Doctoral Dissertation

The Short-term Variability and the Long-term Changes of Individual Spatial Behavior in Urban Areas

Yusak Octavius Susilo

Department of Urban Management
Graduate School of Engineering
Kyoto University
2005

ABSTRACT

It is well recognized that travel is a derived demand from the needs and desires of individuals and household. Difference needs and desires between, as well as within, people from day-to-day thus lead to differences and variability in their travel behavior. Moreover, an individual's desire to seek variety in their travel and activity routines, and to explore the available opportunities as well as desire to spread their risks, have put the individual daily travel and activity pattern into a dynamic process that is characterized by learning and changes on the one hand, and rhythms and routines on the other hand. Over a longer period, along with the changes in the travel environment, job and household status, and fluctuation of economic conditions, the way people travel changes as well as their activity and travel needs.

Despite these dynamic changes, the variability and the stability of travel and activity behavior over time have rarely been examined and accounted in behavioral analysis. Variability and stability analyses are crucial in pinning down relationships between travel patterns and the nature of the external environment (factors that impinge on or shape travel). Specifying such relationships enables the forecasting of travel patterns and the design of policies that will effectively manipulate behavior in desired ways by engineering the appropriate changes in the external environment. Further, it is important to understand about behavioral variability in order to address broader issues of the relationship between the individual/household and the urban environment and in order to grasp the role of mobility in affecting the quality of urban life.

This study analyzes individual's behavior variability based on the variability and the changes of the individual spatial movements and travel-activity patterns over time. The objective of the short-term analysis is to examine the nature of the day-to-day variability of individual action space and to test the conjecture that the individuals with obligation commitments, i.e. workers, have more stable and predictable action space than non-workers. In the long-term analysis, the study objectives are to examine how temporal changes in travel environments and socio-demographic conditions have impacted urban residents' activity and travel patterns, as well as their action space, and how the impact of these changes are different amongst auto commuters, transit commuters and non-commuters who are subjected to different sets of constraints and endowed with different levels of mobility. Examine the stability and the transferability of the model of urban residents' activity and travel patterns and action space over a long-time span is one of the objectives of this study as well.

In analyzing the day-to-day variability of individual action space, the individual's intrapersonal variability and interpersonal variability are accounted for. The individual heterogeneity factor is also accounted for and this treatment has not largely been used before in the study of the variability in individual spatial movement behavior. Moreover, this study offers a variability analysis for a long-time span – and far as the author is aware, this is the first effort in analyzing the changes of individual's spatial movement for a long-period.

In order to achieve the later aim, it is necessary to understand how the individual travel behavior changes over time. Another unique and important contributions of this study are: analyzing the mechanisms underlying activity engagement and travel as one holistic process over a long period; examining the stability of activity engagement and travel; determining empirically whether there exist invariants in urban residents' activity-travel patterns through the period when urban area underwent substantial changes; and inferring general principles that may govern changes in urban residents' activity-travel patterns.

The study uses the *Mobidrive* dataset, a six-week continuous travel diary, for the short-term analysis, and person-trip data of the Osaka metropolitan area for long-term analysis.

In order to examine empirically the variability in individual action space over time, this study represents individual action space as the second moment of the out-of-home activity locations it contains. A panel regression model is employed to analyze the daily variability of individual's action space indices. Interpersonal and intrapersonal variability, as well as individual heterogeneity effects, are separated statistically based on the variance of the model. In analyzing the changes of individual's activity and travel behavior in long period, this study introduces a mechanism which allows an analysis of the activity engagement and travel as one whole process by applying simultaneous equations model systems the embody the structural relationships. The F-test, likelihood ratio test, pair-wise comparison test and the comparison of vector coefficients analyses are employed to examine the changes of activity engagement and travel over time.

The hypotheses of this study are summarized as follow. The variability of action space highly depends on individual's routine activity patterns and locations. Individuals who have routine commitments will have more stable patterns and lower intrapersonal variability than their counterparts. Individual activity and travel engagements will have continuously expanded as a result of the more available opportunities for activity engagement and better accessibility in the last 20 years. However, the expanding trend will be different between out-of-home commitment status as well as chosen trip mode. It is logical to assume that individuals will commit to a never-ending change in their travel and activity behavior, partly due to changes in travel environment and in socio-demographic conditions. Therefore, it is likely that an appropriate behavioral model is not directly transferable over a long period. Finally, as the individual travel and activity engagements are expanding over time, the individual's action space will be also expanding.

The results show that the stability and the variability significantly influence the individual travel and activity behavior over time. The action space variability is highly influenced by individual's out-of-home commitments, their work and home locations as well as their unique preferences. On weekdays, when activities tend to be obligatory and routine, activity locations tend to be fixed and action space tends to be recurrent. On weekends, when the activities tend to be more discretionary, activity locations are more variable and action space tends to be random and non-recurrent. Unobserved heterogeneity and difference commitments across individuals are found as a major component that accounts for the variability of their centroid locations on weekdays.

It is also found that the urban residents have expanded their travel and activities engagement as well as their action space over the 20–year period. The structural relationships underlying their activity-travel patterns were not stable over time, and non-workers and workers exhibit different tendencies of change. Non-workers have been able to expand their activity and travel engagements constantly. This is reasonable because they are not constrained by out-of-home commitments and their activities are only influenced by their in-home conditions.

Although not as much and constant as for non-workers, the auto commuters consistently increased the number of non-work visits, trip chains and total travel time. Under the economic boom in Japan between 1980 and 1990, and then the contraction of the economy between 1990 and 2000, they consistently expanded their travel and activities engagement. Meanwhile, the transit commuters, who do not have as much flexibility in arranging their travel patterns as do their auto-commuter counterpart, while having the tendency to expand the activity engagement as well, tend to have a stable total travel time. Both commuters have developed more effective trip patterns over the 20-year period by making more non-work visits with less expenditure time for non-work activity and fewer trip chains.

The stability test has revealed that only the under-specified model is transferable over periods. The stability test results have shown that a well-specified model is not transferable in any combination of the observation years.

As a closing remark, the results of this study suggest that it is necessary to adopt variability and the changes of individual behavior into the urban and transportation planning process. By adopting variability as well as stability in behavior, we would be able to design more efficient, sustainable and livable systems. Failing to do this will lead to inefficient transportation planning and management and potentially create a social exclusion as well as redundant transportation supply in the community.

ACKNOWLEDMENTS

I would like to express my sincere gratitude to all the people and institutions who have contributed towards the completion of this dissertation.

Throughout my stay at Kyoto University, it is my honor to have Professor Ryuichi Kitamura as my supervisor. I am really grateful for his kind guidance, patient and continuous support during my studies at Kyoto University. Without his help, I would have never finished my study there.

I thank Professor Kiyoshi Kobayashi and Professor Yoshitaka Aoyama who kindly and willingly served as members of the dissertation committee and have given me precious advices.

I am highly indebted to Professor John Black of University of New South Wales who kindly edited an earlier version of the dissertation and gave me precious comments to improve the clarity of this dissertation.

I would like to express my deep gratitude to Dr. Akira Kikuchi for his continuous support and assistance during my study. I also thank Associate Professor Toshio Yoshii for his support and encouragement.

I am particularly indebted to Dr. Wimpy Santosa of Parahyangan Catholic University for his recommendation to study at Kyoto University.

I was privileged to receive financial assistance from the Ministry of Education, Culture, Sports, Science and Technology of Japan and it deserves a special acknowledgement.

I thank Professor Kay W. Axhausen and his colleagues at the Swiss Federal Institute of Technology Zurich (ETH) who kindly provided the *Mobidrive* travel diary data for this research.

I greatly appreciate the kind support I received from all the present and former students and secretaries in my laboratory for their concerns and pleasant environment that they have given me. To Shiomi, Joe, Ushiwaka, Hashiue, Bayarma, A Lin, Arthit, Um, Kyotaro, Nakai, Mr. Senbil, Ms. Katsura, Mrs. Hamada and others, thank you very much, indeed.

My thankfulness is also extended to the administrative staff of the Graduate School of Engineering in Kyoto University.

I am grateful to Santi, Kimiyo and Kiki, for their encouragement during my hard times; and especially for Arie Damayanti, who voluntarily helped me by editing this manuscript.

I am grateful to my parents for their continuous pray, support and encouragement throughout my study period.

Last, but never least, I would like to extend my sincere gratitude to my beloved soul-mate, Mellisa, and my beloved cheerful daughter, Eunike. Without their love, pray, encouragement, and continuous support, this dissertation would not have existed.

Above all, I thank the Almighty God for His loving kindness and grace through Jesus Christ, which has sustained me through this program and always gives hope for a blessed tomorrow.

TABLES OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Chapter 1
Introduction

"If Karenin had been a person instead of a dog, he would surely have long since said to Tereza, `Look, I'm sick and tired of carrying that roll in my mouth everyday. Can't you come up with something different? ` And therein lies the whole of man's plight" (Kundera, 1984; cit. from Huff and Hanson, 1990).
Human daily pattern does not turn in a circle, like a robot or even a dog; it runs ahead in a straight line. Huff and Hanson (1990) noted, "… happiness is the longing for repetition as well as for variety and change".

1.1 Research Background

If we think about our daily travel and activity pattern, it is obvious that we do not repeat the same activity and travel pattern everyday. It might look similar, but it would not be same. The difference becomes more obvious when we compare today's pattern to that of 20 or 30 years ago. It is because a human is a dynamic creature experiencing endless changes in all parts of his or her life. The complex interactions between routine obligatory trips, historical dependences, different needs across days, commitments within household members, changes of travel environment, individual's desire to seek variety in their travel and activity routines, and to explore the available opportunities as well as desire to spread their risks, have put the individual daily travel and activity pattern into a dynamic process that is characterized by learning and changes on one hand, and rhythms and routines on the other hand. Moreover, over longer periods, along with the changes of travel environment, job and household status, and fluctuation of economic conditions, the way people travel changes as well as their activity and travel needs.

Despite of these dynamic changes, most studies on urban and transport planning still treat humans as having a symmetry pattern – like Karenin's fetching in a roll from the bakery each morning – by using one-day data in human behavior analysis and ignoring the existence of variability across time. Indeed, there is an argument that a one-day time span is an acceptable study period because the day is a natural physiological time unit which regulates much of human behavior as well as being a convenient time unit when administering surveys. In fact many human activities, from sleeping to commuting, recur with one-day cycles for physiological and institutional reasons (Kitamura, 1988a). Further, such one-day travel behavior surveys are commonly conducted in such a way that travel behavior information is obtained for different weekdays. Since the sampling methods employed generally avoid the situation where the characteristics of households or individuals are correlated with the days of the week, this approach has been believed to lead to unbiased samples of travel behavior on an average weekday and to unbiased estimates of the parameters in the models estimated with such data (Pas and Sundar, 1994). One-day data, however, inherently limits the scope of the analysis. For example, one-day data would not be able to reveal the day-to-day variations in travel patterns, activity scheduling, and allocation of travel resources over a multi-day period.

The limitation of one-day data can be illustrated as follows. Suppose that a one-day survey data gives that 30 percent of the city population was using the bus as their transportation mode in a given day. Although we could generally assume that 30 percent of the city is a bus user, our analysis could not go far beyond that. We would not be able to recognize regular users from those who are not, while this concern is actually important for bus operation management. We also cannot get the appropriate description of the population who gain the benefit of the current bus operations and those who suffer social exclusion[1] due to lack of access to transportation services. The performance of the bus systems in meeting dynamic demand due to the daily activities cycle cannot be fairly assessed. One-day data also cannot reveal the potential demand of bus users. These shortcomings will hinder us from producing an appropriate city bus policy, in particular, and an efficient and sustainable urban and transportation planning and management system, in general. In order to provide an efficient transport system that meets the needs of society, it is essential to understand not only the stable part on the behavior of the demand side but also its variability.

It is then clear that a variability analysis is crucial in enabling effective planning, building, and management of the transportation system. This prompts analysts to model trip generation and distribution, mode use and route choice with the ultimate goal of being able to predict behavior. The main goal of such modeling efforts is to pin down relationships between travel patterns and the nature of the external environment (factors that impinge on or shape travel). Specifying such relationships enables the forecasting of travel patterns and the design of policies that will effectively manipulate behavior in desired ways by engineering the appropriate changes in the external environment. Further, it is important to understand about the behavioral variability in order to address the broader issues of the relationship between the individual/household and the urban environment and in order to grasp the role of mobility in determining the quality of urban life (Huff and Hanson, 1990).

There are numbers of noticeable studies that make significant contributions in the study of the variability of travel and activity behavior. Some early works comprise classificatory analyses

[1] Social exclusion is defined as individual's lack participation in society due to lack of accessibility (Scott and Horner, 2005)

that extract the salient dimensions along which variations in daily travel patterns and how they can be effectively captured (Pas, 1983, 1984; Koppelman and Pas 1985; Recker et al. 1985) or how to apply sequencing schemes in order to reduce the dimensionality (Kitamura and Kermanshah, 1983, 1984; Lipps, 2000). Further, the classificatory methods have been extended to analyze multi-day travel patterns (Pas and Koppelman 1985, 1986; Pas, 1986, 1987; Hanson and Huff, 1986; Huff and Hanson 1986, 1990), to enumerate feasible activity-travel patterns (Recker et al. 1986; Wilson, 1998; Joh et al., 2001 a,b) or to analyze the repetition of activity patterns as stochastic process using the markovian method (Kitamura, 1988a).

These previous studies have shown that individuals' travel activity patterns are characterized by both repetition and variability. Behavior is not so repetitious that a single day is an adequate characterization of a person's routine travel. For example, the series of Hanson and Huff studies with the Uppsala household travel survey (Hanson & Huff, 1982, 1986, 1988; Huff and Hanson, 1986, 1990) show that whereas some behaviors are very repetitious, these behaviors evidently do not recur as part of the same daily travel activity pattern; every day is clearly not like every other day and no day that is superior to another day for that day to be the most representative day for the majority of individuals. They also noted that the observations that were taken for a single day in the travel history of an individual are not likely to represent the range of daily travel patterns exhibited by that person over a more extended time period, and they also rejected the view that travel is highly routinized in the restricted sense that every weekday is assumed to look much like every other weekday. Pas (1987) noted that behavior is repetitious, but the level of repetition is different for different travel behavior/socio-demographic groups and that the types of behaviors that are most repetitious differ for each group.

However, most of the previous studies did not take the order of the activities into account – they measured the daily activity patterns based on a comparison of trips or number of stops or certain activity engagements, and did not consider the duration or the time at which they are performed. This is unsatisfactory if travel is understood as a derived demand and in the context of the whole day. In measuring the degree of similarity, they also did not consider the different degree of repetition as well as variability for each different activity (e.g. there is a daily working activity pattern, but probably there is only one shopping activity in two weeks). Moreover, the major problem of similarity measurement is the lack of a generally accepted procedure to identify the similarity of activity/travel patterns over long periods.

