics of the activities; and integrates them into a new activity choice modeling framework.

3. DATA & METHODS

As discussed in the previous chapters, the motivation for activity-based travel forecasting is that the travel decisions are predicated on activity decisions. Therefore, understanding travel behavior and predicting travel demand depends on understanding activity choice, scheduling and participation. Based on this idea, the goal of this study is to understand how people make their activity choices and develop a new activity choice framework. This chapter discusses the research design of this study, the dataset used for the empirical analysis and the analytical techniques.

3.1 Research Design

This study consists of ***three parts*** which are linked to one another by their conceptual and empirical findings. These parts and how they are linked to one another is illustrated in Figure 4 and explained in more detail later in this chapter. The ***first part*** identifies the determinants of the planning time horizons- *defined as when people decide about performing their activities*. Several household/ individual characteristics and activity attributes are tested for their association with planning times. The activity attributes which have significant impacts on the planning time horizons of the activities are taken into the second part for generating new activity groups. The ***second part*** clusters activities based on their salient attributes, such as duration, frequency, number of involved people and flexibilities, rather than their function (work, leisure, etc.) and creates activity groups such as “long, infrequent, personally committed activities”,

"quick, spatially fixed, temporally flexible activities" etc. The activity groups generated in this part informs the activity choice modeling structure developed in the ***third part***.

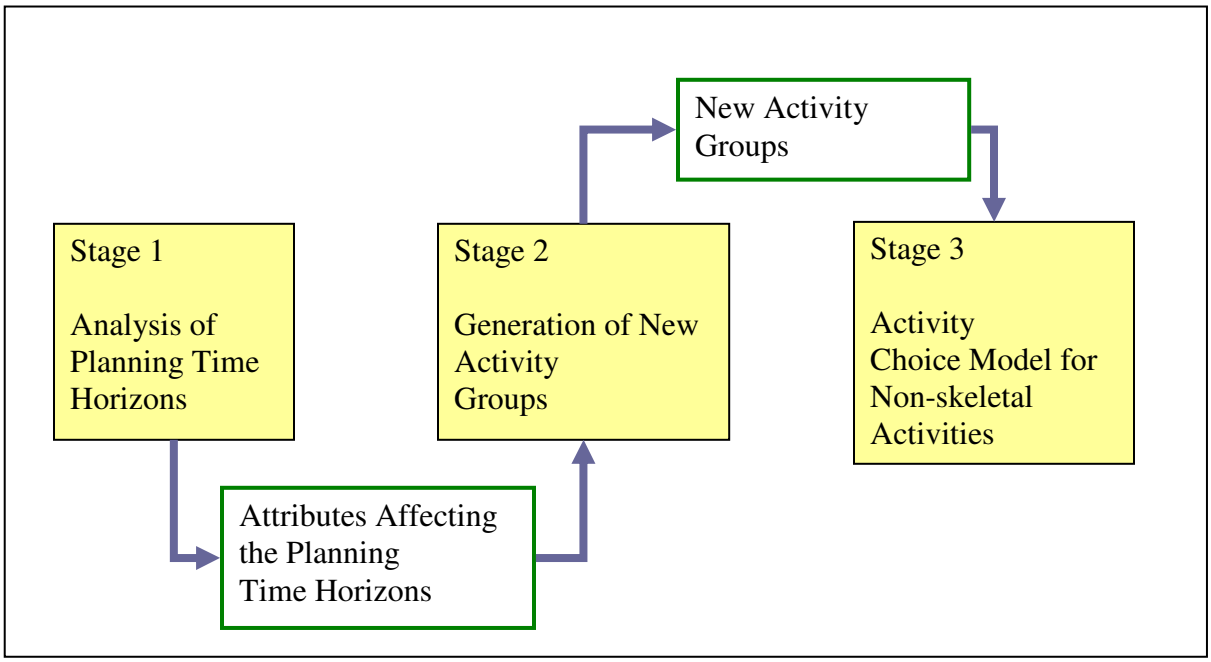

Figure 4: Research Design

3.2 CHASE Dataset

The 2003 CHASE (Computerized Household Activity Scheduling Elicitor) data are used for the empirical study and model estimations. This dataset provides a rich source of detailed information about the scheduling of daily activities, their location, travel incurred and the behavioral processes underlying activity choices of individuals for a seven-day period. The CHASE data were collected from 354 adult individuals residing in the Toronto metropolitan area, who recorded nearly 29,000 total activity episodes. The sample characteristics are demonstrated in Table 1. Detailed information about the survey instrument and the data are well documented in Doherty et al. (2004).

Table 1: Sample Characteristics

	Percentage (%)		Percentage (%)
Household size		**Income**	
1 person households	15.3	Low (<30k)	35.9
2 person households	25.4	Medium (31-75k)	43.2
3 person households	23.7	High (>75)	20.9
4 & 4+ person households	35.6	**Vehicle Ownership**	
Gender		0 car	11.0
Female	54.4	1 car	49.4
Male	45.6	2 cars	34.8
Age		3 & 3+ cars	4.8
18< age < 30	16.4	**Employment status**	
30< age < 55	58.0	Full time	65.5
55< age	25.6	Part time	11.9
		Not employed	20.1
Number of respondents	354		

The CHASE dataset includes a wide range of personal, household, activity, and travel attributes. **Socio-demographic information** is included for the individuals and their household, such as: gender, age, individual income, number of children, household size, employment status, education status, vehicle ownership, etc.

Locations of both in-home and out-of-home activities are recorded. These locations are geo-coded which brings the opportunity to calculate the network distances and travel times in order to develop a mode choice model and incorporate the findings in the analysis.

A wide range of in and out-of-home activities are organized into **ten main activity groups** (work/school, shopping, services, recreation/entertainment, social, basic needs, household obligations, meals, drop-off/pick up, other) and **53 specific activity types** (grocery shopping, personal shopping, hosting visitors, visiting, etc.). Several **activity attributes** are recorded, including the time of day, duration, number of people

involved (adults and children separately), when the activity is planned, and interpersonal, spatial and temporal flexibilities associated with the activity. The next section provides a detailed description of these activity groups and attributes.

3.2.1 Activity Types and Activity Attributes

The CHASE dataset includes ***53 specific activity groups*** originally aggregated into ***10 main types***. For instance the specific activity groups, *cleaning, preparing meals* and *attending to children* are all grouped under the main activity group *household obligations.* Tables 2 and 3 present the full array of the specific activity types with their main groupings and their attributes.

One major difference of this grouping from the existing studies is the further segmentation of the leisure activities into three groups (active, passive and social activities) based upon the degree of physical, mental or social engagement required. This categorization is consistent with the previous work in this area (Mokhtarian et al. 2006; Passmore & French 2001). The assumptions behind these conceptual groupings for the leisure activities are clarified below.

Active activities require the participant to engage in an activity, physically or mentally, in a way that affects the outcome (Mohktarian et al. 2006). In this research exercising, going to gym, playing and going to parks are considered as active activities as they involve physical participation. This grouping is not limited to physical engagement, it also includes some activities that may be considered sedentary in nature but still require mental effort to influence the event outcome. Examples of these types of activities

include hobbies such as playing a musical instrument, painting, etc. This classification is consistent with the category '*achievement leisure'* used by Passmore and French (2001).

Passive activities are strictly spectator activities where the participant does not affect the outcome. Examples include watching TV or movies, attending a play, listening to music, and attending spectator sporting events. In these activities, the participant observes, listens or takes in information but does not have the ability to engage in a way that effects what is happening. These activities are similar to *'time out leisure'* category used by Passmore and French (2001). Socializing and interacting with others are the primary aims of social activities. Examples include meeting friends for drinks, visiting with family members, or attending parties. These activities are grouped as '*social leisure'* in Passmore and French (2001).

One of the unique features of this dataset is that the respondents were asked "*When did you originally plan this activity?*" while they were recording their activities. These responses allow the activity planning sequence to be determined, whether it is a part of a routine, planned weeks, months ago or planned days ago, the same day or spontaneously.

In addition to the planning time horizons, another unique feature of the dataset is the inclusion of the *flexibilities*. The flexibilities associated with the activities are recorded in three dimensions: temporal, spatial and personal. These three flexibility measures are discussed below.

Temporal flexibility is defined as the possibility of an activity to be performed at a different time. It is categorized into five groups by the survey team: (1) fixed to one or more specific time periods, (2) somewhat variable, (3) very variable, (4) variable- but

limited to opening hours, (5) completely variable- any waking hour. In this research, temporal flexibility is conceptualized as whether the activity could be performed at another time or is fixed to one time, and categorized into two groups.

Spatial flexibility is measured as the number of locations considered for the activity, derived from responses of the individual. Originally, in the survey instrument, a value of 1 indicates that it is fixed to just one location, whereas higher values indicate a greater level of flexibility in space. In this research, the spatial flexibility is defined as a dummy variable, 1; if the activity could be performed at another location, 0; if the location is fixed.

Interpersonal flexibility is a measure to indentify whether the activity has to be conducted with or for other people. The survey instrument includes three categorical responses including: “Normally conducted alone”, “Can be optionally conducted with/for other people”, and “Must be conducted with/for other people”. In this research to be able to effectively assess the role of social commitments in planning time horizons and activity groups, the interpersonal flexibility is defined as a dummy variable, 1 if the activity could either be conducted alone or other people, 0 if the activity has to be conducted with/for other people.

As already reported by Doherty (2006), the activity attributes differ among the main activity groups (active, passive, household obligations) and within a main activity group, among the specific activity types.

The differences among the *specific activity types* which belong to a *same main group* introduce high variations in activity attributes. For instance, while the temporal flexibility of the work related activities (considering the main activity group) seems low

(the mean score is 0.12; with 0 being temporally fixed and 1 being flexible), there is a large difference between the temporal flexibility of tele-working (0.82) and working at the office (0.03), as one may expect. Hobbies tend to be longer in duration compared to other active activities (playing, parks and exercising). Shopping for clothes and personal items tend to be longer in duration and more likely to be done with other adults compared to other types of shopping (i.e. grocery shopping, drugstore shopping). Even within the specific activity types, these attributes may vary among different individuals and each occurrence of the activity. These examples confirm that the inherent characteristics of the activities and how they may change may be overlooked if one focuses solely on the function of the activity and assumes fixed values for activity attributes, such as work activities being fixed in time and space, social activities being flexible, etc.

Table 2: Activity Attributes – 1

	Duration		Frequency		Involved people		Location	
	Mean	S. Dev.	Mean	S. Dev.	Mean	S. Dev.	Out-of-home (%)	N
Meals								
In-home meal	41.96	(28.95)	11.65	(4.58)	0.86	(1.04)	0.52	3091
Restaurants	72.54	(41.47)	2.89	(1.69)	1.38	(1.12)	100.00	320
Coffee/snack shop	28.45	(27.62)	2.90	(1.53)	0.62	(0.84)	96.61	119
Total	44.27	(31.63)	10.56	(5.20)	0.90	(1.06)	12.75	3530
Work								
At work	342.24	(205.65)	8.21	(4.79)	0.16	(0.49)	100.00	1686
Tele work	107.60	(78.24)	7.57	(5.60)	0.08	(0.30)	3.83	210
Total	316.25	(209.06)	8.14	(4.89)	0.15	(0.48)	89.38	1896
Hh. obligations								
Cleaning	77.46	(77.23)	7.95	(5.11)	0.26	(0.52)	0.53	1328
Meal preparation	52.17	(48.93)	7.77	(4.27)	0.33	(0.55)	0.99	1310
Attending to children	73.78	(64.93)	14.71	(11.00)	1.35	(1.13)	0.55	733
Other obligations	80.68	(89.01)	7.37	(4.96)	0.33	(0.65)	8.64	486
Attending to pets	24.96	(18.29)	8.82	(4.37)	0.09	(0.39)	16.89	297
Total	65.46	(67.90)	9.08	(6.82)	0.47	(0.80)	2.79	4154
Pick up-drop off								
People	19.52	(26.97)	11.96	(7.33)	0.73	(0.77)	92.26	1046
Meal	44.71	(43.74)	3.63	(2.26)	0.62	(0.93)	85.53	160
Snacks/drinks	36.82	(25.84)	4.76	(3.72)	0.71	(0.74)	36.73	49
Video rental	22.33	(17.45)	1.48	(0.63)	0.60	(0.66)	100.00	42
Other items	29.17	(31.76)	6.14	(6.38)	0.43	(0.83)	65.78	187
Total	24.10	(30.71)	9.79	(7.47)	0.68	(0.80)	86.58	1484
Shopping								
Minor groceries	34.57	(28.49)	2.51	(1.32)	0.33	(0.57)	99.52	207
Major groceries	58.88	(37.71)	2.15	(1.68)	0.52	(0.67)	100.00	255
House-wares	61.39	(47.08)	2.04	(1.15)	0.54	(0.76)	98.82	85
Clothing/personal	99.67	(75.02)	1.79	(0.81)	0.77	(0.76)	100.00	172
Drug store	27.77	(19.89)	1.38	(0.61)	0.23	(0.47)	100.00	48
Other shopping	59.23	(69.45)	3.10	(2.50)	0.57	(0.73)	99.29	282
Total	59.65	(57.84)	2.37	(1.79)	0.53	(0.70)	99.62	1049
Services								
Medical/professional	72.97	(50.51)	2.50	(1.81)	0.48	(0.65)	95.17	145
Barber/salon/beauty	80.35	(68.81)	1.37	(0.62)	0.28	(0.63)	90.70	43
Banking	49.91	(99.45)	2.13	(1.41)	0.22	(0.52)	91.94	124
Other service	83.31	(102.63)	3.40	(3.49)	0.60	(1.05)	69.12	136
Total	70.43	(85.72)	2.56	(2.39)	0.42	(0.78)	85.94	448

	Duration		Frequency		Involved people		Location	
	Mean	S. Dev.	Mean	S. Dev.	Mean	S. Dev.	Out-of-home (%)	N
Active activities								
Hobbies	102.60	(90.28)	4.72	(3.12)	0.36	(0.73)	21.89	169
Exercise/active sports	81.87	(94.86)	6.07	(3.77)	0.49	(0.80)	81.27	614
Playing/ parks	95.82	(77.72)	4.17	(3.19)	0.72	(0.89)	50.77	65
Total	87.07	(93.06)	5.66	(3.67)	0.48	(0.80)	67.10	848
Passive activities								
Spectator events	154.36	(75.00)	2.12	(1.44)	1.25	(1.08)	97.20	107
Regular TV	97.16	(68.98)	9.64	(5.94)	0.52	(0.65)	1.11	1618
Unspecific TV	92.94	(61.32)	7.01	(4.34)	0.47	(0.62)	1.54	389
Watching video	113.66	(63.36)	3.98	(4.18)	0.87	(0.91)	4.78	209
Other recreation	121.11	(129.08)	3.91	(2.60)	0.80	(0.86)	54.50	202
Total	100.57	(68.73)	8.35	(5.86)	0.58	(0.72)	5.94	2323
Social activities								
Hosting visitors	137.46	(121.04)	2.97	(2.13)	2.02	(1.40)	3.64	248
Visiting	177.99	(194.82)	3.44	(2.29)	1.49	(1.34)	100.00	420
Planned social events	189.25	(120.91)	2.04	(1.21)	1.71	(1.54)	89.71	136
Cultural/ clubs	125.99	(79.79)	4.34	(3.38)	1.55	(1.35)	87.79	131
Other social	91.85	(99.27)	3.76	(2.67)	1.61	(1.49)	66.07	224
Total	148.11	(149.63)	3.34	(2.46)	1.66	(1.42)	70.29	1159

Table 3: Activity Attributes - 2 (Flexibilities)

	Temporal flex.		Spatial flex.		Personal flex.		
	Mean	S. Dev.	Mean	S. Dev.	Mean	S. Dev.	N
Meals							
In-home meal	0.97	(0.17)	0.07	(0.26)	0.98	(0.14)	3091
Restaurants	0.79	(0.41)	0.89	(0.31)	0.64	(0.48)	320
Coffee/snack shop	0.71	(0.46)	0.59	(0.49)	0.82	(0.38)	119
Total	0.95	(0.23)	0.16	(0.37)	0.94	(0.23)	3530
Work							
At work	0.03	(0.18)	0.25	(0.43)	0.97	(0.18)	1686
Tele work	0.82	(0.39)	0.12	(0.32)	0.97	(0.17)	210
Total	0.12	(0.33)	0.24	(0.42)	0.97	(0.18)	1896
Household obligations							
Cleaning/maintenance	0.99	(0.07)	0.03	(0.18)	1.00	(0.00)	1328
Meal preparation	0.96	(0.20)	0.06	(0.24)	0.99	(0.11)	1310
Attending to children	0.04	(0.20)	0.02	(0.15)	0.07	(0.25)	733
Other hh obligations	0.77	(0.42)	0.07	(0.25)	0.70	(0.46)	486
Attending to pets	0.97	(0.18)	0.16	(0.37)	0.06	(0.25)	297
Total	0.79	(0.41)	0.05	(0.22)	0.73	(0.44)	4154

	Temporal flex.		Spatial flex.		Personal flex.		
	Mean	S. Dev.	Mean	S. Dev.	Mean	S. Dev.	N
Pick up-drop off							
People	0.16	(0.37)	0.54	(0.50)	0.14	(0.35)	1046
Meal	0.60	(0.49)	0.58	(0.50)	0.86	(0.35)	160
Snacks/drinks	0.45	(0.50)	0.24	(0.43)	1.00	(0.00)	49
Video rental	0.74	(0.45)	0.48	(0.51)	0.93	(0.26)	42
Other items	0.73	(0.45)	0.23	(0.42)	0.94	(0.24)	187
Total	0.31	(0.46)	0.49	(0.50)	0.37	(0.48)	1484
Shopping							
Minor groceries	0.80	(0.40)	0.89	(0.31)	0.98	(0.15)	207
Major groceries	0.73	(0.45)	0.92	(0.28)	0.97	(0.16)	255
House-wares	0.86	(0.35)	0.82	(0.38)	0.98	(0.15)	85
Clothing/personal	0.86	(0.35)	0.94	(0.25)	0.97	(0.17)	172
Drug store	0.81	(0.39)	0.90	(0.31)	1.00	(0.00)	48
Other shopping	0.86	(0.35)	0.66	(0.47)	0.85	(0.35)	282
Total	0.81	(0.39)	0.84	(0.37)	0.94	(0.23)	1049
Services							
Medical/professional	0.24	(0.43)	0.16	(0.37)	0.88	(0.32)	145
Barber/salon/beauty	0.67	(0.47)	0.21	(0.41)	0.95	(0.21)	43
Banking	0.82	(0.38)	0.31	(0.46)	0.99	(0.09)	124
Other service	0.75	(0.43)	0.15	(0.36)	0.79	(0.41)	136
Total	0.60	(0.49)	0.20	(0.40)	0.89	(0.31)	448
Active activities							
Hobbies	0.80	(0.40)	0.11	(0.31)	0.89	(0.31)	169
Exercise or active sports	0.33	(0.47)	0.37	(0.48)	0.86	(0.35)	614
Playing/parks	0.72	(0.45)	0.23	(0.42)	0.62	(0.49)	65
Total	0.46	(0.50)	0.31	(0.46)	0.85	(0.36)	848
Passive activities							
Spectator events/theatre	0.43	(0.50)	0.70	(0.46)	0.64	(0.48)	107
Regular TV programs	0.06	(0.23)	0.06	(0.23)	1.00	(0.05)	1618
Unspecific TV	0.93	(0.26)	0.08	(0.27)	0.98	(0.14)	389
Watching video	0.95	(0.22)	0.01	(0.10)	0.97	(0.18)	209
Other recreation	0.67	(0.47)	0.23	(0.42)	0.74	(0.44)	202
Total	0.30	(0.46)	0.09	(0.28)	0.98	(0.16)	2323
Social activities							
Hosting visitors	0.95	(0.22)	0.13	(0.33)	0.13	(0.34)	248
Visiting	0.79	(0.41)	0.67	(0.47)	0.16	(0.37)	420
Planned social events	0.75	(0.43)	0.82	(0.39)	0.15	(0.36)	136
Cultural/clubs	0.71	(0.46)	0.65	(0.48)	0.09	(0.29)	131
Other social	0.82	(0.38)	0.66	(0.47)	0.40	(0.49)	224
Total	0.82	(0.39)	0.57	(0.50)	0.19	(0.40)	1159

In addition to differences among activity groups, the attributes of activities also differ significantly within the same activity groups based on their locations (in-home versus out-of-home). The following table, Table 4 reports the activity attributes separately for in-home versus out-of-home activities for the ***main activity groups***. The in-home and out-of-home activity attributes of ***specific activity types*** can be found in Appendix A, Table 17 and Table 18 respectively.

Table 4: Activity Attributes (In-home and out-of-home)

	Duration (Mean)	Weekly Frequency (Mean)	Involved people (Mean)	Spatial flexibility (Mean)	Temporal flexibility (Mean)	Personal flexibility (Mean)	N
In-home							
Active	77.77	5.86	0.18	0.16	0.61	0.95	279
Meals	42.05	11.64	0.87	0.07	0.97	0.98	3079
Passive	97.64	8.65	0.54	0.05	0.29	0.99	2184
Pick up/drop off	30.50	9.81	0.61	0.39	0.45	0.57	199
Service	92.10	4.84	0.25	0.10	0.81	0.84	63
Social	125.60	3.61	1.92	0.24	0.92	0.16	344
Work	109.88	7.61	0.07	0.10	0.82	0.97	201
Household obligations	65.85	9.07	0.47	0.04	0.79	0.74	4035
Out-of-home							
Active	91.63	5.56	0.62	0.38	0.38	0.80	569
Meals	59.50	3.23	1.14	0.81	0.76	0.70	450
Passive	147.55	3.52	1.16	0.71	0.43	0.71	138
Pick up/drop off	23.09	9.79	0.69	0.51	0.28	0.34	1284
Service	66.89	2.19	0.45	0.22	0.56	0.90	385
Shop	59.58	2.37	0.53	0.84	0.81	0.94	1044
Social	157.58	3.23	1.55	0.70	0.77	0.21	814
Work	340.94	8.20	0.16	0.25	0.04	0.97	1691
Household obligations	52.73	9.43	0.40	0.51	0.84	0.45	116

Kruskal-Wallis –one way analysis of variance tests- are conducted to check whether the differences in activity attributes among in-home and out-of-home activities are statistically significant. This statistical method is chosen as the activity attributes do not follow normal distribution. Kruskal-Wallis test is a non-parametric method for testing equality of population means. Since it is a non-parametric method, the Kruskal-Wallis test does not assume a normal distribution (Kruskal and Wallis 1952). The test results reveal that several of the activity attributes vary significantly among in-home and out-of-home activities. The results of these tests can be found in Appendix A (Table 19).

Generally the number of people involved in the activity is higher for out-of-home activities with an exception of social activities and household obligations. This could be explained by the fact that people may prefer staying at home and hosting their friends at home, as the number of people involved in the social interactive activity gets larger. For household obligations the number of people involved may not change drastically whether running errands in-home or out-of-home.

The duration of out-of-home activities are generally longer than the in-home activities. This finding points to the complex relationship between travel and activity duration. On one hand, travel (going out-of-home) is a constraint on out-of-home activity durations, as time is limited, however on the other hand people may not go out-of-home for a very short activity.

The weekly frequencies of in-home activities such as meals and passive activities are higher than that of their out-of-home counterparts. This may be explained by increasing travel costs as well as costs incurred out-of-home (such as restaurants, tickets, etc.) for frequent activities. Compared to the passive activities, such as watching TV and

video, other types of leisure activities (social and active activities) are more likely to be performed out-of-home.

3.2.2 Discussions on the Data

The CHASE dataset provides rich source of data, however it is still difficult to set clear cut boundaries among many activities types. For example, if an episode is recorded as "meals" and this activity is performed with friends, then it is unclear whether this activity should be categorized as an eating activity or a social activity. Also, the dataset does not have information on whether multi-tasking occurred. As a result, since detailed information or observations on these instances are not available, this study relies on the self reports of the individuals to classify the activities.

The data on flexibilities contribute to the uniqueness of the dataset. While the concept of flexibility has been pronounced in many models and studies, empirical measurement of flexibility have been lacking. This is one of the main reasons why most models and researchers assume a fixed level of flexibility associated with activity types, for instance work activities being fixed, leisure activities being flexible etc. Modelers assume a static level of flexibility by activity types. The findings based on the CHASE data reveal that flexibility varies within the same activity types and among different people. While the inclusion of data on the flexibilities is an important contribution, one should not forget that these data depend on the responses of the individuals which may be subjective.

While having a week-long activity diary is a great opportunity, given that most of the activity and time use studies utilize one or two day diaries, still some disadvantages

exist. For instance, some individuals have no record of some activities, so it is not known whether the individual does not participate in this type of activity at all (such as exercising) or did not participate in this activity during the survey period. This may have important implications in structuring the choice set and raises the question whether to include the activities which are not reported by some individuals in their choice set. Cirillo and Axhausen (2008) chose to define such activities as *"not available"* for certain individuals in their models, however, their dataset (Mobidrive) covers six weeks, whereas the CHASE data covers only one week. If a person does not perform a specific activity during six consecutive weeks, it is safer to assume that the person does not participate in this type of activity at all, while for one week, this assumption could be unrealistic. Therefore, in this research, such activities are still included in the choice set, with an exception of work related activities, which are only available for employed individuals.

3.3 Analytical Techniques

The main analytical techniques used in this research are the Principal Components Analysis (PCA) and discrete choice models.

Principle Components Analysis (PCA) is conducted as an exploratory analysis to understand the interrelationships among the activity attributes and to define new activity groups based on their attributes. PCA technique is summarized as a method of transforming the original variables into uncorrelated new variables (Afifi and Clark 1996; Dunteman 1989). The new variables are called as *principal components* and each of them is a linear combination of the original variables. The variance of each component is a measure of the information conveyed by that component. Therefore, the principal

components are arranged in the order of decreasing variance, with the first one conveying the most information and the last one conveying the least amount of information. PCA is generally used to reduce the dimensionality of the problem by reducing the number of variables without loosing the information by taking the first few principal components into consideration. Another common use of PCA is exploring the interrelationships among the variables, which is the purpose of the analysis in this research.

The empirical models in this study are developed based on the **discrete choice theory** which has been used extensively in the activity-based approach. Based on the random utility theory, discrete choice models assume that the decision maker's preference for an alternative can be captured by the value of an index, called *utility*. It is assumed that the decision maker chooses the alternative that yields the highest utility. Because the analyst will have imperfect information about an individual's utility level, uncertainty is introduced into the utility equation (Ben-Akiva and Lerman 1985; Train 2002).