Despite of difference between the methods, there is similarity in result among previous studies in defining the variability and repetition of individual behavior. In spite of the high level of randomness in the timing of repetitious behaviors, they found a considerable persistence in the locations of the stops and a low degree of spatial variability, even when they measured location very precisely (Huff and Hanson, 1990; Schonfelder and Axhausen, 2001). It is understandable since, despite of the daily variability in the expenditure time for individual's activity as well as the sequential of the engagement, the individual's travel and activity pattern are rooted at their obligation locations (e.g., office or school) which tend to be fixed meanwhile the obligation engagement time is relatively fixed over time (Pred, 1977; Cullen and Godson, 1975; Golledge and Simpson, 1997). Moreover, with the limitation of individual's movement ability in space and time (e.g., the available time for out-of-home activity and travel) (Hägerstrand, 1970), the daily observed movement area, which is a synthesis from the interaction between the individual's daily activities and the travel components, would logically show a more stable pattern across time compared to other patterns that arise from a certain travel component. The set of places where an individual visits to carry out activities shall be called the *action space*.

Analyzing behavior variability that is rooted in location will allow us to deal with social exclusion issues as well as to the management and operation of the transport infrastructure planning. Moreover, since the individual's movement in space as well as their chosen activity locations are a result from the interaction of various facets of individual behavior, a focus on activity location analysis as well as on its variability should also permit a more "holistic" view of repetitious behavior than previous approaches that only focused on certain parameters, like number of trips per day. An analyses based on individual spatial movement in space allows the analyst to see how the various components of a travel-activity pattern are interdependent and integrated within a space-time context.

Indeed, there have been several studies of individual's spatial diversification among available opportunities in space on a given time. However, the day-to-day variability of the individual's spatial movement overtime has rarely been examined. The changes of individual's ability movement in space over a long-time span, as far as the author is aware, have never been examined before. A significant difference between long-period analysis and short-period analysis lies in the stability of the preferences that underlying the individual behavior. In the short term, the relationships underlying the individual's travel and activity behavior as well as the conditions of travel environment are assumed to be constant. Meanwhile, the environment conditions, the individual behaviors, as well as their preferences in the long-term period, are subject to change.

To understand more about the reasons that underlie the changes in individual's spatial movement over long periods, it is necessary to examine the changes of behavior over the long period as well. With the emerging era of motorization and suburbanization in metropolitan regions in last three decades, the constraints travel over time, as well as the urban form in many metropolitan areas has changed. This implies substantial changes in the physical and social environment for trip making, which, in the end, these changes imply changes in the needs for, resources available for, and constraints imposed on, travel. However, how the individual composing their travel pattern and how the travel parameters are evolving through time is still largely unknown. Indeed, the changes in specific indices of activity and travel behavior (e.g., the number of trips, or travel time expenditure) have been often examined, most typically using cross-sectional data from multiple regions or repeated cross-sectional data from a region (e.g. Yunker, 1976; Hupkes, 1977; Zahavi and Ryan, 1980; Zahavi and Talvitie, 1980; Supernak, 1984, 1987; etc.). Little is known, however, as to how urban residents' adaptations to the vast changes in their travel environments have modified their time use and travel patterns as a whole.

Analyzing the individual travel behavior by treating separately the causal mechanisms underlying activity engagement and travel and ignoring the individual adaptation processes over time could lead to bias descriptions and produce overestimated results. Hence, it is important to analyze holistically the causal mechanisms underlying activity engagement and travel and examine the stability in activity engagement and travel by individual, in this case urban residents, behavior over time. Analyzing the invariants in their activity and travel patterns through the period when urban areas underwent substantial changes on one hand, and inferring the general principle that may govern changes in urban residents' activity and travel patterns, on the other hand, are needed to understand how individual travel behavior changes overtime.

This study intends to provide answers to questions such as:

- (For short-term analysis, i.e. day-to-day variability): How is the day-to-day variability of individual's movement on space? Who has a stable pattern and who has not? How the variability between individual and within individual as well as the individual uniqueness can explain the errors in the model? How the result from examining individuals' movement variability can be used for better infrastructure planning and management?
- (For long-term analysis): How individual travel behavior changes over long periods? Are they stable? Are the behavioral models transferable? Which changes are caused by socio-economic and travel environment factors and which ones are caused by the change in the relationship that underlying individual's travel pattern? How individual spatial movement changes over long periods? And, what is the implication of the trend in the changes in the individual's spatial movement on the urban planning and management?

1.2 Research Objectives

The objectives of this study are:

1. To examine the nature of the day-to-day variability of individual action space.
2. To test the conjecture that the individuals with obligation commitments, i.e. workers, have more stable and predictable action space than non-workers.
3. To show how temporal changes in travel environments and socio demographic conditions have impacted urban residents' activity and travel patterns as well as their action space. The more available opportunities in many metropolitan areas, and the emerging era of suburbanization as well as motorization, are assumed have encouraged urban residents to expand their activity and travel patterns as well as action space in the last two decades.
4. To show how the impacts of changes are different amongst auto commuters, transit commuters and non-commuters who are subjected to different sets of constraints and endowed with different level of mobility.
5. To examine whether the model of urban residents' activity and travel patterns as well as action space are transferable over a long-time span.

Analyzing the day-to-day variability of the individual action space with accounting for individual unobserved heterogeneity is one of the uniqueness of this study. Moreover, this study offers the variability analysis of action space for a long-time span – and, as far as the author knows, this is the first effort in this scope of study.

Analyzing the mechanisms underlying activity engagement and travel as one whole process over long periods, examining the stability of activity engagement and travel, determining empirically whether there exist invariants in urban residents' activity-travel patterns through the period when urban area underwent substantial changes and inferring general principles that may govern changes in urban residents' activity-travel patterns are unique and important contribution of this study as well.

Two dataset are employed in this study. The *Mobidrive* dataset, a six-week continuous travel diary, is used for short-term analysis. This is a survey carried out in Karlsruhe and Halle cities in Germany in 1999, which was funded by the German Ministry of Research and Education with the aim to analyze the rhythms in the behavior of the urban residents. A total of 317 persons over 6 years of age in 139 households participated in the main study (Axhausen et. al., 2002). The main dataset used for the long-term analysis is person-trip data of the Osaka metropolitan area. This is a conventional large-scale household travel surveys conducted in the Osaka metropolitan area of Japan in 1970, 1980, 1990 and 2000, with sampling rates of 2.4% to 3.0%. This dataset is supplemented by land use and network data (Kitamura et al., 2003).

1.3 Outline of Dissertation

The outline of the dissertation is as follows. **Chapter 1** explains the background, the objectives of the study.

Previous studies about the individual travel behavior, the variability of the travel pattern, individual spatial movement in space and time and the model stability and transferability over long periods are presented in **Chapter 2**. The *hypotheses* of this study are presented in the last part of this chapter.

Chapter 3 describes the used database, i.e. the person-trip data of the Osaka metropolitan area and the *Mobidrive* six-week continuous travel diary data.

Chapter 4 provides the analysis of day-to-day variability of individual action space, which is introduced in this study by the *concept of the second moment* of the out-of-home activity locations it contains. The statistical analysis to decompose the nature of the individual variability is also presented in this chapter.

Before analyzing the changes of individual action space over long periods, the changes and the stability of individual's activity and travel behavior during that period is examined. This is done in **Chapter 5**. With applying simultaneous equations model systems, this chapter introduces a mechanism to analyze the activity engagement and travel as one whole process. The stability of activity engagement and travel is examined and the general principles that may govern changes in urban residents' activity-travel patterns are inferred.

Using the concept of the second moment introduced in Chapter 4, the analyses of the changes of individual action space over long span period are presented in **Chapter 6**.

Chapter 7 closes the dissertation with a conclusion.

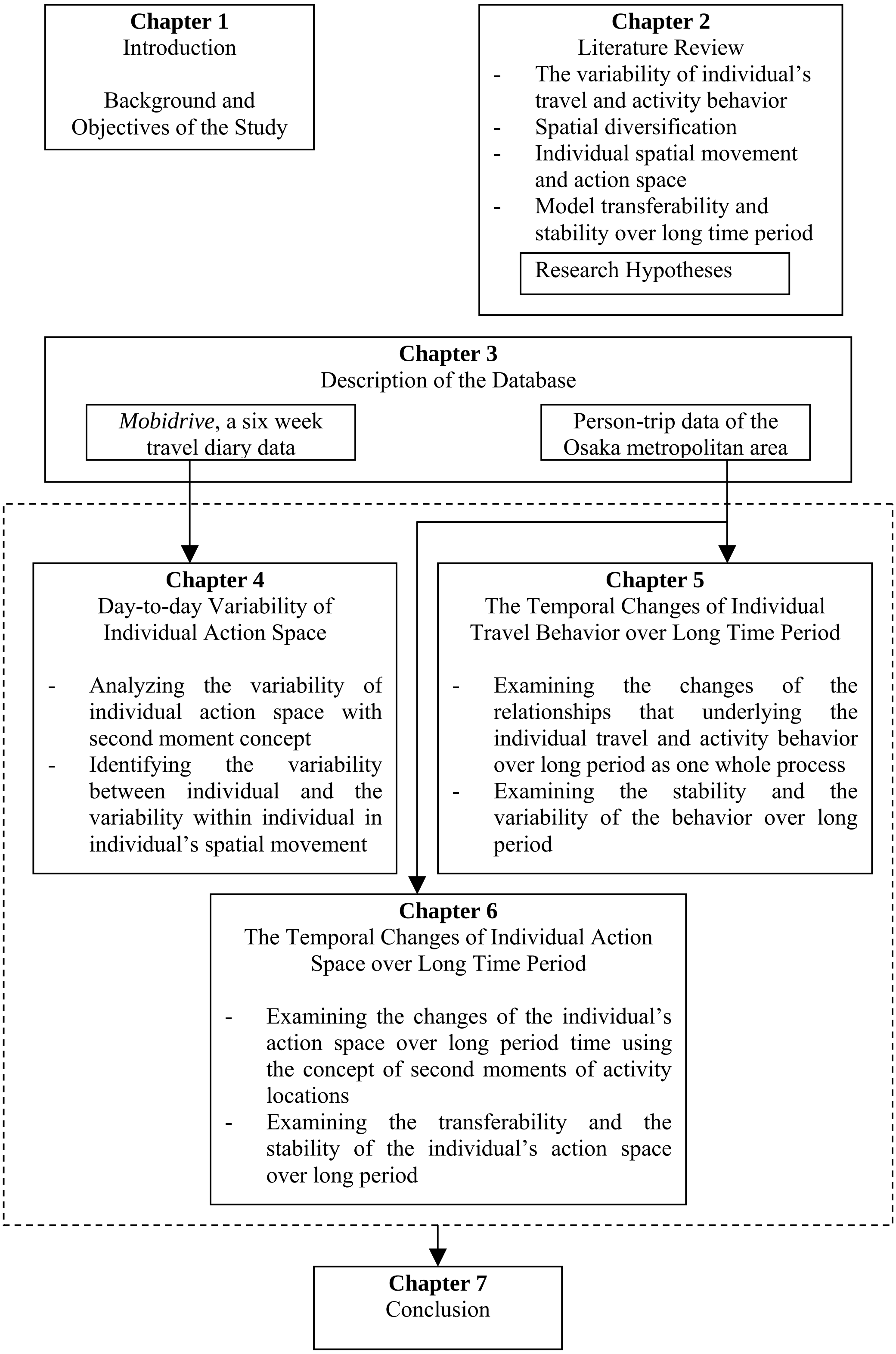


FIGURE 1.1 Outline of the Dissertation

Chapter 2
The Variability of Individual Travel Behavior

This chapter provides a literature review of previous studies about individual travel behavior, repetition and variability of the travel pattern, individual spatial movement in space and time, and stability and transferability of the travel behavior over long periods. Referring to the objectives of this study as well as the results of the previous studies, the *hypotheses* of this study are presented in the last part of this chapter.

2.1 Habit and Variability in Individual Travel Patterns

It is well recognized that travel is a derived demand that is based on the needs and desires of individuals and household. Differences between people thus lead to differences in their travel behavior. Since the needs and the desires of individuals are not constant from day-to-day, the individual travel pattern is neither totally repetitious nor totally random. There are some activities (e.g., working, studying, eating, sleeping) that are repeated on a day-to-day basis. On the other hand, other activities such as shopping, personal business and social recreation are not necessarily repeated on a day-to-day basis.

Routine obligations, different needs across different days, commitments within household members, changes of travel environment, historical dependences, individual’s desire to modify their boredom of travel and activity routines and to explore the available opportunities as well as a desire to spread their risks, have put the individual daily travel and activity patterns into a dynamic process which have learning and changes on the one hand and rhythms and routines on the other hand.

Huff and Hanson (1990), for example, note that, although each person has a few highly repetitious behaviors (for example, going to work by car), these tend to be repeated as parts of different daily patterns. Each person has more than one "typical" daily travel pattern, and interestingly, more than one "typical" weekday travel pattern. Furthermore, these archetypical daily patterns tend to be quite different from each other in terms of the number and types of stops comprising the pattern. They have also identified certain core, or frequently occurring, behaviors, but when they examined the temporal recurrence of these core behaviors, they found that even these core behaviors do not tend to recur at regular intervals in the individual's longitudinal record.

Since travel and activity behaviors are a continuous learning and adopting process, understanding the repetition and the variability of individual travel behavior becomes necessary in order to provide an efficient and sustainable transportation planning. Ignoring the existence of variability would give an inappropriate travel behavior description that leads a misleading policy of transportation planning and infrastructure management.

Habit and history dependences

The idea that individuals establish stable, relatively fixed travel patterns has been a convenient, compelling, and widely adopted simplifying assumption among transportation researchers (Adler and Ben-Akiva 1979; Golledge 1970). Hanson and Huff (1982, p.18) note that, "Given that most people are satisfiers rather than optimizers and given that routine behavior is a stress-minimizing, satisfying strategy because it eliminates the need for constant decision making, there are certainly grounds for expecting that most people establish habitual patterns. Yet there are also grounds for believing that travel behavior is cyclical, with cycles that are daily, weekly, monthly, and yearly, but perhaps also of two to three days length." For example, one can assume that commuting trips resemble each other concerning mode choice, route choice or departure times due to nearly stable constraints for these trips.

It is unlikely that humans will judge their activities anew every time and attach a new subjective utility to each possible activity or activity pattern. They will rather repeat an activity pattern that offered them a satisfying experience without carefully judging the alternatives. This tendency to use old patterns of behavior as templates to structure future behavior certainly applies in situations where the person interprets the general stimulus/purpose/need for action as similar to a purpose that has arisen, before within a context similar to the present situation, such that the same successful response is called for – i.e. a repetition of a previous action. Cullen (1978) noted that the repetition of daily behavior is to be expected because it is one way for a person to cope with the complexity and variety of the urban environment. Engaging in routine behavior obviates the necessity of making myriad decisions every day.

Kasturirangan et al. (2002) showed that there is a relatively high degree of consistency in activity engagement from day to day. When a person engages in a certain activity on one day, the person appears to be more likely to repeat the activity the next day compared with a person who did not perform that activity on the first day. Similarly, when a person does not engage in a certain activity on one day, then the person is more likely not to engage in that activity the next day too. The results of the analysis also indicate that daily activity frequency and activity time allocation are positively influenced by the previous day's activity frequency and activity time allocation respectively. Focused to specific activity engagement, Kitamura (1988a) showed that those who engaged in shopping in the past tend to engage in shopping again in the future, and those who forewent shopping tend to forego in future also. Moreover, for long period, Kitamura and van der Horn (1987) found that 69.8 % of the male workers and 58.6 % of the female workers in the Dutch sample had identical daily patterns of shopping participation (or non participation) on five or more of days of each of the two weeks (six months apart) in the study; (e.g. if they shopped on a Tuesday and not on a Wednesday in the first week, they repeated this in the second week six month later).

The existence of variability

On the other hand, like habit and repetitious behavior, there are also grounds for expecting variability in individual behavior. With the same reason with habitual behavior, in order to reducing "stress", which was caused by boredom of daily routine engagements, individual desires an addition of variety of travel pattern and/or visit new places. Individuals also have a desire to reduce uncertainty by learning about available options and to spread risks by developing a portfolio of regularly visited destinations (Smith, 1978; Hay and Johnston, 1979). Moreover, Brög (1980) argued that individual's behaviors are likely to vary in the short run because the decision-making environment within which travel takes place is likely to vary over time in the short run. In Brög's view, observed behavior is, to a large extent, the result of constraints faced by the individual, and these constraints are likely to vary from day to day. A total repetitive behavior would result only if the individual faced the same constraints every day, a situation that is highly improbable.

Further, even if the constraints or obligations may be similar from day-to-day, the chosen activities are not necessarily identical. Differences occur because people do not have the same needs every day (e.g., it is not necessary to go a grocery store every day) and in particular, the motives for non-work activity engagement are not identical from day to day. Individual's commitments, either out-of-home or in-home, either with household member or others, are also vary from day to day. And, although hard to be accounted for in empirical analysis, there are always unexpected events (e.g. variation in weather) that will vary the behavior from day-to-day.

From the reasons above, it is clear that the variability exists in individual travel patterns and it is an important, essential and an unavoidable component in analyzing the individual activity and travel pattern behavior. For example, in examining the individual daily trip generation rate, Koppelman and Pas (1984) have showed that individual variability exists which has a considerable influence on the pattern. Considering the cause, there are two types of variability that can be identified in analyzing the individual travel and activity behavior pattern, i.e. the variability that refers to variation from day-to-day in the behavior of a given person (intrapersonal variability) and the variability that caused by the differences in the behavior of different individuals on the same or different days (interpersonal variability). This variability is various and unique for each person and each time. Moreover, their patterns are change continuously over time.

It is important to understand how individual varies their activity and travel pattern from day-to-day and from each other in order to provide an efficient transportation management and livable infrastructure planning. By understanding the variability of individual's needs and desires as well as their impact to their activity travel pattern, we would be able to design and manage the transportation system based on the variability of demands. Moreover, we would be able to address the social exclusion issues that caused by transportation system, e.g., who gains the most benefit of a certain infrastructure planning and who experiences less of a service from the system.

However, in spite of the fact that theoretical discussions recognize the day-to-day variability inherent in travel behavior, most of the recent urban travel demand analyses are still based on one-day data, which containing records of trips made by household members on a given survey day. The basic reason of this approach is that if the behavior reported is for a randomly chosen day (out of some longer time period) then an unbiased sample of behavior (over that time period) is obtained. Further, such one-day travel behavior surveys are commonly conducted in such a way that travel behavior information is obtained for the different weekdays. Since the sampling methods employed generally avoid the situation where the characteristics of households or individuals are correlated with the days of the week, this approach leads to unbiased samples of travel behavior on an average weekday and to unbiased estimates of the parameters in the models estimated with such data (Pas and Sundar, 1994).

One-day data, however, inherently limits the scope of the analysis. For example, one-day data would not be able to reveal the day-to-day variations in travel patterns, activity scheduling, and allocation of travel resources over a multi-day period (Kitamura, 1988a). Moreover, in a long-period analysis, people change, their travel needs change, and the travel environment changes. The relationships that underlay the reason of the way people travel also will change. Assuming complete stability in the decision-making environment, and the ignorance of variability and changes of behavior could provide a far than predicted results (Brög and Erl, 1983) and clearly, it would not achieve the desired policy and planning purposes.

Results from previous studies

There are numbers of perceptible studies that make significant contributions in revealing the variability of travel and activity behavior. Some early works comprise classificatory analyses that extract the salient dimensions along which variations in daily travel patterns can be effectively captured (Pas, 1983, 1984; Koppelman and Pas 1985; Recker et al. 1985) or apply sequencing schemes in order to reduce the dimensionality (Kitamura and Kermanshah, 1983, 1984). Further, the classificatory methods are extended to analyze multi-day travel patterns (Pas and Koppelman 1985, 1986; Hanson and Huff, 1986; Huff and Hanson 1986), to enumerate feasible activity-travel patterns (Recker et al. 1986) or to analyze the repetition of activity patterns as stochastic process using the markovian method (Kitamura, 1988a).

Using the Uppsala household travel survey that contains 35 consecutive days of 149 individuals and 94 households, Hanson and Huff tried to describe the behavior repetition as well as the intrapersonal variability among individual (Hanson & Huff, 1982, 1986, 1988; Huff and Hanson, 1986, 1990). They examined the frequency of individuals who exhibit activities with the same attributes during the entire investigation period. They developed a repetition index as a sum of the deviations from the uniform distribution in relation to the concentration of all activities in only one cell. The closer this index is to 1, the more concentrated are all trips in a small number of cells and the more repetitious the behavior is. The results showed that each person performed only a small number of all possible trip combinations and indeed there is a significant repetition of activities groups. Furthermore, they introduced a similarity index in order to examine the number of matches between patterns on two different days based on the contingency tables and divided this by the number of stops of the longer activity chains. A value of 1 indicates identical travel pattern on two different days, while value of 0 occurs when two days do not have any trips with the same attribute combination in common. The results showed that whereas that selected behaviors are very repetitious, these behaviors evidently do not recur as part of the same daily travel activity pattern; every day is clearly not like every other day and no one weekday that is superior to other days in that it is the most likely to be the most representative day for the majority of individuals. They also noted that the observations that were taken for a single day in the travel history of an individual are not likely to be representative of the range of daily travel patterns exhibited by that person over a more extended time period, and they are led to reject the view that travel is highly routinized in the restricted sense that every weekday is assumed to look much like every other weekday. Unfortunately, neither the order of activities nor the time at which they are performed have any influence on the analysis. Moreover, they did not consider that each activity will have a different repetitious rate, for example, in weekdays, people will engage in work everyday, however, probably they only engage in shopping once in two weeks.

Using Reading activity diary surveyed between January and March 1973 of 112 employed persons, Pas (1983, 1984, 1987) and Pas and Koppelman (1986) developed another similarity index which compares the trips of a day pair-wise. They adopted the "primary-secondary attributes" concept that was introduced for analytical classification of plants and animals. Only in case of a match between the primary attribute of two compared trips, otherwise the comparison is not made. The similarity index varies between 1 and 0 with 0 indicating that there are no matches between the two daily activity patterns. Further, using the similar method, Pas (1988) assumed the daily travel-activity behavior as the outcome of a two-stage process. In the first stage, individuals select a weekly travel-activity pattern, while in the second stage each individual selects a daily travel-activity pattern conditional on the selected weekly pattern. Pas and colleagues results showed that the degree of intrapersonal variability in daily trip generation rates might be considerable. The intrapersonal variability, which varies across subgroups of populations, was found to comprise about 50 percent of the total variability in trip-making rates. Pas (1987) showed that the existence of intrapersonal variability leads to lower estimates of the goodness-of-fit of travel demand models. Moreover, behavior is repetitious, but the level of repetition is different for different travel behavior/socio-demographic groups and that the types of behaviors that are most repetitious differ for each group.

Extending these previous works, using three-day travel data set collected in Seattle, Pas and Sundar (1994) showed that about 38 percent of the total variability in the daily trip rate is due to the intrapersonal or day-to-day variation in the respondents' travel behavior. However they measured the daily activity patterns based on a comparison of trips and did not consider the duration or the time at which they were performed. This is unsatisfactory if travel is understood as a derived demand and in the context of the whole day. Moreover, similar with Hanson and colleagues, in comparing similarity between days, they did not consider different repetitious rates for each activity.

Unlike Hanson's and Pas's works, Jones and Clarke (1988) calculated similarity based on the time budget instead of trips. They developed a similarity index, which divides the day in temporal intervals and compares the chosen activities of two days within the same interval, the based index increases by 1; if it is performed at one day one interval earlier or later than on the other day, the index increases by 0.5. The result is divided by the maximum possible value if all 96 intervals on a day were identical (based on a division of the day in 15 minutes interval). A value of 0 indicates again that two daily pattern have nothing in common while a value of 1 represents identical activity patterns. A disadvantage of this method is that it ignores other attributes such as transport mode which is important for transport planning; the index is based exclusively on the performed activities (Schlich and Axhausen, 2003).

Using *Mobidrive* data, a six-week travel diary (Axhausen et al., 2002, for more explanation of *Mobidrive* database, see chapter 3), Schlich and Axhausen (2003) compared Hanson's, Pas's and Jones and Clarke's works. They found that the methods produce similar variability patterns (behavior), with the similarity measured by a trip-based index (Hanson and Pas) is lower than the similarity based on time budget. They noted that the measured similarity declines if the method captures more of the complexity.

Beside those methods, there are several other interesting approaches to analyze the variability of individual behavior. Kitamura (1988a) described the variation in travel as a stochastic process. Markovian process was used to define the "latent" (representative) pattern and its recurrence structure. The markovian process allows interconnections between behaviors (e.g., driving a car to work) that may be integrally related to a set of other behaviors (e.g., picking up children after school and then going to the park). Lipps (2000; quoted from Schlich and Axhausen, 2003) tried to reduce the complexity of daily patterns. In a first step each trip is reduced to a main activity that is assigned according to a predefined hierarchy. Thus, if one trip of a higher priority was performed, the trips of lesser priorities are neglected. The idea of this approach is to reduce the complexity and corresponds to the intuitive impression concerning variability – the working days of an employee look very similar at a first view, regardless if a person started an activity fifteen minutes earlier or later or if he stopped by at a shop on his way home. But in the context of transport planning these minor attributes can make big difference since they may be the reason for the choice of a particular mode. Wilson (1998) adopted the sequence alignment technique from the field of molecular biology. The idea is to look at a daily pattern as a whole and to measure the number of operation necessary to equalize two sequences instead of ensuring the pair- wise Euclidean attribute distance (later, the method were improved and developed under DANA simulation program by Joh et al., 2001 a,b).

Stability on locational variability

The previous efforts have shown that individuals' travel activity patterns are characterized by both repetition and variability. It is also evident that behavior is not so repetitious that a single day is an adequate characterization of a person's routine travel. Unfortunately, most of the previous methods do not take the order of the activities into account. Also, the major problem of similarity measurement is the lack of a generally accepted procedure to identify similarity of activity/travel patterns over long periods.

However, there is a similarity in result among previous efforts in defining the variability and repetitious of individual behavior. In spite of high level of randomness in the timing of repetitious behaviors, it is clear that the repetitious aspects of complex travel-activity patterns are rooted in space. Huff and Hanson (1990) did, however, find considerable persistence in the locations of the stops, even when they measure location very precisely. Based on *Mobidrive* data, Schonfelder and Axhausen (2001) also noticed a low degree of spatial variability (see Figure 2.1). According to their results, there are 2 – 4 locations that normally cover about 70% of all locations within 6 weeks. Although the maximum number of visited locations reached 60, about 90% of all trips were made to the same 8 locations.

It is understandable since, despite of the daily variability in the expenditure time for activity as well as the sequential of the engagement, the individual's travel and activity pattern are rooted at their obligation locations (e.g., office or school), which tend to be fixed, and the obligation engagement time is relatively fixed over time. Chapin (1974, pp.33) noted: "the activity patterns are determined by the individual's propensity and opportunity to engage in particular activities". The individual's propensity depends on the number of 'predisposing' factors (such motives, way of thinking, etc.) and 'preconditioning' factors (such as role obligations, traits, etc) and the individual's opportunity on the perception of the accessibility to the necessary facilities, and to perceive the performance of these facilities.

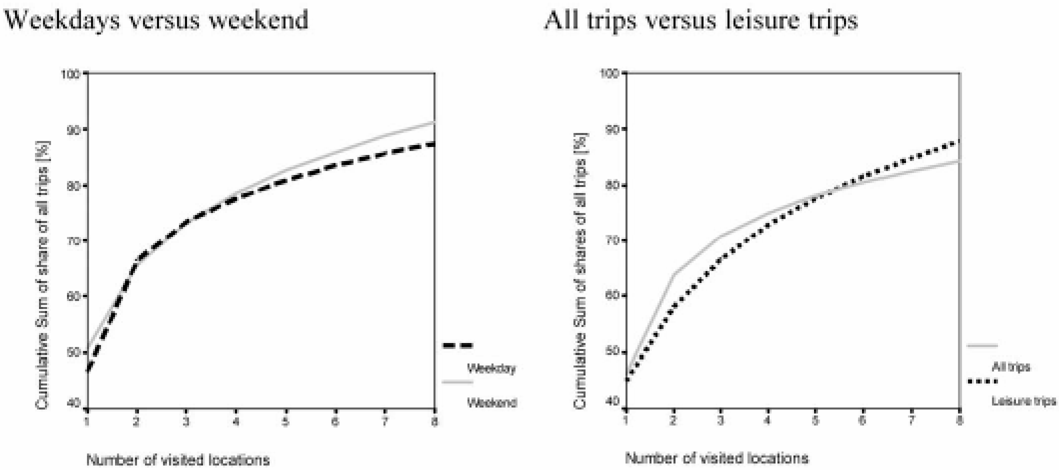


FIGURE 2.1 Number of Visited Locations and Their Average Share of All Trips per Persons[2]

Analyzing behavior variability that is more firmly rooted in location will provide significant contribution in sustainable infrastructure planning, social exclusion issue as well as to the management and operation of the transportation system. Since the individual's movement in space as well their chosen activity locations are a result from the interaction of various facet of individual behavior, a focus on activity location analysis and its variability would produce a more "holistic" view of repetitious behavior compared to previous approaches that only focused on certain parameters, like number of trips/day. An analysis based on individual spatial movement in space allows the analyst to see how the various components of a travel-activity pattern are interdependent and integrated within a space-time context.

In order to analyze individual behavior in space and time, we need to understand the individual's ability in spatial movement as well their *activity space*. This topic will be discussed in Section 2.3. Before discussing individual's movement ability in space as well as their action space, a discussion about the individual's reason to make spatial diversification will be provided in Section 2.2.