By far the easiest and most widely used discrete choice model is ***logit***. Its popularity is due to the fact that the formula for the choice probabilities takes a closed form and is readily interpretable. While logit is the most extensively used model it has important limitations. First of all, logit can not represent the random taste variations (differences in tastes that can not be linked to observed characteristics). Second, the logit model implies proportional substitution across alternatives which gives rise to IIA (independence from irrelevant alternatives) property. To capture more flexible forms of substitution, and introduce correlations among alternatives, other models are needed. Third, logit cannot handle situations where unobserved factors are correlated over time.

Due to the heterogeneity among individuals, repeated observations and correlations among alternatives, ***mixed logit*** models are formulated in this study to overcome the limitations of logit and estimate the planning time horizon and activity choice models. Mixed logit is defined as a highly flexible model that can approximate any random utility model resolving the limitations of standard logit by allowing for random taste variations and correlations in unobserved factors over time (Train 2002). Different specifications with error components and random parameters are tested to find the best fitting models.

The mixed logit probability can be derived from utility maximizing behavior in several ways that are formally equal but provide different interpretations. The ***random coefficients logit*** allows the coefficients vary over the decision makers in the population rather than being fixed. ***Error components logit*** can approximate any substitution pattern by error components that create correlations among the utilities for different alternatives overcoming the IIA property.

These two types of mixed logit interpretations, random coefficients and error components formulations, are formally equivalent. The way the researcher thinks about the model affects the specification of the mixed logit. For example, if the researcher is interested in the presence and/or pattern of taste variations, random parameters approach is pursued (Cirillo and Axhausen 2006; Revelt and Train 1998; Train 1998). If the main goal of the researcher is to be able to represent the correlations among alternatives, the error components approach is pursued (Brownstone and Train 1999). In this study, the ***random coefficients*** approach is used for the analysis of planning time horizons in order

to account for random taste variations, whereas ***error components logit*** is developed for the activity choice model to accommodate correlations among choice alternatives.

3.4 Analysis Plan

This study commences with a comprehensive analysis of the planning horizons of the activities and the results of this analysis used as inputs for the activity group generation. These new activity groups inform the structure of the new activity choice framework for the non-skeletal activities. This section gives a brief synopsis of the research undertaken in each stage.

3.4.1 First Part: Analysis of Planning Time Horizons

As discussed before, the related literature states that people tend to have *skeletal schedules* for their weeks (Doherty et al. 2002; Kitamura et al. 2000). These skeletal structures, made up of highly routine and fixed activities, are generally determined by the external effects, activity attributes and socio-demographics of the individuals.

The main objective of this analysis is to examine the effects of several activity attributes, household and personal characteristics on planning time horizons and develop a model to predict the planning time horizons of these activities. The analysis of the planning time horizons is performed by developing ***mixed logit models*****.** The choice set in this model is defined as the time at which the activity is originally planned, based on the responses of the individuals. Therefore, the choice set is expressed as: C_j= {impulsive, same day, same week, months/weeks ago, routine}

The variables included in the utility functions can be summarized as:

- *Household and individual characteristics*

- *Variables related to the number of involved people in the activity*
- *Variables related to the temporal characteristics of the activity*
- *Variables related to the flexibilities*
- *Travel measures*
- *Functional activity types* (shopping, social activities, etc.)

While in practice, the planning times are assumed to be based on the function of the activity, this research confirms the hypothesis that household and individual characteristics, activity attributes and travel characteristics have significant effects on the planning time horizons.

The results of the models presented in Chapter 4 prove that the activity attributes chosen for this analysis have significant effects on the outcomes, therefore contribute to the "uniqueness" of the activities in terms of their planning time horizons. The findings of this stage set the ground for the second stage, grouping the activities based on these attributes.

3.4.2 Second Part: Generating Activity Groups

As discussed before, salient attributes of the activities are used for generating the activity groups in this study. The primary step for categorizing the activities based on their salient attributes is deciding which attributes to focus on. The methodology followed here is an integrated approach, considering both theory and empirical data analysis.

The results of the analysis conducted in the first stage confirmed that the activity attributes which are hypothesized by other researchers (Doherty 2006; Mohammadian and Doherty 2005) are actually important determinants of the planning times. In addition

to this, one previous study by the author exploring the location (in-home versus out-of-home) choice for discretionary activities revealed that the same attributes have significant effects on the location choice (Akar et al. 2007). These results, together, confirm that these attributes contribute to the uniqueness of the activities by determining their planning times and locations. These attributes are: (1) Frequency, (2) Duration, (3) Number of involved people, (4) Temporal flexibility, (5) Spatial flexibility, and (6) Personal flexibility.

The in-home and out-of-home activities are analyzed separately as the explanatory data analysis (statistical tests presented in Appendix A, Table 19) and previous research revealed that the activity attributes of in-home and out-of-home activities differ significantly (Akar et al. 2007; Doherty 2006). Principle Components Analysis (PCA) is performed to define the new activity groups. The results yielded new activity groups such as temporally and personally flexible in-home activities; long and infrequent in-home activities; short and personally flexible activities out-of-home activities, etc. Then the distributions of the activities (work, social, meals, etc.) among these new groups are identified. As a result, the activities are categorized into groups which are defined both by their function and their attributes, such as long and infrequent social activities; temporally flexible and spatially fixed meals, etc.

3.4.3 Third Part: New Activity Choice Framework

In the third stage, a new activity choice modeling framework is developed for the non-skeletal activities based on the activity groups generated in Stage 2. In this research the skeletal and non-skeletal activities are identified based on the responses of the

individuals. The activity-choice model is developed for the non-skeletal activities, while the skeletal activities are taken as inputs to define the constraints and the opportunities for the available time windows.

The *skeletal activities* consist of the activities which are planned as a part of a *routine* and the activities which are *planned weeks/months in advance*. The activities which are planned *impulsively, during the same day* and *same week* are defined as *non-skeletal* activities. As these groupings are based on the individuals' responses, a work activity which is planned spontaneously is taken as a non-skeletal activity whereas a social activity planned months ago is taken as a skeletal activity, as opposed to the traditional approaches where all work activities are defined as skeletal and all social activities as non-skeletal.

Individuals choose the activities to perform from a range of activities available. However, identifying the choice set, in other words, developing the structure of the choice framework is a challenging step. The main contribution of this study is at this stage. As indicated in the previous section the activities are categorized into groups which are defined both by their function and their attributes, such as long and infrequent social activities; temporally flexible and spatially fixed meals, etc. This yields 34 choices for each available time window.

Error components logit formulation is used to model the activity choices by introducing correlation patterns among the activities which have common attributes. The variables of interest in this model are:

- *A group of household and individual characteristics,*
- *Variables related to the temporal characteristics of the activity,*

- *Travel measures,*
- *Variables related to the previous and following activities in the schedule, and*
- *Variables related to the characteristics of the skeletal structure.*

The significant coefficients of the error components and increased log-likelihood values reveal that introducing correlation patterns among activities with similar attributes increases the explanatory power of the models and achieves a better fit.

The next chapter, Chapter 4, presents the analysis of the planning time horizons, which is the initial part of this research.

4. ANALYSIS OF PLANNING TIME HORIZONS

The understanding of activity schedules and how they are formed is essential to the development of realistic models. While some of the activities in our schedules are routinely planned, some of them are pre-planned, and some are spontaneous. The planning time horizons – *defined as when people decide about performing their activities*, may change depending on the individual or the specific attributes of an activity. These timing mechanisms need to be replicated to be able to develop any behaviorally realistic scheduling model. This leads to the need of examining the planning time horizons of the activities in detail (Doherty 2005; Doherty et al. 2002; Mohammadian and Doherty 2006; Mohammadian and Doherty 2005).

This chapter contributes to the existing knowledge in the area of activity modeling by developing mixed logit models to analyze and predict the planning time horizons of the activities. These models incorporate the individual and household characteristics, activity attributes and travel measures in the analysis. Separate models are developed and estimated for different activity types to evaluate the varying effects of different variables.

4.1 Activity Groups and Planning Time Horizons

Table 5 presents the descriptive statistics for the planning time horizons. The data are based on the responses of the survey participants and they include planning the activity:

- Impulsively (Just prior to the activity),
- During the same day,
- Before the day of the activity (within the same week),

- Weeks/ months ago, and
- As a part of a regular routine

The responses indicate that a large portion of activities was planned impulsively (31% of all activities), and a significant portion of all activities (22%) was planned during the same day. While the percentage of activities that are planned impulsively is high for household obligations, shopping, meals and passive activities, the activities related to work and services are less likely to be performed impulsively.

Table 5 reveals that the planning times of activities in the same group may also differ from one another. For instance, while the percentages of the hobbies and playing at parks that are planned impulsively are 38% and 37% respectively, the percentage of exercising activities that are planned impulsively are significantly less (19%). These results are the consequences of the inherent characteristics of the activities; such that active activities which involve exercising and sports involve more people and hence higher levels of social commitments, which requires them to be planned more in advance as compared to hobbies and going to parks.

While in-home meals tend to be routinely or impulsively planned, having meals at restaurants are more likely to be pre-planned (during the same day or same week). As expected, the percentages of tele-working episodes reported as impulsive (14%) or planned during the same day (39%) are higher than that of the percentages of work related activities at the office (9% - impulsive and 12%- planned the same day).

Table 5: Planning Time Horizons

	Planning Time					
	Impulsive	**Same day**	**Same week**	**Weeks ago**	**Routine**	N
Meals	%	%	%	%	%	
In-home meal	34.0	17.2	11.1	19.3	18.3	2728
Restaurants	32.1	38.5	19.0	6.4	4.0	327
Coffee/snack shop	45.2	14.8	11.3	16.5	12.2	115
Total	30.4	17.1	10.6	15.9	14.9	3107
Work						
At work	9.3	11.5	22.9	39.3	17.0	1600
Tele-work	14.3	39.1	25.5	11.8	9.3	161
Total	9.1	13.0	21.5	34.2	15.1	1761
Household obligations						
Cleaning/maintenance	44.2	24.0	11.8	9.0	11.0	1204
Meal preparation	32.0	18.7	12.7	22.1	14.5	1188
Attending to children	30.9	18.6	13.4	18.4	18.7	635
Other hh obligations	47.2	26.9	10.8	4.1	11.0	464
Attending to pets	33.7	10.4	17.0	20.0	18.9	270
Total	34.1	18.8	11.4	13.5	12.7	3761
Pick up/ drop off						
People	16.4	19.6	21.6	31.0	11.3	961
Meal	32.0	23.8	18.4	8.8	17.0	147
Snacks/drinks	37.8	20.0	11.1	17.8	13.3	45
Video rental	54.8	23.8	11.9	2.4	7.1	42
Other items	36.0	28.5	24.2	1.6	9.7	186
Total	21.0	19.9	19.5	21.8	10.9	1381
Shopping						
Minor groceries (<10items)	46.3	42.8	8.5	1.0	1.5	201
Major groceries (10+ items)	27.7	37.3	23.3	4.8	6.8	249
House wares	27.7	48.2	22.9	0.0	1.2	83
Clothing/personal items	31.5	46.1	17.6	3.0	1.8	165
Drug store	38.3	36.2	21.3	2.1	2.1	47
Other shopping	34.4	39.8	18.3	6.1	1.4	279
Total	33.5	40.3	17.5	3.5	2.8	1023
Services						
Medical/professional	8.6	15.7	42.9	32.1	0.7	140
Barber/salon/beauty	18.6	34.9	27.9	16.3	2.3	43
Banking	36.4	34.7	17.8	7.6	3.4	118
Religious	10.4	6.9	22.2	42.4	18.1	144
Total	20.5	27.5	32.8	14.5	1.8	445
Active activities						
Hobbies	38.0	25.9	14.6	13.3	8.2	158
Exercise or active sports	19.4	19.3	26.7	25.1	9.5	581

	Planning Time					
	Impulsive	**Same day**	**Same week**	**Weeks ago**	**Routine**	N
Playing/parks	37.3	23.7	16.9	8.5	13.6	59
Total	23.0	19.7	22.2	20.3	9.0	798
Passive activities						
Watching TV	47.0	18.7	10.9	11.6	11.8	1790
Watching video	40.3	34.7	9.7	7.1	8.2	196
Spectator events/theatre	9.6	27.9	42.3	17.3	2.9	104
Total	40.1	18.6	11.2	10.3	9.9	2090
Social activities						
Hosting visitors	29.3	32.9	25.8	7.6	4.4	225
Visiting	25.2	32.5	28.6	9.6	4.1	416
Planned social events	11.5	20.6	38.2	26.7	3.1	131
Recreational/special clubs	31.7	26.7	17.5	17.5	6.7	120
Other social	42.3	18.9	26.9	8.0	4.0	175
Total	26.6	26.8	25.9	11.5	4.0	1067
All activities	31.2	21.7	16.9	17.8	12.2	15697

The percentage of attending spectator events at theatres that are impulsively planned (10%) are far less than the percentages of watching TV (47%) or videos (40%) impulsively. This may be explained by the resource requirements; the activities which require more resources in terms of cost and time (travel time and ticket costs for out-of-home spectator activities) are more likely to be planned ahead.

The next table, Table 6, presents how activity attributes change over the planning time horizons. As these variables do not have normal distributions, Kruskal- and Wallis tests[1] are conducted to check the statistical significance of these differences.

[1] As discussed in Chapter 3, Kruskal-Wallis method, which is a non-parametric method for testing the equality of population means, is chosen to test the differences, as the activity attributes do not follow normal distribution. Since it is a non-parametric method, the Kruskal-Wallis test does not assume a normal distribution (Kruskal and Wallis, 1952).

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Table 6: Activity Attributes and Planning Time Horizons

	Impulsive		Same day		Days ago		Weeks ago		Routine	
	Mean	S.Dev	Mean	S.Dev	Mean	S.Dev	Mean	S.Dev	Mean	S.Dev
Duration										
Active	65.78	(48.3)	79.87	(53.3)	122.84	(158.4)	88.59	(68.5)	73.67	(74.7)
Hh oblig.	61.53	(59.0)	73.67	(68.4)	81.32	(100.1)	49.92	(51.7)	65.55	(71.5)
Meals	42.6	(33.6)	51.16	(32.7)	53.25	(34.7)	31.41	(19.9)	45.29	(26.7)
Passive	97.55	(69.1)	105.84	(62.5)	109.02	(75.6)	94.31	(75.8)	101.91	(61.7)
Pick	28.3	(34.9)	26.45	(25.9)	26.9	(32.0)	13.55	(18.7)	27.29	(42.3)
Service	46.03	(40.7)	55.67	(72.8)	73.84	(63.8)	115.22	(136.2)	106.88	(182.3)
Shop	49.11	(53.9)	58.8	(53.1)	77.69	(69.8)	46.35	(34.4)	79.48	(71.8)
Social	101.06	(100.6)	133.98	(125.8)	178.58	(154.4)	205.62	(202.4)	136.61	(131.9)
Work	171.2	(150.8)	165.15	(149.0)	318.82	(207.2)	417.84	(184.9)	316.38	(206.1)
Number of involved people										
Active	0.49	(0.8)	0.44	(0.8)	0.59	(0.9)	0.32	(0.8)	0.74	(0.9)
Hh oblig.	0.4	(0.7)	0.46	(0.8)	0.52	(0.9)	0.45	(0.7)	0.54	(0.9)
Meals	0.78	(1.0)	1.13	(1.1)	1.15	(1.3)	0.76	(1.1)	0.84	(1.0)
Passive	0.54	(0.7)	0.65	(0.8)	0.69	(0.8)	0.46	(0.7)	0.66	(0.7)
Pick	0.67	(0.9)	0.7	(0.8)	0.77	(0.9)	0.59	(0.7)	0.62	(0.7)
Service	0.24	(0.6)	0.34	(0.6)	0.63	(1.0)	0.4	(0.6)	0.75	(1.4)
Shop	0.53	(0.8)	0.55	(0.7)	0.54	(0.7)	0.27	(0.6)	0.48	(0.5)
Social	1.59	(1.3)	1.72	(1.4)	1.65	(1.5)	1.92	(1.6)	1.46	(1.4)
Work	0.3	(0.8)	0.14	(0.5)	0.17	(0.5)	0.08	(0.3)	0.18	(0.5)
Spatial flexibility										
Active	0.32	(0.5)	0.31	(0.5)	0.36	(0.5)	0.17	(0.4)	0.51	(0.5)
Hh oblig.	0.06	(0.2)	0.04	(0.2)	0.05	(0.2)	0.05	(0.2)	0.06	(0.2)
Meals	0.2	(0.4)	0.24	(0.4)	0.21	(0.4)	0.1	(0.3)	0.07	(0.3)
Passive	0.06	(0.3)	0.09	(0.3)	0.23	(0.4)	0.08	(0.3)	0.07	(0.3)
Pick	0.52	(0.5)	0.53	(0.5)	0.47	(0.5)	0.4	(0.5)	0.52	(0.5)
Service	0.26	(0.4)	0.28	(0.5)	0.13	(0.3)	0.2	(0.4)	0	(0.0)
Shop	0.81	(0.4)	0.83	(0.4)	0.86	(0.4)	0.92	(0.3)	0.93	(0.3)
Social	0.56	(0.5)	0.56	(0.5)	0.59	(0.5)	0.54	(0.5)	0.52	(0.5)
Work	0.48	(0.5)	0.32	(0.5)	0.27	(0.5)	0.13	(0.3)	0.22	(0.4)
Temporal flexibility										
Active	0.6	(0.5)	0.72	(0.5)	0.39	(0.5)	0.22	(0.4)	0.25	(0.4)
Hh oblig.	0.82	(0.4)	0.82	(0.4)	0.78	(0.4)	0.76	(0.4)	0.73	(0.5)
Meals	0.95	(0.2)	0.93	(0.3)	0.94	(0.2)	0.95	(0.2)	0.97	(0.2)
Passive	0.37	(0.5)	0.36	(0.5)	0.21	(0.4)	0.1	(0.3)	0.26	(0.4)
Pick	0.43	(0.5)	0.38	(0.5)	0.32	(0.5)	0.15	(0.4)	0.3	(0.5)
Service	0.74	(0.4)	0.82	(0.4)	0.51	(0.5)	0.18	(0.4)	0.63	(0.5)
Shop	0.84	(0.4)	0.82	(0.4)	0.79	(0.4)	0.68	(0.5)	0.76	(0.4)
Social	0.86	(0.4)	0.84	(0.4)	0.79	(0.4)	0.7	(0.5)	0.76	(0.4)
Work	0.11	(0.3)	0.41	(0.5)	0.12	(0.3)	0.05	(0.2)	0.06	(0.2)

	Impulsive		Same day		Days ago		Weeks ago		Routine	
	Mean	S.Dev	Mean	S.Dev	Mean	S.Dev	Mean	S.Dev	Mean	S.Dev
Personal flexibility										
Active	0.89	(0.3)	0.92	(0.3)	0.82	(0.4)	0.77	(0.4)	0.82	(0.4)
Hh oblig.	0.77	(0.4)	0.79	(0.4)	0.72	(0.5)	0.71	(0.5)	0.62	(0.5)
Meals	0.94	(0.2)	0.9	(0.3)	0.93	(0.3)	0.96	(0.2)	0.97	(0.2)
Passive	0.99	(0.1)	0.97	(0.2)	0.93	(0.3)	0.97	(0.2)	0.99	(0.1)
Pick	0.52	(0.5)	0.41	(0.5)	0.38	(0.5)	0.22	(0.4)	0.4	(0.5)
Service	0.95	(0.2)	0.89	(0.3)	0.86	(0.4)	0.89	(0.3)	0.88	(0.4)
Shop	0.93	(0.3)	0.95	(0.2)	0.95	(0.2)	0.95	(0.2)	0.97	(0.2)
Social	0.26	(0.4)	0.15	(0.4)	0.14	(0.4)	0.21	(0.4)	0.28	(0.5)
Work	0.98	(0.1)	0.93	(0.3)	0.96	(0.2)	0.98	(0.2)	0.98	(0.1)

The whole set of the Kruskal Wallis tests performed among five planning time horizons for each activity type and attribute are presented in Appendix B, Table 20. For some of the cases, Kruskal Wallis tests are conducted between two specific groups and the results are discussed below.

The mean spatial flexibility of active activities which are planned weeks/months ahead is lower than that of the ones planned in any other planning time horizon (Kruskal-Wallis test results between active activities planned *impulsively* and *weeks ago: chi^2= 12.83, p=0.0003;* between *routine* and planned *weeks ago: $chi^{2=}$26.19, p=0.0001*). This indicates that the active activities which are fixed in space are more likely to be planned well in advance as opposed to being part of a routine or planned shortly.

While the temporal flexibility of household obligations do not differ significantly among different planning time horizons, the temporal flexibility of active activities which are planned weeks in advance is significantly lower than the ones which are planned during the same day or impulsively (*chi^2=117.17, p=0.0001 & chi^2=117.76, p=0.0001* respectively). The passive activities are also affected by the temporal flexibility. The temporal fixity of the passive activities (such as watching videos with others, spectator events) necessitates advance planning.

Shopping activities which are a part of a routine have longer durations compared to spontaneous shopping episodes ($chi^2=75.83, p=0001$). The work related activities which are planned during the same day or spontaneously have lower durations than that of the routine work activities or work activities which are planned ahead.

The way the attributes of the activities differ over the planning time horizons show differences based on their locations as well (in-home versus out-of-home). For instance, while the duration of in-home meals do not vary significantly between impulsive and same day, the out-of-home meals which are planned during the same day or same week have higher durations than that of the impulsive ones. The descriptive statistics of activity attributes over time horizons are reported separately for in-home and out-of-home activities in Appendix B, Table 21 and Table 22 respectively.

The fact that the activity attributes vary among different planning times support the hypothesis that the activity attributes are important determinants of the planning time horizons. For instance, Table 5 reports that 34% of the household obligations are planned impulsively, while 13% of them are being planned as a part of a routine, so what determines which household obligations are planned impulsively? The varying attributes among different planning time horizons is one of the answers to this question, but definitely, not the only one. Several other factors affect these timing mechanisms, such as household characteristics, scheduling constraints and travel characteristics. The following section discusses the travel characteristics and how they are taken into consideration in this research.

4.2 Travel Characteristics: Mode Choice and the Logsum Variable

The travel time, cost and the availability of transportation options also affect the planning time horizons (Bowman and Ben-Akiva 2001; Doherty 2006). If an individual chooses to perform an activity out-of-home, then he/she performs a mode choice to access this location and this travel choice has implications on the location choice and ultimately the planning time horizon. The implications of this choice can be introduced in the model by using conditionality and expected utility (Bowman and Ben-Akiva 2001). One of the main contributions of this study is integrating the travel attributes, such as cost, time and availability, in the analysis.

The expected utility that the individual will get from travelling to the out-of-home location is referred to as ***accessibility***, as it measures how accessible the out-of-home location alternative is based on the utilities estimated in the mode-choice model (Ben-Akiva and Lerman 1985; Bowman and Ben-Akiva 2001; G. Jong et al. 2005). It is also referred to as the ***logsum*** as it is calculated as the logarithm of the sum of the utilities of the alternatives which is the log of the denominator of the choice probability. To be able to examine the effects of the travel characteristics on activity location choice, the ***logsum term*** from the mode choice model, estimated with the same dataset, is introduced in the analysis.

The CHASE dataset includes the locations (geo-coordinates) of the activities which gives the opportunity to calculate the network distances and travel times to chosen out-of-home activities. The network travel times are obtained by utilizing the travel time matrices for the Greater Toronto Metropolitan Area (GTA) based on the network distances between centroids of TAZs by mode and time of day. The auto travel times

were collected for three different time periods; morning peak, evening peak and free flow speeds. The travel times for the transit network were also collected. The travel times for non-motorized modes are approximated based on the walking speed (3 miles per hour), as there were very few bicycle trips and no information on bicycle ownership. The cost of travel is approximated based on the miles traveled and the price of gasoline (2.81 Canadian Dollars/galloon) and public transportation fares (2.25 Canadian Dollars) of year 2003 in GTA. The availability of different modes is also considered. For instance, transit service does not exist between some origins and destinations and walking is not considered to be an option if the distance between the origin and destination is more than three miles.

The logsum variable is obtained by estimating a simple mode-choice model, with three choices; driving, public transportation and non-motorized transportation. The utility ($U_{n,i}$) of person *n* choosing mode *i* can be expressed as:

$$U_{ni} = \beta_i + \beta_{cost} x_{cost,i} + \beta_{time} x_{time,i} + \varepsilon_{ni} \qquad \text{Eq. 1}$$

As the above formula presents, the utilities are specified as a function of the level of service variables (time and cost) and alternative specific constants. Therefore, the logsum measure is sensitive to changes in travel time, travel cost and the availability of alternatives. As the travel time and cost decreases, the logsum term increases. The logsum is calculated as:

$$Logsum = log\ \left(\exp(U_{car}) + \exp(U_{transit}) + \exp(U_{non-motorized})\right) \qquad \text{Eq. 2}$$

Different mode choice models are estimated for different activity types (active, passive, social, meals, household obligations, work, services and shopping). The reason for segmenting the data on the activity types and estimating separate mode choice models is because people have *different value of times* (the monetary amount that a person is willing to pay to decrease the travel time by one minute) for different activity types (Cirillo and Axhausen 2009).

The results of the mode choice models are presented in Appendix B. These results confirm the hypothesis that people have different values of time to attend different activities. The value of time measure changes among the activities- for instance work activities have higher values, while social activities have lower values.

4.3 Analysis

The analysis of the planning time horizons is performed by ***mixed logit formulation***. The reason for choosing mixed logit formulation is the fact that mixed logit allows efficient estimation when there are repeated choices by the same respondent and resolves the limitations of standard logit by allowing for random taste variations (McFadden and Train 2000).

The choice probability in mixed logit is a mixture of logits with a specified mixing distribution. Mixed logit probabilities are the integral of standard logit probabilities over a density of parameters. The choice probabilities in the mixed logit model can be expressed as:

$$P_{ni} = \int L_{ni}(\beta) f(\beta) d(\beta), \qquad \text{Eq. 3}$$

where $L_{ni}(\beta)$ is the logit probability evaluated at parameters β , and $f(\beta)$ is a density function. For the fixed parameters, the mixing distribution is degenerate: $f(\beta)=1$ for $\beta = b$ and zero for $\beta \neq b$.

Let the alternatives be $i = \{i_1, ..., i_T\}$ for each time period. As there are repeated choices from each individual, considering a sequence of choices, the probability that the person makes this sequence of choices is the product of the logit formulas:

$$L_{ni}(\beta) = \prod_{t=1}^{T} \left(\frac{e^{\beta' {}_n x_{ni_t t}}}{\sum_j e^{\beta' {}_n x_{njt}}} \right). \qquad \text{Eq. 4}$$

Then the mixed logit takes the form:

$$P_{ni} = \int \prod_{t=1}^{T} \left(\frac{e^{\beta' {}_n x_{ni_t t}}}{\sum_j e^{\beta' {}_n x_{njt}}} \right) f(\beta)\, d(\beta) \qquad \text{Eq. 5}$$

The mixed logit models in this study are estimated with the AMLET software.