[2] Source: Schönfelder and Axhausen (2001)

2.2 Variability in Spatial Diversification

Since the individual activity engagements are vary from day-to-day, the locations of non-routine (non-obligation) activities tend to vary over time. Understanding the way individual choose their activity place under given possible locations will provide important insight into sustainable urban planning as well as travel behavior analysis, i.e. like the compatibility of compact city and mixed development issues toward achieving the sustainable and livable urban development.

Despite its importance, little attention has been paid to the issue of spatial diversification in the individual's habitual pattern of destination selection. Spatial diversification occurs when, over some extended period of time, the individual regularly visits more than one destination of a given type of activity.

Generally speaking, the spatial choice problem is to determine the probability that an individual selects, from a set of possible destinations (also referred to as interaction opportunities or activity sites), a given opportunity; the individual's locations are given, as are the locations and attributes of the set of alternative destinations (Hanson, 1980). Since spatial behavior was mostly bounded rational or *satisficing*, rather than being utility maximizing and optimal, in the decision-making process, the individual's beliefs are critical, especially in situations involving uncertainty. These beliefs constitute the individual's *mental map*, an environmental knowledge, which is represented in maplike form and could be recalled and or externally represented by cartographic-like presentation. The expected utility function represents a combination of the decision maker's preferences, beliefs, and attitudes towards risk. *Cognitive maps*, as a means of structuring, interpreting, and coping with complex sets of information that exist in different environments - not only physical experience but also knowledge from books, film, media, etc., plays significant role in deciding what overt spatial behaviors are to be performed in any problem-solving situation. Golledge's *anchor point theory* (Golledge and Stimson, 1997) postulates that spatial knowledge and orientation skills are acquired by linking important individual nodes and links amongst these locations. People build up a cognitive structure of frequently visited places that are mentally linked by hierarchical paths. The cognitive map plays a role in deciding what choice to make and whether one has to travel or not to achieve a goal; it help decide where to go, which route to take, and what travel mode to take to get there. Cognitive maps have also played a role in research on movement patterns both in a migration and a mobility context, as well as for movement associated with recreational and leisure choice (Golledge and Stimson, 1997).

Habit and variability of spatial diversification

Like habit in travel behavior, individuals have favorite places as well as fixed obligation locations in carrying out their daily activity. Marble and Bowlby (1968) have shown that travel for work purposes tends to be highly repetitious, and that repetitiveness of destination selection varies with the purpose of the trip. On the other hand, individuals also have desire to reduce boredom by adding some varieties to visit new place and they are constantly learning about their environment over time and constantly modifying their knowledge set as they travel throughout the local environment and accumulate further information (Golledge and Stimson, 1997). These behaviors define the individual peg locations as well as the variability of individual's activity locations.

Further, there are also several reasons that contribute to the diversification of activity location (Hanson, 1980):

1. Traveler's desire to spread risks by developing a portfolio of regularly visited destinations. Consider a consumer wishing to purchase some commodity available at several spatially separated markets. In general, one would expect certain characteristics of the commodity, such as price and "quality", to be random variables whose distribution functions vary from place to place (and depend, for example, on the order of the market). There would also be time and money costs involved in transacting in any particular market. In order to have less risk aversion, intuitively, individual will "shop around" along the available markets. As long as the correlation between various markets is not too great, and as long as the costs of locating in distant markets is not great (where one presumes the correlation is generally lower), it may be worthwhile to consider another branch (Smith, 1978).
2. Individual's desire to explore and reduce uncertainty by learning about available options (Hay and Johnston, 1979) will increase the spatial variability.
3. The variability in the spatial, temporal, and modal constraints faced by the individual also contribute to the variability of activity locations; for example, lack of time or the temporary unavailability of the family car might rule out the possibility of shopping at food store x and render y the only viable alternative.
4. The differentiation of stores (or activity sites) within a given functional class means that different stores may meet different needs at different times (e.g. buying milk and bread in convenient store versus weekly food shopping in a super mall).
5. One's need for two goods or services (m and n) coincide time. When this occurs the traveler is likely to choose the establishment of type m that can easily be combined on the same trip to accomplish or acquire n. Because n varies over time, the individual will visit different establishments of type m over time.

Despite the number of studies that mention various possible reasons for spatial diversification, the investigation how the spread of individual spatial diversification varies from day-to-day for a given person is rarely been done. With Uppsala household travel survey, Hanson (1980) tried to analyze the repetition rate of the chosen activity locations along 35 consecutive days. She found that over half of the individual's stops were made at similar place (the most frequently visited); for example, a mean of 68 percent of the individual's stop for food were made at one location. However, Hanson only focused on the number of repetition of certain locations without considering the daily trip pattern as a whole. It is hard to recognize whether repetitions were to happen in one day or were fairly spread within a certain period.

In order to achieve an effective planning, building, and management of the transportation system, accessing variability and stability of individual movement ability in space and time is very important. The main goal of such analysis is to pin down relationships between daily travel patterns and the nature of the external environment (factors that impinge on or shape travel). Specifying such relationships enables the forecasting of travel patterns and the design of policies that will effectively manipulate behavior in desired ways by engineering the appropriate changes in the external environment.

One of this study's contributions is to give more understanding about the spatial diversification among individuals by analyzing the variability of individual *activity space* from day to day.

2.3 Individual's Movement Ability in Space and Time

In order to take part in activities, individuals often have to travel between places. Their ability to travel in space and time depends in part on the resources available to them, e.g. time, money, and the automobile. Individuals' daily travel patterns and activity locations evolve under the constraints of these resources. Also influential are institutional, social, environmental and transportation network conditions. These factors affect the set of places where an individual visits to carry out activities. This set shall be called *action space*.

It is important to examine the characteristics of the action space of urban residents because such an examination will aid in evaluating their ability and flexibility in pursuing daily activities under the various constraints. The success of transportation policy depends on an exact description and prediction of aggregate flows as well as the disaggregate travel behavior of individuals. Measuring mobility therefore requires suitable indicators for the quantities of travel as well as the complex travel pattern combining people's movement in space and in time. By analyzing the spatial manifestation of our daily life activity needs and preferences will help us to improve our forecasts on locational choice and the interaction between urban space, socio-demographics and travel behavior (Kutter, 1980).

The concepts of spatial movement and action space

The activity space concept, which was developed in parallel with a range of related approaches to describe individual perception, knowledge and actual usage of space in the 1960s and 1970s (see Golledge and Stimson, 1997) aims to represent the spatial unit which contains the places frequented by an individual over a period of time. Lenntorp (1976) notes that the individual's possibilities of engaging in events and processes are constrained and depend on a set of circumstances linked to the individual as well as to his environment. Consequently, the individual's reach ability is limited. The volume in space and time in which the individual's physical presence is possible is called *prism*, which represents the extension of potential activity locations.

Hägerstrand (1970) notes that a prism is defined by constraints, including *capability constraints*, *coupling constraints*, and *authority constraints*. The *capability constraint* means that individual's activities will be limited by his ability to do the activities. It's not only a geographical boundary, but also have time-space walls on all side. And these walls might change from day to day. The *coupling constraint* means that the freedom of individual's activities will be bounded by where, when, and for how long, the individual has to join other individuals, tools or materials. The *authority constraint* relates to the time-space aspects of authority – a time-space entity within which things and event are under the control of a given individual or a given group. This perspective views the person in space and time as the center of social and economic phenomena. The three aggregations of constraints interact in many ways (direct and in-direct ways). For more descriptions of these concepts and their applications to travel behavior analysis, see Burns, (1979), Kitamura et al. (1981), Jones et al., (1983), Damm (1983), Jones et al, (1990), Axhausen and Gärling (1992), and Ettema and Timmermans (1997).

Governed by these constraints, and also conditioned by the urban environment and transportation networks, the individual's daily travel and activity engagement evolve in space and time. This generates a distribution of locations where activities are pursued. *Action space*, or *activity space*, is defined as “the set of places where the individual frequents for a particular period of time to carry out particular activities” by Dangschat et al. (1982, p. 1155). In activity spaces, travelers choose routes through time and space to meet their obligations, needs and desires. The travelers will try to choose these routes optimally, but they are constrained by their knowledge (*mental map*), by their reasoning abilities and by the time and concentration they have available to construct and select a route. In a wider sense, the activity space comprises both those locations of which a traveler has personal experience, as well as those of which the traveler has second hand experiences through family, friends, books, films, or other media (*the knowledge space*) (Djist, 1999).

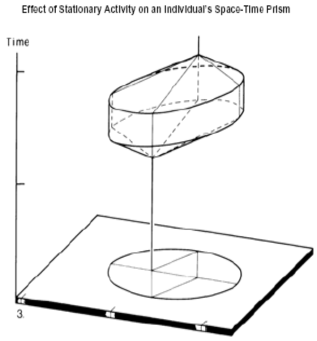


FIGURE 2.2 Space Time Path in Spatial Movement[3]

An individual’s action space thus defined depends strongly on the locations of those activities to which the individual is committed, and if the locations are fixed in both space and time, they tend to act as “pegs” around which other activities are arranged (Pred, 1977). Cullen and Godson (1975, p. 9) point out that “activities to which the individual is strongly committed and which are both space and time fixed tend to act as pegs around which the ordering of other activities is arranged and shuffled according to their flexibility rating”. In addition, the action space of an individual also depends on temporal constraints associated with activity locations.

As noted earlier, action space may be interpreted as a set of potential opportunities where activities can possibly be pursued given a set of governing constraints. This may be called *potential action space*. Djist (1999, p. 196) notes that “Theoretically, the actual action space is situated within the potential action space.” In addition, there is a set of opportunities that the individual perceives as potential activity locations. Dijst (1999) calls this *perceptual action space*, which “covers the *actual action space*. The *potential action space* can be covered entirely by the *perceptual action space*. As a consequence of *imperfect knowledge* by people, in practice a large part of the potential action space will be situated outside this subjective action space” (Djist, 1999, p. 196). Operationalizing these concepts, however, involves many measurement issues, including most obviously that perceptual action space is difficult to observe.

The concept of activity space has been put forward for four decades, and most empirical works have focuses on the travel potential or opportunities, with geometrical representation like an ellipse was often used. The simplest is just to show on a map the geographical

[3] Source: Lenntorp (1976)

distribution of the locations where a particular set of individuals engaged in activities. Markov chains are adopted by Horton and Wagner (1969) on a simple zone system to measure the extent of individuals' action spaces. Beckmann et al. (1983) describe the action space of an individual in an abstract city as the volume of reachable opportunities. Note that both spatial accessibility of an opportunity and the amount of time that can be spent there are taken into account in this measure. This is an extension of the work by Burns (1979) in which one-dimensional representation of urban space is adopted.

Lenntorp (1976) has developed a prototype simulation program (PESASP) to analyze an individual's potential choices of time and location for food purchase while incorporating various alternatives for activity engagement and travel. Djist and Vidakovic (1997) list as simulation programs which examine whether activity pattern can be realized within specified time-space environments, CARLA (Jones et al., 1983), STARCHILD (Recker et al., 1986) and SMASH (Ettema et al.,1995). Following these efforts, there are on-going efforts that attempt to develop rigorous methodologies for time geographic and activity analysis with GIS software (Miller, 2004), using micro-simulation model systems (Arentze et al., 2001) or based on the concept of the reach of potential action spaces (MASTIC; Djist and Vidakovic, 1997).

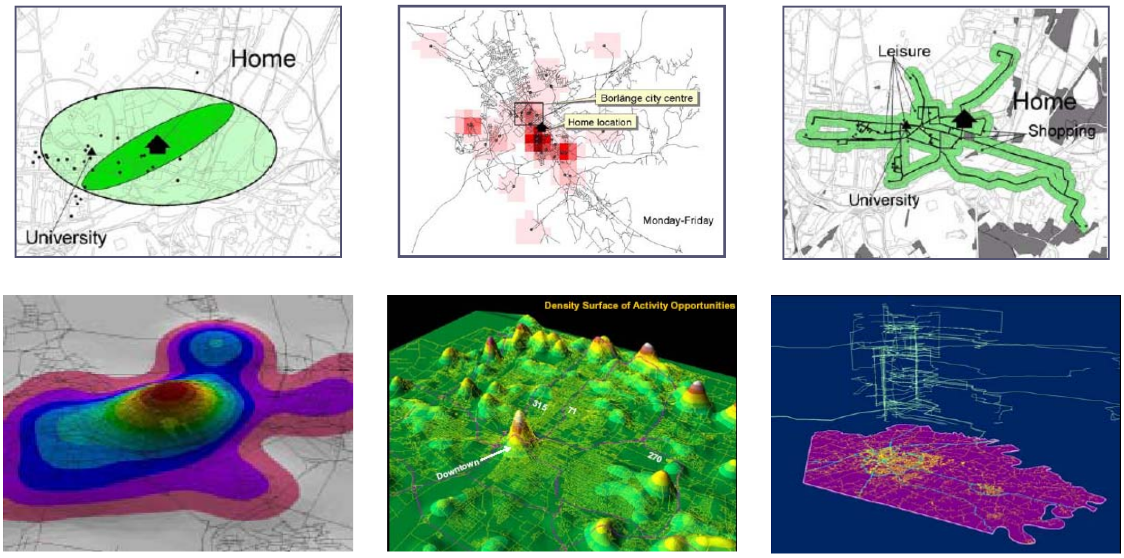


FIGURE 2.3 Examples of Action Space Representation in Various Studies[4]

The day-to-day variability of individual action space

While, most studies tested on aggregate data based on cross sectional observations, Djist's and Schönfelder's series studies are an exception. These studies used disaggregate travel and activity diary data to develop more detail measurement of individual action space. Using disaggregate data, there are an opportunity to access the variability of individual action space. Dijst and Vidakovic (1997, p. 121) noted: "For different persons, different activity places are important. As a result, the time-space characteristics of action spaces for different individual will vary".

[4] Source: Series of Schönfelder and colleague's studies (2002,2003), Kwan (1998), Miller (2004)

Using activity and travel diary data for three consecutive days (Thursday through Saturday) obtained from two-worker families in two adjacent Dutch municipalities of Utrecht and Houten, Dijst (1999) represent an individual's action space as an ellipse, circle and line. A *reachable distance* is defined by deploying the notion of travel time ratio (Dijst and Vidakovic, 2000), i.e., the ratio between the travel time and the sum of the travel time to and the activity time at the destination. Cluster and discriminant analyses are applied to group action spaces of different characteristics and to predict the type of actual action space and potential action space for each individual, given his socio-economic attributes and time allocation.

Schönfelder and Axhausen (2002) with the Mobidrive six-weeks travel diary data, introduce confidential ellipse, kernel densities, and minimum spanning tress (network) methods to estimate the size of an individual's actual action space over six-weeks period. Using those methods, they examine the suitability of different measures of activity space size to identify persons at risks of social exclusion (Schönfelder and Axhausen, 2003). They found that action space (or their methods in define the individual action space) might not be a suitable approach to measuring social exclusion. Further, using the Mobidrive data and Uppsala survey results, Srivastava and Schönfelder (2003) compared the areas of individuals' action spaces across days of the week (workdays, Saturday and Sunday). Action space is evaluated based on locations visited over two-week periods. The results indicate that two-week action spaces tend to repeat themselves over the six-week study period.