4.3.1 Model Specification

The choice set in this model is defined as the time at which the activity is originally planned, based on the responses of the individuals. Therefore, the choice set is expressed as:

C_j= {impulsive, same day, same week, months/weeks ago, routine}

The variables included in the utility functions can be summarized as:

- *A group of household and individual characteristics*
    - Household size
    - Number of autos per adult
    - Gender (1, female; 0, male)
    - Education (1, has a bachelors degree or higher; 0, otherwise)
    - Age (Three dummy variables are specified.)
        - Group 1 (1 if age≤30; 0, otherwise)
        - Group 2 (1 if 30<age≤55; 0, otherwise)
        - Group 3 (1 if age>55; 0, otherwise)
- *Variables related to the number of involved people in the activity*
    - Number of children
    - Number of adults
- *Variables related to the temporal characteristics of the activity*
    - Duration (in 10 minute increments)
    - Frequency over the week
    - Time of day (morning (binary), daytime (binary), evening (binary))
    - Weekend (1, weekend; 0, weekday)
- *Variables related to the flexibilities*
    - Temporal flexibility- whether the activity has to be performed at a certain time window (1, flexible; 0 , otherwise)
    - Spatial flexibility -whether the activity has to take place at a fixed location (1, flexible; 0 , otherwise)

- Personal flexibility- whether the activity has to be performed with other people(1, flexible; 0 , otherwise)

- *Travel*
  - Logsum variable

- *Functional activity types* (shopping, social activities, etc.)

An individual, *n,* faces a choice among the alternatives in the choice set C_j in each of the choice situations (activity episodes). The number of choice situations varies across individuals. The utility that individual *n* obtains from planning the activity at time horizon alternative *j* in choice situation *t* is:

$$U_{njt} = \beta'_n x_{nj} + \varepsilon_{nj}$$

where, x_{nj} are observed variables that relate to the alternative and decision maker, β_n is a vector of coefficients of these variables for person *n* representing that person's tastes, and ε_{nj} is a random term that is i.i.d. (independent and identically distributed) extreme value. The coefficients vary over decision makers in the population with density $f(\beta)$. This density is a function of parameters θ that represent the mean and covariance of the βs in the population (Train 2002)

In the model specification, the flexibility coefficients (spatial, temporal and personal) are assumed to be independently and normally distributed, and the rest of the coefficients are assumed to be fixed. The normal distribution allows coefficients of both signs. The parameters which are specified as random are generally chosen based on prior information and theory. In this study, the assumption that flexibilities vary among

individuals in the previous study by Mohammadian and Doherty (2005) is considered while choosing the random parameters.

First, a full model at the activity episode level with all the activity types is estimated. The results of this model are presented in Table 7. The dataset is then segmented based on the functions of the activities (active, passive, social, meals, household obligations, shopping) to analyze the similarities and differences among these groups.

4.3.2 Discussion of Results

Table 7 provides the estimation results of the full model of planning time horizons. The base case is routine activities. All of the parameters are reported to be able to have a better understanding of all variables. The log-likelihood result of the mixed logit model is significantly higher than the multinomial logit model estimated with the same set of variables, indicating that the explanatory power of the mixed logit model is considerably greater. The model results reveal that the estimated standard deviations of the flexibility coefficients are highly significant. This indicates that the flexibility parameters do indeed vary among the population, as is hypothesized.

Table 7: Mixed Logit Results for Planning Time Horizons

	Impulsive		Same day		Same week		Weeks ago	
	Coef.	t stat	Coef.	t stat	Coef.	t stat	Coef.	t stat
Alternative spec.	**1.712**	**8.60**	**0.168**	**2.95**	**-0.340**	**-6.04**	**-1.937**	**-14.71**
Individual and household characteristics								
Household size	-0.044	-0.72	-0.019	-0.29	0.065	1.02	**0.175**	**2.45**
Autos per adult	-0.031	-0.49	**0.197**	**2.67**	-0.022	-0.35	**-0.232**	**-3.02**
Age group=1	**0.872**	**18.57**	**0.670**	**30.17**	**0.813**	**17.42**	**0.098**	**2.37**
Age group=3	-0.198	-1.94	-0.130	-1.41	-0.006	-0.05	**0.974**	**13.18**
Education	0.108	1.16	**0.387**	**6.00**	**0.159**	**2.33**	**0.224**	**2.21**
Employed	**-0.470**	**-2.83**	-0.031	-0.32	-0.114	-1.32	**0.602**	**4.98**
Female	-0.169	-1.72	-0.012	-0.15	0.158	1.87	**0.461**	**5.63**
Variables related to involved people in the activity								
Number of children	**-0.356**	**-4.94**	-0.117	-1.40	-0.136	-1.56	0.055	0.56
Number of adults	**-0.109**	**-1.97**	0.072	1.36	**0.140**	**2.58**	-0.035	-0.45
Variables related to the temporal characteristics of the activity								
Duration	**-0.032**	**-4.75**	-0.010	-1.58	**0.014**	**2.63**	0.009	1.33
Weekly frequency	-0.024	-1.63	**-0.029**	**-1.93**	-0.030	-1.82	0.028	1.46
Weekend	**0.354**	**4.03**	**0.185**	**2.17**	**-0.351**	**-4.09**	**-1.216**	**-11.64**
Morning	**-0.743**	**-10.31**	**-1.172**	**-16.43**	-0.038	-0.49	**0.722**	**8.25**
Evening	-0.035	-0.46	**0.142**	**2.24**	**-0.306**	**-3.86**	**-0.225**	**2.75**
Variables related to the spatial characteristics of the activity								
Location	**-0.120**	**-2.01**	**0.374**	**5.78**	**0.613**	**9.42**	**0.901**	**11.89**
Logsum	0.061	0.94	**-0.133**	**2.24**	**-0.227**	**-4.34**	**-0.346**	**5.15**
Flexibilities								
Personal	**0.208**	**2.18**	-0.034	0.42	**-0.143**	**-2.50**	**-0.648**	**7.48**
Standard dev.	**1.613**	**15.13**	**1.453**	**10.60**	**1.081**	**11.90**	**2.433**	**14.60**
Spatial	**0.390**	**7.33**	**0.269**	**4.90**	**0.173**	**2.96**	**-0.402**	**5.23**
Standard dev.	-0.070	-0.70	**0.135**	**2.23**	**-0.230**	**-2.99**	**1.167**	**9.00**
Temporal	**0.420**	**5.10**	**0.537**	**6.11**	0.060	0.82	**-0.275**	**3.00**
Standard dev.	**-0.864**	**-9.07**	**0.626**	**6.87**	**0.869**	**9.80**	**1.357**	**12.24**
Activity type (household obligations is the base case)								
Work	**-0.595**	**6.05**	0.137	1.77	**0.207**	**3.06**	**0.408**	**7.90**
Active	**0.263**	**7.01**	**0.343**	**10.33**	**0.924**	**24.50**	**1.057**	**26.95**
Meals	**-0.352**	**4.60**	**-0.479**	**6.88**	**-0.255**	**-4.76**	0.083	1.09
Passive	**0.609**	**11.13**	**0.171**	**3.94**	**0.282**	**6.49**	0.055	0.81
Pick-up/drop off	**-0.166**	**2.52**	-0.029	0.45	**0.458**	**7.69**	**0.245**	**3.11**
Shopping	**1.390**	**20.47**	**1.653**	**20.87**	**1.229**	**11.73**	**-0.418**	**9.46**
Social	**0.826**	**18.03**	**0.876**	**19.74**	**1.355**	**21.43**	**1.378**	**22.22**
Services	**0.322**	**10.98**	**0.704**	**26.02**	**1.137**	**40.93**	**0.578**	**11.65**
Number of observations*						13568		
Number of individuals						346		
Log-likelihood at optimal						-16443.83		
Log-likelihood at zero coefficients						-21836.85		
Log-likelihood at constants						-20955.74		

*The estimation is at the activity episode level.

The results of the full model (with all activity types) are consistent with common sense and the earlier studies (Mohammadian and Doherty 2005). The activities which are personally, temporally and spatially flexible are more likely to be planned closer to their execution time. Active, social, passive and shopping activities are less likely to be routinely planned compared to household obligations. Morning activities are less likely to be planned during the same day or impulsively compared to daytime and evening activities. As the duration and the number of people involved in the activity increase, the activity is more likely to be planned ahead, frequent activities are more likely to be a part of the routine structure.

The interesting contribution of this study is incorporating the **logsum term from the mode choice model** as a more robust measure of travel attributes, in the planning time horizon choice analysis. The full model demonstrates that the out-of-home activities are more likely to be planned ahead compared to routine and impulsive activities. The logsum term is statistically significant and negative for the activities that are planned during the same day, days ago, while the coefficient of logsum for the impulsive activities is not significantly different from the routine activities. This indicates that as the cost and travel time to arrive at the activity locations increase, the probability of these activities being a part of a routine or being planned impulsively decreases. This may be explained by the fact that significant commitments of travel time or cost may require more planning.

The coefficients of activity type variables in the full model are significant indicating that the choice of planning time horizon varies among different activity types. This observation raises the question of whether the effects of socio-demographic

characteristic, activity attributes and travel characteristics vary among different activity groups. For example, does increasing duration have the same affect on the planning time horizons for social activities and household obligations? *Do changes in travel characteristics affect different activities in different ways?* To be able to answer these questions, separate models for planning time horizons are estimated for different activity groups (household obligations, shopping, meals, active, passive, work and social activities). The results of the segmented models can be found in Appendix B. Some of the most relevant findings of the segmented models are summarized below.

While a very strong influence of travel characteristics and location is observed on household obligations and active activities, this effect is less important for social events. Increasing duration decreases the tendency to plan an active activity impulsively compared to routinely planning. However, increasing duration increases the probability of planning the household obligations during the same day or same week and increases the probability of planning social activities same week or weeks ago. Females are more likely to plan their active activities routinely or weeks ago. As the weekly frequency of active activities increase, the propensity to plan these activities impulsively increases, while the propensity to plan meals impulsively or same day decrease with increasing frequency. The non-significant variables are dropped in these models however, the location and logsum variables are kept in the models regardless of the fact that they may be non-significant, to identify the varying effects of location and travel characteristics.

The results of these segmented models not only demonstrate the differences and similarities between the functional activity groups in terms of the effects of attributes on planning time horizons, but also shed light on why the activities with the same function

may be planned in different times. For instance, not all the active activities are being planned impulsively, so what determines which active activities are planned spontaneously and which are pre-planned? According to the model results the duration, weekly frequency, location, travel characteristics, timing (morning, evening) and the flexibility of the activity in time, space and personal are important determinants of the planning time horizons for active activities. This result indicates that the planning times that are based only of the function of the activities fail to notice the effects of these activity attributes.

4.4 Conclusions

This chapter presents the results of a series of mixed logit models developed to analyze and predict the planning sequence of the activities in an individuals' schedule. Understanding how the activity schedules are formed is crucial to be able to model individuals' behavior and develop behaviorally-realistic, activity-travel simulation models.

The models presented in this chapter incorporate the individual and household characteristics, activity attributes and travel measures in the analysis. Separate models are estimated for different activity types to evaluate the varying effects of different variables, particularly travel characteristics and location over different activity groups.

The results of this research reveal that the affects of location and travel characteristics on planning time horizon choice vary among different activity types, both in sign and magnitude. According to the models, household obligations, active and social activities are very sensitive to the travel time, cost and the availability of transportation

modes. Therefore, significant changes in planning and execution of these activities may be expected with changes in the transportation system characteristics. These changes may also affect the overall activity planning and execution process.

The models developed in this study can predict the changes in the planning time horizons of the activities due to changes in the travel characteristics, activity attributes and household characteristics which in turn, will affect the whole activity-travel patterns.

The findings of these models could be integrated in the activity sequencing modules of the existing activity-travel simulation models. This could be done either by applying the comprehensive model using the activity attributes, household and individual characteristics as independent variables (which may be limited due to the availability of data) or integrating the findings of the models in the decision rules, so that instead of deciding the planning sequence solely based on the activity types, the decisions could be based on the activity attributes. For instance, temporally flexible work activities may be planned impulsively; spatially fixed active activities may be planned weeks/months ahead, etc.

The immediate use of the findings of these results in this research is the identification of the important activity attributes that significantly contribute to the determination of the planning time horizons. These activity attributes are utilized in Chapter 5 for creating new activity groups.

5. NEW ACTIVITY GROUPS

As discussed in the previous chapters, activity attributes are important determinants of the planning time horizons and contribute to the underlying processes for generating activity schedules. This chapter mainly draws upon the research undertaken by Doherty (2006) calling to replace the activity grouping based solely on their function with the ***salient attributes of the activities***. As discussed in the literature review, his study focuses on the measures of spatial, temporal, interpersonal flexibilities, and the other attributes (frequency, duration, involved people, travel time and location) of activities to create new activity groups.

The difference between the traditional way of structuring the activity choice set and the approach taken in this study was illustrated in Figure 3 of Chapter 1. For instance, the choice set could be defined based on the function of the activity: (1) Work, (2) Leisure, (3) Mandatory; or it could be defined based on the important attributes of the activity, such as: (1) Long and spatially fixed activities, (2) Short and frequent activities, (3) Personally and temporally fixed activities, etc. As the structure of the activity choice model is based on the activity groups, the correlations among these alternatives affect the model results and thus the accuracy of the activity-travel simulation models. Therefore, grouping the activities is a key step in activity analysis.

Within these considerations, this chapter aims to achieve ***two main objectives***:

1- Understanding how different activity attributes cluster together (long and infrequent activities; spatially flexible, temporally fixed activities, etc.)

2- Examining how activities with different or same function fall into these clusters and how these may vary among different planning time horizons.

This chapter adds to the existing literature by generating new activity groups based on their attributes and analyzing how these may change over different planning time horizons. The findings of this analysis set the ground for the activity choice models developed in *Chapter 6*. The rest of this chapter presents the methodology, the analysis results and the new activity groups.

5.1 Methodology: Principal Components Analysis

Principle Components Analysis (PCA) is conducted to explore the interrelationships among the activity attributes and to define new combined indicators of activity types based on their attributes.

PCA is a method of transforming the original variables into new, uncorrelated variables. The new variables are called the "principal components". PCA may be carried on as an exploratory analysis that may be useful in gaining a better understanding of the interrelationships among the variables and/or to reduce the dimensionality of the problem; reducing the number of variables without loosing the information associated with them (Afifi and Clark 1996; Dunteman 1989). The main objective of the PCA conducted in this study is to explore the interrelationships among the variables to identify the interrelationships between the activity attributes and define new activity groups based on these interrelationships.

The variables chosen for this analysis are chosen based on the earlier studies on the salient attributes of the activities (Akar et al. 2007), examining the activities attributes

which have implications on the activity location choice; Doherty (2006), exploring the salient attributes of the activities in general) and the model results of the previous chapter. The variables chosen for the PCA are: duration, weekly frequency, number of involved people, temporal flexibility, spatial flexibility, and personal flexibility.

These variables are similar to the variables that are utilized by Doherty (2006). However, unlike Doherty's work, *travel time is not included* as an attribute for clustering the activities. As the focus of this study, overall, is activity choice from the transportation perspective, it is decided to keep the travel characteristics apart from the activity attributes, so that it could be examined in the final activity choice models separately, as opposed to being in a cluster of activity attributes.

The in-home and out-of-home activities were analyzed separately. The basis for this decision is two-fold. First, the exploratory analysis results and the Kruskal-Wallis tests (as discussed in Chapter 3) revealed significant differences in activity attributes among in-home and out-of-home activities. Second, out-of-home activities necessitate travel and therefore require special attention from the transportation point-of-view. The implications of this decision extend to the activity choice models developed in Chapter 6. Separating the in-home and out-of-home activities enables us to introduce the travel measures solely for the out-of-home activities. Consequently, separate PCA are conducted for in-home and out-of-home activities. The next section presents and discusses the results of these analyses.

5.2 Results of the PCA

Table 8 demonstrates the PCA results for in-home and out-of-home activities. This table demonstrates the components, % variance explained by each component and the loadings for each variable on that particular component. There are not any clear cut rules for deciding how many principal components should be retained. Various rules have been proposed in the literature; discarding the components with small variances (such as, the ones with variances smaller than 5% or 10% of the total variance), keeping a sufficient number of components to explain a certain percentage of the total variance, etc. (Afifi and Clark 1996). In this study the latter approach is taken and the cutoff point is chosen as 80%, which is common.

A high coefficient (loading) of a principal component on a given variable indicates a high correlation of that variable and the principal component, and the principal components can be interpreted within the context of the variables with high coefficients. In this study, the variables which demonstrate correlations greater than 0.5 are taken as the most dominant variables of the corresponding component and they are highlighted in Table 8. (*Table 8 illustrates the factor loadings, the correlations table can be found in Appendix C, Table 26*). Although factor rotation can be performed to obtain more easily interpreted components, the rotation had little to no effect on these results and therefore it is not reported.

The way the variables load on these principal components is an indicator of how the activities attributes cluster together. For instance, the first component of the in-home activities is characterized by high temporal and personal flexibilities and low number of people involved. The way the activity attributes cluster and the determinants of the

components are different from Doherty's work, as travel times are not included in the analysis, and certain activity types, such as sleeping, washing dressing, and basic needs are excluded in this study.

Table 8: PCA Results for In-Home and Out-of-Home Activities

In-home activities (N=10515)				
	Comp1	Comp2	Comp3	Comp4
Eigenvalues	1.44	1.18	1.04	0.94
Proportion of variance	0.25	0.21	0.18	0.16
Total variance explained	80%			
	Factor loadings			
Duration	-0.29	**0.64**	-0.13	-0.31
Frequency	-0.12	**-0.71**	-0.30	0.03
Number of adults	**-0.47**	0.12	0.26	**0.68**
Spatial flexibility	-0.10	-0.22	**0.78**	**-0.51**
Temporal flexibility	**0.53**	0.09	**0.44**	**0.42**
Personal flexibility	**0.63**	0.14	-0.17	-0.06

Out-of-home activities (N= 6629)				
	Comp1	Comp2	Comp3	Comp4
Eigenvalues	1.83	1.33	1.02	0.75
Proportion of variance	0.31	0.22	0.17	0.13
Total variance explained	82%			
	Factor loadings			
Duration	**-0.43**	0.25	**-0.44**	**0.60**
Frequency	-0.23	**-0.70**	0.24	0.19
Number of adults	**0.41**	-0.09	**-0.63**	0.24
Spatial flexibility	**0.46**	-0.15	0.38	**0.69**
Temporal flexibility	**0.55**	0.37	0.13	-0.08
Personal flexibility	-0.28	**0.53**	**0.43**	0.27

As can be seen in Table 8, the way the activity attributes cluster together is different for in-home and out-of-home activities. The following activity groups are formed based on the PCA results.

For in-home activities:

(1) Temporally and personally flexible activities,

(2) Long, infrequent activities,

(3) Spatially and temporally flexible activities and

(4) Temporally flexible, spatially fixed activities which are conducted with other people.

For out-of-home activities:

(5) Short activities which are flexible in time and space and conducted with others

(6) Infrequent activities which have high personal flexibility

(7) Short, personally flexible activities

(8) Activities with long duration and spatial flexibility.

While some of these new groups show similarities to the ones in Doherty's (2006) work, some are different, as some of the activity types are excluded from the analysis (such as sleep) and also travel time is not taken into consideration. For instance, the out-of-home activities which are grouped as short, space and time flexible (Group 5) and the ones which have high personal flexibilities and low frequencies (Group 6) are similar to Doherty's groups which he refers as "space and time flexible needs" and "occasional goods/service outings", respectively. However, the other two out-of-home activity groups are different from his groupings. The differences among the in-home activities are higher due to the fact that the activities related to sleep and other needs are excluded from the analysis in this study.

5.2.1 PCA Results and the Activity Types

An interesting question at this stage is how the functional activity groups would fall under these categories. For instance, which in-home activities would fall under the first category, characterized by being personally and temporally flexible; active activities,

social activities or work related activities? Moreover, will the activities with the same function fall into only one cluster or is it possible that the they may fall into different clusters based on their attributes, such as temporally and personally flexible (group 1) active activities, long and infrequent (group 2) active activities, etc.? To take the analysis results further and explain how different activity types would fall under these new clusters of activity attributes, the mean component scores by each specific activity group is calculated. Tables 9 and 10 demonstrate the component scores[2] for the activity types (based on their function) for in-home and out-of-home respectively.

The component scores presented in Tables 9 and 10 inform which activity groups based on their functions correspond to these new activity clusters based on mean component scores. The activities which have less than 5 observations are not reported in the tables above. The activities which score on the top 30% of a given component are assumed to be characterized by the dominant variables of that corresponding component. As the principal components are normally distributed with a mean of 0 and standard deviation of 1, the top 30% correspond to scores higher than 0.52. For instance, in-home hobbies score 0.65 on the second component, therefore they are assumed to be long and infrequent in-home activities. In the absence of activity groups scoring over 0.52, the closest ones (such as over 0.40) are assumed to be categorized by that component. The highest component scores for each activity type are bolded in the following tables.

[2] The principal components are standardized; they are normally distributed with a mean of 0 and a standard deviation of 1.

Table 9: Component Scores for Specific Activity Types (In-home)

	Component1		Component2		Component3		Component4		
	Mean	S.Dev.	Mean	S.Dev.	Mean	S.Dev.	Mean	S.Dev.	Freq.
Meals									
In-home meals	0.39	0.57	-0.36	0.65	0.18	0.85	**0.54**	0.97	3075
Total	0.39	0.57	-0.36	0.65	0.18	0.85	0.54	0.97	3075
Work									
Tele-work	0.38	0.60	**0.52**	1.05	-0.03	1.01	-0.63	0.84	201
Total	0.33	0.61	0.42	1.15	0.24	1.26	-0.79	1.92	237
Household obligations									
Cleaning	**0.65**	0.36	0.32	0.95	0.01	0.60	-0.03	0.65	1320
Meal prep	**0.65**	0.39	0.10	0.73	0.14	0.75	0.06	0.69	1296
Attend children	-2.23	0.83	-0.81	1.39	-0.52	0.83	0.11	0.92	729
Other	-0.01	0.94	**0.35**	0.98	-0.09	0.61	-0.13	0.74	444
Attending pets	-0.58	0.26	-0.69	0.60	**0.75**	0.99	0.09	0.72	246
Total	-0.02	1.23	-0.02	1.07	-0.01	0.78	0.02	0.73	4035
Pick-up/drop-off									
People	-1.82	0.57	-1.79	1.04	**1.79**	1.57	-1.47	1.11	81
Meals	-0.40	0.90	-0.16	0.49	**2.30**	1.49	-1.31	0.96	23
Snacks/drinks	-0.14	0.52	0.11	0.46	-0.36	0.80	-0.13	0.85	31
Other items	**0.44**	0.77	-0.21	1.07	-0.20	0.56	0.14	0.77	64
Total	-0.66	1.20	-0.80	1.24	0.87	1.62	-0.72	1.21	199
Services									
Medical	0.12	1.06	0.07	0.36	**0.67**	1.53	0.09	1.13	7
Banking	**0.56**	0.45	**0.82**	0.56	-0.17	0.44	-0.47	0.46	10
Other services	0.10	0.87	**0.65**	0.78	0.28	1.36	-0.46	0.77	42
Total	0.21	0.84	0.64	0.73	0.23	1.24	-0.40	0.78	63
Active									
Hobbies	**0.50**	0.71	**0.65**	0.81	0.08	0.92	-0.40	0.81	132
Exercise	-0.03	0.53	**0.31**	0.71	0.13	1.45	-1.22	1.03	115
Playing/parks	-0.10	1.16	0.33	0.54	**0.48**	1.22	-0.47	1.09	32
Total	0.21	0.76	0.34	0.80	0.14	1.20	-0.74	1.02	279
Passive									
Regular TV	-0.51	0.45	**0.35**	0.92	-0.89	0.79	-0.85	0.76	1599
Unspecific TV	0.40	0.57	**0.57**	0.83	0.14	0.76	-0.08	0.74	383
Video	0.24	0.65	**1.11**	0.81	0.19	0.40	0.24	0.78	199
Other rec.	0.08	0.88	**0.86**	1.34	0.04	0.93	-0.30	0.80	91
Total	-0.28	0.62	0.31	0.94	-0.61	0.89	-0.62	0.86	2184
Social									
Hosting visitors	-1.60	0.99	**1.22**	1.21	**1.23**	1.13	**0.92**	1.26	238
Planned social	-2.54	1.00	**1.05**	1.18	**3.49**	1.56	-0.39	1.82	14
Cultural/clubs	-1.62	0.44	-0.16	0.78	**2.05**	1.70	-1.23	0.97	16
Other social	-1.14	1.08	0.19	0.85	**2.12**	1.68	0.19	1.46	76
Total	-1.54	1.03	0.92	1.22	1.56	1.43	0.60	1.42	344

Table 10: Component Scores for Specific Activity Types (Out-of-home)

	Component1		Component2		Component3		Component4		
	Mean	S.Dev.	Mean	S.Dev.	Mean	S.Dev	Mean	S.Dev.	Freq.
Meals									
Restaurants	**1.01**	0.60	0.27	0.60	-0.10	0.97	0.31	0.73	320
Coffee/snacks	**0.52**	0.65	0.47	0.61	0.44	0.92	-0.39	0.84	114
Total	0.84	0.68	0.29	0.63	0.09	1.00	0.12	0.81	434
Work									
At work	-1.22	0.57	0.10	0.78	-0.11	0.84	**0.56**	0.89	1683
Total	-1.22	0.57	0.10	0.78	-0.11	0.84	0.56	0.89	1683
Household obligations									
Meal prep	0.41	0.47	0.08	0.46	**0.87**	0.71	-0.11	0.93	13
Other	0.44	0.63	-0.68	1.17	**0.60**	0.88	-0.21	0.90	42
Attending pets	0.35	0.70	-0.53	0.44	**0.39**	0.49	-1.00	0.82	50
Total	0.40	0.63	-0.46	0.88	0.43	0.85	-0.52	0.99	112
Pick-up/drop-off									
People	0.07	0.65	-1.54	1.07	-0.05	0.75	-0.49	0.94	965
Meals	0.30	0.62	**0.42**	0.48	**0.42**	1.00	-0.34	0.86	136
Snacks/drinks	0.45	0.56	**0.77**	0.36	0.60	0.71	-0.33	0.83	18
Video rental	0.44	0.48	**0.79**	0.42	0.41	0.71	-0.62	0.90	42
Other items	0.17	0.57	0.49	0.68	**0.52**	0.87	-0.71	0.91	123
Total	0.12	0.64	-1.03	1.32	0.08	0.82	-0.50	0.93	1284
Shopping									
Minor groceries	**0.62**	0.45	**0.69**	0.34	**0.96**	0.53	0.08	0.54	206
Major groceries	**0.61**	0.43	**0.69**	0.38	**0.77**	0.60	0.26	0.56	255
House-wares	**0.66**	0.43	**0.82**	0.30	**0.72**	0.77	0.11	0.62	84
Clothing	**0.75**	0.42	**0.84**	0.32	**0.53**	0.60	0.47	0.58	172
Drug store	**0.63**	0.48	**0.85**	0.27	**1.03**	0.42	-0.01	0.49	48
Other shopping	**0.58**	0.54	**0.61**	0.50	0.51	0.82	-0.19	0.88	279
Total	0.63	0.47	0.71	0.40	0.71	0.69	0.11	0.70	1044
Services									
Medical	-0.35	0.53	**0.47**	0.47	-0.01	0.59	-0.85	0.63	138
Barber/salon	0.02	0.61	**0.93**	0.34	0.27	0.75	-0.86	0.72	39
Banking	0.21	0.61	**0.94**	0.29	**0.58**	0.59	-0.81	0.81	114
Other services	0.21	0.67	**0.65**	0.56	-0.15	1.13	-0.93	0.79	94
Total	-0.01	0.65	0.70	0.48	0.16	0.82	-0.86	0.74	385
Active									
Hobbies	0.22	0.65	**0.47**	0.64	-0.68	0.90	-0.57	0.98	37
Exercise	-0.16	0.63	0.04	0.69	**0.42**	0.89	-0.32	1.00	499
Playing/parks	**0.43**	0.50	0.35	0.60	-0.59	1.19	-0.74	0.95	33
Total									
Passive									
Spectator	**0.43**	0.77	0.25	0.59	-0.50	0.94	0.36	0.94	104
Regular TV	-0.17	0.30	-0.24	0.48	0.39	0.73	**0.99**	0.67	18
Unspecific TV	0.28	0.14	-1.00	0.04	**1.96**	0.26	**0.86**	0.12	6
Video	0.39	0.30	**1.07**	0.36	-0.48	0.61	-0.67	0.66	10
Other rec.	0.33	0.60	**0.39**	0.69	-0.48	1.13	-0.31	1.03	109
Total	0.34	0.71	0.19	0.67	-0.28	1.04	0.39	0.94	138

	Component1		Component2		Component3		Component4		
	Mean	S.Dev.	Mean	S.Dev.	Mean	S.Dev	Mean	S.Dev.	Freq.
Social									
Hosting visitors	**1.17**	0.32	-0.02	0.30	-1.30	0.64	-0.93	0.87	9
Visiting	**0.91**	0.74	-0.09	0.60	-1.01	1.11	0.10	1.13	420
Planned social	**1.02**	0.83	0.02	0.40	-1.07	1.14	0.35	0.89	122
Cultural/clubs	**0.98**	0.74	-0.32	0.51	-1.07	1.05	-0.07	0.97	115
Other social	**0.99**	0.88	0.09	0.59	-0.55	1.24	0.17	0.93	148
Total	0.95	0.78	-0.07	0.57	-0.95	1.14	0.12	1.05	814

Table 11 reports how the activities (based on their function) are distributed among these new groups. These results confirm the hypothesis that the activities which are categorized in different groups based on their function (such as leisure and work) may have similar attributes, while the ones in the same category may have varying attributes. For instance, not all the household obligations have similar attributes, some may be temporally and spatially flexible and generally conducted alone, and some may be fixed in space and performed with others. While work and leisure are treated as different categories, some activities from these two groups may show similar attributes, they may both be spatially flexible and personally committed, etc.