As this brief review may indicate, knowledge is yet to be accumulated on the day-to-day variability in daily action space, i.e., a set of locations visited during the day. Likewise little is known about the association between the characteristics of action space and the individual's attributes, transportation networks, or urban structure. In fact some speculate such an association is weak, if not nonexistent. For example, Timmermans et al. (2003, p. 45) note: "As far as the relationships between spatial context, transportation system and space-time consumption patterns is concerned, we found little evidence of such a relationship, at least at the chosen level of (spatial) aggregation, after accounting for the differences between cities and regions. … There is some evidence that people in suburban locations, and people in urban locations with poor transport tend to chain more destinations in a single trip, but this relationship is weak and not significant." Timmermans et al. continue to conclude: "Within a particular society, psychological principles seem more important in shaping activities than the specific characteristics of the urban structure and the transportation system …"

In this context, it is noteworthy that the roles of unobserved heterogeneity across individuals in the evolution of an individual's action space have not been explored at all so far. An axiom in behavioral research is that an individual's behavior is dependent on his perception of the environment rather than on the actual construction of the environment itself. Horton and Reynolds (1971) and Dangschat et al. (1982) have noted that even when a group of individuals had perfect information concerning opportunities and their locations, their mental maps and the perceptions of urban space would differ across individuals.

One of the purposes of this study is to examine the individual's action space, as represented by the second moment of the activities locations contained therein, focusing on its day-to-day variability and unobserved heterogeneity across individuals. It remains the case that the "central problem of action space research is that as yet there is no theory describing the relationship between these dimensions [pertaining aspects of action space] and the variables used" (Dangschat et al., 1982, p. 1156). This study is an attempt to accumulate some basis for the construction of such a theory.

The changes of individual action space for a long time span

Moreover, little is known about the changes and the stability of individual's action space over a long span of time. With the emerging era of motorization and suburbanization in metropolitan in last three decades, the constraints travel over time, as well as the urban form in many metropolitan areas have changed. For example, vehicle ownership has increased rapidly in industrialized countries after World War II. Suburbanization progressed and metropolitan areas expanded geographically in the same period, resulting in new spatial distributions of residences and jobs. This implies substantial changes in the physical environment for trip making. Social changes are also numerous. More women are now employed, while household size is shrinking. Various commodities, appliances and services have been invented to reduce the time required for domestic chores, such as cleaning, cooking and yard work. Household income has in general increased, in part because of the increased number of two-worker households. All these imply changes in the need for, resources available for, and constraints imposed on, travel. For more discussion about the impacts of motorization and suburbanization to the way people do their activity and travel, see Cohen and Kocis (1980), Kollo and Purvis (1984), Levinson and Kumar (1994), Cervero (1986), Roberts (1986), van Beek et al. (1986), Fukui (2003), and Kitamura et al. (2003).

This motorization and suburbanization trend has produce urban forms with spread-out opportunities and less essential city centers. Activity locations of suburban residents shift away from city center towards places that are more accessible for them. These changes induce changes in the way trips are made; changes in trip destinations caused by changes in accessibility may prompt changes in travel mode or patterns of trip chaining. Kitamura and Susilo (2005) show that individual activity and travel engagement over long span periods is not constant, nevertheless expanding. However, there are not any studies that examine the changes of individual action space as well as its stability over time.

Meier (1959) argued that the individual's action space also evolves from birth through maturity. Through personal observation, the individual is likely to be more familiar with local areas (the areas in the vicinity of his residence and his workplace, in particular) than those points and areas at greater distances from him and about which available information is limited.

Examining the changes of individual action space over long time period will be the original contribution of this study as well.

2.4 The Stability and the Transferability of Behavior over a Long Time Span

As mentioned in previous section, the emerging era of motorization and suburbanization gave substantial changes to the way people travel in most metropolitan areas in the second half of the 20th century. For example, in Japan, vehicle ownership increased from 0.0018 vehicle per person in 1955 to 0.33 in 1999. Rail's share, dominant at 90.0% of total person-kilometers in 1950, declined to 34.0% in 1995, while auto's share increased from a mere 0.6% to 51.7% in the same period. Although Japanese urban areas have retained its dense and mixed land use patterns, the weight of suburbs has been steadily increasing, and declines of central cities are noticeable in all but the few largest metropolitan areas (Kitamura et al., 2003).

It is clear that the changes in the travel environment over time affect travelers in many ways. However, how individual changes their travel pattern a long time period, either due to the changes of travel environment or due to the changes of their socio-economics, are not clear. Moreover, how the changes of the relationships that underlying of individual travel pattern overtime is largely unknown. Urban travelers react in many, often complex, ways to changes. Factors influencing travel behavior interact differently across individuals, demographic and socio-economic groups, or residential neighborhoods. Some aspects of travel may change and some may remain the same over time.

It is essential to understand how individuals change their travel patterns over long time periods, as well as the relationships that underlying individual travel behavior. Analyzing the individual travel behavior by treating separately the causal mechanisms underlying activity engagement and travel and ignoring the individual adaptation processes over time could lead to bias descriptions and produce overestimated results. However, there are several questions that are still hardly answered, e.g. are the individual's travel parameters as well as the way of how individual make travel is stable over time? Is the model of travel behavior is transferable for a long period? If not, how are the changes of the behavior? What is the impact due to the changes of the relationships that underlying the travel behavior?

Zahavi and Ryan (1980) have shown the presence of stability in mean travel time expenditure of urban residents over time or across areas, and Zahavi and Talvitie (1980) show that travel time expenditures are associated with household socio-economic characteristics, transport system supply, and urban structure. Zahavi and Talvitie (1980) then note that the allocation of time for travel on an aggregate basis tends to be both stable and transferable across countries. There are empirical observations supporting this conjecture: the commute trip duration in the Osaka metropolitan of Japan remained at about 36 minutes between 1980 and 2000 (Kitamura et al., 2003); Levinson and Kumar (1994) found that in Washington, DC, the average commute duration from home to work remained at 28.5 minutes in 1958, 1968, and 1988.

Such stability, however, can be observed only at aggregate levels. Pointing this out, Supernak (1982) critiqued the claim of stability in travel time expenditure and later proposed trip generation models based on "person categories" (Supernak, 1984, 1987; Supernak and Schoendorfer, 1985). This approach achieves improved accuracy by reducing the heterogeneity across individuals within the respective categories. Yet, it essentially takes on the same position as Zahavi and Talvitie (1980), in that stability in behavior is assumed within each person category.

There are studies that have examined changes in factors that influence travel behavior such as population, age distribution, vehicle ownership and driver's license holding (e.g., Cervero, 1986; Roberts, 1986; van Beek et al., 1986; Prevedouros and Schofer, 1989). Some studies, in addition to those by Zahavi and his colleagues referenced above, have examined changes in trip making, including Cohen and Kocis (1980) and Kollo and Purvis (1984). Quite interestingly, studies in the latter group stress stability in travel, while studies in the former group emphasize changes in population composition or urban structure. As an exception, Kostyniuk and Kitamura (1984) conclude that travel behavior is longitudinally unstable, except for the sequencing of activities and the time-of-day dependence of activity engagement.

Conflicting empirical findings from studies on temporal stability of travel behavior arise in part from differences in study design. Quite often, study designs mask whether an observed change in behavior is due to changes in contributing factors, or in the behavior itself, given the contributing factors. For example, Cohen and Kocis (1980) examined household trip rates using 1962 and 1973 data from the Buffalo metropolitan area and show that, while the trip rate given the household size has increased (overall by 19.0%), the rate given the number of vehicles owned has decreased (overall by 5.8%). This is presumably due to a decrease in household size and an increase in the number of vehicles owned, but it is not clear from the study whether the trip rate has been stable given household size *and* vehicle ownership.

One of the functions expected of a model that links observed behavior to contributing factors is to reveal the structure that lies behind the behavior. For a model to be able to accurately describe future behavior, it is necessary that the behavioral structure itself be stable over time. In fact, almost without exceptions, models have been applied to forecasting with the assumption that the structure is temporally stable. Yet, Yunker (1976) notes: “This assumption of temporal stability has never been adequately tested, as comparable data for the same area for two points in time have been available in only a limited number of instances”. The number of studies that have evaluated the temporal and spatial transferability of disaggregate models of travel behavior (e.g., see Atherton and Ben-Akiva, 1976; Koppelman and Wilmot, 1982; Badoe and Miller, 1995; Fujiwara and Sugie, 1997; Elmi et al., 1999) appear to converge to form the consensus that model parameters are not entirely transferable.

The stability of a model depends on the model being examined (e.g., an over-specified model with excessive parameters is likely to be subject to sampling errors and is unlikely to be transferable, while an under-specified model may appear transferable, although it is nonetheless mis-specified), and it is unreasonable to hope for a general answer to the question of model transferability. Furthermore, it has been shown that a model that fits best the estimation data does not necessarily offer the most accurate predictions with application data (Badoe and Miller, 1995). The statistical methods and evaluation criteria also affect the conclusion drawn about the stability of a model.

For example, Yunker (1976) applied the trip generation, modal split and trip distribution models developed for the Southeastern Wisconsin area using 1963 travel survey data to predict travel demand in 1972 when the next household travel survey was conducted. He notes that “although trip length characteristics were predicted with reasonable accuracy with the 1963 models, a better test of the time stability of the trip distribution procedure would have been a test of its ability to predict zone-to-zone trip interchanges over time”. The problem with this study stems from the way in which the sequence of conventional four-step procedure is applied, which makes it impossible to determine to which step a prediction error can be attributed. Consequently, although the discrepancies between predictions and observations are inspected, whether the models used for prediction have been transferable cannot be examined.

Hupkes (1977) formulated the “Law of Constant Travel Time and Trips”, which among others implies that, notwithstanding changes in model split, the individual’s total time spent on transport remains (and will remain) unchanged. However, he used highly aggregated data from various years and countries, without a necessary statistical elaboration.

As another example, Karasmaa and Pursula (1997) applied different methods to transfer a 1981 work trip destination-mode choice model in the Helsinki area to 1988, for which validation data are available. This study also statistically rejects the hypothesis that the models are transferable over time. The model, however, is an extremely simple one in which only total travel time, travel cost and the number of transfers are included as level-of-service (LOS) variables, and the only attribute of the traveler included is the number of cars per household. With the omission of the walking distance to a transit stop or service frequencies, the model is potentially mis-specified and this could be the reason for the concluded lack of transferability.

Likewise, conclusions about the variability over time of the individual's travel do not appear to be transferable. Based on weekly travel diary data obtained from panel surveys conducted six months apart in the Netherlands, Kitamura and van der Hoorn (1987) note that 69.8% of the male workers and 58.6% of the female workers in the sample had identical daily patterns of shopping participation on five or more of the days of each of the two weeks. Huff and Hanson, on the other hand, note that "our earlier results tend to run counter to the dominant trends in thinking in this area, and apparently contradict the conclusions of Kitamura and Van der Hoorn's study" (Huff and Hanson, 1990, p. 235), and indicate "… the majority of core stop classes are neither regular nor clustered …" (op cit., p. 241); "… more than 60% of core work stops do not exhibit a more regular than random pattern, even when only weekdays are considered" (op cit., p. 242); "… there is much more random day-to-day and week-to-week variation in individual travel behaviour than analysts have assumed …" (op cit., p. 244). Echoing this, Ma and Goulias (1997) report that from the results of their analysis of two-day diary data from panel surveys in Seattle, only 35% of individuals exhibited the same activity or travel patterns.

As this review indicates, there seems to be no coherent body of empirical findings that leads to a certain conclusion about the temporal stability of travel behavior. The literature can offer only ambivalent answer to such a question as, "*ceteris paribus*, does the urban resident's trip rate tend to increase, decrease, or remain stable over time?" This is in part due to limitations in available data, and also due to deficiencies in the models and methodologies used in the analysis of stability. The lack of behavioral theory on stability has also been a problem. Efforts are made in this study to overcome at least part of these problems.

2.5 The Hypotheses of the Temporal Changes and Variability of Individual Spatial Movement Behavior

There are several hypotheses that are conceivable in examining the variability of individual's spatial movement over time and changes in the relationships that underlying individual travel behavior over long periods.

In the analysis of day-to-day variability of individual action space:

- As workers tend to have more rigid activity schedules than non-workers and have more fixed routine (obligation) locations, they will have less variable action spaces and more stable moment values than the others.
- On weekends when individuals tend to pursue more discretionary activities, their action spaces will be more variable from day to day.

- Since engagements in discretionary activities reflect individuals' preferences, action spaces on weekend days are more variable across individuals than those on weekdays.

In the analysis to the temporal changes of relationships that underlay the individual travel behavior:

- As the more available opportunities for activity engagement as well as better accessibility that provided, the individual activity and travel engagements will continuously expand. However, the expanding trend will be different between workers and non-workers. Non-workers would be able to expand their activity and travel engagements constantly as their needs. On the other hand, workers' expanding pattern will be highly limited by their working environment conditions.
- Moreover, the relationship of workers' activity and travel indices will depend on their commute mode characteristics. For auto commuters, the commute time could positively influence the number of visits. It can also be postulated that the number of visits will be positively influenced by the accessibility to opportunities at the work location as well as at the home base. An auto commuter is more likely to visit more locations for non-work activities because the automobile is more suited for chained trips. Indeed, it has been often observed that auto users tend to chain trips, combining more visits into one trip chain.
- A competing hypothesis is that transit commuters (primarily rail commuters in the study area of Osaka) are more likely to visit more non-work locations because railroad stations, especially terminals, provide superb access to a number of non-work opportunities in Japanese urban areas, including the Osaka metropolitan area.
- Since individual behavior is an endless learning process, the changes of travel environment as well as the socio-demographic conditions will change the individual's behavior and the appropriate behavioral models are not transferable over long period.

The changes of travel behaviors over long periods will influence the individual's action space:

- As the individual travel and activity engagements are expanding over time, the individual's action space also will be expanding over time.
- Since individual action space is primarily defined by home locations and their routine engagement locations (like working), which tend to be fixed in long periods, the workers will have more stable action space than non-workers.

Chapter 3
Description of the Database

In order to analyze the stability and the variability of individual travel behavior from day-to-day and over long span period, two sets of database were employed. The *Mobidrive* dataset, a six weeks travel diary data, was employed to analyze the variability of individual behavior from day-to-day. For long term analysis, conventional large-scale household travel surveys that were conducted in the Osaka metropolitan area of Japan in 1980, 1990 and 2000 were used. This chapter describes each dataset, survey description and the profiles of the samples. The contents of *Mobidrive* main survey forms are presented in Appendix A.