According to the component scores, the in-home activities which could be categorized as temporally and personally flexible, and conducted alone and/or with low number of adults (*Group 1*) are: in-home meals, tele-working, some of the household obligations (meal preparation and cleaning), services (banking), active activities (hobbies) and some passive activities (watching TV). The activities which score high on the second component (*Group 2*) have high durations and low frequencies include: work related activities, watching TV, video, hosting visitors, planned social events and hobbies. The activities which are characterized by high spatial and temporal flexibilities (*Group 3)* are: work related (volunteer) activities, attending to pets, and social activities.

The activities which have high numbers of people involved in the activity, high temporal and low spatial flexibilities *(Group 4)* are: in-home meals, and hosting visitors.

Table 11: New Activity Groups- Explanatory Results

	New Activity Group	Activity Type
In-Home		
1	Temporally and personally flexible activities	In-home meals Work (tele-work) Household obligations Active activities (hobbies)
2	Long, infrequent activities	Work (tele-work) Services Active activities (hobbies) Passive activities Social activities
3	Spatially and temporally flexible activities	Attending to pets Pick-up/ drop-off Active activities (playing & parks) Social activities
4	Temporally flexible, spatially fixed activities which are conducted with others	In-home meals Social (hosting visitors)
Out-of-home		
5	Short activities which are flexible in time and space and conducted with others	Meals (restaurants) Household obligations Pick-up/drop-off Shopping Passive (Spectator events) Social
6	Infrequent activities which have high personal flexibility	Meals (coffee, snacks) Pick-up/drop-off Shopping Services Active
7	Short, personally flexible activities .	Meals (coffee, snacks) Household obligations Pick-up/drop-off Shopping Active (exercise)
8	Activities with long duration and spatial flexibility	Meals (restaurants) Work Shopping (clothes shopping) Passive (spectator events)

The out-of-home activities which have shorter durations, temporal and spatial flexibility and performed with other people *(Group 5)* include: meals (restaurants, coffee and snack shops), some pick-up/drop off activities, shopping activities, playing at parks, social activities and spectator events. The component scores of activities like going to coffee and snack shops, pick-up/drop off activities (except for picking up people), services and shopping activities are high on the second component indicating high personal flexibilities and low frequencies and place these activities in *Group 6*. Activities with lower durations and personal flexibilities are categorized under *Group 7* and include: household obligations (attending to pets, doing laundry, and gardening), shopping, banking, and exercising. The fourth component defines the activities in *Group 8* of the out-of-home activities with high durations and spatial flexibilities and include work related activities, clothes shopping, spectator events.

5.3 Planning Time Horizons and the New Activity Categories

One contribution of this study beyond Doherty's research is analyzing how the activity attributes, and hence, the component scores vary among the planning time horizons. For instance, do the activities which are planned impulsively and as a part of a routine have similar attributes and therefore have similar scores on these components? If not, then how do the component scores change among the activities which are planned in different times? To be able to find the answers to these questions, the data are segmented based on the planning time horizons and the component scores are calculated for each time horizon. Table 12 summarizes these results.

Table 12: Component Scores by Planning Time Horizons

	Component 1		Component 2		Component 3		Component 4		
	Mean	S.Dev.	Mean	S.Dev.	Mean	S.Dev.	Mean	S.Dev.	N
In-home									
Impulsive	0.09	(0.92)	0.05	(0.93)	0.02	(1.00)	-0.05	(0.94)	3560
Same day	0.00	(1.02)	0.15	(1.05)	0.06	(1.04)	0.00	(1.00)	1956
Days before	-0.20	(1.13)	0.19	(1.27)	0.05	(1.02)	-0.02	(1.18)	1192
Weeks ago	0.06	(0.94)	-0.39	(0.86)	-0.14	(0.99)	0.05	(1.00)	1424
Routine	-0.05	(1.04)	-0.08	(0.96)	-0.01	(0.90)	0.08	(0.97)	1302
Out-of-home									
Impulsive	0.42	(0.80)	0.04	(1.03)	0.29	(0.98)	-0.03	(0.92)	1343
Same day	0.44	(0.80)	0.14	(0.95)	0.14	(1.01)	-0.09	(0.94)	1477
Days before	0.02	(0.98)	0.08	(0.87)	-0.14	(1.04)	0.01	(1.06)	1509
Weeks ago	-0.65	(0.98)	-0.10	(1.05)	-0.31	(0.91)	0.04	(1.06)	1357
Routine	-0.46	(0.93)	-0.26	(1.04)	0.05	(0.91)	0.11	(1.00)	602

Comparing the component scores among different planning time horizons reveal more information than comparing single activity attributes, as the components represent the clusters of activity attributes. Several *t-tests* are conducted to test the statistical significance of the differences the component scores reveal among different planning time horizons. The full list of these t-test results are demonstrated in Appendix C (Table 32 and Table 33).

Based on the statistical test results, the out-of-home activities which are planned impulsively and during the same day score significantly higher on the first component compared to the activities which are planned days before, weeks ago and as a apart of a routine (results of the t-tests between impulsive and routine: $t=31.1,\ p<0.001$; same day and routine: $t=20.6,\ p<0.001$; same day and same week: $t=12.71,\ p<0.001$). This indicates that the activities which are planned impulsive or during the same day tend to have shorter durations and higher spatial and temporal flexibilities, which is consistent with the common sense and the model results of Chapter 4.

The out-of-home activities which are planned as a part of a routine or weeks ago are likely to have higher durations and spatial flexibilities compared to the activities which are planned impulsively or during the same day (t-test results on Component 4 between impulsive and routine: $t=3.08, p<0.001$, same day and routine: $t=4.36, p<0.001$). The activities which are planned closer to the execution time have shorter durations, less number of people involved and higher personal flexibilities (t-test results on Component 3 of out-of-home activities, between impulsive and same week: $t=11.38, p<0.001$, same day and same week: $t=7.51, p<0.001,$ same day and weeks ago: $t=12.36, p<0.001$).

The in-home activities which are planned impulsively score higher on the first component, which means they are more likely to be temporally and personally flexible and performed with less number of individuals compared to the activities planned during the same day ($t=3.09$, $p<0.01$), same week ($t=8.04$, $p<0.01$), and routine ($t=4.15$, $p<0.01$). The activities which are planned weeks ago and routine score significantly higher on the 4^{th} component compared to the impulsive activities indicating that they are more likely to be fixed in space and conducted with other people (t-test results on Component 4, between impulsive and routine: $t=4.05, p=0.001$, impulsive and weeks ago : $t=3.35, p<0.001$).

This analysis is extended to explore how the component scores may change for activity groups with the same function among different planning time horizons. While performing the analysis on specific activity types reveals more comprehensive information, the number of observations for each activity type decreases significantly when the data are segmented by the planning time horizons. This leads to many specific

activity types having just a few observations. Therefore, the analysis at this stage is conducted at the main activity group level. The results of this analysis can be found in Appendix C, Table 34 and 35.

The results of this analysis confirm the hypothesis that the activity attributes do indeed vary among different planning time horizons within the same activity types. Activities from the same group (based on their function) may end up being planned in different times based on their attributes. For instance, the in-home active activities which are planned impulsively tend to score high on the first and second components, while the ones planned as a part of routine score high on the third component. This finding reveals that as the number of people involved and the spatial flexibility increases, the active activities are more likely to belong to the routine schedule, such as routine sports and exercising events, routine events with children and adults which involves playing and going to parks.

5.4 The New Activity Groups

As discussed before, the aim of this chapter is grouping the activities based on their salient attributes to define the activity choice structure to be used in Chapter 6. The previous sections provide the explanatory analysis at the specific activity type level and examine how the activity attributes shape the new activity categories. This section discusses how the final activity groups are decided.

The analysis in the previous sections is at the specific activity type level. For instance, according the results in Table 9 household obligations performed in-home generally score low on the third component; however, the large standard deviation

indicate that there may be some episodes which do score high on the third components, therefore could be characterized by being spatially and temporally flexible.

In addition to this, the detailed analysis on the component scores for each activity episode reveal that some activity episodes score high on more than one component therefore may be counted in two or more different categories. For instance, an out-of-home activity episode may score higher than 0.5 on both the first and second components and therefore grouped as both being in Group 1 (short, spatially and temporally flexible) and Group 2 (infrequent and personally flexible). This finding points to the fact that grouping these activities into discrete categories is not easy and more flexible groupings might be necessary to retain all this information. Nevertheless, in this research it is assumed that the component on which the activity episode scores the highest explains the inherent characteristics of the activity the most. Therefore, each activity episode is assigned to the group on which it scores the highest. The following table, Table 13, reports the distribution of the activities among the new groups, which form the basis for the new activity choice framework introduced in the next chapter.

Table 13: Distribution of Activities Based on Their Function & New Groupings

	Group 1 Temporally and personally flexible activities	**Group 2** Long, infrequent activities	**Group 3** Spatially and temporally flexible activities	**Group 4** Temporally flexible, spatially fixed activities conducted with others	Total
In-home					
Active	121	98	46	14	279
Hh. obligations	1,718	866	361	1,090	4,035
Meals	1,221	95	217	1,546	3,079
Passive	482	1350	99	253	2,184
Pick up/ drop off	47	31	87	34	199
Service	24	30	7	2	63
Social	4	116	110	114	344
Work	87	90	20	4	201
Total	3704	2676	947	3057	10384

	Group 5 Short, time-space flexible activities, conducted with others	**Group 6** Infrequent activities with high personal flexibility	**Group 7** Short, personally flexible activities	**Group 8** Activities with long duration & spatial flexibility	
Out-of-home					
Active	107	194	173	95	569
Hh. obligations	51	14	47	4	116
Meals	269	51	97	33	450
Passive	40	42	17	39	138
Pick up/ drop off	478	148	499	159	1284
Service	50	264	67	4	385
Shopping	283	198	462	101	1044
Social	628	79	23	84	814
Work	19	576	436	660	1691
	1925	1566	1821	1179	6491

5.5 Discussions

This chapter presents a detailed analysis of the activity attributes, how they cluster for in-home and out-of-home activities and how they vary over the planning time horizons. The motivation for this analysis is the fact that the characteristics of the activities are changing with the increasing use of technology and these changes are bringing increased

choices regarding the timing, duration, location and involved people in the activities. Therefore, the activity groups based solely on the function of the activities have been overlooking these aspects.

The research undertaken in this chapter is inspired by the earlier work of Doherty (2006) and extends his ideas by categorizing *each activity episode* by its attributes as well as its function and analyzing how these attribute clusters vary among different planning time horizons. The analysis results show that some of the activities score high on more than one component, indicating that grouping the activities into discrete groups may lead to loosing some of the information and more flexible groupings may be used in future research in order to retain this information. For instance, the number of new groups may be extended to include groups such as "activities which score high *only* on Component 1", "activities which score high on *both* Components 1 and 2", etc. Another approach might be using cluster analysis based on the original variables, instead of using the principal component scores; generating the new groups based on the variable means (for continuous variables; duration, frequency, and number of people involved) and then using the binary variables (flexibilities) to further segment the groups.

The PCA results yield eight new activity groups such as temporally and personally flexible in-home activities, short and flexible out-of-home activities, etc. A detailed analysis is conducted to determine how the activities based on their function fall under these new activity categories. The results of this step confirm the hypothesis that the activities which are categorized in different groups based on their function (such as leisure and work) may have similar attributes and while the ones in the same category

may have different attributes. This approach lead to activity groups such as long and infrequent social activities; temporally flexible and spatially fixed meals, etc.

This chapter also presents how the component scores (which are indicators of the activity attributes) vary among the planning time horizons. Comparing the component scores among different planning time horizons revealed more information than comparing single activity attributes, as the components represent the clusters of activity attributes. The results of this chapter set the ground for the activity choice set of the activity choice models in the next chapter.

6. ACTIVITY CHOICE MODEL - A NEW FRAMEWORK

Activity choice has been a subject for many studies (Bhat and Lockwood 2004; Bhat and Gossen 2004; Bhat and Misra 1999; Bhat et al. 2006; Cirillo and Axhausen 2009; Golob and McNally 1997; Kemperman et al. 2006; Lu and Pas 1999). These studies have been examining activity choice focusing only on the function of the activity, therefore, have been lacking the details regarding the attributes of the chosen activity, such as its location, duration, temporal, spatial and personal flexibilities, which subsequently affect the choice for the other activities in the schedule.

Within this consideration this chapter builds on the findings of the previous chapter, Chapter 5, and utilizes the new activity groups to develop ***a new activity choice framework for non-skeletal activities***.

In this study, it is assumed that after the routine and pre-planned activities are entered in our schedules, (in other words, after the skeletal structure is formed) the schedule is left with available time windows to be filled with other activities. Figure 5 illustrates a simplified sketch of how an individual's weekly schedule may look like with the pre-planned activities, routine structure and available time windows. For each of these available time windows, an activity choice is performed to choose an activity. This decision is subject to the activity attributes, the scheduling characteristics, required travel and the individual and household characteristics.

The choice framework developed in this study focuses on the ***non-skeletal activities*** (planned impulsively, during the same day and same week) in order to be able to examine effects of the skeletal structure. The planning time horizons of the activities

(skeletal versus non-skeletal) are introduced in the model as reported by the respondents. The main contribution of this model is the way the activity choice set is structured which is discussed in detail in the following section.

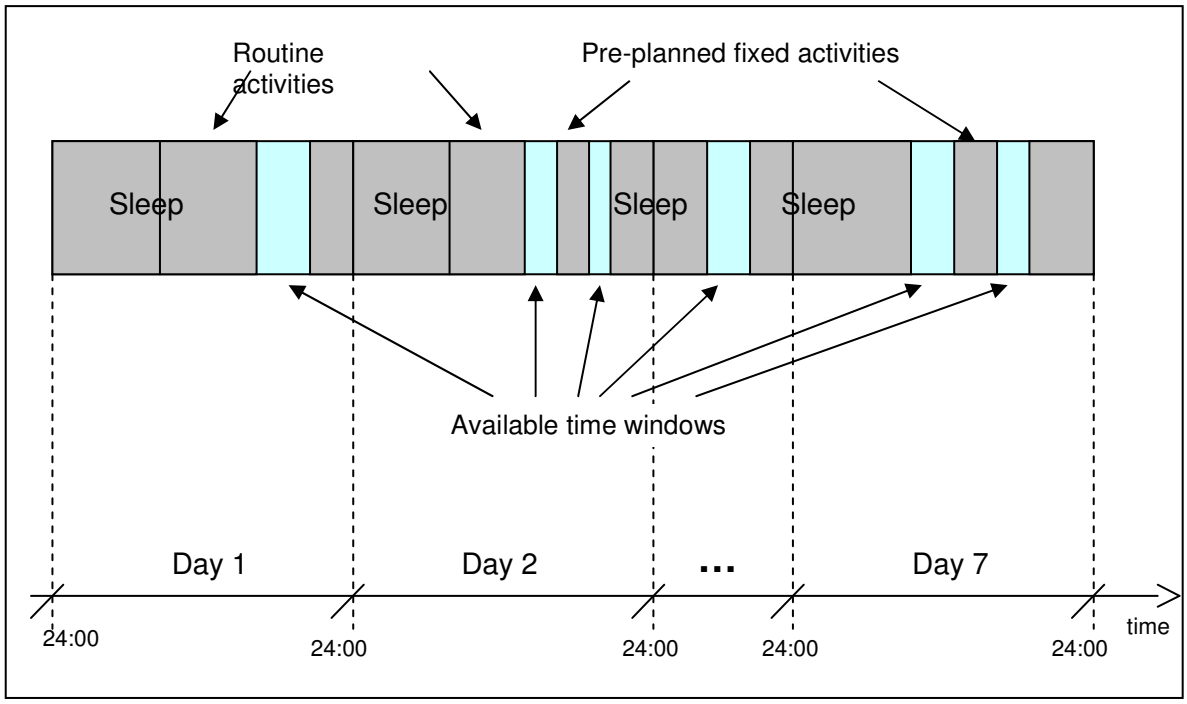

Figure 5: A simplified sketch of an individual's weekly schedule

6.1 Activity Choice Set: New Activity Groups

Activities are categorized in eight new groups in the previous chapter (Chapter 5) based on their important attributes. These attributes include the activity duration, frequency, number of people involved in the activity, and the spatial, personal and temporal flexibilities associated with the activity. These **eight new groups** are going to be referred to as the **main groups** throughout the rest of this dissertation, and are listed below:

For in-home activities:

(1) Temporally and personally flexible activities,

(2) Long, infrequent activities,

(3) Spatially and temporally flexible activities and

(4) Temporally flexible, spatially fixed activities which are conducted with other people.

For out-of-home activities:

(5) Short activities which are flexible in time and space and conducted with others

(6) In-frequent activities which have high personal flexibility

(7) Short, personally flexible activities and

(8) Activities with long duration and spatial flexibility.

The analysis performed in Chapter 5 assigns each activity episode to one of these eight groups and analyzes how the activities based on their function (social, work, etc.) are distributed among these new groups. As a result, the activities are categorized into groups which are defined both by their function and their attributes, such as long and infrequent social activities; temporally flexible and spatially fixed meals, etc. These new activity groups generated in Chapter 5 inform the choice set for the individuals' available time windows. For a given time window, an individual may choose between a temporally and personally flexible active activity, long and infrequent work activity, spatially and temporally flexible active activity, etc.

As the activity choice models developed in this chapter focus on the non-skeletal activities, only the activities planned within the week of the survey (same week, same day and impulsive) are considered for the activity choice set. This had some implications for the activity groups. Some of the activity groups yielded very low number of observations when the skeletal activities were taken out of consideration, for instance in-home social

activities which correspond to Group 1 had only 3 observations, in-home work related activities which correspond to Group 4 had only 4 observations, etc. In these cases, the activities are re-assigned to groups based on their next highest component score in order to avoid activity groups with very few observations. The following table, Table 14, reports the new activity groups after these re-assignments. This table forms the basis for the new activity choice framework.

Table 14: Distribution of Non-Skeletal Activities among New Groups

	Group 1 Temporally and personally flexible activities	**Group 2** Long, infrequent activities	**Group 3** Spatially and temporally flexible activities	**Group 4** Temporally flexible, spatially fixed activities conducted with others	Total
In-home					
Active	111	71	.	.	182
Hh. obligations	1237	644	.	710	2,591
Meals	770	.	.	914	1,684
Passive	433	1078	.	.	1,511
Pick up/ drop off	.	.	140	.	140
Service	.	62	.	.	62
Social	.	99	79	101	279
Work	81	76	.	.	157
Total	2632	2030	219	1,725	6,606

	Group 5 Short, time-space flexible activities, conducted with others	**Group 6** Infrequent activities with high personal flexibility	**Group 7** Short, personally flexible activities	**Group 8** Activities with long duration & spatial flexibility	
Out-of-home					
Active	.	194	174	.	368
Hh. obligations	.	.	81	.	81
Meals	267	.	100	.	367
Passive	54	.	.	55	109
Pick up/ drop off	385	.	372	.	757
Service	.	300	.	.	300
Shopping	264	.	598	91	953
Social	560	.	78	.	638
Work	.	169	240	256	665
	1530	663	1643	402	4,238

As a result of these groupings, for each available time window, an individual *n* is presented with 34 activity choices, grouped in eight main groups based on their attributes. Figure 6 illustrates the full choice set and how the activities distribute among these activity groups based on their attributes and their function.

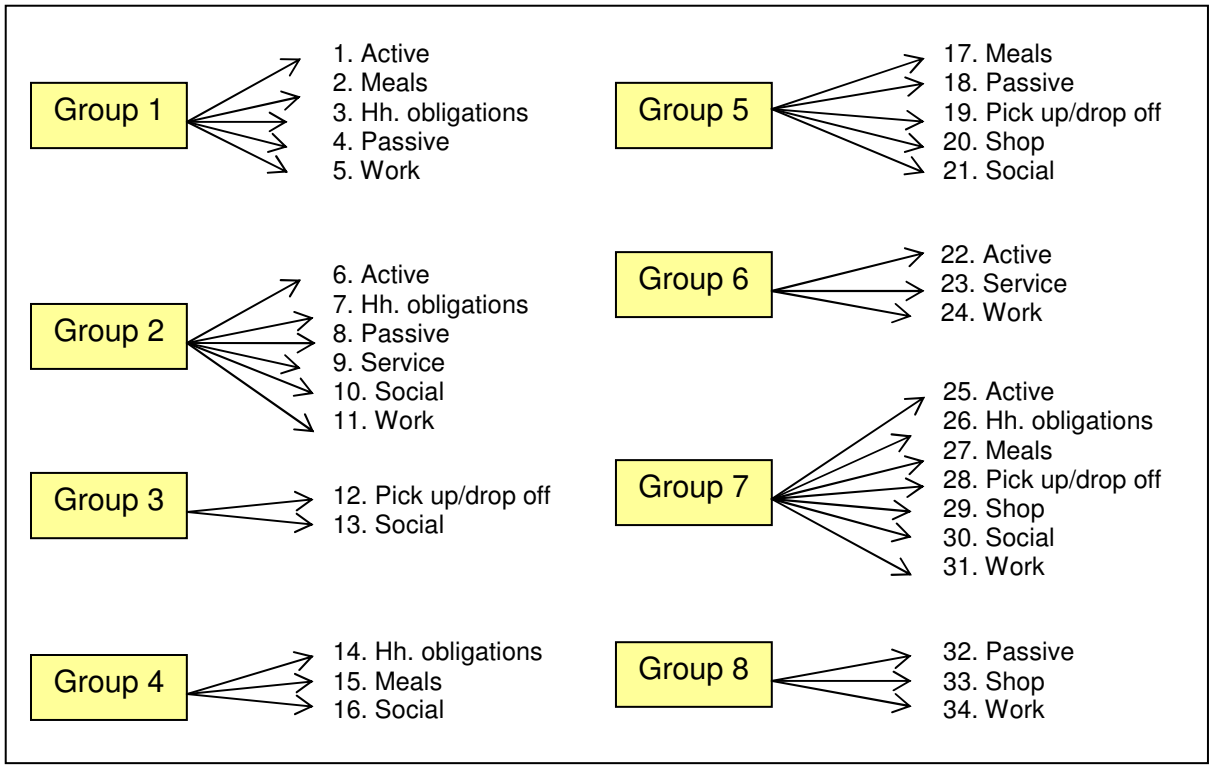

Figure 6: Full choice set for activities.

6.2 Analysis: Error Components Logit

The models developed in this chapter are also based on the ***discrete choice theory***. While *random coefficients logit* is used in Chapter 4 to analyze the planning time horizons and test for random taste variations, *error components logit* is used in this chapter, in order to introduce correlation patterns among the alternatives.

Error components logit do not exhibit the logit's independence from irrelevant alternatives (IIA) property and can approximate any substitution pattern by error components that can create correlations among the utilities for different alternatives (Cirillo and Axhausen 2009; Train 2002). The utility is specified as:

$$U_{nj} = \alpha' x_{nj} + \mu' z_{nj} + \varepsilon_{nj}, \qquad \text{Eq. 6}$$

where x_{nj} and z_{nj} are vectors of observed variables relating to alternative j, α is a vector of fixed coefficients, μ is a vector of random terms with zero mean and ε_{nj} is iid extreme value. The terms in z_{nj} are error components that, along with ε_{nj}, define the stochastic portion of utility. As a result, the random (unobserved) portion of the utility is:

$$\eta_{nj} = \mu' z_{nj} + \varepsilon_{nj}. \qquad \text{Eq. 7}$$

The random portion of the utility can be correlated over alternatives depending on the specification of z_{nj}. For the standard logit model z_{nj} is zero, so that there is no correlation over alternatives. This lack of correlation in logit models gives rise to the IIA property and restrictive substitution patterns.