3.1 *Mobidrive* Six-weeks Travel Diary Data

The *Mobidrive* survey is a continuous six-week travel diary survey that was conducted in the German cities of Halle and Karlsruhe in the spring and autumn of 1999, funded by the German Federal Ministry of Education and Research. The survey was carried out with the aim to obtain a more detailed picture of mobility patterns and to develop methodological approaches to capture behavioral variability. A total of 317 persons over 6 years in 139 households participated in the main phase of the survey, after testing the survey instruments in a pre-test with a smaller sample in spring 1999. The paper based diary instrument was supplemented by further survey elements providing a unique level of socio-demographic detail for surveys of this type (see Axhausen et al., 2002, for a detailed description of the survey).

This *Mobidrive* survey contains:
- Socio-demographic characteristics of the households and their members (face-to-face interview).
- Commitments to specific regular activities, both private and social (face-to-face interview).
- Details of the car fleet and the public transport season tickets owned (face-to-face interview).
- Six-week continuously travel diary (in six weekly installments) (self-administered).
- Attitude and value inventory (towards the different modes and towards general value, respectively) (self-administered).

In addition, the weather forecast and geo-codes of all destinations within the study areas were added from other sources.

The study areas of *Mobidrive* database

Halle has currently 260,000 inhabitants and is a regional center of industry, shopping and services. Its well-established university and other college-level institutions have about 16,000 students. While the city is recovering from a particularly massive restructuring of its once dominant chemical industry, it still has an above-average rate of unemployment of about 22 %. This partially reflects the very high of labor force participation in the old East Germany economy. Karlsruhe has about 270,000 inhabitants and a similar mixture of industrial, retail and service employment as Halle. Its student population is 50% larger with 25,000 students in 1997. Both cities are served by extensive light rail and tram networks with matching bus feeder services. The map the locate in Germany the City of Karlsruhe and the City of Halle can bee seen in Figure 3.1

FIGURE 3.1 Map of City of Karlsruhe and City of Halle[5]

The samples are recruited through a telephone screening and recruitment process. The contents of the trip diary data of the main survey can be seen on Table 3.1. The contents of the household, individual and vehicle questionnaires can be seen on Appendices A.1, A.2 and A.3, respectively. The *Mobidrive* complete questionnaires can be seen at PTV AG et al.

[5] Source from Wikipedia Encyclopedia (http://www.wikipedia.org)

(2000), and the detailed description of each variable's imputation, analysis processes and statistical distributions can be found at Schönfelder et al. (2002).

TABLE 3.1 Contents of the Trip Diary Data (Main study)

Item	Coding and Comments
Day of trip	Days of the week
Starting time	Military time
Purpose	Work, education, daily shopping, shopping for major items, personal business, work related business, leisure (please specify), other (please specify)
Modes used	Walk only, walk to mode; bicycle, motorcycle, car driver, car passenger, bus, street car and light rail, heavy rail, other (please specify), walk from mode; time spent on each
Accompanying person	Number of household member, number of other persons
Presence of a dog	Yes, no
Exact destination	Street address and municipality
Activity costs	Zero, up to 10 DM, 10 – 25 DM, 25 – 100 DM, 100 DM and over
Expenditures on travel	Open
Arrival time	Military time
Estimated distance traveled	[m]

Source: Axhausen et al., 2002

Address Geo-coding

One objective of the *Mobidrive* consortium was to provide exact locational data in order to facilitate the analysis of the variability in spatial behavior over time. This data were obtained by geo-coding the trip destination addresses of all main study trips (approximately 40,000 trips). The addresses – including home and workplace locations were transformed into Gauss-Krüger coordinates in a WGS 84 (World Geodetic System) geodetic reference system. The geo-coding was possible for about 95% of the reported trips.

Survey Results

The number of reported movements and days are shown in Table 3.2. The samples' profiles of the *Mobidrive* main survey, which used as basic database in subsequent analyses, are shown in Table 3.3.

TABLE 3.2 The Number of Reported Movements and Days

Contents	Pre-test	Main Study	
	Karlsruhe	Halle	Karlsruhe
Trips	6,741	30,549	38,152
Journeys	2,801	9,323	10,210
Long-distance journey days	113	214	329
Activities	6,785	21,150	24,699
Person days *	1,725	6,378	6,257
Immobile days	100	593	267
Missing days	10	44	92

* The number of person days includes the number of immobile days
Source: Axhausen et al., 2002

TABLE 3.3 Sample Profiles of the *Mobidrive* Main Survey

Variables	N	%	Mean
Number of individuals	317		
Number of households	139		
Total number of reported days	11737		
Total number of reported trips	45532		
Individual Attributes			
Male [D]		49.84	
Married [D]		52.05	
Driver's license ownership [D]		67.51	
Less than 25 years old [D]		26.81	
25 - 34 years old [D]		10.41	
35 - 44 years old [D]		19.24	
45 - 54 years old [D]		17.98	
55 - 64 years old [D]		16.72	
65 years old or over [D]		8.83	
Status			
Worker [D]		35.02	
Student [D]		21.14	
Non-worker [D]		27.13	
Other [D]		16.72	
Household Attributes			
Number of household members			2.29
Number of motor vehicles			1.17
Number of telecommunications connections			2.39
Family with child < 15 years old (dependent child) [D]		20.86	
Household income [x 1,000 DM]			3.95
Residential Area Type			
CBD [D]		7.19	
Inner-city [D]		30.22	
Suburbs [D]		61.87	
Elsewhere [D]		0.72	
Karlsruhe [D]		51.08	
Halle [D]		48.92	
Trip Characteristics			
Average of number of trips per day			3.88
Average of number of visits per day			2.22
Average travel time expenditure per day (minutes)			23.08
Average out-of-home activity time per day (minutes)			202.05
Monday [D]		15.54	
Tuesday [D]		15.51	
Wednesday [D]		15.18	
Thursday [D]		15.61	
Friday [D]		16.49	
Saturday [D]		12.80	
Sunday [D]		8.87	

[D] indicates a 0-1 dummy variable.

3.2 The Osaka Metropolitan Area Person-trip Data

For a longer time span analysis, the Osaka metropolitan area person trip data were used. The data are obtained from a conventional large-scale household travel surveys that were conducted in the Osaka metropolitan area of Japan in 1970, 1980, 1990 and 2000, with sampling rates of 2.4% to 3.0%.

The Osaka metropolitan area is Japan's second largest after the Tokyo metropolis, with three core cities of Osaka, Kyoto, and Kobe. Osaka is the second largest city in Japan and is the center of commerce in the Kansai Area; Kyoto was the ancient capital of Japan established in 794 AD; and Kobe is the maritime center of the area. It covers a total area of 7,800 square kilometers within a radius of about 50 to 60 km from the center of Osaka. With a population totaling about 17 million as of 2000, it is one of the largest metropolitan areas in the world. The area has very dense, mixed-use land developments, and has well-developed rail networks. The map of the Osaka metropolitan area is shown on Figure 3.2.

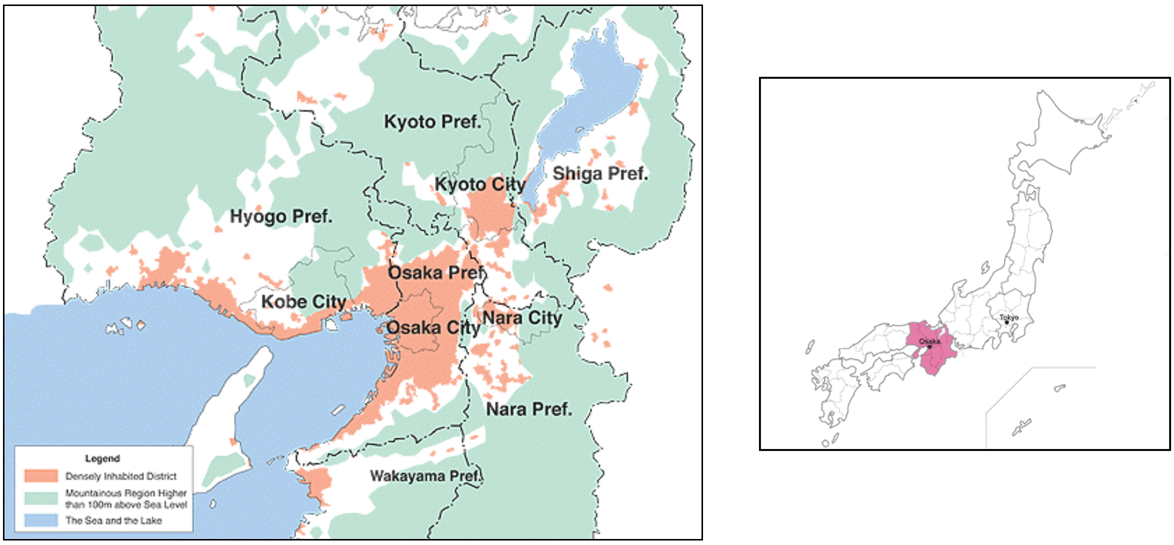


FIGURE 3.2 Map of the Osaka Metropolitan Area[6]

The Osaka Metropolitan Area person-trip data contains:
- Socio-demographic characteristics of the observed samples as well as their household characteristics.
- The duration, purpose and number of activities and trip engagements of the observed samples on the observed day.
- The chosen mode, as well as home and work locations (zone), of the observed individual.

The survey produced comparable data sets whose samples are large enough for a variety of analyses. The travel data have been supplemented with land use and network data for subsequent analyses.

The sample profiles of the person trip data can be seen on Table 3.4. However, due to the unavailability of accessibility indices in 1970 data, for subsequent analyses, the 1970 data is excluded.

[6] Source from Kinki Regional Development Bureau's Websites (http://www.kkr.mlit.go.jp/en/index.html)

TABLE 3.4 Database Profiles of the Osaka Metropolitan Area Person Trip Data

Variables	1970	1980	1990	2000
Number of samples	56,019	326,241	323,424	312,632
Male [D]	73.1%	46.4%	46.1%	46.0%
Less than 25 years old [D]	45.9%	34.3%	32.1%	25.9%
25 - 34 years old [D]	10.9%	17.8%	12.9%	15.9%
35 - 44 years old [D]	14.2%	17.1%	16.5%	12.3%
45 - 54 years old [D]	10.3%	13.6%	15.8%	14.7%
55 - 64 years old [D]	8.7%	8.6%	12.3%	14.3%
65 years old or over [D]	10.0%	8.5%	10.6%	16.9%
Number of household members	4.31	3.56	3.42	3.34
Family with dependent child [D]	67.9%	59.9%	52.2%	45.1%
Number of cars per adult household members	0.28	0.33	0.37	0.40
Driver's license ownership [D]	29.6%	26.3%	39.8%	50.5%
Resides in commercial area [D]	3.6%	2.8%	3.1%	2.9%
Resides in mixed commercial/residential area [D]	24.3%	24.8%	25.2%	30.0%
Resides in autonomous city [D]	33.6%	7.6%	9.7%	6.1%
Resides in suburbs area [D]	37.1%	63.6%	61.8%	60.3%
Resides in un-urbanized side [D]	1.5%	1.2%	0.3%	0.7%
Worker [D]	46.0%	43.0%	46.1%	45.7%
Non-worker [D]	20.8%	29.1%	29.0%	34.2%
Student [D]	33.2%	27.9%	24.8%	20.1%
Average number of trip/day	1.78	2.09	2.05	2.15

[D] indicates a 0-1 dummy variable.

3.3 Estimation Sample

In this study, not all samples from the database are used in the analysis.

In the analysis of the day-to-day variability of individual's action space (Chapter 4), the study only accounted the individual whose all activity location geo-code information are available. Moreover, in order to avoid incomparable second moment values, the daily trips data which contain long journey trips (regional trips) were excluded.

For the long term analysis (Chapter 5 and 6), estimation sample are drawn from the original data files randomly at the rate of approximately 10%.

The profiles and the behavior description of estimation sample used in the analysis are described later in each following chapter.

Chapter 4
The Day-to-day Variability of the Individual's Action Space

This chapter describes the analysis of day-to-day variability in the action space of urban residents. Using the *Mobidrive* dataset, the analysis focuses on the association between the extension and variability of an individual's action space, and attributes and also unobserved heterogeneity across individuals. The analysis of this study is based on the representation of the extension of action space in terms of the second moment of the activity locations it contains with respect to their centroid, and the second moment of the centroid with respect to the home location. In the following sections, the concept of action space and second moments of activity locations are described briefly. Results of descriptive analyses of second moments and those of model estimation are then presented. The chapter is concluded with a section that offers a summary of results.

4.1 Individual's Action Space

Individuals' daily lives consist of activities in space and time, and the activities that structure them, such as personal care, family interaction, work, shopping, recreation and socializing, occur at a relatively few geographic locations and for limited durations. In order to take part in activities, individuals often have to travel between different places. Their ability to travel in space and time depends in part on the resources available to them, e.g., time, money, and automobile availability. Individuals' daily activity and travel patterns evolve under the constraints of these resources. Also influential are institutional, social, environmental and transportation network conditions. These factors affect the set of places where an individual visits to carry out activities. This set shall be called *action space*.

It is important to examine the characteristics of the action space of urban residents because such an examination will aid in evaluating their ability and flexibility in pursuing daily activities under the various constraints. Of course care must be exercised in such an evaluation because high mobility has dual implications—that one is capable of pursuing activities at various locations, and that one must travel to various locations in order to satisfy his or her needs. From the former perspective, high mobility is desirable, while from the latter viewpoint travel is a necessity to be minimized. From this latter viewpoint high mobility simply implies the presence of some deficiencies in urban activity-transportation system. In any event, an individual's ability in engaging in activities is linked to the level of welfare. In this sense the examination of action space is one of the primary concerns of transportation planning.

Action space has often been examined, most typically using cross-sectional data, and also with panel data in a few recent studies (see chapter 2 for literature review of individual's action space and spatial movement). The day is used to define the action space of an individual in many of these studies simply because the data used were daily data (e.g., Djist, 1999; Timmermans et al., 2003). One-day data, however, reveal only limited aspects of travel behavior as researchers have eloquently articulated (e.g., Hanson and Huff, 1982; Pas, 1988). Reflecting on our own daily travel patterns would make it obvious that people do not repeat the same travel pattern everyday. The question that then arises is how to define an individual's action space when it varies from day to day. The notion of "typical" daily patterns (Hanson and Huff, 1988) has emerged as one of the key concepts in addressing the variability in daily travel patterns. Yet, a typical pattern reveals little about the variability in travel patterns and action space.

Even when data are available for multiple days, how the day-to-day variations in action space can be best captured is not obvious. The main reason for this is presumably the fact that travel patterns are multi-faceted; there are a number of ways in which a travel pattern can be characterized. For example, a very simple scheme has been adopted to characterize daily travel patterns by whether a trip for a particular purpose is included in them or not (Kitamura, 1988a). One may focus on simple indices such as the number of trips or trip chains to represent travel patterns. More elaborate multivariate analytic procedures are adopted to develop classification schemes by which any travel pattern is identified as one of a manageable number of travel pattern classes (e.g., Kansky, 1967; Oppenheim, 1975; Pas, 1988; Joh et al., 2001a,b). This issue of representation also arises when one wishes to examine the variability in action space, whether across individuals or from day to day for a given individual.