Various correlation patterns can be obtained by appropriate choice of variables to enter as error components. In this study, a *nest structure* is aimed with activities belonging to the nests as defined by the eight new activity groups. This structure is obtained by specifying a *dummy variable* for each of the *eight new activity groups* that is equal to 1 for each alternative in the nest (same group based on their attributes), and zero

for the other alternatives. As a result 8 dummy variables are specified. With *8* non-overlapping nests, the error components are:

$$\mu'_n z_{nj} = \sum_{k=1}^{K=8} \mu_{nk} d_{jk} , \qquad \text{Eq. 8}$$

where d_{jk} (dummy) =1 if *j* is in nest *k* and zero otherwise. The random utility μ_{nk} enters the utility of each alternative in nest *k*, introducing correlation among these alternatives. As d_{jk} is zero for the other alternatives (the alternatives not in nest *k*), there is no correlation between the alternatives in nest *k* and those not in nest *k*.

As there are repeated choices from each individual, considering a sequence of choices, the probability that the person makes this sequence of choices is the product of the logit formulas:

$$L_{nj}(\alpha,\mu) = \prod_{t=1}^{T} \left[\frac{e^{\alpha_n x_{ni_t t} + \mu_n z_{nj_t t}}}{\sum_j e^{\alpha_n x_{ni_t t} + \mu_n z_{nj_t t}}} \right]. \qquad \text{Eq. 9}$$

The unconditional probability is the integral of this product over all values of μ:

$$P_{nj} = \int L_{nj}(\mu)\, f(\mu)\, d\mu . \qquad \text{Eq. 10}$$

The models are estimated using the software AMLET, as in Chapter 4.

6.3 Model Specification

As discussed before, activities are grouped under eight main groups, based on their attributes. The activities are further categorized based on their function (work, social, active, etc.) under these main groups and the error components logit allows for correlating the unobserved (random) portion of the utility among the alternatives within the same main group (nest). It is assumed that all of these alternatives are available to each decision maker, with an exception for work related activities. If an individual is not employed, than work related activities are not available to her in the choice set.

The variables of interest can be summarized as follows:

- A group of household and individual characteristics
    - Household size
    - Number of autos per adult
    - Gender (1, female; 0, male)
    - Education (1, has a bachelors degree or higher; 0, otherwise)
    - Age (Three dummy variables are specified.)
        - Group 1 (1 if age≤30; 0, otherwise)
        - Group 2 (1 if 30<age≤55; 0, otherwise)
        - Group 3 (1 if age>55; 0, otherwise)
- Variables related to the temporal characteristics of the activity
    - Time of day (morning (binary), daytime (binary), evening (binary))
    - Weekend (1, weekend; 0, weekday)
- Travel

- Logsum variable (the derivation of the logsum variable was discussed in Chapter 4, Subsection 4.2)

- Number of activities which belong to the 8 main activity groups (based on the attributes) in the skeletal structure. (Number of activities which belong to *Group1*, Number of activities which belong to *Group 2*, etc.)
- The main group of the previous activity
- Functional activity types (work, active, social, household obligations, meals, pick up/ drop off, services and shopping)
- Location of the previous and following activities (1, out-of-home; 0, in-home)
- The planning time of the following and previous activity (skeletal, 1; non-skeletal, 0)

In addition to these, eight error components (one for each main group) are introduced in the model to account for the correlations among the alternatives within the same group. While there are 10693 activity episodes available for this analysis, the models are estimated with approximately 90% of the whole data (9393 observations). Nearly 10% of the data (1300 observations) are randomly chosen and set aside to validate the estimation results.

6.4 Discussion of Results

The estimation results of the best fitting model are presented in Table 15. The log likelihood results of the mixed logit model with error components and panel effects is significantly higher than the MNL model estimated with the same set of variables, indicating that accounting for correlations among alternatives and panel effects

significantly improve the model. The model results of the MNL model estimated with the same set of coefficients can be found in Appendix D, Table 36.

First a model with only household and individual characteristics is estimated. The variables related to the temporal characteristics, travel (logsum variable), activity purposes, and the effects of the schedule are added sequentially to the model. The log-likelihood results for these models (both for MNL and error components logit) are summarized in Table 16. The results reveal that adding these variables sequentially in the analysis increases the statistical explanatory power of each model with respect to the previous models.

The model results reveal the significant relationships between household and individual characteristics and activity choice. Based on the model results, gender has significant effects on activity choice. Females are more likely to choose the in-home activities with temporal and personal flexibilities (Group 1). They are less likely to participate in long and infrequent in-home activities (Group 2), as well as short, personally flexible out-of-home activities (Group 7) and long, spatially flexible out-of-home activities (Group 8).

The individuals who are employed are more likely to engage in long in-home activities (Group 2), which may include tele-working and less likely to engage in in-home activities which are temporally flexible with personal commitments (Group 4), which may include household obligations, meals and social activities. The employed individuals are more likely to participate in out-of-home personally flexible activities (Groups 6 and 7); such as out-of-home household obligations, services, pick up drop off activities, etc.

Table 15: Results of the Activity Choice Model

	Group 1		Group 2		Group 3		Group 4		Group 5		Group 6		Group 7		Group 8	
	Coef.	t stat.	Coef.	t stat.	Coef.	t stat.	Coef.	t stat.	Coef.	t stat.	Coef.	t stat.	Coef.	t stat.	Coef.	t stat.
Gender	0.415	5.14	-0.256	6.25	-0.630	11.59							-0.222	5.55	-0.974	15.06
Age gr. 1			-0.436	11.67			-0.550	7.94					-0.529	13.93		
Age gr. 3	0.641	16.47	0.472	11.43							0.568	20.58				
Employed			0.158	3.15			-0.365	6.97			0.773	16.31	0.271	6.99	0.779	18.32
Education	0.211	3.51			-0.387	9.98			0.081	1.91					0.054	2.51
Autos per adult					-0.593	9.49			-0.318	8.05	0.363	8.07	-0.088	2.61	-0.390	6.50
Hh size					-0.277	6.11	0.121	5.53	-0.066	1.74			-0.064	1.71	-0.255	6.93
Temporal characteristics																
Weekend	-0.418	6.63									-0.758	12.63	-0.621	12.53	-1.051	15.87
Morning					-0.913	11.07			-1.058	15.92			-0.682	11.38		
Evening			0.551	10.22			0.495	8.61			-1.045	16.01	-0.864	15.17	-1.697	19.30
Number of activities in the skeletal structure that is:																
Group 1							-0.099	1.56	-0.143	2.08						
Group 2									0.139	3.71			0.213	6.95		
Group 3			-0.299	8.09	0.185	6.94	-0.215	4.01					-0.161	4.31	0.070	2.66
Group 4					0.152	4.73					0.243	5.90				
Group 5					0.232	12.09					-0.050	1.75			0.168	6.13
Group 6	0.075	1.75	0.078	2.08											-0.401	11.59
Group 7	0.148	2.64											0.070	1.46	0.096	3.33
Group 8							0.166	4.02	0.233	5.00			0.131	2.82		
Previous activity group:																
Group 1			0.118	2.57					-0.894	15.57	-0.891	13.15	-0.384	9.60	-0.318	7.26
Group 2	0.158	4.27	0.697	15.62	0.385	30.24	0.483	14.37								
Group 3			0.374	14.98	0.689	35.00			-0.564	8.94						
Group 4			0.624	14.03			0.502	10.13	-0.184	6.02	-0.352	7.96			0.413	23.47
Group 5	-0.339	8.27	-0.110	2.79	0.640	39.22			0.719	14.77			0.213	6.12	0.299	18.44
Group 6	-0.520	10.74	-0.507	9.12			-0.246	5.46					0.447	11.43		
Group 7	0.152	4.11			0.860	25.06					-0.291	8.02	0.736	20.59	0.652	37.87
Group 8	-0.379	7.20	-0.284	5.43	0.385	22.56	-0.273	5.76					0.590	19.38	1.137	37.88
Error comp	0.757	12.61	0.360	5.79	1.220	23.55	0.702	17.70	0.374	4.00	0.719	13.33	0.587	10.92	1.055	25.85

Table 15, continued (variables specified specific to functional types and out-of-home activities)

Variable	Alternative	Coef.	t stat.
Functional types	Active	-1.633	14.91
	Hh obligations	0.268	3.80
	Meals	0.099	1.59
	Pick	0.174	1.51
	Services	-1.009	13.03
	Shop	0.241	2.37
	Social	-0.858	7.65
	Work	-0.785	5.99
Travel related			
Logsum	all- out-of-home	0.673	3.27
Locations of previous and following activities (1, out-of-home)			
Following	out-of-home activities	1.133	15.62
Previous	out-of-home activities	0.580	7.91
Following and previous activity planning times (1, skeletal)			
Following	Meals	-0.178	4.07
	Passive	0.647	9.67
	Shopping	-0.278	6.85
	Work	0.080	2.23
Previous	Meals	0.194	3.81
	Passive	-0.187	3.00
	Pick up/ drop off	0.139	3.38
	Services	0.358	14.49
	Shopping	0.347	8.21
	Work	0.364	7.90
Number of observations		9393	
Number of individuals		345	
Log likelihood at optimal		-28274.70	
Log likelihood at zero coefficients		-32735.62	
Adjusted r-squared		0.132	

Table 16: Log likelihood Results for Different Models

			Log likelihood at optimal	
Model no.	Variables included	Number of variables(*)	Multinomial Logit (MNL)	Error components logit
1	Socio-demographics	30	-31.584	-30.807
2	Temporal characteristics	42	-31.000	-30.227
3	Logsum	43	-30.980	-30.212
4	Activity function	51	-29.833	-29.050
5	Effects of the schedule	124	-28.773	-28.274

* This number does not include the error components. Error components logit model includes 8 error components in addition to these variables.

The individuals are less likely to choose in-home activities which are flexible in time and space as well as out-of-home activities with personal flexibility, (Groups 6 and 7) and long durations (Group 8) over the weekend. The in-home and out-of-home activities which are spatially and temporally flexible are less likely to be performed in the morning. The out-of-home activity groups, (particularly Groups 6, 7 and 8) are less likely to be performed in the evening, compared to daytime.

The types of the activities in the skeletal structure have significant impacts on the activity-choice for the available time windows. On one hand, these relations may point to *substitution patterns*, such as an individual who participates in activities of a certain nature in her skeletal structure may not choose similar activities for her available time windows. On the other hand, some activities in the skeletal structure may call for more activities in the same nature. For instance, as the number of in-home temporally and personally flexible activities (Group 1) in the skeletal structure increase, it is less likely to

choose temporally and spatially flexible out-of-home activities which are conducted with others (Group 5) for the available time windows. Increasing number of in-home activities with long durations (Group 2) increases the propensity of choosing short out-of-home activities which are either personally flexible (Group 7) or conducted with others but have temporal and spatial flexibilities (Group 5) for the available time windows compared to other types of activities. As the number of spatially flexible out-of-home activities with long durations (Group 8) increase, the probabilities of choosing short out-of-home activities (Groups 5 and 7) and temporally flexible in-home activities with other individuals (Group 4) increase.

The attributes of the previous and following activities also affect the activity choice. For example, the temporally and personally flexible in-home activities (Group 1) are less likely to be followed by either of the out-of-home activities. They are more likely followed by in-home activities with long durations (Group 2) compared to the other in-home categories. If the previous activity is flexible in time and space, it is more likely that the individuals will choose an activity similar in nature or a long infrequent in-home activity for the available time. The previous activity being a temporally and spatially flexible activity (Group 3) significantly decreases the propensity of choosing a short, time and space flexible out-of-home activity (Group 5). If the previous activity is an out-of-home short personally flexible activity (Group 7), it is more likely to choose a temporally and personally flexible (Group 1) or long and infrequent (Group 2) in-home activity as well as a long and spatially flexible out-of-home activity (Group 8). The previous activity being short and personally flexible out-of-home activity (Group 7) decreases the probability of infrequent out-of-home activities. Everything else being equal, in general,

the out-of-home activities are more likely to be preceded or followed by out-of-home activities.

The logsum variable is significant and positive. The logsum variable in this model represents the maximum utility one would gain from a travel choice for an out-of-home activity. Therefore, as expected, a positive logsum coefficient reveals that as the time and cost of travel decreases, the probability of choosing an out-of-home activity increase. Further research is required to analyze this effect in detail as the mode choice model (from which the logsum is calculated in this study) only includes the time and cost of travel due to data limitations.

The planning times of the previous and following activities also have significant effects on activity choice. For instance, meals and shopping activities are less likely to be scheduled before skeletal activities and more likely to be scheduled after skeletal activities. The previous activity being a skeletal activity increases the probability of picking up/ dropping off people and items, and also performing service related activities, (such as banking and medical appointments) afterwards.

6.5 Application Results

As discussed before, the models are estimated with approximately 90% of the data, and 10% of the data are set aside for validation purposes. In order to test the performance of the models (both MNL and mixed logit estimations), the most comprehensive models including the household and individual characteristics, temporal characteristics, travel (logsum variable), activity purposes, and the effects of the individual's schedule are applied to forecast the activity choices.

The models are applied both to the validation data and the original data (the data on which the models are estimated). The application results of the error components logit on the validation data are illustrated in Figure 7 and 8, for in-home activity groups and out-of-home activity groups respectively. These figures compare the observed and predicted frequencies for each activity group.

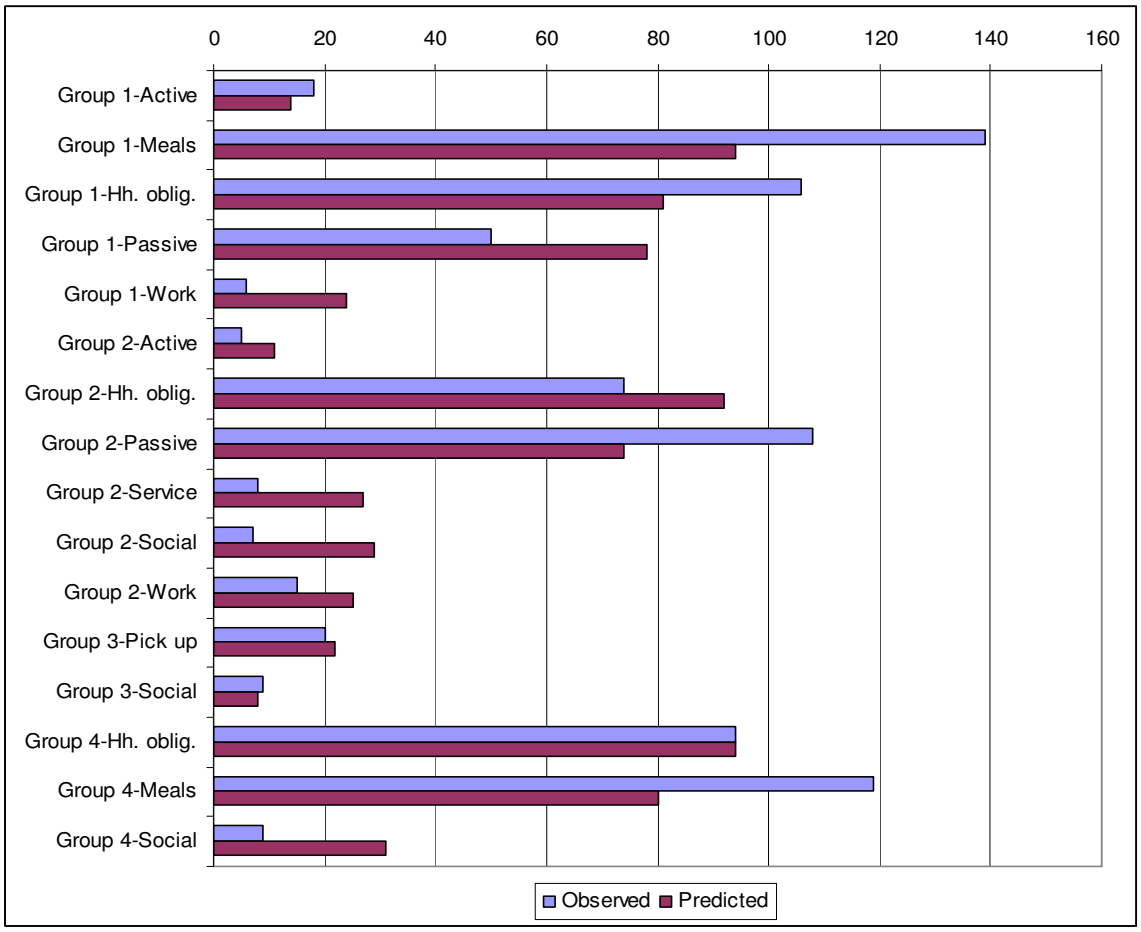

Figure 7: In-Home Activities: Forecasts vs. Observed Frequencies

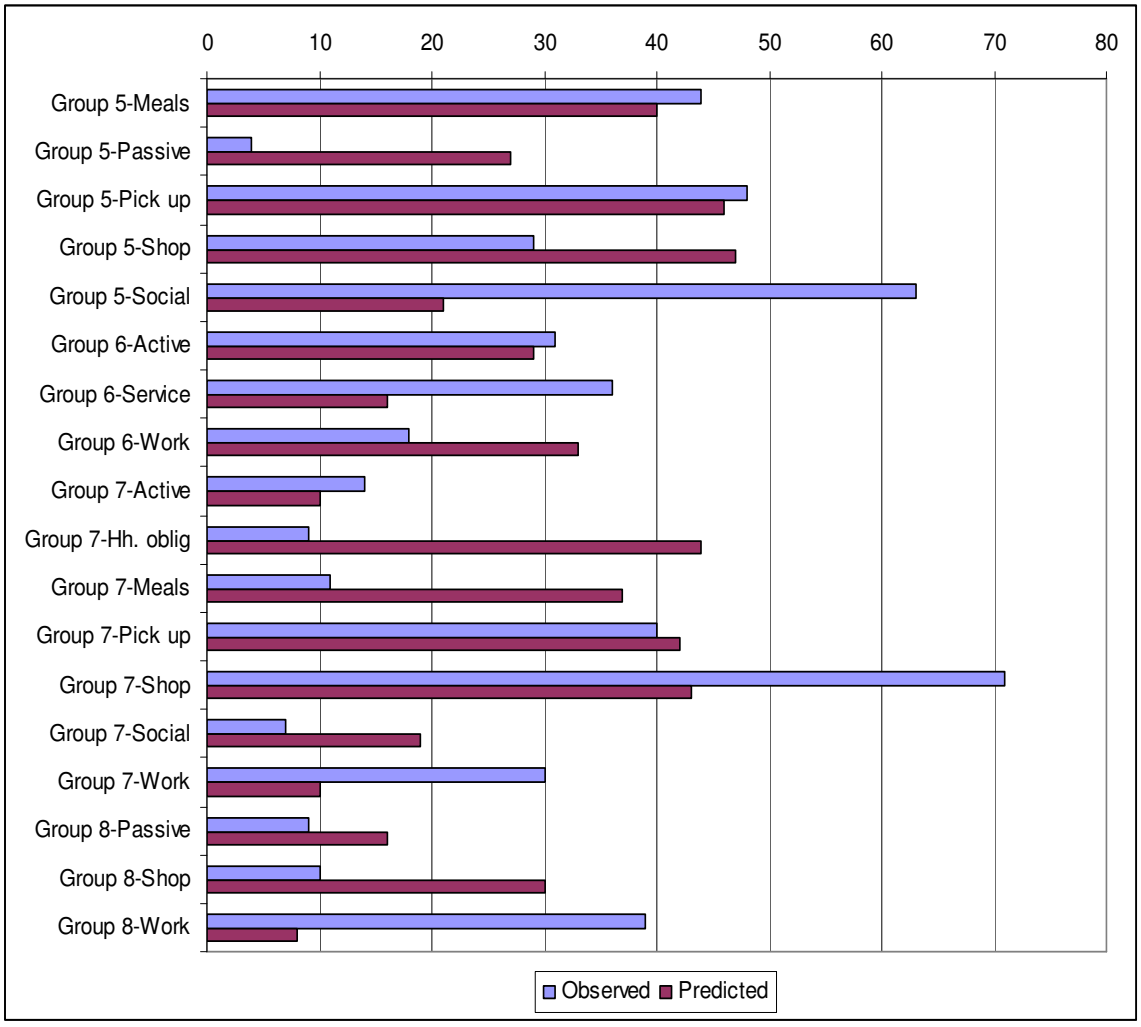

Figure 8: Out-of-Home Activities: Forecasts vs. Observed Frequencies

For all of these forecasts, statistical tests are performed to examine the significance of differences between the predicted and observed proportions for each of the 34 activity groups. The detailed results are tabulated Table 37 and Table 38 in Appendix D. While the models perform better on the original data, the differences are not to a large extent, which indicates that the models are able to replicate the choice patterns not only on the original data but also on the validation data.

Based on the forecasts of the error components logit model with panel effects on the validation data, household obligations are generally estimated close to observed values with an exception of out-of-home short and personally flexible household obligations which are underestimated. While the in-home meals are generally overestimated, short and personally flexible out-of-home meals are underestimated. The differences between the observed and predicted frequencies of active activities of different groups (temporally and personally flexible, long and infrequent, short and personally flexible) are not statistically significant from one another. While the in-home long and infrequent passive activities are overestimated, the in-home passive activities which are flexible in time and space, and the out-of-home passive activities with short in durations and conducted with others are underestimated.

These results indicate that there are some factors that are not captured and the models can still be improved. However, it should be noted that the high number of choices (34 choices) in the activity choice set also contributes to the level of error in the forecasts. One immediate improvement on this model may be adding variables to account for the opportunities and constraints that the external environment introduces, such as the availability of restaurants, activity centers, and shopping malls. In addition to this, the measures of flexibility, which are the key points in this research in terms of grouping the activities, relies on subjective data. More robust measures of flexibilities may improve the way the new activity groups are generated, which will have direct implications of the resulting choice models.

6.6 Conclusions

The framework developed and presented in this chapter extends the current activity choice modeling by structuring the choice set based on the activity attributes as well as the function of the activity. The results of the activity choice models reveal the significant associations between the household and individual characteristics, travel, temporal characteristics and the characteristics of the schedule. While these results are expected and consistent with common sense in general, the details revealed in the models are interesting in terms of how the activity choices may vary with changing characteristics in the population. For instance, the model results reveal that employed individuals are less likely to participate in in-home activities which are conducted with others, fixed in space but flexible in time, such as meals, household obligations and social events. This indicates that, as more of individuals enter the work-force, the probability of choosing activities with these characteristics will decrease, while the probability of choosing short and personally flexible out-of-home activities including active activities, household obligations, meals, social events, etc. will increase. With the aging population, the model results suggest that the propensity of choosing in-home activities which are flexible in time and space, and the ones with low frequencies and high durations will increase.

These findings point to the possible substitution patterns among the activities with the same function. As the individuals get older, the in-home social activities with high durations and low frequencies may take over the out-of-home social activities with short durations and personal flexibilities. As the employment rates increase, short personally flexible out-of-home meals may be chosen over the in-home meals eaten with others.

These substitution patterns have important implications for activity choice and the resulting travel patterns.

The models developed in this study can forecast the activity choices of the individuals based on their individual and household characteristics, temporal characteristics of the available time window, the types of activities already existing in their skeletal schedules and travel characteristics. As discussed before, a realistic representation of the choice process is essential for developing sound travel demand models to assess the impacts of TDM policies and changing lifestyles. The findings of this research can be integrated into the activity travel simulation models, which are used for this purpose, to improve their resulting forecasts.

7. CONCLUSIONS

Activity-based approaches are gaining more attention as the researchers continue revealing the links between activity participation and travel (Bhat and Koppelman 1999; Bowman and Ben-Akiva 1996; Doherty et al. 2002; Kitamura 1988; Kitamura et al. 1997; Kurani and Lee-Gosselin 1996; McNally 2000; Pas 1996).

Improving the current activity choice models and achieving more realistic demand forecasts predicate on better understanding the factors associated with activity choice. Within this consideration, this research is undertaken to understand how people make their activity choices, more specifically to understand the determinants of the planning time horizons of the activities, the role of activity attributes and the characteristics of the schedules.

7.1 Main Contributions

The results of this research reveal the significant relationships between activity attributes, planning time horizons, activity choice, individual and household characteristics and travel. These findings confirm that to be able understand the resulting activity and travel patterns and forecast changes, one has to first understand the factors associated with these choices. The contributions of this dissertation are mostly in modeling and understanding human behavior (which lead to understanding the resulting travel patterns), however less practically applicable in the shorter term. The analysis performed for this research included three main parts, as discussed below.

Part 1: Planning Time Horizons

The planning time horizons of the activities are important determinants of the resulting activity-travel patterns. When individuals enter their pre-planned, fixed and routine activities to their schedules, these bring many temporal, spatial and interpersonal constraints for the activities which are added later in the schedule. These timing decisions need to be replicated to be able to develop realistic demand models, as they introduce constraints and opportunities for the subsequent activity-travel choices.

The detailed analysis of planning time horizons is performed following the recent calls in the literature (Doherty 2005; Mohammadian and Doherty 2005; Roorda et al. 2007) to reconsider the assumptions regarding the planning times of the activities. While several activity-travel simulation models assume the function of the activity as the sole determinant of the planning time horizon, the results of this study reveal that several activity attributes (duration, frequency, number of involved people and children, spatial, temporal and personal flexibilities), as well as household and individual characteristics, location (in-home versus out-of-home) and travel characteristics, also have clear impacts on the planning time horizons.

It is suggested that many policies will first affect the planning time horizon of the activities and their distribution over time and space which would then bring a scheduling response and changes in activity and travel patterns (Bowman and Ben-Akiva 1996). The findings of the models developed in this study confirm this hypothesis, and reveal the detailed and significant relationships among the activity attributes, travel characteristics and socio-demographic characteristics. For example, the implementation of flexible work hours will have clear implications for the schedule; the flexible activities are more

likely to be planned closer to their execution time. The activities with higher travel time and costs are generally planned ahead, consequently increasing fuel costs may suggest that some of the activities that are currently added spontaneously to our agendas will more likely be planned ahead in the future or they will be replaced with the other activities which incur less travel time and cost. As the employment levels increase, more activities will be planned as a part of a routine and/or weeks ago, compared to impulsive activities. These changes will subsequently affect the overall activity planning and execution process.

While developing a comprehensive activity travel simulation model is beyond the scope of this research, the findings of these models could be integrated in the existing models. This could be done either by applying the comprehensive model using the activity attributes, household and individual characteristics as independent variables (which may be limited due to the availability of data) or integrating the findings of the models in the decision rules, so that instead of deciding the planning sequence solely based on the activity types, the decisions could be based on the activity attributes. For instance, temporally flexible work activities may be planned impulsively; spatially fixed active activities may be planned weeks/months ahead, etc.

Part 2: New Activity Groups Based on Their Attributes

Instead of grouping the activities based on their function (such as work, leisure, etc.) this study groups the activities based on their important attributes. This approach is inspired by the earlier work of Doherty (2006). Focusing on the attributes instead of the function is particularly important as the *attributes of the activities are changing while the*

functions remain the same. For example, the purpose of the work related activities is still the same; however, the increased use of technology and internet brought spatial and temporal flexibilities. Work related activities are not the only ones that are affected by the increased use of internet. Some of the service related activities (such as banking) and shopping used to be limited to working hours and fixed in location; nowadays, several individuals shop online and perform their transactions through internet.

In this study, activities are categorized under 8 main groups based on their important attributes, such as duration, frequency, involved people and spatial, temporal and interpersonal flexibilities. This categorization is based on the results of the principal components analysis (PCA), which yielded new activity groups such as temporally and personally flexible in-home activities; long and infrequent activities in-home activities; short, personally flexible out-of-home activities, etc.

The findings of this study reveal the varying attributes among and across different activity types. These results confirm the hypothesis that activities which have been categorized in different groups based on their function (leisure, work, etc.) may have similar attributes while there may be significant differences in activity attributes among the activities within the same group. For instance, some household obligations may show similarities to active activities in the sense that they are both temporally and personally flexible (Group 1). On the other hand, some household obligations would differ from those, as they may be fixed in space and must be conducted with others (Group 4).

The examination of how the activities based on their purposes are distributed among these new groups advances the analysis a step further. As a result, the activities are categorized into groups which are defined both by their functional types and their

attributes, such as long and infrequent social activities; temporally flexible and spatially fixed meals, etc. These new activity groups informed the structure of the activity choice set for the new activity choice framework.

Part 3: New Activity Choice Framework

The activity groups generated in *Part 2* inform the structure of the choice set for the new activity choice framework. This study assumed that after the routine and pre-planned activities are entered in our schedules, the schedule is left with available time windows. For each of these time windows, an activity choice is performed to choose an activity. The activity choice models developed in this study focuses on the activities which are added later in our schedules *(non-skeletal activities)*, in order to be able to examine effects of the existing structure.

With the increased choices brought about by technology, the models predicting only the function of the activity (Bhat and Lockwood 2004; Bhat and Gossen 2004; Golob and McNally 1997; Kemperman et al. 2006) lack the details regarding the attributes of the chosen activity, such as its location, duration, temporal, spatial and personal flexibilities which will subsequently affect the choice for the other activities in the schedule. To fill this gap, in this research, the choice set is structured considering both the important attributes and the function of the activity. For instance, for a given time window, an individual chooses between a spatially and temporally flexible social activity, a short personally flexible shopping activity, a spatially fixed social activity, etc. The groups generated in Chapter 5 are used in this model to generate the choice set, which yields 34 choices for each available time window.

The results of the activity choice models reveal the significant associations between the household and individual characteristics, travel, temporal characteristics and the effects of the schedule. The results of the models reveal interesting substitution patterns among activities, with the changes in the population, travel characteristics and the characteristics of the skeletal structure. For instance, the model results suggest that the characteristics of the activities chosen by different groups of individuals, such as employed and unemployed, males and females, and individuals from different age groups differ from one another. While the employed individuals are less likely to participate in in-home activities which are conducted with others, they are more likely to participate in short, personally flexible out-of-home activities. With the aging of the population, the probability of choosing in-home activities which are flexible in time and space, and the ones with low frequencies and high durations will increase. So, even if the function of the activity will be same (such as social, meals, etc.), the way it is performed (location, duration, involved people, etc.) will be different. These substitution patterns have important implications for activity choice and hence the resulting travel patterns.

7.2 Transferability of the Models

While the transferability and application of these results to other cities and countries may impose some challenges, it is certainly an interesting avenue for research. Before applying these results to other locations, if possible, comparable data should be collected and analyzed (Cirillo and Toint 2002). These data would be used to check whether similar groupings exist in terms of activity groups based on their salient attributes.

Doherty (2006) argues that in different locations (cities or countries), again there will be activities with characteristically distinct levels of flexibilities, frequencies and durations, just like the ones identified with the CHASE dataset. However, the means and variances of these attributes may differ which in turn may or may not lead into similar groups as introduced in this study. Moreover, while the groups based on attributes may end up being similar, such as short flexible activities, long infrequent activities, etc. the way the activities (based on their function) fall under these categories may vary. For instance, while the availability of technology and internet is increasing in the developing world, the levels of use are still lower compared to the developed countries. As a result, while several work and service related activities are associated with temporal and/or spatial flexibilities in this study, this might not have been the case if the data were collected elsewhere in the developing world.

A valuable and interesting future study would be looking at the available data (or collecting similar data) from several other locations and examining the similarities and differences across the cities and countries. This may lead to a new activity choice framework, which may have broader applications.

7.3 Limitations of the Study

The majority of the limitations faced in this study are related to the data. While the CHASE dataset provides a rich source of data, still some details have been missing. For instance, there is no information on multitasking. If an individual is watching TV while attending to children, the dataset only includes information on the activity the respondent reports. In addition to this, it is difficult to set clear cut boundaries among some activities types. For example, having a meal with friends could either be perceived as a "social"

activity or an “eating” activity. In these cases, the self-reports of the individuals are taken into consideration, which may be subjective; one may record this as a social interactive event, while another individual may record this as a meal.

Recent studies reveal that the lack of information regarding multi-tasking may result in underreporting of some of the key activities, may lead to inaccuracy in time use measurements and misrepresentation of change in behavior (Kenyon and Lyons 2007). The availability of information regarding multi-tasking may lead to more accurate representation of time use behavior, activity participation and possible changes in behavior. Such information would also enable us understand the attributes which make the activities available for multi-tasking: for instance, which combinations of activities could be performed simultaneously, which ones could not?

For instance, if we observe that increasing flexibility in time and space increases the propensity to multi-task; can we say that with increasing flexibility individuals will have more time available during the day or week (as they perform more multi-tasking)? Then what happens to the amount of time which becomes available through multi-tasking? Does this mean longer travel times for some of our activities? Does this introduce more activity participation, and if so, which types of activities? With the availability of information regarding multi-tasking, the choice set may be structured in a different way to include the choice alternatives where two or more activities are performed simultaneously. For instance, these alternatives may be a spatially fixed in-home activity (such as taking care of children) being performed together with a temporally and personally flexible activity (such as on-line shopping, passive recreation), etc.

Another limitation of this study is related to the mode choice model. While CHASE data includes the travel mode information and the geo-coordinates of origins and destinations, since the focus of the data collection was not on the mode choice aspect, some information related to travel are missing, such as whether the person is paying for parking, whether the person is carpooling, etc. This reduces the accuracy of the mode choice model and therefore the logsum measure.

While having a week-long activity diary is a great opportunity, given that most of the activity and time use studies utilize one or two day diaries, still some disadvantages exist. For instance, some individuals have no record of some activities, so it is not known whether the individual does not participate in this type of activity at all (such as exercising) or did not participate in this activity during the survey period. This may have important implications in structuring the choice set and raises the question whether to include the activities which are not reported by some individuals in their choice set. Cirillo and Axhausen (2009) chose to define such activities as *"not available"* for certain individuals in their models, however, their dataset (Mobidrive) covers six weeks, whereas the CHASE data covers only one week. If a person does not perform a specific activity during six consecutive weeks, it is safer and acceptable to assume that the person does not participate in this type of activity at all, while for one week, this assumption could be unrealistic. Therefore, in this research, such activities are still included in the choice set, with an exception of work related activities, which are only available for employed individuals.

Some of the assumptions regarding the new activity groups might have been the underlying reasons for the over and underestimations of the resulting activity choice

models. An activity is assigned to only one group based on its component scores. However, as discussed in Chapter 5, some of the activities score high in more than one component. In addition to this, some of the activities were re-assigned to groups based on their second highest scores to avoid activity groups with very few observations for the activity choice models. Therefore, it is important to note that while these assumptions were required to be able to develop the activity choice models, they might have affected the accuracy of the models.

7.4 Future Work

The models developed in this research analyze the planning time horizons, activity attributes and the determinants of activity choice. The results reveal several interesting relationships and there are still many research questions remain to be explored.

One of the immediate questions which remains to be explored is how land use patterns, opportunities and constraints introduced by the external environment fit into these models. For instance, does higher accessibility and mixed use bring more flexibility? If so, how do they affect the overall activity travel patterns? The future research will integrate the land use patterns in the analysis to examine links between the external environment and activity choice.

The results of this study suggest that the spatial, temporal and personal *flexibilities* are important determinants of both the planning time horizons and the new groupings of the activities. While the CHASE dataset includes data regarding the flexibilities through self-reports of the survey respondents, several other activity datasets do not include this information. As a result, to be able to apply the models presented in

this dissertation on other datasets, it is essential that the *indicators of flexibilities* are identified. For instance, could one use the *variations* in location and timing as an alternative to flexibility? The number of times a certain activity takes place at different times and different locations may be an indicator of how flexible the activity is in time and space. On the other hand, an activity, such as shopping, which is performed at the same several times, may not be an indicator of fixity, but habit. While this may be a worthwhile approach to test with datasets covering longer time periods (such as Mobidrive, which covers 6 weeks) with the ones covering only a limited time period, such as a day or two, examining the variations would not be possible, since some activities may appear only a few times, or even only once during the survey period. So, what would be the other indicators of flexibility, would the other activity attributes serve as indicators of flexibility, such as duration, frequency, location, etc.? Would it be possible to characterize flexibility with household and individual characteristics, so that one may associate certain types of activities being flexible in some or all dimensions (temporal, spatial and personal) for some individuals?

A very detailed data collection effort is necessary to accurately understand and measure flexibilities. The flexibilities associated with each activity vary among individuals. In addition to this not all episodes of the same activity may have the same flexibility for the same individual, for instance, one might have the flexibility to work from home, but on a given day he/she may have to work at the workplace because of a meeting. It is this level of detail that makes it difficult to address flexibilities. A very detailed data collection effort, focusing mainly on the flexibilities, should be undertaken to understand what makes some activities be temporally, personally and spatially flexible

and how this may vary across different individuals with different characteristics. Only with this level of detail, we can conclude whether we could develop objective measures of flexibility or we should continue relying on self-report data.

Another interesting venue for extending this research stems from the application of this model in different locations. As discussed before, while confirming the transferability of the models developed in this study brings challenges, it also introduces several interesting research avenues. To be able to confirm the transferability of this model to other regions, first the similarities and differences among activity participation and travel patterns across different cities or nations should be analyzed. The analysis will follow the framework introduced in this study and compare the resulting activity groups based on their salient attributes and how the activity types distribute among these groups. While this is a methodological step necessary to be taken to check the transferability of these models, it would be an innovative study in itself comparing the behavior and developing an activity choice framework with broader applications.

Appendix A: Descriptive Statistics

Table 17: Activity Attributes (In-home)

	Duration mean	Freq. mean	# People mean	Spatial flex. mean	Temporal flex. mean	Personal flex. mean	N
Meals							
In-home meal	42.06	11.65	0.87	0.07	0.97	0.98	3075
Coffee/snack shop	38.75	1.50	1.00	0.00	0.25	1.00	4
Total	42.05	11.64	0.87	0.07	0.97	0.98	3079
Work							
Telework	109.88	7.61	0.07	0.10	0.82	0.97	201
Volunteer work	121.94	10.44	0.08	0.67	0.97	0.83	36
Total	109.88	7.61	0.07	0.10	0.82	0.97	201
Household obligations							
Cleaning/maintenance	77.25	7.97	0.25	0.03	0.99	1.00	1320
Meal preparation	52.39	7.74	0.32	0.06	0.96	0.99	1296
Attending to children	73.42	14.76	1.35	0.02	0.04	0.07	729
Other hh obligations	82.86	7.03	0.33	0.01	0.77	0.73	444
Attending to pets	22.43	8.78	0.09	0.12	0.99	0.02	246
Total	65.85	9.07	0.47	0.04	0.79	0.74	4035
Pick							
People	15.54	13.17	0.69	0.74	0.19	0.06	81
Meal	48.30	3.74	0.78	0.74	0.61	0.74	23
Snacks/drinks	42.06	6.39	0.81	0.03	0.29	1.00	31
Other items	37.42	9.41	0.36	0.00	0.80	0.94	64
Total	30.50	9.81	0.61	0.39	0.45	0.57	199
Services							
Medical/professional	34.29	5.00	0.57	0.14	0.86	0.71	7
Barber/salon/beauty	93.75	1.50	0.00	0.00	0.75	1.00	4
Banking	76.00	2.60	0.00	0.00	0.70	1.00	10
Other service	105.40	5.67	0.29	0.12	0.83	0.81	42
Total	92.10	4.84	0.25	0.10	0.81	0.84	63
Active							
Hobbies	93.71	5.48	0.14	0.07	0.87	0.97	132
Exercise or active sports	58.51	6.30	0.16	0.27	0.27	0.99	115
Playing/parks	81.25	5.88	0.44	0.19	0.72	0.75	32
Total	77.77	5.86	0.18	0.16	0.61	0.95	279
Passive							
Spectator events/theatre	75.00	3.00	1.00	0.00	1.00	1.00	3
Regular TV programs	96.73	9.67	0.52	0.05	0.06	1.00	1599
Unspecific TV	93.85	6.82	0.48	0.06	0.92	0.98	383
Watching video	112.61	4.08	0.85	0.01	0.94	0.97	199
Other rec.	103.32	4.27	0.51	0.05	0.70	0.91	91
Total	97.64	8.65	0.54	0.05	0.29	0.99	2184
Social							

	Duration mean	Freq. mean	# People mean	Spatial flex. mean	Temporal flex. mean	Personal flex. mean	N
Hosting visitors	139.19	3.00	2.03	0.11	0.95	0.14	238
Planned social events	178.21	2.57	2.79	0.86	0.79	0.07	14
Cultural/clubs	112.38	7.50	0.69	0.63	0.69	0.00	16
Other social	76.14	4.88	1.66	0.46	0.93	0.29	76
Total	125.60	3.61	1.92	0.24	0.92	0.16	344

Table 18: Activity Attributes (Out-of-home)

	Duration Mean	Freq. Mean	# People Mean	Spatial flex. Mean	Temporal flex. Mean	Personal flex. Mean	N
Meals							
In-home meal	22.50	11.81	0.00	0.69	0.44	1.00	16
Restaurants	72.54	2.89	1.38	0.89	0.79	0.64	320
Coffee/snack shop	28.08	2.96	0.61	0.61	0.72	0.82	114
Total	59.50	3.23	1.14	0.81	0.76	0.70	450
Work							
At work	342.33	8.21	0.16	0.25	0.03	0.96	1683
Tele work	48.75	6.25	0.25	0.63	0.75	1.00	8
Volunteer work	205.55	3.76	1.03	0.66	0.55	0.52	29
Total	340.94	8.20	0.16	0.25	0.04	0.97	1691
Household obligations							
Cleaning/maintenance	120.00	5.29	1.00	0.43	1.00	1.00	7
Meal preparation	33.46	9.92	0.69	0.54	1.00	1.00	13
Attending to children	139.00	4.50	2.50	0.50	0.00	0.00	4
Other household obligations	57.62	10.90	0.36	0.67	0.83	0.43	42
Attending to pets	37.32	9.04	0.10	0.38	0.86	0.28	50
Total	52.73	9.43	0.40	0.51	0.84	0.45	116
Pick up-drop off							
People	19.86	11.85	0.73	0.52	0.16	0.15	965
Meal	44.03	3.60	0.60	0.55	0.60	0.88	136
Snacks/drinks	27.78	1.94	0.56	0.61	0.72	1.00	18
Video rental	22.33	1.48	0.60	0.48	0.74	0.93	42
Other items	24.87	4.45	0.46	0.35	0.69	0.94	123
Total	23.09	9.79	0.69	0.51	0.28	0.34	1284
Shopping							
Minor groceries	34.72	2.50	0.33	0.89	0.80	0.98	206
Major groceries	58.88	2.15	0.52	0.92	0.73	0.97	255
House-wares	62.01	2.05	0.54	0.83	0.87	0.98	84
Clothing/personal items	99.67	1.79	0.77	0.94	0.86	0.97	172
Drug store	27.77	1.38	0.23	0.90	0.81	1.00	48
Other shopping	58.61	3.11	0.58	0.67	0.86	0.85	279
Total	59.58	2.37	0.53	0.84	0.81	0.94	1044
Services							
Medical/professional	74.93	2.38	0.47	0.16	0.21	0.89	138
Barber/salon/beauty	78.97	1.36	0.31	0.23	0.67	0.95	39
Banking	47.62	2.09	0.24	0.33	0.83	0.99	114
Other service	73.44	2.38	0.74	0.17	0.71	0.78	94
Total	66.89	2.19	0.45	0.22	0.56	0.90	385
Active							
Hobbies	134.32	2.00	1.11	0.24	0.57	0.62	37
Exercise or active sports	87.25	6.02	0.56	0.39	0.35	0.83	499
Playing/parks	109.94	2.52	1.00	0.27	0.73	0.48	33

	Duration Mean	Freq. Mean	# People Mean	Spatial flex. Mean	Temporal flex. Mean	Personal flex. Mean	N
Total	91.63	5.56	0.62	0.38	0.38	0.80	569
Passive							
Spectator events/theatre	156.65	2.10	1.26	0.72	0.41	0.63	104
Regular TV programs	139.78	7.50	0.89	0.89	0.06	1.00	18
Unspecific TV	35.00	19.00	0.17	1.00	1.00	1.00	6
Watching video	134.40	1.90	1.20	0.10	1.00	0.90	10
Other recreation	138.10	3.51	1.06	0.39	0.65	0.60	109
Total	147.55	3.52	1.16	0.71	0.43	0.71	138
Social							
Hosting visitors	86.78	2.22	1.67	0.33	1.00	0.00	9
Visiting	177.99	3.44	1.49	0.67	0.79	0.16	420
Planned social events	190.52	1.98	1.58	0.81	0.75	0.16	122
Cultural/clubs	127.89	3.90	1.67	0.65	0.71	0.10	115
Other social	99.92	3.18	1.58	0.76	0.76	0.46	148
Total	157.58	3.23	1.55	0.70	0.77	0.21	814

Table 19: Kruskal-Wallis test results for in-home versus out-of-home activity attributes

	Duration	Frequency	Involved	Personal	Spatial	Temporal
Active						
chi-squared	3.272	**4.795**	**49.679**	**13.566**	**25.027**	**27.798**
p =	0.0705	**0.0285**	**0.0001**	**0.0002**	**0.0001**	**0.0001**
Household obligations						
chi-squared	**11.356**	3.65	1.293	**28.396**	**74.3**	1.175
p =	**0.0008**	0.0561	0.2555	**0.0001**	**0.0001**	0.2784
Meals						
chi-squared	**53.034**	**965.377**	**29.93**	**93.052**	**653.781**	53.119
p =	**0.0001**	**0.0001**	**0.0001**	**0.0001**	**0.0001**	0.0001
Passive						
chi-squared	**68.507**	**166.382**	**56.485**	**30.868**	**172.03**	8.177
p =	**0.0001**	**0.0001**	**0.0001**	**0.0001**	**0.0001**	0.0042
Pick						
chi-squared	**22.785**	0.028	1.599	**26.551**	**7.212**	**13.719**
p =	**0.0001**	0.8683	0.206	**0.0001**	**0.0072**	**0.0002**
Service						
chi-squared	**15.134**	**8.488**	2.707	0.535	2.554	**9.798**
p =	**0.0001**	**0.0036**	0.0999	0.4647	0.11	**0.0017**
Shop						
chi-squared	0.341	0.011	0.492	0.039	**4.171**	0.049
p =	0.5591	0.9147	0.4828	0.8426	**0.0411**	0.8245
Social						
chi-squared	**12.994**	1.831	**21.395**	1.457	**152.381**	**16.949**
p =	**0.0003**	0.176	**0.0001**	0.2275	**0.0001**	**0.0001**
Work						
chi-squared	**222.745**	**15.856**	1.988	0.014	**12.611**	**331.282**
p =	**0.0001**	**0.0001**	0.1585	0.9066	**0.0004**	**0.0001**

*The bold statistics reveal that the difference between the mean values of the given attribute for in-home and out-of-home locations is statistically significant at the 95% level.

Appendix B: Analysis Planning Time Horizons

Table 20: Kruskal Wallis Tests for Differences in Activity Attributes among Planning Time Horizons

Attribute	Activity Type	Chi-squared	Probability
Duration	Active	43.13	0.0001
	Hh obligations	71.42	0.0001
	Meals	238.16	0.0001
	Passive	22.15	0.0002
	Pick up/ drop off	132.04	0.0001
	Services	44.29	0.0001
	Shop	48.32	0.0001
	Social	111.57	0.0001
	Work	362.73	0.0001
Frequency	Active	8.18	0.0853
	Hh obligations	93.70	0.0001
	Meals	154.60	0.0001
	Passive	88.07	0.0001
	Pick up/ drop off	103.11	0.0001
	Services	4.30	0.3666
	Shop	12.96	0.0115
	Social	30.66	0.0001
	Work	148.62	0.0001
Involved people	Active	20.80	0.0003
	Hh obligations	8.64	0.0709
	Meals	77.88	0.0001
	Passive	19.63	0.0006
	Pick up/ drop off	4.86	0.3016
	Services	10.71	0.0300
	Shop	7.33	0.1195
	Social	6.71	0.1522
	Work	7.60	0.1076
Personal flexibility	Active	6.80	0.1471
	Hh obligations	32.94	0.0001
	Meals	5.15	0.2725
	Passive	2.17	0.7037
	Pick up/ drop off	44.09	0.0001
	Services	1.34	0.8546
	Shop	0.22	0.9946
	Social	9.15	0.0575
	Work	1.79	0.7737
Spatial flexibility	Active	20.17	0.0005
	Hh obligations	0.65	0.9576
	Meals	37.26	0.0001
	Passive	16.92	0.0020
	Pick up/ drop off	10.27	0.0361
	Services	6.70	0.1525

Attribute	Activity Type	Chi-squared	Probability
	Shop	2.46	0.6522
	Social	1.16	0.8854
	Work	59.06	0.0001
Temporal flexibility	Active	88.86	0.0001
	Hh obligations	14.15	0.0068
	Meals	1.60	0.8092
	Passive	52.92	0.0001
	Pick up/ drop off	41.55	0.0001
	Services	60.47	0.0001
	Shop	3.52	0.4756
	Social	8.73	0.0682
	Work	75.10	0.0001

Table 21: Activity Attributes and Planning Time Horizons (In-home)

	IMPULSIVE		SAMEDAY		DAYSAGO		WEEKSAGO		ROUTINE	
	Mean	S.Dev.	Mean	S.Dev.	Mean	S.Dev.	Mean	S.Dev.	Mean	S.Dev.
Duration										
Active	79.97	56.23	79.21	57.42	99.15	121.02	64.11	38.99	62.19	48.30
Hh. oblig.	61.82	58.88	74.71	69.04	82.08	101.17	49.58	51.05	66.48	72.51
Meals	42.47	33.51	45.75	27.10	46.35	26.21	29.79	15.22	45.30	26.64
Passive	97.71	69.22	101.18	60.30	98.33	71.17	86.21	70.18	101.11	61.73
Pick up	25.83	30.31	35.43	30.28	46.73	56.99	18.00	10.33	23.12	13.74
Service	76.00	50.08	84.19	68.46	139.08	119.77	120.00	0.00		
Social	73.94	57.37	133.82	134.18	185.92	122.60	141.15	88.98	111.94	98.79
Work	93.70	70.10	96.22	59.83	138.43	93.51	66.18	43.75	153.60	118.08
Frequency										
Active	5.37	3.50	5.82	3.19	4.79	2.88	7.75	3.33	4.63	2.36
Hh. oblig.	8.37	6.10	8.83	7.94	9.27	7.24	11.10	7.03	8.93	6.77
Meals	11.22	4.71	11.20	4.89	11.30	4.87	13.03	4.07	12.20	4.56
Passive	7.98	5.44	7.73	6.30	9.83	6.41	11.89	6.27	8.04	4.48
Pick up	11.29	8.47	7.00	5.41	7.20	6.62	13.11	8.29	8.41	7.06
Service	4.58	4.49	5.42	5.13	3.42	3.60	13.00	0.00		
Social	3.65	2.48	3.21	2.44	2.77	2.14	3.62	2.37	6.00	3.77
Work	5.22	3.01	9.47	6.76	6.98	5.55	5.35	2.18	6.40	2.56
Involved people										
Active	0.22	0.56	0.16	0.37	0.24	0.50	0.11	0.45	0.13	0.34
Hh. oblig.	0.41	0.72	0.46	0.83	0.52	0.85	0.45	0.71	0.54	0.89
Meals	0.75	0.95	1.05	1.04	1.06	1.25	0.76	1.09	0.86	0.97
Passive	0.53	0.68	0.59	0.71	0.57	0.75	0.41	0.63	0.63	0.67
Pick up	0.53	0.91	0.73	0.88	0.47	0.63	0.94	0.64	0.47	0.51
Service	0.13	0.34	0.35	0.69	0.33	0.65	0.00	0.00		
Social	1.63	1.14	1.99	1.44	2.42	1.74	2.12	1.61	1.50	1.29
Work	0.13	0.46	0.01	0.10	0.19	0.45	0.00	0.00	0.00	0.00
Spatial flexibility										
Active	0.14	0.35	0.21	0.41	0.21	0.41	0.13	0.33	0.31	0.48
Hh. oblig.	0.05	0.22	0.03	0.16	0.04	0.20	0.05	0.21	0.04	0.19
Meals	0.08	0.27	0.06	0.24	0.05	0.23	0.06	0.24	0.06	0.23
Passive	0.05	0.21	0.03	0.17	0.12	0.32	0.03	0.16	0.05	0.23
Pick up	0.33	0.47	0.50	0.51	0.23	0.43	0.22	0.43	0.53	0.51
Service	0.08	0.28	0.15	0.37	0.00	0.00	0.00	0.00		
Social	0.21	0.41	0.30	0.46	0.15	0.36	0.27	0.45	0.39	0.50
Work	0.09	0.29	0.09	0.28	0.07	0.26	0.18	0.39	0.13	0.35
Temporal flexibility										
Active	0.79	0.41	0.76	0.43	0.56	0.50	0.27	0.45	0.44	0.51
Hh. oblig.	0.82	0.38	0.81	0.39	0.78	0.41	0.76	0.43	0.72	0.45
Meals	0.97	0.17	0.97	0.17	0.98	0.13	0.99	0.10	0.98	0.15
Passive	0.36	0.48	0.35	0.48	0.19	0.39	0.09	0.28	0.26	0.44
Pick up	0.66	0.48	0.45	0.50	0.37	0.49	0.11	0.32	0.47	0.51