One cannot fully characterize an individual's action space without knowing how it varies from day to day. Yet, variability in action space has rarely been explored before. The only study found that addresses the temporal variability of the individual's action space is by Srivastava and Schönfelder (2003). With the *Mobidrive* travel diary data (described in chapter 3) and Upssala survey data (Hanson and Huff, 1988), they compared the area of an individual's potential action space across two-week periods. This study, however, did not examine day-to-day variability in action space within each individual.

As Timmermans et al. (2003, p. 45) noted: "Within a particular society, psychological principles seem more important in shaping activities than the specific characteristics of the urban structure and the transportation system …", it is important to examine the roles of unobserved heterogeneity across individuals in the evolution of an individual's action space. An axiom in behavioral research is that an individual's behavior is dependent on his perception of the environment rather than on the actual construction of the environment itself. Moreover, as described in Chapter 2, Horton and Reynolds (1971) and Dangschat et al. (1982) have showed that even when a group of individuals had perfect information concerning opportunities and their locations, their mental maps and the perceptions of urban space would differ across individuals.

The study in this chapter is an attempt to explore the day-to-day variability in the action space of urban residents. The analysis focuses on the association between the extension and variability of an individual's action space, and attributes and also unobserved heterogeneity across individuals. The analysis of this chapter is based on the representation of the extension of action space in terms of the second moment of the activity locations it contains with respect to their centroid, and the second moment of the centroid with respect to the home location. The analysis uses the *Mobidrive* data set, which was obtained from a six-week travel diary survey conducted in Karlsruhe and Halle, Germany, in 1999, and represents a total of 317 individuals over 6 years of age from 139 households (see chapter 3 for more description about *Mobidrive* dataset).

Examining the day-to-day variability in the individual's action space is anticipated to enhance our understanding of travel behavior as it will provide opportunities to probe into the relation between potential and actual action spaces, spatial and temporal fixities of activities, their regularity, variability and diversification, or the binding effects of mandatory routine activities such as work.

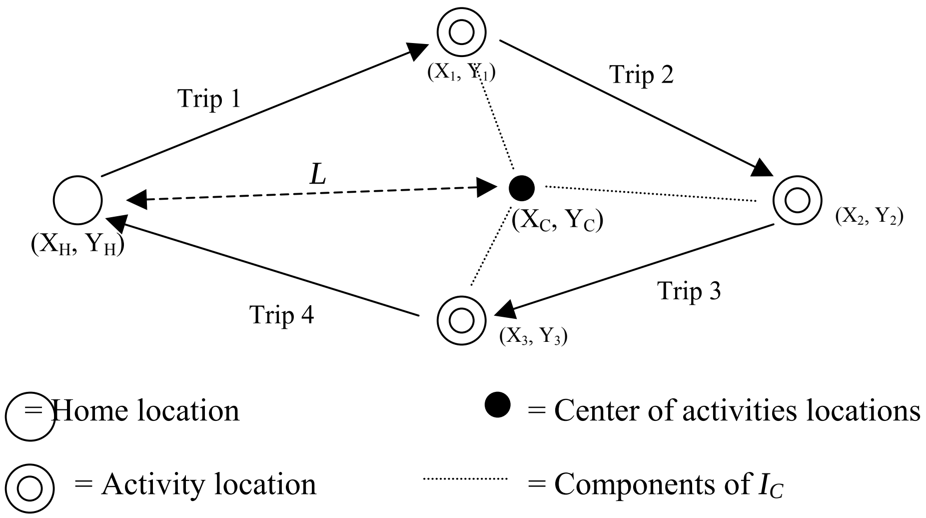
As mentioned in section 2.5, there are several hypotheses that guide this study:

- As workers tend to have more rigid activity schedules than non-workers, they will have less variable action spaces and more stable moment values than the others.
- On weekends when individuals tend to pursue more discretionary activities, their action spaces will be more variable from day to day.
- Since engagements in discretionary activities reflect individuals' preferences, action spaces on weekend days are more variable across individuals than those on weekdays.

4.2 Second Moments of Activity Locations

The action space of an individual is represented in this study by the second moment of the out-of-home activity locations it contains. Let C be the centroid of the activity locations of an individual on a given day, and let I_C be the second moment of the activity locations about C, evaluated in terms of Euclidean distance. Also let I_H be the second moment of the centroid about the home location, i.e., $I_H = L^2$, where L is the distance between the home and the centroid (see Figure 4.1).

Let N be the number of activity locations. If N is 1, then $I_C = 0$ and $I_H = L^2$, where L in this case equals the length of the trip from the home to the activity location. If N is greater than 1, then I_C indicates how spread the activity locations are, and I_H indicates how far away from the home they collectively are. Thus I_C and I_H describe how far away from the home the center of activities locations is (I_H), and how spread the activity locations are around their center (I_C).



$$I_H = L^2 = (X_H - X_C)^2 + (Y_H - Y_C)^2,\ X_C = \frac{1}{3}\sum_{i=1}^{3} X_i \text{ and } Y_C = \frac{1}{3}\sum_{i=1}^{3} Y_i$$

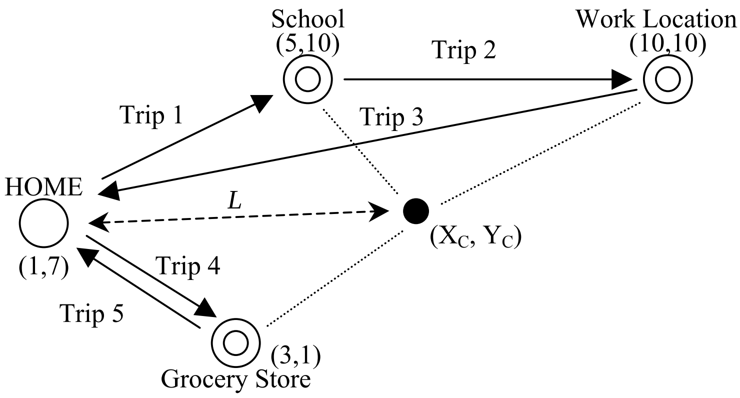
$$I_C = \sum_{i=1}^{3}\left\{(X_i - X_C)^2 + (Y_i - Y_C)^2\right\}$$

FIGURE 4.1 Second Moment of Activity Locations

For example, suppose an individual engaged in activities at three locations on a given day as shown in Figure 4.2. These activity locations are situated at the coordinates shown in the figure. Their centroid has coordinates, (X_C, Y_C) = (6.0,7.0), as computed in the figure, and the distance from the home location (*L*) is determined as 5 km. The second moment of the activity locations about their centroid is computed as the sum of the squared distances between the centroid and the respective activity locations.

Like any other method, the second moment as a method of representing action space has its advantages and disadvantages. For example, it does not represent the topology of an action space. Also, the second moment alone may misrepresent the spread of activity locations in urban space. For example, a second moment value of 20 around the activity centroid may imply five activity locations, each 2 kilometers away from the centroid, or two locations each 3.16 ($=\sqrt{10}$) kilometers from the centroid (Figure 4.3). On the other hand, there are cases where the second moment is capable of distinguishing between actions spaces while other methods fail to do so as illustrated in Figure 4.4.

Moreover, the use of second moments offers the advantage in its simplicity that the expansion of action space can be represented by just two parameters, I_H and I_C, which are well defined and easy to compute. Its simplicity is an important advantage as it facilitates application of standard statistical methods. Note that the analysis of this study is concerned with *actual* action space, but not with *potential* action space or *predicted* reachable distance (Golledge and Stimpson, 1997; Dijst, 1999; Schönfelder and Axhausen, 2003).



<u>Travel Pattern</u>: An individual dropped off his child at school, went to work at the office, returned home, went for grocery shopping, then returned home. There are three out-of-home activities and five trips as shown in the figure.

Centroid: The centroid of his activity locations has the coordinates:

$$X_C = \frac{5+10+3}{3} = 6\,;\; Y_C = \frac{10+10+1}{3} = 7\,,$$

Home-to-Centroid Distance, *L*:

$$L = \sqrt{(X_H - X_C)^2 + (Y_H - Y_C)^2} = \sqrt{(1-6)^2 + (7-7)^2} = \sqrt{25} = 5\,,$$

Elements of the Second Moment, I_H and I_C:

$$I_H = L^2 = 5^2 = 25 \text{ and } I_C = \left\{\left((-1)^2 + 3^2\right) + \left(4^2 + 3^2\right) + \left((-3)^2 + (-6)^2\right)\right\} = 80\,.$$

FIGURE 4.2 Second Moment of Activity Locations: Numerical Illustration

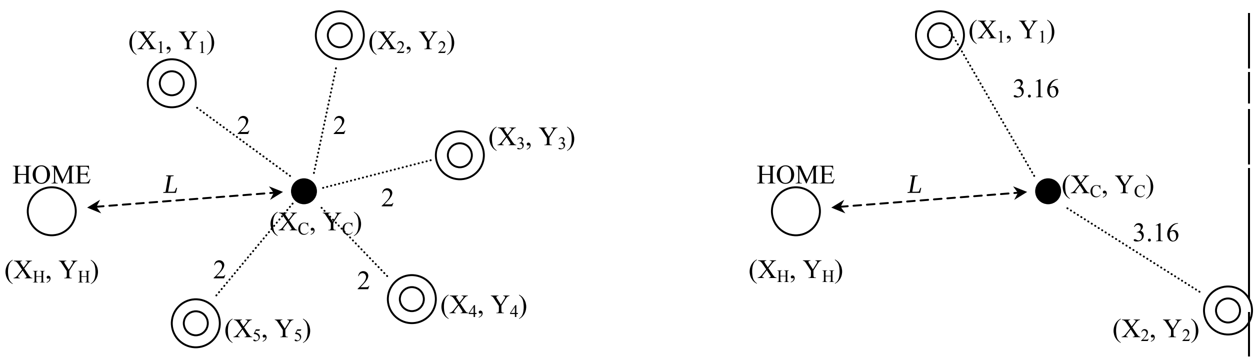
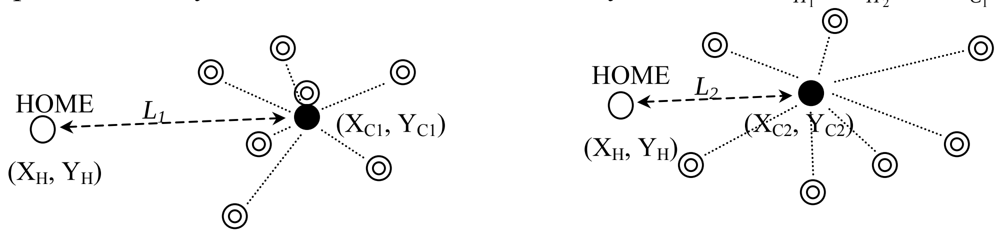
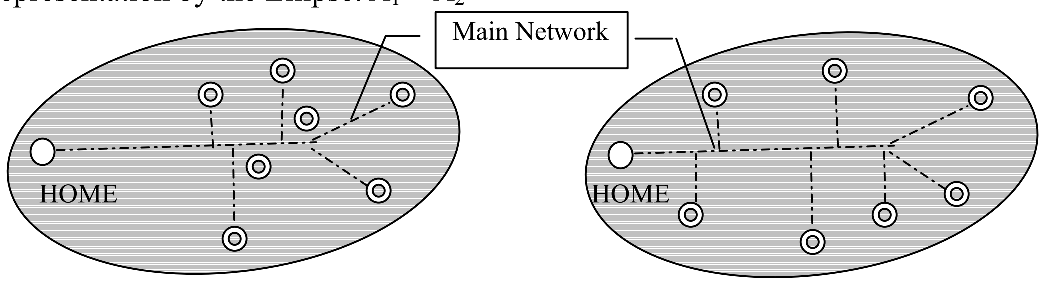


FIGURE 4.3 Two Sets of Activity Locations with Identical Second Moments

1. Representation by the Second Moment of Activity Locations: $I_{H_1} > I_{H_2}$ and $I_{C_1} < I_{C_2}$



2. Representation by the Ellipse: $A_1 = A_2$



Area of ellipse = A_1

Area of ellipse = A_2

FIGURE 4.4 A Comparison of Different Approaches of Action Space Representation

As noted earlier, the empirical analysis of this study is based on the *Mobidrive* data, which contain information from six-week continuous travel diaries. In the data set, every activity location is geo-coded into Gauss-Krüger coordinates in a WGS 84 (World Geodetic System) geodetic reference system, facilitating accurate computation of second moments. The analysis only used the individual whose all activity location geo-code information are available. To avoid incomparable second moment values, the daily trips data which contain long journey trips (regional trips) were excluded. The database used in the analysis involves 32,539 person trips made by 261 sample individuals. Sample profiles can be found in Table 4.1.

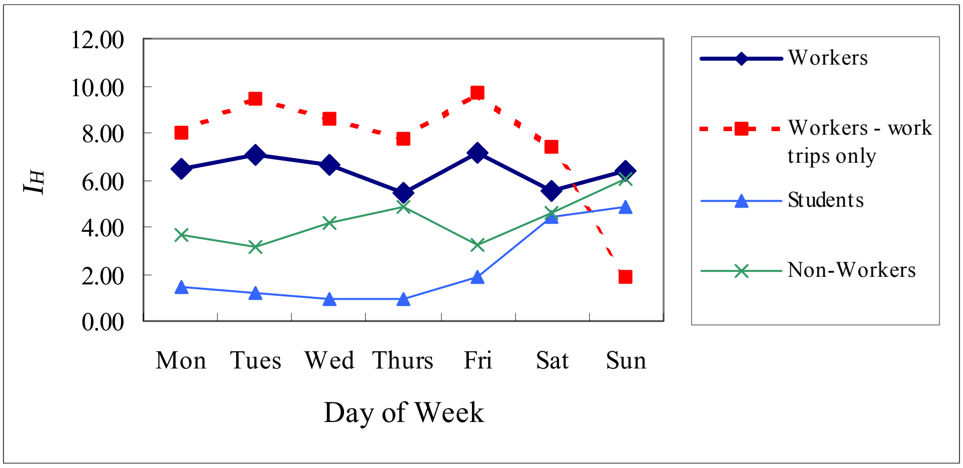
TABLE 4.1 The Profiles of the Used Sample for Second Moment Analysis

Variable	N	Mean
Number of individuals	261	
Number of households	131	
Total number of reported days	8430	
Total number of reported trips	32539	
Average of number of trips per day		3.86
Average of number of visits per day		2.20
Average travel time expenditure per day (minutes)		20.19
Average out-of-home activity time per day (minutes)		432.7
Male [D]		0.544
Married [D]		0.502
Driver's license holding [D]		0.640
Less than 25 years old [D]		0.280
25 - 34 years old [D]		0.123
35 - 44 years old [D]		0.188
45 - 54 years old [D]		0.138
55 - 64 years old [D]		0.165
65 years old or over [D]		0.107
Worker [D]		0.422
Student [D]		0.257
Non-worker [D]		0.322
Number of household members		2.84
Number of motor vehicles in household		1.29
Number of telecommunications connections per household		2.44
Family with dependent children (younger than 15 years old) [D]		0.349
Household income [x 1,000 DM]		4.36
CBD resident [D]		0.069
Inner city resident [D]		0.287
Suburban resident [D]		0.644
Karlsruhe resident [D]		0.467
Halle resident [D]		0.533
Monday [D]		0.155
Tuesday [D]		0.154
Wednesday [D]		0.153
Thursday [D]		0.156
Friday [D]		0.155
Saturday [D]		0.123
Sunday [D]		0.103

[D]: 0-1 dummy variable

4.3 The Distribution of Second Moment Values

The distribution of I_H and I_C values are presented in Figure 4.5 and Figure 4.6 by employment status and residence area type, respectively. Residence area is classified into three: central business district (CBD), inner city, and suburbs. Variations in second moment values are summarized as follows.