	IMPULSIVE		SAMEDAY		DAYSAGO		WEEKSAGO		ROUTINE	
	Mean	S.Dev.	Mean	S.Dev.	Mean	S.Dev.	Mean	S.Dev.	Mean	S.Dev.
Service	0.75	0.44	0.88	0.33	0.75	0.45	1.00	0.00		
Social	0.91	0.28	0.91	0.29	0.91	0.29	1.00	0.00	0.94	0.24
Work	0.83	0.39	0.91	0.28	0.69	0.47	0.71	0.47	0.80	0.41
Personal flexibility										
Active	0.95	0.21	1.00	0.00	0.88	0.33	0.98	0.13	0.94	0.25
Hh. oblig.	0.78	0.42	0.80	0.40	0.72	0.45	0.71	0.45	0.64	0.48
Meals	0.98	0.14	0.97	0.17	0.98	0.13	0.99	0.09	0.97	0.16
Passive	0.99	0.11	0.99	0.09	0.99	0.10	1.00	0.00	1.00	0.07
Pick up	0.69	0.47	0.50	0.51	0.47	0.51	0.78	0.43	0.47	0.51
Service	0.92	0.28	0.77	0.43	0.83	0.39	1.00	0.00		
Social	0.27	0.45	0.11	0.32	0.13	0.34	0.12	0.33	0.06	0.24
Work	1.00	0.00	0.97	0.18	0.93	0.26	1.00	0.00	1.00	0.00

Table 22: Activity Attributes and Planning Time Horizons (Out-of-Home)

	IMPULSIVE		SAMEDAY		DAYSAGO		WEEKSAGO		ROUTINE	
	Mean	S.Dev.	Mean	S.Dev.	Mean	S.Dev.	Mean	S.Dev.	Mean	S.Dev.
Duration										
Active	54.59	37.51	80.26	51.04	128.07	165.38	100.41	76.31	76.73	80.29
Hh. oblig.	52.24	64.29	41.00	30.03	63.11	63.12	73.11	84.82	43.19	36.14
Meals	43.37	34.31	70.26	42.30	79.83	48.42	51.43	45.00	45.12	28.88
Passive	94.59	63.70	150.20	66.05	158.52	76.45	188.05	77.57	137.80	53.19
Pick up	29.02	36.14	25.04	24.92	24.62	27.04	13.29	19.02	27.59	44.57
Service	35.46	30.92	48.03	72.39	68.04	53.28	115.14	137.25	106.88	182.33
Shop	48.95	53.86	58.70	53.02	77.69	69.77	46.35	34.43	79.48	71.82
Social	116.66	116.29	134.05	122.75	176.00	164.30	221.28	218.80	152.46	148.96
Work	183.16	156.47	205.32	170.08	340.49	206.21	427.31	177.90	325.35	206.17
Frequency										
Active	6.38	4.21	4.97	3.12	5.15	3.89	4.50	2.63	7.05	4.92
Hh. oblig.	10.34	4.96	9.63	5.80	5.32	2.91	7.00	3.28	13.43	4.55
Meals	3.15	2.15	2.70	1.64	3.29	2.96	3.88	2.86	4.44	3.42
Passive	8.50	7.19	2.83	2.69	2.41	2.46	1.95	1.51	4.00	1.41
Pick up	8.31	8.48	8.19	7.05	8.08	6.58	12.35	6.75	10.55	6.14
Service	1.91	1.18	2.20	1.57	2.01	1.09	2.84	2.01	1.88	1.13
Shop	2.32	1.31	2.26	1.45	2.18	1.69	5.32	4.87	2.41	2.11
Social	3.71	2.46	3.34	2.35	2.94	2.29	2.45	1.56	3.07	2.12
Work	12.42	6.70	10.60	6.15	7.51	3.98	6.54	3.01	9.30	5.07
Involved people										
Active	0.71	0.82	0.60	0.89	0.66	0.90	0.42	0.89	0.90	0.88
Hh. oblig.	0.18	0.46	0.46	0.72	0.53	0.84	0.00	0.00	0.62	1.20
Meals	0.96	0.94	1.41	1.15	1.48	1.36	0.76	0.93	0.48	0.65
Passive	0.91	1.19	1.20	1.10	1.22	0.87	1.05	0.78	1.80	1.79
Pick up	0.71	0.83	0.70	0.82	0.80	0.90	0.57	0.69	0.64	0.70
Service	0.28	0.62	0.34	0.59	0.65	1.03	0.41	0.56	0.75	1.39
Shop	0.53	0.77	0.55	0.67	0.54	0.68	0.27	0.61	0.48	0.51
Social	1.56	1.42	1.61	1.33	1.38	1.37	1.87	1.61	1.43	1.50
Work	0.33	0.78	0.22	0.55	0.17	0.55	0.08	0.32	0.19	0.52
Spatial flexibility										
Active	0.47	0.50	0.36	0.48	0.39	0.49	0.20	0.40	0.57	0.50
Hh. oblig.	0.50	0.51	0.58	0.50	0.37	0.50	0.33	0.50	0.62	0.50
Meals	0.91	0.29	0.86	0.35	0.83	0.38	0.50	0.51	0.44	0.51
Passive	0.77	0.43	0.66	0.48	0.74	0.44	0.68	0.48	0.80	0.45
Pick up	0.57	0.50	0.53	0.50	0.50	0.50	0.41	0.49	0.52	0.50
Service	0.32	0.47	0.32	0.47	0.14	0.35	0.20	0.41	0.00	0.00
Shop	0.82	0.39	0.83	0.37	0.86	0.35	0.92	0.28	0.93	0.26
Social	0.76	0.43	0.66	0.48	0.74	0.44	0.61	0.49	0.61	0.50
Work	0.54	0.50	0.46	0.50	0.30	0.46	0.13	0.33	0.22	0.42

	IMPULSIVE		SAMEDAY		DAYSAGO		WEEKSAGO		ROUTINE	
	Mean	S.Dev.	Mean	S.Dev.	Mean	S.Dev.	Mean	S.Dev.	Mean	S.Dev.
Temporal flexibility										
Active	0.45	0.50	0.70	0.46	0.35	0.48	0.20	0.40	0.20	0.40
Hh. oblig.	0.82	0.39	1.00	0.00	0.74	0.45	0.67	0.50	0.86	0.36
Meals	0.81	0.40	0.77	0.42	0.77	0.43	0.45	0.50	0.80	0.41
Passive	0.59	0.50	0.51	0.51	0.33	0.47	0.32	0.48	0.40	0.55
Pick up	0.37	0.48	0.37	0.48	0.32	0.47	0.16	0.36	0.29	0.45
Service	0.74	0.44	0.80	0.40	0.49	0.50	0.17	0.38	0.63	0.52
Shop	0.84	0.37	0.82	0.39	0.79	0.41	0.68	0.47	0.76	0.44
Social	0.83	0.38	0.82	0.39	0.75	0.43	0.63	0.49	0.64	0.49
Work	0.00	0.00	0.11	0.31	0.05	0.21	0.03	0.18	0.01	0.12
Personal flexibility										
Active	0.83	0.37	0.87	0.34	0.81	0.40	0.67	0.47	0.78	0.42
Hh. oblig.	0.37	0.49	0.50	0.51	0.58	0.51	0.56	0.53	0.33	0.48
Meals	0.72	0.45	0.65	0.48	0.73	0.45	0.55	0.50	0.92	0.28
Passive	0.91	0.29	0.73	0.45	0.65	0.48	0.58	0.51	0.80	0.45
Pick up	0.47	0.50	0.40	0.49	0.37	0.48	0.18	0.39	0.38	0.49
Service	0.96	0.21	0.92	0.28	0.86	0.35	0.89	0.31	0.88	0.35
Shop	0.93	0.25	0.95	0.22	0.95	0.23	0.95	0.23	0.97	0.19
Social	0.25	0.44	0.17	0.37	0.15	0.36	0.23	0.43	0.43	0.50
Work	0.98	0.14	0.90	0.30	0.96	0.20	0.97	0.16	0.98	0.13

Table 23: Mode Choice Models (Multinomial Logit Results)

		Coef.	t stat.		
ALL	ASC (Walk)	-0.424	-6.70	Number of obs.	5749
	ASC (Public tr)	-0.560	-4.35	LL at optimal	-3185.44
	Cost	-0.741	-10.67	LL at zero	-6315.92
	Time	-0.019	-8.00		
ACTIVE	ASC (Walk)	0.240	1.44	Number of obs.	397
	ASC (Public tr)	-2.395	-2.79	LL at optimal	-219.86
	Cost	-0.173	-0.35	LL at zero	-436.15
	Time	-0.004	-0.78		
WORK	ASC (Walk)	-0.321	-1.79	Number of obs.	1340
	ASC (Public tr)	0.069	0.31	LL at optimal	-758.94
	Cost	-0.543	-4.63	LL at zero	-1472.14
	Time	-0.033	-5.99		
SHOP	ASC (Walk)	-0.538	-2.87	Number of obs.	899
	ASC (Public tr)	-1.104	-1.51	LL at optimal	-382.43
	Cost	-0.875	-2.26	LL at zero	-987.65
	Time	-0.035	-4.31		
PICK	ASC (Walk)	-1.172	-10.92	Number of obs.	1125
	ASC (Public tr)	-2.103	-5.42	LL at optimal	-454.26
	Cost	-0.901	-3.84	LL at zero	-1235.94
	Time	-0.006	-2.03		
MEALS	ASC (Walk)	0.447	1.89	Number of obs.	346
	ASC (Public tr)	-0.079	-0.10	LL at optimal	-184.60
	Cost	-1.126	-2.56	LL at zero	-380.12
	Time	-0.052	-4.48		
SOCIAL	ASC (Walk)	-0.566	-4.15	Number of obs.	585
	ASC (Public tr)	-1.806	-5.87	LL at optimal	-311.91
	Cost	-0.130	-0.71	LL at zero	-642.69
	Time	-0.001	-0.32		
SERVICES	ASC (Walk)	0.175	0.64	Number of obs.	347
	ASC (Public tr)	2.579	3.49	LL at optimal	-157.60
	Cost	-2.503	-6.00	LL at zero	-381.22
	Time	-0.084	-5.66		
PASSIVE	ASC (Walk)	0.906	1.47	Number of obs.	89
	ASC (Public tr)	0.863	0.86	LL at optimal	-42.34
	Cost	-1.272	-2.38	LL at zero	-97.78
	Time	-0.085	-3.25		
HHOBLIG	ASC (Walk)	2.258	4.53	Number of obs.	84
	ASC (Public tr)	-6.999	-0.77	LL at optimal	-39.08
	Cost	2.569	0.59	LL at zero	-92.28
	Time	-0.031	-1.01		

Table 24: Planning Time Horizons for Household Obligations

	Impulsive		Same day		Same week		Weeks ago	
	Coef.	t stat	Coef.	t stat	Coef.	t stat	Coef.	t stat
Alternative specific constant	**2.152**	**9.98**	-0.231	1.44	**-0.754**	**9.29**	**-1.071**	**5.61**
Household size	**-0.160**	**3.87**					**0.277**	**4.34**
Autos per adult	0.082	1.11	**0.305**	**3.39**	**1.024**	**5.28**		
Age group=1	**1.457**	**9.99**	**1.300**	**4.80**	**0.577**	**7.33**		
Age group=3	**-0.826**	**6.31**	**-0.588**	**3.79**	**-0.933**	**4.82**		
Education			**0.417**	**5.18**	**0.162**	**2.57**		
Employed	**-0.644**	**4.17**	**-0.269**	**2.63**	**-0.995**	**5.58**		
Female	**-0.407**	**2.83**	**-0.531**	**7.34**				
Involved children	**-0.453**	**4.35**	**-0.262**	**2.80**	**-0.406**	**6.41**	**-0.316**	**2.92**
Involved adults	-0.093	1.20						
Duration			**0.020**	**2.45**	**0.027**	**2.84**	**-0.049**	**3.29**
Weekly freq.			**0.025**	**2.96**			0.008	0.60
Weekend			**0.113**	**2.06**	**-0.293**	**4.43**	**-2.010**	**13.14**
Morning	**-0.412**	**5.32**	**-0.846**	**9.44**	**0.542**	**4.94**	**0.924**	**13.85**
Evening								
Location	**-0.527**	**2.04**	**0.344**	**7.16**	**0.488**	**7.29**	**-0.718**	**4.44**
Logsum	**0.353**	**6.62**	**-0.660**	**2.14**	**-0.594**	**2.03**	**-0.971**	**3.05**
Personal	**0.731**	**8.60**	**1.027**	**6.61**	0.138	1.49	**-0.729**	**8.12**
St. dev	**1.671**	**21.00**	**1.267**	**19.23**	**1.811**	**27.83**	**2.778**	**23.57**
Temporal St. dev								
Spatial	**-0.226**	**2.98**						
St. dev	**1.176**	**21.50**						
Number of observations			3724					
Number of individuals			330					
Log-likelihood at optimal			-4645.87					
Log-likelihood at zero coef.			-5993.55					
Log-likelihood at constants			-5638.86					

Table 25: Planning Time Horizons for Meals

	Impulsive		Same day		Same week		Weeks ago	
	Coef.	t stat	Coef.	t stat	Coef.	t stat	Coef.	t stat
Alternative specific constant	**1.407**	**13.63**	**0.546**	**4.09**	**-0.510**	**3.67**	**-1.290**	**9.79**
Household size	0.082	1.58	-0.066	1.10	**0.234**	**3.17**	**0.330**	**5.26**
Autos per adult			**0.538**	**4.49**				
Age group=1	**0.987**	**7.37**	**0.854**	**7.49**	**1.112**	**7.94**	**0.821**	**6.50**
Age group=3			**-0.271**	**2.14**			**0.563**	**3.95**
Education								
Employed			**-0.372**	**3.79**				
Female			**-0.411**	**5.96**				
Involved children	-0.153	1.79			**-0.259**	**3.42**		
Involved adults	**-0.204**	**3.25**			0.121	1.84		
Duration	-0.042	1.77						
Weekly freq.	**-0.060**	**4.24**	**-0.043**	**2.84**	**-0.057**	**2.60**		
Weekend	**0.474**	**4.21**	**0.350**	**2.96**	**-0.580**	**4.08**	**-1.438**	**8.14**
Morning	**-0.622**	**6.92**	**-1.038**	**7.16**			**0.842**	**7.24**
Evening			**0.599**	**6.98**				
Location	0.069	0.27	**0.810**	**3.69**	**1.106**	**3.77**	0.588	1.83
Logsum	-0.559	1.64	**-0.717**	**2.16**	-0.504	1.50	**-0.758**	**2.25**
Personal								
St. dev								
Temporal								
St. dev								
Spatial	**0.644**	**9.73**	**0.457**	**5.02**				
St. dev	**1.428**	**18.26**	**0.908**	**6.02**				
Number of observations				3125				
Number of individuals				340				
Log-likelihood at optimal				-4347.38				
Log-likelihood at zero coef.				-5029.49				
Log-likelihood at constants				-4831.97				

Table 26: Planning Time Horizons for Passive Activities

	Impulsive		Same day		Same week		Weeks ago	
	Coef.	t stat	Coef.	t stat	Coef.	t stat	Coef.	t stat
Alternative specific constant	**1.981**	**10.04**	**0.180**	**2.67**	-0.169	1.38	**-1.511**	**7.32**
Household size							**0.197**	**2.70**
Autos per adult	**-0.434**	**3.16**					**-0.751**	**8.49**
Age group=1	**0.867**	**5.52**	**0.858**	**9.75**				
Age group=3	**-0.305**	**2.03**			**-0.526**	**4.44**	0.305	1.88
Education								
Employed	**0.248**	**2.23**					0.173	1.77
Female								
Involved children	**-0.180**	**1.95**						
Involved adults	**-0.243**	**4.13**						
Duration								
Weekly freq.					**0.042**	**2.55**	**0.118**	**4.37**
Weekend			**-0.315**	**2.73**	**-0.527**	**4.05**	**-1.032**	**6.27**
Morning	**-0.699**	**4.19**	**-1.530**	**8.74**			**1.369**	**5.12**
Evening	**-0.376**	**4.03**						
Location	0.775	1.53	**2.384**	**5.63**	**3.287**	**8.22**	**2.987**	**7.80**
Logsum	**0.593**	**3.60**	0.065	0.89	**0.541**	**4.40**	-0.105	1.02
Personal			**0.152**	**2.32**			**-2.232**	**9.94**
St. dev			**1.126**	**10.37**			**2.982**	**18.97**
Temporal	**0.459**	**3.56**	**0.599**	**3.59**	**-0.687**	**3.60**	**-1.934**	**3.25**
St. dev	**1.105**	**13.85**	**0.751**	**5.99**	**1.410**	**7.14**	**2.160**	**6.04**
Spatial			**-0.963**	**6.59**	**0.765**	**4.14**		
St. dev			**1.799**	**9.66**	**1.428**	**9.68**		
Number of observations				2075				
Number of individuals				318				
Log-likelihood at optimal				-2512.93				
Log-likelihood at zero coef.				-3339.58				
Log-likelihood at constants				-2975.26				

Table 27: Planning Time Horizons for Active Activities

	Impulsive		Same day		Same week		Weeks ago	
	Coef.	t stat	Coef.	t stat	Coef.	t stat	Coef.	t stat
Alternative specific constant	**1.824**	**6.60**	0.548	1.07	**1.708**	**5.67**	-0.293	1.32
Household size							**0.507**	**4.30**
Autos per adult			**0.797**	**3.95**				
Age group=1								
Age group=3			**-0.667**	**4.52**	**-0.564**	**4.17**	0.282	1.57
Education								
Employed			**-0.602**	**6.00**				
Female	**-0.519**	**2.12**	**-0.583**	**2.61**	**-1.169**	**6.41**		
Involved children								
Involved adults							-0.241	1.25
Duration	**-0.087**	**3.94**						
Weekly freq.	**0.073**	**2.71**					0.082	0.98
Weekend			**-0.640**	**3.59**	**-0.746**	**4.43**	**-1.736**	**6.34**
Morning	**-0.667**	**4.36**	**-1.738**	**7.43**				
Evening					**-0.987**	**6.86**	**-1.718**	**7.45**
Location	**-0.882**	**5.07**	**-0.371**	**2.03**	**0.489**	**3.02**	**1.549**	**6.82**
Logsum	0.228	0.80	**0.471**	**1.72**	**-0.745**	**3.58**	**-1.076**	**4.21**
Personal			**0.893**	**6.71**			**-2.423**	**9.00**
St. dev			**0.745**	**4.64**			**3.525**	**13.68**
Temporal	**1.287**	**7.66**	**2.145**	**9.13**	**0.706**	**3.30**		
St. dev	**1.912**	**10.08**	**-0.447**	**1.52**	**0.953**	**4.37**		
Spatial							**-1.825**	**4.13**
St. dev							**2.362**	**3.24**
Number of observations			701					
Number of individuals			191					
Log-likelihood at optimal			-803.500					
Log-likelihood at zero coef.			-1128.220					
Log-likelihood at constants			-1084.450					

Table 28: Planning Time Horizons for Shopping

	Impulsive		Same day		Same week		Weeks ago	
	Coef.	t stat	Coef.	t stat	Coef.	t stat	Coef.	t stat
Alternative specific constant	**2.921**	**14.32**	**3.104**	**13.64**	**1.562**	**9.73**	0.730	1.68
Household size			-0.097	1.77				
Autos per adult							-0.887	1.72
Age group=1								
Age group=3								
Education								
Employed								
Female								
Involved children								
Involved adults								
Duration	**-0.067**	**3.62**	**-0.026**	**2.07**	**-0.075**	**2.32**		
Weekly freq.							**0.335**	**2.16**
Weekend								
Morning					**1.170**	**5.53**	**1.055**	**2.19**
Evening	**0.610**	**3.53**	**0.671**	**3.89**				
Location								
Logsum	**0.463**	**2.58**	**0.335**	**2.04**	-0.175	1.17	-0.371	1.62
Personal								
St. dev								
Temporal							**-3.335**	**4.12**
St. dev							**2.466**	**4.88**
Spatial								
St. dev								
Number of observations			1019					
Number of individuals			305					
Log-likelihood at optimal			-1192.68					
Log-likelihood at zero coef.			-1640.02					
Log-likelihood at constants			-1286.86					

*As there are no in-home shopping activities, the location parameter is not estimated.

Table 29: Planning Time Horizons for Social Activities

	Impulsive		Same day		Same week		Weeks ago	
	Coef.	t stat	Coef.	t stat	Coef.	t stat	Coef.	t stat
Alternative specific constant	**2.114**	**6.26**	**2.095**	**5.92**	**2.151**	**6.21**	**0.766**	**1.56**
Household size								
Autos per adult							**-1.081**	**5.51**
Age group=1	**0.552**	**10.74**						
Age group=3							**0.597**	**4.76**
Education							**0.534**	**3.64**
Employed								
Female					**0.371**	**3.11**	**0.765**	**4.43**
Involved children	**-0.281**	**2.28**						
Involved adults								
Duration					**0.037**	**5.01**	**0.044**	**5.86**
Weekly freq.					**-0.123**	**2.73**	**-0.189**	**3.48**
Weekend	**-0.998**	**3.05**	**-0.830**	**2.63**	**-1.226**	**3.79**	**-0.716**	**2.11**
Morning								
Evening								
Location	**-0.511**	**1.50**	0.230	0.76	0.357	1.18	**0.678**	**2.25**
Logsum	**0.687**	**2.71**	0.395	1.72	-0.190	0.80	-0.126	0.37
Personal			**-1.057**	**5.62**	**-0.904**	**5.16**		
St. dev			**0.744**	**4.46**	**0.910**	**4.57**		
Temporal	**0.420**	**4.23**	**0.487**	**3.89**				
St. dev	**0.980**	**8.31**	**0.834**	**5.88**				
Spatial	**0.327**	**2.66**						
St. dev	0.179	0.87						
Number of observations			983					
Number of individuals			268					
Log-likelihood at optimal			-1311.02					
Log-likelihood at zero coef.			-1582.08					
Log-likelihood at constants			-1422.85					

Table 30: Planning Time Horizons for Work Activities

	Impulsive		Same day		Same week		Weeks ago	
	Coef.	t stat	Coef.	t stat	Coef.	t stat	Coef.	t stat
Alternative specific constant	**3.358**	**6.10**	**1.303**	**3.56**	**3.308**	**4.33**	-0.102	0.31
Household size	**-0.232**	**2.38**	-0.113	1.62				
Autos per adult			**0.693**	**5.34**				
Age group=1	**1.068**	**2.41**	**1.666**	**4.53**	**2.857**	**8.17**	**1.554**	**6.19**
Age group=3	-0.161	1.87	**-0.414**	**3.05**				
Education	**-0.803**	**6.81**			**-0.479**	**4.63**		
Female	**-0.399**	**2.76**			**-0.296**	**2.23**		
Involved children			**0.571**	**3.11**	**0.913**	**6.10**		
Involved adults			**-0.419**	**3.59**	**0.443**	**4.14**	**-0.370**	**2.05**
Duration	**-0.004**	**4.96**	**-0.002**	**2.36**	-0.001	1.55	0.001	1.04
Weekly freq.	**-0.104**	**3.50**			**-0.087**	**3.21**	**-0.117**	**3.74**
Weekend	**1.045**	**7.05**	**0.852**	**6.81**	**0.569**	**5.14**		
Morning	**-0.897**	**4.76**	**-1.333**	**6.24**	-0.369	1.68	**0.515**	**2.23**
Evening	-0.492	1.80	-0.184	1.47	**-1.847**	**7.49**	0.485	1.91
Location	**-0.677**	**2.42**	**-0.792**	**2.82**	**-1.009**	**2.65**	**1.057**	**3.04**
Logsum	**0.318**	**3.92**	0.175	1.35	-0.020	0.24	-0.074	0.56
Personal			**-0.658**	**3.19**	**-1.214**	**5.16**		
St. dev			**0.976**	**10.88**	**1.812**	**11.11**		
Temporal			**1.397**	**6.65**	-0.157	1.22	**0.551**	**2.30**
St. dev			**0.872**	**6.95**	**0.781**	**11.40**	**1.019**	**4.40**
Spatial	0.146	1.34	**0.707**	**4.43**	**0.929**	**6.18**		
St. dev	**2.095**	**13.21**	**0.325**	**2.26**	**0.476**	**5.59**		
Number of observations				1736				
Number of individuals				263				
Log-likelihood at optimal				-2062.85				
Log-likelihood at zero coef.				-2793.98				
Log-likelihood at constants				-2609.84				

Appendix C: Principal Components Analysis

Table 31: Correlations between the Activity Attributes and Principal Components

	Principal Components			
In-home	1	2	3	4
Duration	-0.342	**0.696**	-0.134	-0.305
Frequency	-0.144	**-0.768**	-0.307	0.033
Number of people	**-0.564**	0.129	0.264	**0.659**
Spatial	-0.115	-0.244	**0.793**	**-0.497**
Temporal	**0.633**	0.097	**0.444**	0.406
Personal	**0.754**	0.148	-0.174	-0.055

	Principal Components			
Out-of-home	1	2	3	4
Duration	**-0.580**	0.289	-0.445	**0.517**
Frequency	-0.309	**-0.804**	0.247	0.169
Number of people	**0.557**	-0.107	**-0.640**	0.206
Spatial	**0.629**	-0.172	0.383	**0.598**
Temporal	**0.742**	0.431	0.134	-0.070
Personal	-0.380	**0.613**	0.436	0.230

Table 32: t-test Results for the Difference in Component Scores among Different Planning Time Horizons for In-Home Activities

	Two planning time horizons among which the t-test is conducted:		
	Time 1	**Time 2**	**t-stat***
Component1	Impulsive	Same day	**3.090**
	Impulsive	Same week	**8.043**
	Impulsive	Weeks ago	0.954
	Impulsive	Routine	**4.151**
	Same day	Same week	**5.119**
	Same day	Weeks ago	-1.697
	Same day	Routine	1.339
	Same week	Weeks ago	**-6.384**
	Same week	Routine	**-3.581**
	Weeks ago	Routine	**2.815**
Component2	Impulsive	Same day	**-3.404**
	Impulsive	Same week	**-3.484**
	Impulsive	Weeks ago	**16.019**
	Impulsive	Routine	**4.115**
	Same day	Same week	-0.958
	Same day	Weeks ago	**16.335**
	Same day	Routine	**6.260**
	Same week	Weeks ago	**13.453**
	Same week	Routine	**5.860**
	Weeks ago	Routine	**-9.005**
Component3	Impulsive	Same day	-1.189
	Impulsive	Same week	-0.763
	Impulsive	Weeks ago	**5.134**
	Impulsive	Routine	0.953
	Same day	Same week	0.223
	Same day	Weeks ago	**5.513**
	Same day	Routine	1.835
	Same week	Weeks ago	**4.702**
	Same week	Routine	1.410
	Weeks ago	Routine	**-3.616**
Component4	Impulsive	Same day	**-1.965**
	Impulsive	Same week	-0.819
	Impulsive	Weeks ago	**-3.347**
	Impulsive	Routine	**-4.051**
	Same day	Same week	0.562
	Same day	Weeks ago	-1.415
	Same day	Routine	**-2.067**
	Same week	Weeks ago	-1.668
	Same week	Routine	**-2.193**
	Weeks ago	Routine	-0.620

* Absolute value of t-statistics greater than 1.96 are significant at the 95% level.
**A negative value of t-statistic mean that the population mean of the second time horizon is greater than the first planning time horizon.

Table 33: t-test Results for the Difference in Component Scores among Different Planning Time Horizons for Out-of-Home Activities

	Two planning time horizons among which the t-test is conducted:		
	Time 1	**Time 2**	**t-stat**
Component1	Impulsive	Same day	-0.784
	Impulsive	Same week	**11.739**
	Impulsive	Weeks ago	**31.064**
	Impulsive	Routine	**19.855**
	Same day	Same week	**12.713**
	Same day	Weeks ago	**32.391**
	Same day	Routine	**20.642**
	Same week	Weeks ago	**18.460**
	Same week	Routine	**10.502**
	Weeks ago	Routine	**-4.222**
Component2	Impulsive	Same day	**-2.656**
	Impulsive	Same week	-1.197
	Impulsive	Weeks ago	**3.570**
	Impulsive	Routine	**5.918**
	Same day	Same week	1.689
	Same day	Weeks ago	**6.440**
	Same day	Routine	**8.174**
	Same week	Weeks ago	**5.134**
	Same week	Routine	**7.180**
	Weeks ago	Routine	**3.096**
Component3	Impulsive	Same day	**3.953**
	Impulsive	Same week	**11.379**
	Impulsive	Weeks ago	**16.343**
	Impulsive	Routine	**5.190**
	Same day	Same week	**7.509**
	Same day	Weeks ago	**12.358**
	Same day	Routine	1.942
	Same week	Weeks ago	**4.506**
	Same week	Routine	**-4.258**
	Weeks ago	Routine	**-8.069**
Component4	Impulsive	Same day	1.691
	Impulsive	Same week	-1.279
	Impulsive	Weeks ago	**-1.981**
	Impulsive	Routine	**-3.083**
	Same day	Same week	**-2.914**
	Same day	Weeks ago	**-3.581**
	Same day	Routine	**-4.360**
	Same week	Weeks ago	-0.708
	Same week	Routine	**-2.038**
	Weeks ago	Routine	-1.442

* Absolute value of t-statistics greater than 1.96 are significant at the 95% level.
**A negative value of t-statistic mean that the population mean of the second time horizon is greater than the first planning time horizon.

Table 34: Component Scores of Activity Groups by Planning Times (In-home)

		Component 1		Component 2		Component 3		Component 4		
		Mean	S.dev	Mean	S.dev	Mean	S.dev	Mean	S.dev	Freq
Impulsive	Active	0.39	(0.60)	0.47	(0.72)	0.28	(1.17)	-0.50	(0.94)	86
	Hh oblig.	0.12	(1.11)	0.03	(0.95)	0.07	(0.81)	-0.01	(0.71)	1378
	Meals	0.43	(0.56)	-0.33	(0.68)	0.20	(0.89)	0.41	(0.94)	918
	Passive	-0.19	(0.65)	0.40	(0.90)	-0.51	(0.92)	-0.56	(0.88)	908
	Pick	-0.23	(1.21)	-0.87	(1.22)	0.74	(1.48)	-0.44	(1.40)	70
	Service	0.38	(0.63)	0.53	(0.67)	0.11	(1.17)	-0.47	(0.65)	24
	Shop	0.78	(0.16)	0.49	(0.96)	1.11	(1.85)	-0.82	(0.94)	3
	Social	-1.07	(0.91)	0.49	(0.72)	1.41	(1.39)	0.68	(1.15)	114
	Work	0.50	(0.55)	0.66	(0.58)	0.09	(1.00)	-0.50	(0.94)	23
Same day	Active	0.42	(0.54)	0.36	(0.77)	0.40	(1.33)	-0.72	(0.92)	62
	Hh oblig.	0.08	(1.21)	0.12	(1.15)	-0.06	(0.70)	0.01	(0.74)	758
	Meals	0.29	(0.63)	-0.25	(0.67)	0.22	(0.82)	0.67	(0.94)	469
	Passive	-0.23	(0.62)	0.47	(0.95)	-0.55	(0.83)	-0.51	(0.85)	390
	Pick	-0.81	(1.08)	-0.55	(1.10)	1.39	(1.87)	-0.89	(1.14)	40
	Service	0.14	(0.95)	0.46	(0.63)	0.52	(1.49)	-0.33	(0.86)	26
	Shop	-0.29	(0.00)	0.38	(0.00)	-0.36	(0.00)	-0.07	(0.00)	1
	Social	-1.69	(1.02)	0.98	(1.36)	1.75	(1.51)	0.49	(1.50)	87
	Work	0.51	(0.50)	0.22	(1.07)	-0.06	(0.91)	-0.48	(0.68)	92
Same week	Active	-0.03	(1.04)	0.58	(1.17)	0.28	(1.27)	-0.93	(1.28)	34
	Hh oblig.	-0.13	(1.27)	0.11	(1.35)	-0.03	(0.77)	-0.02	(0.82)	455
	Meals	0.32	(0.60)	-0.24	(0.67)	0.20	(0.82)	0.70	(1.05)	297
	Passive	-0.44	(0.65)	0.12	(1.12)	-0.54	(1.04)	-0.84	(1.09)	213
	Pick	-0.80	(1.29)	-0.32	(1.33)	0.42	(1.32)	-0.66	(0.91)	30
	Service	-0.01	(0.96)	1.28	(0.75)	-0.11	(0.63)	-0.44	(0.92)	12
	Social	-1.99	(1.04)	1.67	(1.21)	1.35	(1.31)	0.87	(1.61)	78
	Work	0.05	(0.78)	0.84	(1.17)	-0.21	(0.86)	-0.75	(0.95)	42
Weeks ago	Active	-0.02	(0.70)	-0.01	(0.73)	-0.40	(1.03)	-0.97	(0.88)	56
	Hh oblig.	-0.06	(1.18)	-0.40	(0.99)	-0.07	(0.88)	0.07	(0.72)	551
	Meals	0.49	(0.51)	-0.61	(0.55)	0.10	(0.79)	0.54	(1.01)	519
	Passive	-0.42	(0.46)	-0.17	(0.85)	-1.04	(0.75)	-0.80	(0.72)	220
	Pick	-0.78	(0.89)	-1.07	(0.89)	-0.10	(1.86)	-0.40	(0.78)	18
	Service	0.53	(0.00)	0.15	(0.00)	-0.47	(0.00)	-0.33	(0.00)	1
	Social	-1.68	(1.02)	1.06	(1.07)	1.75	(1.57)	0.71	(1.24)	26
	Work	0.50	(0.50)	0.29	(0.36)	0.25	(1.35)	-0.76	(1.00)	17
Routine	Active	0.08	(0.96)	0.17	(0.53)	0.51	(1.21)	-1.18	(1.42)	16
	Hh oblig.	-0.26	(1.37)	-0.03	(1.08)	0.00	(0.81)	0.03	(0.72)	505
	Meals	0.37	(0.53)	-0.38	(0.62)	0.11	(0.77)	0.55	(0.92)	502
	Passive	-0.35	(0.56)	0.41	(0.90)	-0.57	(0.80)	-0.62	(0.83)	225
	Pick-up	-0.72	(1.23)	-0.87	(1.23)	1.40	(1.45)	-1.05	(1.31)	17
	Social	-1.53	(0.84)	0.35	(1.25)	1.86	(1.46)	0.10	(1.53)	18
	Work	0.28	(0.41)	1.01	(1.21)	-0.01	(1.18)	-1.00	(0.81)	15

Table 35: Component Scores of Activity Groups by Planning Times (Out-of-home)

		Component 1		Component 2		Component 3		Component 4		
		Mean	S.dev	Mean	S.dev	Mean	S.dev	Mean	S.dev	Freq
Impulsive	Active	0.07	(0.70)	0.00	(0.74)	0.31	(0.79)	-0.29	(0.89)	109
	Hh oblig.	0.31	(0.59)	-0.64	(0.79)	0.52	(0.80)	-0.60	(1.06)	38
	Meals	0.91	(0.56)	0.32	(0.58)	0.35	(0.88)	0.17	(0.60)	156
	Passive	0.28	(0.69)	-0.12	(0.80)	0.51	(1.34)	0.52	(0.71)	22
	Pick	0.22	(0.56)	-0.69	(1.53)	0.17	(0.85)	-0.37	(0.97)	242
	Service	0.18	(0.58)	0.85	(0.35)	0.51	(0.65)	-0.87	(0.78)	68
	Shop	0.66	(0.46)	0.72	(0.39)	0.70	(0.73)	0.02	(0.74)	348
	Social	1.08	(0.78)	-0.11	(0.59)	-0.73	(1.10)	0.09	(0.89)	193
	Work	-0.85	(0.49)	-0.65	(0.97)	0.57	(0.92)	0.64	(1.00)	149
Same day	Active	0.15	(0.64)	0.42	(0.55)	0.27	(0.81)	-0.47	(0.83)	105
	Hh oblig.	0.59	(0.33)	-0.36	(1.11)	0.57	(0.73)	-0.41	(0.94)	24
	Meals	0.99	(0.64)	0.29	(0.65)	-0.15	(1.05)	0.26	(0.74)	134
	Passive	0.39	(0.78)	0.36	(0.65)	-0.34	(0.85)	0.30	(1.07)	41
	Pick	0.23	(0.62)	-0.74	(1.32)	0.09	(0.91)	-0.50	(0.94)	255
	Service	0.24	(0.53)	0.84	(0.42)	0.43	(0.68)	-0.84	(0.81)	97
	Shop	0.64	(0.47)	0.73	(0.38)	0.69	(0.66)	0.10	(0.69)	421
	Social	1.03	(0.73)	-0.12	(0.56)	-0.98	(1.04)	-0.06	(1.02)	223
	Work	-0.80	(0.72)	-0.40	(0.87)	0.41	(0.89)	0.43	(1.00)	154
Same week	Active	-0.16	(0.62)	0.15	(0.68)	-0.01	(1.05)	-0.19	(1.17)	154
	Hh oblig.	0.31	(0.84)	0.10	(0.55)	0.12	(0.90)	-0.73	(0.88)	19
	Meals	0.92	(0.74)	0.31	(0.58)	-0.14	(1.16)	0.35	(0.85)	77
	Passive	0.33	(0.66)	0.19	(0.64)	-0.45	(0.87)	0.43	(0.90)	46
	Pick	0.22	(0.69)	-0.80	(1.22)	-0.05	(0.87)	-0.54	(0.92)	260
	Service	-0.04	(0.64)	0.64	(0.49)	-0.10	(0.96)	-0.94	(0.64)	135
	Shop	0.60	(0.48)	0.74	(0.38)	0.66	(0.69)	0.21	(0.68)	184
	Social	0.91	(0.77)	-0.09	(0.54)	-0.93	(1.13)	0.16	(1.04)	222
	Work	-1.14	(0.59)	0.17	(0.66)	-0.11	(0.86)	0.60	(0.98)	362
Weeks ago	Active	-0.36	(0.55)	0.03	(0.64)	-0.12	(1.04)	-0.76	(0.84)	116
	Hh oblig.	0.00	(0.73)	-0.09	(0.49)	0.45	(0.72)	-0.83	(1.04)	9
	Meals	0.32	(0.74)	-0.03	(0.69)	-0.07	(0.98)	-0.52	(1.10)	42
	Passive	0.23	(0.77)	0.23	(0.56)	-0.55	(0.94)	0.34	(0.96)	19
	Pick	-0.07	(0.67)	-1.53	(1.03)	0.04	(0.69)	-0.70	(0.89)	305
	Service	-0.46	(0.64)	0.43	(0.55)	-0.02	(0.62)	-0.62	(0.72)	64
	Shop	0.42	(0.42)	0.28	(0.58)	1.06	(0.70)	0.26	(0.59)	37
	Social	0.77	(0.86)	0.02	(0.55)	-1.43	(1.29)	0.31	(1.29)	107
	Work	-1.43	(0.46)	0.44	(0.54)	-0.43	(0.62)	0.61	(0.75)	631
Routine	Active	-0.05	(0.53)	-0.31	(0.71)	0.12	(0.97)	0.05	(1.04)	60
	Hh oblig.	0.50	(0.68)	-1.07	(0.68)	0.46	(1.10)	-0.23	(0.90)	21
	Meals	0.30	(0.69)	0.54	(0.66)	0.54	(0.56)	-0.52	(0.88)	25
	Passive	0.54	(0.61)	0.12	(0.54)	-0.51	(1.10)	0.76	(1.28)	5
	Pick	0.07	(0.55)	-1.06	(1.25)	0.18	(0.81)	-0.41	(0.89)	143
	Service	-0.07	(0.77)	0.83	(0.53)	-0.32	(1.01)	-1.01	(0.85)	8
	Shop	0.59	(0.47)	0.70	(0.35)	0.76	(0.56)	0.35	(0.52)	29
	Social	0.66	(0.83)	0.11	(0.65)	-0.77	(1.20)	0.07	(0.89)	28
	Work	-1.26	(0.52)	-0.03	(0.80)	-0.06	(0.84)	0.51	(0.87)	272

Appendix D: Activity Choice Models

Table 36: Activity Choice Model, MNL vs. Mixed Logit Results

			MNL		Mixed logit	
No.	Variable	Alternative	Coef.	t.stat	Coef.	t.stat
1	Female	Group 1	0.461	17.94	0.415	5.14
2		Group 2	-0.262	17.74	-0.256	6.25
3		Group 3	-0.599	14.52	-0.630	11.59
4		Group 7	-0.178	8.74	-0.222	5.55
5		Group 8	-0.920	34.60	-0.974	15.06
6	Age group 1	Group 2	-0.415	24.69	-0.436	11.67
7		Group 4	-0.537	23.54	-0.550	7.94
8		Group 7	-0.489	21.58	-0.529	13.93
9	Age group 3	Group 1	0.566	33.30	0.641	16.47
10		Group 2	0.392	21.54	0.472	11.43
11		Group 6	0.504	38.76	0.568	20.58
12	Employed	Group 2	0.075	2.85	0.158	3.15
13		Group 4	-0.356	14.58	-0.365	6.97
14		Group 6	0.724	21.28	0.773	16.31
15		Group 7	0.239	10.79	0.271	6.99
16		Group 8	0.777	15.37	0.779	18.32
17	Education	Group 1	0.193	7.92	0.211	3.51
18		Group 3	-0.359	9.51	-0.387	9.98
19		Group 5	0.094	3.99	0.081	1.91
20		Group 8	0.131	3.25	0.054	2.51
21	Autos per adult	Group 3	-0.301	7.89	-0.593	9.49
22		Group 5	-0.371	12.36	-0.318	8.05
23		Group 6	0.303	11.95	0.363	8.07
24		Group 7	-0.232	9.02	-0.088	2.61
25		Group 8	-0.318	8.44	-0.390	6.50
26	Household	Group 3	-0.217	7.62	-0.277	6.11
27	size	Group 4	0.114	11.17	0.121	5.53
28		Group 5	-0.080	6.13	-0.066	1.74
29		Group 7	-0.082	5.81	-0.064	1.71
30		Group 8	-0.237	11.09	-0.255	6.93
31	Activity Types	Active	-1.609	37.15	-1.633	14.91
32		Hh oblig	0.264	10.44	0.268	3.80
33		Meals	0.100	3.85	0.099	1.59
34		Pick up/ drop	0.134	3.81	0.174	1.51
35		Services	-0.998	24.52	-1.009	13.03
36		Shop	0.200	6.09	0.241	2.37
37		Social	-0.882	25.06	-0.858	7.65
38		Work	-0.789	23.73	-0.785	5.99
39	Logsum	All: out-of-home	0.695	12.82	0.673	3.27
40	Weekend	Group 1	-0.324	11.28	-0.418	6.63
41		Group 6	-0.639	28.15	-0.758	12.63
42		Group 7	-0.541	26.07	-0.621	12.53
43		Group 8	-0.934	20.46	-1.051	15.87
44	Morning	Group 3	-1.064	9.45	-0.913	11.07

No.	Variable	Alternative	MNL Coef.	t.stat	Mixed logit Coef.	t.stat
45		Group 5	-1.094	22.26	-1.058	15.92
46		Group 7	-0.618	16.53	-0.682	11.38
47	Evening	Group 2	0.505	19.63	0.551	10.22
48		Group 4	0.369	16.78	0.495	8.61
49		Group 6	-0.958	26.37	-1.045	16.01
50		Group 7	-0.834	25.62	-0.864	15.17
51		Group 8	-1.524	23.73	-1.697	19.30
	Locations of the following an previous activities (1, out-of-home)					
52	Following	Out-of-home acts.	1.178	37.24	1.133	15.62
53	Previous	Out-of-home acts.	0.597	19.00	0.580	7.91
	Planning time of the following and previous activities (1, skeletal)					
54	Following	Meals	-0.196	8.43	-0.178	4.07
55		Passive	0.635	19.04	0.647	9.67
56		Shopping	-0.265	8.81	-0.278	6.85
57		Work	0.097	3.21	0.080	2.23
58	Previous	Meals	0.182	9.29	0.194	3.81
59		Passive	-0.166	5.52	-0.187	3.00
60		Pick up/ drop off	0.174	7.90	0.139	3.38
61		Services	0.410	20.87	0.358	14.49
62		Shopping	0.378	17.33	0.347	8.21
63		Work	0.375	19.03	0.364	7.90
	Number of activities in the skeletal structure by groups					
64	Group 1	Group 4	-0.071	2.73	-0.099	1.56
65		Group 5	-0.151	5.88	-0.143	2.08
66	Group 2	Group 5	0.165	15.17	0.139	3.71
67		Group 7	0.265	16.25	0.213	6.95
68	Group 3	Group 2	-0.239	8.87	-0.299	8.09
69		Group 3	0.170	7.99	0.185	6.94
70		Group 4	-0.215	9.36	-0.215	4.01
71		Group 7	-0.095	6.88	-0.161	4.31
72		Group 8	0.087	2.73	0.070	2.66
73	Group 4	Group 3	0.191	11.69	0.152	4.73
74		Group 6	0.279	20.18	0.243	5.90
75	Group 5	Group 3	0.207	16.78	0.232	12.09
76		Group 6	-0.031	2.90	-0.050	1.75
77		Group 8	0.242	10.66	0.168	6.13
78	Group 6	Group 1	0.118	4.89	0.075	1.75
79		Group 2	0.127	7.54	0.078	2.08
80		Group 8	-0.372	15.87	-0.401	11.59
81	Group 7	Group 1	0.126	5.61	0.148	2.64
82		Group 7	0.119	4.87	0.070	1.46
83		Group 8	0.077	4.15	0.096	3.33
84	Group 8	Group 4	0.200	11.49	0.166	4.02
85		Group 5	0.193	10.09	0.233	5.00
86		Group 7	0.191	14.65	0.131	2.82
	Previous activity group					
87	Group 1	Group 2	-0.163	4.92	0.118	2.57
88		Group 5	-1.101	31.11	-0.894	15.57

No.	Variable	Alternative	MNL Coef.	t.stat	Mixed logit Coef.	t.stat
89		Group 6	-1.086	15.89	-0.891	13.15
90		Group 7	-0.545	21.82	-0.384	9.60
91		Group 8	-0.662	12.10	-0.318	7.26
92	Group 2	Group 1	0.040	2.33	0.158	4.27
93		Group 2	0.734	37.78	0.697	15.62
94		Group 3	0.443	11.48	0.385	30.24
95		Group 4	0.536	35.47	0.483	14.37
96	Group 3	Group 2	0.249	6.12	0.374	14.98
97		Group 3	0.870	8.61	0.689	35.00
98		Group 5	-0.632	7.17	-0.564	8.94
99	Group 4	Group 2	0.557	24.56	0.624	14.03
100		Group 4	0.826	45.76	0.502	10.13
101		Group 5	-0.177	5.94	-0.184	6.02
102		Group 6	-0.291	5.33	-0.352	7.96
103		Group 8	0.302	5.37	0.413	23.47
104	Group 5	Group 1	-0.454	13.69	-0.339	8.27
105		Group 2	-0.225	5.32	-0.110	2.79
106		Group 3	0.567	14.83	0.640	39.22
107		Group 5	0.698	16.35	0.719	14.77
108		Group 7	0.095	2.46	0.213	6.12
109		Group 8	0.096	1.67	0.299	18.44
110	Group 6	Group 1	-0.564	15.43	-0.520	10.74
111		Group 2	-0.556	9.55	-0.507	9.12
112		Group 4	-0.191	4.53	-0.246	5.46
113		Group 7	0.394	14.04	0.447	11.43
114	Group 7	Group 1	0.235	16.15	0.152	4.11
115		Group 3	1.052	13.53	0.860	25.06
116		Group 6	-0.269	5.94	-0.291	8.02
117		Group 7	0.956	51.31	0.736	20.59
118		Group 8	0.514	36.94	0.652	37.87
119	Group 8	Group 1	-0.508	6.84	-0.379	7.20
120		Group 2	-0.397	6.05	-0.284	5.43
121		Group 3	0.332	3.06	0.385	22.56
122		Group 4	-0.316	4.83	-0.273	5.76
123		Group 7	0.545	10.46	0.590	19.38
124		Group 8	1.217	13.92	1.137	37.88
125	Error	Group 1			0.757	12.61
126	components	Group 2			0.360	5.79
127		Group 3			1.220	23.55
128		Group 4			0.702	17.70
129		Group 5			0.374	4.00
130		Group 6			0.719	13.33
131		Group 7			0.587	10.92
132		Group 8			1.055	25.85
	Log likelihood at optimal			-28773.9		-28274.7
	Number of observations			9393		9393
	Number of individuals			(345)		345

Table 37: Forecasts with Validation Data

Main Group	Activity type	Choice no.	Observed Frequency	Predicted frequency: Mixed logit	Predicted frequency: MNL	Z test results (*): Mixed vs. observed	Z test results (*): MNL vs. observed
1	Active	1	18	14	15	-0.70	-0.48
	Meals	2	139	94	99	-3.08	-2.71
	Hh. obligations	3	106	81	85	-1.92	-1.57
	Passive	4	50	78	82	2.52	2.88
	Work	5	6	24	25	3.27	3.46
2	Active	6	5	13	13	1.97	1.94
	Hh. obligations	7	74	90	86	1.28	1.00
	Passive	8	108	74	71	-2.64	-2.86
	Service	9	8	27	26	3.21	3.15
	Social	10	7	29	27	3.72	3.51
	Work	11	15	25	24	1.54	1.41
3	Pick up	12	20	22	20	0.29	-0.07
	Social	13	9	8	7	-0.34	-0.53
4	Hh. obligations	14	94	94	96	0.01	0.12
	Meals	15	119	80	82	-2.84	-2.74
	Social	16	9	31	30	3.46	3.44
5	Meals	17	44	40	42	-0.41	-0.24
	Passive	18	4	27	28	4.17	4.25
	Pick up	19	48	46	47	-0.17	-0.14
	Shop	20	29	47	47	2.06	2.08
	Social	21	63	21	21	-4.69	-4.61
6	Active	22	31	29	28	-0.30	-0.41
	Service	23	36	16	15	-2.86	-3.03
	Work	24	18	33	31	2.16	1.92
7	Active	25	14	10	10	-0.92	-0.82
	Hh. obligations	26	9	44	44	4.83	4.85
	Meals	27	11	37	37	3.75	3.77
	Pick up	28	40	42	41	0.22	0.12
	Shop	29	71	43	42	-2.73	-2.83
	Social	30	7	19	19	2.34	2.32
	Work	31	30	10	11	-3.09	-3.07
8	Passive	32	9	16	15	1.47	1.22
	Shop	33	10	30	27	3.21	2.82
	Work	34	39	8	8	-4.49	-4.58
Total			1300	1300	1300		

*Negative sign indicates under estimation. Z values over |1.96| indicate that the difference between the observed frequencies and prediction results are significant at the %5 level.

Table 38: Forecasts with Original data

				Predicted frequency		Z test results (*)	
Main Group	Activity type	Choice no.	Observed Frequency	Mixed logit	MNL	Mixed vs. observed	MNL vs. observed
1	Active	1	16	13	14	-0.63	-0.44
	Meals	2	143	85	89	-4.07	-3.75
	Hh. obligations	3	83	72	76	-0.87	-0.57
	Passive	4	84	70	73	-1.20	-0.88
	Work	5	45	25	26	-2.46	-2.25
2	Active	6	9	13	13	0.85	0.80
	Hh. obligations	7	58	87	83	2.47	2.15
	Passive	8	94	71	68	-1.86	-2.12
	Service	9	13	26	25	2.05	1.96
	Social	10	6	28	26	3.83	3.61
	Work	11	6	27	25	3.64	3.48
3	Pick up	12	9	27	22	3.02	2.32
	Social	13	9	9	8	0.10	-0.32
4	Hh. obligations	14	100	87	88	-0.99	-0.90
	Meals	15	88	74	75	-1.12	-1.02
	Social	16	3	28	28	4.56	4.54
5	Meals	17	25	46	48	2.50	2.77
	Passive	18	18	31	33	1.89	2.08
	Pick up	19	40	53	54	1.32	1.46
	Shop	20	32	53	54	2.31	2.44
	Social	21	63	24	25	-4.32	-4.18
6	Active	22	26	26	26	0.04	-0.04
	Service	23	25	14	13	-1.73	-1.90
	Work	24	21	33	31	1.71	1.45
7	Active	25	33	10	11	-3.57	-3.42
	Hh. obligations	26	26	45	46	2.29	2.44
	Meals	27	15	38	39	3.16	3.31
	Pick up	28	48	43	44	-0.50	-0.47
	Shop	29	76	44	44	-3.04	-3.02
	Social	30	8	19	20	2.18	2.25
	Work	31	37	12	12	-3.65	-3.56
8	Passive	32	12	21	19	1.54	1.20
	Shop	33	5	37	33	4.99	4.54
	Work	34	24	11	10	-2.25	-2.43
Total			1300	1300	1300		

*Negative sign indicates under estimation. Z values over |1.96| indicate that the difference between the observed frequencies and prediction results are significant at the %5 level.

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