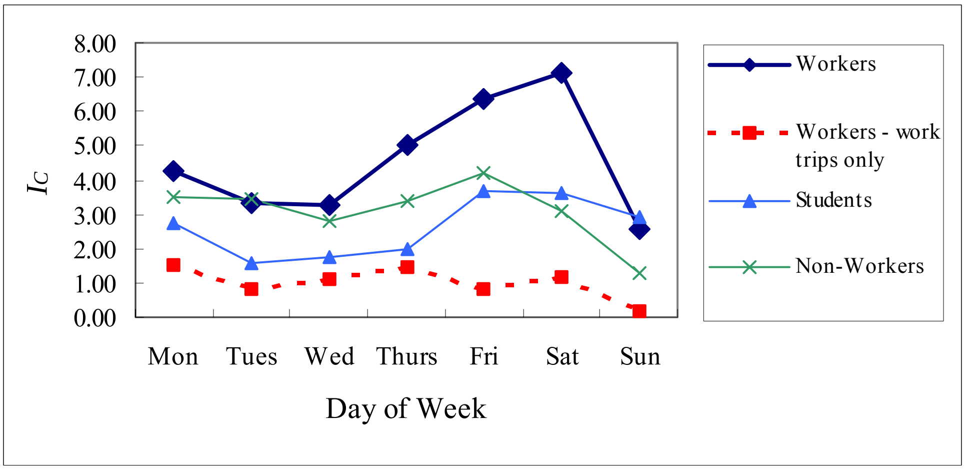


FIGURE 4.5 Mean I_H and I_C by Day of the Week and Employment Status

As workers and students tend to have fixed obligatory trips with fixed activity locations on weekdays, their second moments are relatively stable on Mondays through Thursdays. On Fridays and Saturdays, when they are more oriented toward discretionary activities, activity locations become farther from home and more dispersed. The results here are consistent with those by Srivastava and Schönfelder (2003) who note "The full time workers have a highly stable activity space during the weekdays, but during the weekends they become highly unstable". Although non-workers do not have obligatory trips, they also have relatively stable action spaces on weekdays, presumably because their have daily routines. On Sundays, where stores are closed in Germany, individuals tend to make fewer trips and visit fewer locations regardless of employment status. Consequently I_C takes on smaller values.

It can be seen from Figure 4.5 that workers' I_H based on work trips only are larger than those based on all trips on weekdays. This implies that workers tend to pursue their non-work activities between their home and work locations. This result supports the notion that individuals' action spaces are defined primarily by their residential and work locations and other activities are located around these two locations (see Pred, 1977; Cullen and Godson, 1975). Overall, as work locations tend to be farther from the home base than other locations, workers have more expansive action spaces with dispersed activity locations. Djist (1999), in his study of two-earner families in Dutch communities, also obtained this result. Irregularities in Thursday's I_H are presumably because Thursdays are market days in the survey area.

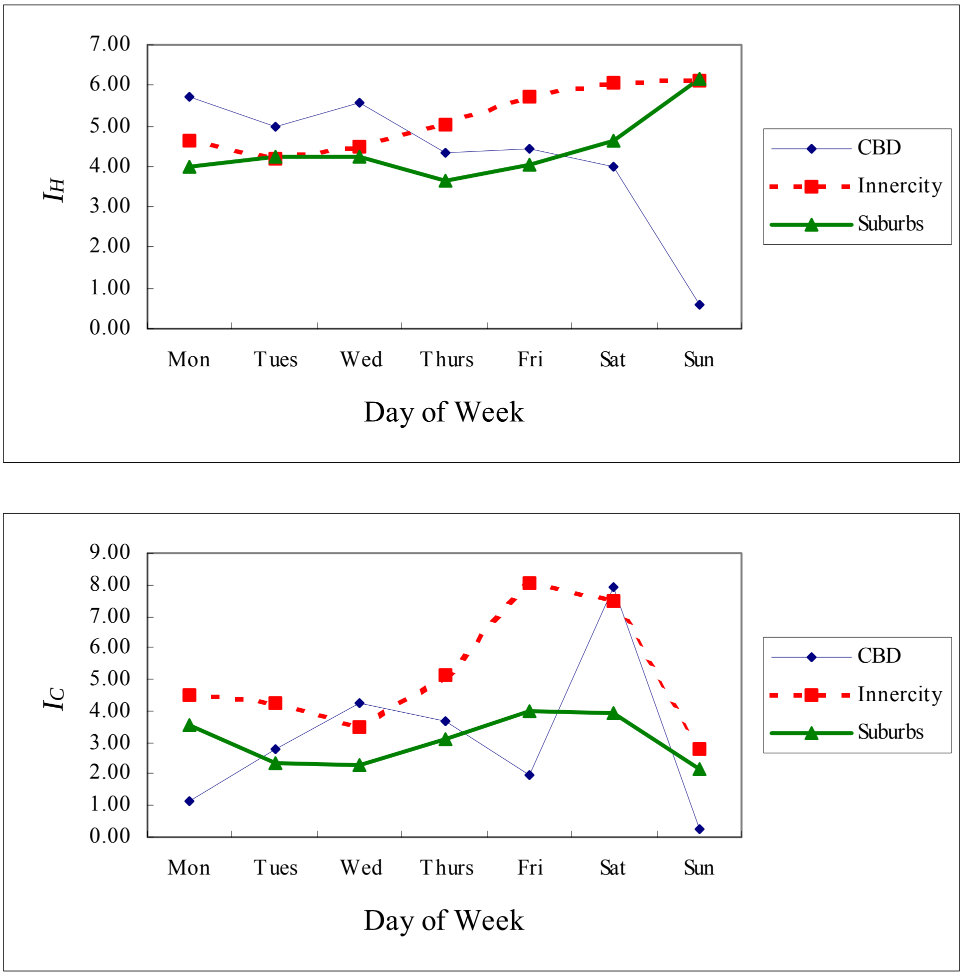


FIGURE 4.6 Mean I_H and I_C by Day of Week and Residential Area Type

Inner-city residents tend to have larger second moments than those in the other residence area types, especially on weekend days. This may be because the inner-city area, which lies between the CBD and suburbs, has mixed opportunities for various activities, encouraging the residents to be more mobile, especially in weekend days. Suburban residents tend to have stable second moments for the whole week.

4.4 Unobserved Heterogeneity in Action Space

To examine the effect of an individual-specific error component on second moment values, panel regression analysis is carried out. The general form of the model is:

$$Y_{it} = \beta' X_{it} + \alpha_i + \varepsilon_{it}, \quad i = 1,2,...N, \quad t = 1,2,...,T \tag{4.1}$$

where *i* refers to the individual, *t* to the day, and

Y_{it} = components of the individual's action space for individual *i* on day *t*,
X_{it} = a vector of explanatory variables,

α_i = individual-specific error term, and
ε_{it} = random error term (white noise).

This model includes unobserved heterogeneity across individuals, represented by the individual-specific error term, α_i, which varies across individuals but assumes a constant value from day to day for a given individual. All error components are assumed to be normally distributed, mutually independent, and serially uncorrelated. The estimation software used is LIMDEP Version 8.0 by the Econometric Software, Inc. Because of differences in activity engagement between workers/students and non-workers on weekdays, some of which have been demonstrated in the above discussions, weekday models are estimated separately for these two groups of individuals. In the following discussions, workers and students are collectively referred to as "commuters."

TABLE 4.2 Models of Second Moments for Workers and Students on Weekdays

	I_H		I_C	
	Coeff.	t-ratio	Coeff.	t-ratio
Constant	-1.84	-0.47	1.99	0.82
Male [D]	-0.37	-0.29	-0.29	-0.38
25 - 34 years old [D]	0.40	0.13	-1.33	-0.71
35 - 44 years old [D]	2.18	0.68	-3.68	-1.89
45 - 54 years old [D]	2.97	0.88	-3.92	-1.91
55 - 64 years old [D]	-2.53	-0.66	-1.76	-0.76
Married [D]	-2.81	-1.38	1.05	0.84
Worker [D]	1.88	0.60	-1.24	-0.65
Driver's license holding [D]	2.38	1.09	1.01	0.76
Number of household members	0.33	0.38	-0.90	-1.69
Number of motor vehicles	-0.05	-0.05	-0.24	-0.36
Number of telecommunications connections	0.32	0.78	0.02	0.10
Family with dependent children [D]	1.00	0.54	0.48	0.42
Household income [x 1,000 DM]	0.15	0.41	0.21	0.97
Inner city [D]	-2.17	-0.87	2.98	1.94
Suburbs [D]	-2.39	-1.03	1.47	1.03
Karlsruhe [D]	-2.12	-1.61	-0.04	-0.05
Duration of residence (years)	0.20	2.28	-0.01	-0.20
Monday [D]	0.21	0.57	0.70	1.42
Tuesday [D]	0.31	0.82	-0.22	-0.44
Thursday [D]	-0.63	-1.70	1.13	2.28
Friday [D]	0.38	1.02	2.45	4.93
Commute distance	1.24	32.82	0.90	21.34
Out-of-home school/work duration (hours)	-0.16	-3.54	-0.37	-6.52
Number of work trips/day	-2.16	-12.26	0.75	3.29
Number of observations	4449		4449	
Mean of dependent variable value	4.536		3.646	
SD of dependent variable	15.75		12.39	
R^2	0.290		0.232	
Degrees of Freedom	(24, 4244)		(24, 4244)	
F	221.48		43.44	
Var[α]	75.78		28.40	
Var[ε]	64.02		90.97	

Results of estimation are shown in Table 4.2 through Table 4.4, for commuters on weekdays, non-workers on weekdays, and all individuals on weekend days, respectively. Salient results are summarized as follows.

Commute distance is the variable that has predominant influences on commuters' second moments on weekdays (Table 4.2). It has positive influences on both I_H and I_C and, judging from the coefficient estimates of 1.24 for I_H and 0.90 for I_C, as commute distance increases, activity locations become farther from the home base as a whole, and they become more spatially spread or/and there will be more activity locations visited.

A longer work/school duration reduces the time available for other activities and consequently is expected to reduce the commuter's action space as well. The coefficient estimates indicate that work/school duration influences I_C more than I_H; as work/school duration increases, activity locations contract around their centroid (or/and the number of activity locations decreases) faster than the centroid approaches the home base.

TABLE 4.3 Models of Second Moments for Non-Workers on Weekdays

	I_H		I_C	
	Coeff.	t-ratio	Coeff.	t-ratio
Constant	12.20	1.95	-0.77	-0.16
Male [D]	-0.84	-0.50	0.07	0.06
25 - 34 years old [D]	-10.36	-2.11	9.32	2.45
35 - 44 years old [D]	-10.32	-2.07	5.47	1.42
45 - 54 years old [D]	-10.59	-2.18	1.89	0.50
55 – 64 years old [D]	-8.12	-1.74	-0.05	-0.01
65 years old or over [D]	-9.37	-2.02	-0.89	-0.25
Married [D]	0.75	0.43	0.01	0.01
Driver's license holding [D]	0.37	0.18	0.19	0.12
Number of household members	-0.54	-0.39	-3.79	-3.52
Number of motor vehicles	0.31	0.20	-0.23	-0.20
Number of telecommunications connections	1.69	2.53	-0.03	-0.06
Family with dependent children [D]	-2.86	-0.86	0.54	0.21
Household income [x 1,000 DM]	-0.40	-0.59	1.62	3.07
Inner city [D]	3.13	0.76	5.68	1.77
Suburbs [D]	3.19	0.79	5.99	1.92
Karlsruhe [D]	-4.13	-2.66	-2.26	-1.89
Duration of residence (years)	-0.04	-0.68	0.01	0.33
Monday [D]	-0.66	-0.77	0.64	0.80
Tuesday [D]	-1.17	-1.38	0.58	0.72
Thursday [D]	0.39	0.46	0.43	0.54
Friday [D]	-1.00	-1.18	1.50	1.89
Number of observations	1958		1958	
Mean of dependent variable value	3.808		3.488	
SD of dependent variable	13.15		12.07	
R^2	0.063		0.078	
Degrees of Freedom	(21, 1936)		(21, 1936)	
F	5.82		7.34	
Var[α]	27.70		8.76	
Var[ε]	114.25		96.00	

The results also show that a worker with more work trips per day tends to have an action space that is more extensive, but is centered around the home base. A commuter who has lived longer in the area, on the other hand, tends to have a larger I_H and smaller I_C.

Non-workers' I_C values are negatively influenced by the number of household members (Table 4.3). This may be a result of intra-household task allocation; with more household members, fewer household tasks are assigned to each member. On the other hand, higher household income contributes positively to I_C. Non-workers' I_H values are positively influenced by the number of telecommunication connections. It appears as if the ease in communicating with others or acquiring information encourages non-workers to travel farther from home. The age of non-workers has significant influences on I_H with those in the youngest age category (24 and younger; the coefficient is set to 0 in the model) having larger I_H.

Both commuters and non-workers have larger I_C on Fridays among weekdays; they tend to be more active on Fridays and visit more locations and/or more spread locations for activity engagement. The residents of inner city and suburban areas tend to have larger I_C than CBD residents. However, in few cases, the statistical indications are weak (not significant at α = 10 %).

TABLE 4.4 Models of Second Moments on Weekend Days

	I_H		I_C	
	Coeff.	t-ratio	Coeff.	t-ratio
Constant	4.31	1.31	0.25	0.09
Male [D]	-0.27	-0.27	-0.06	-0.07
25 - 34 years old [D]	5.04	2.04	2.39	1.09
35 - 44 years old [D]	1.42	0.58	-2.57	-1.18
45 - 54 years old [D]	1.57	0.62	-3.12	-1.38
55 – 64 years old [D]	2.95	1.08	-1.15	-0.47
65 years old or over [D]	1.17	0.39	-0.79	-0.29
Married [D]	-2.06	-1.45	-0.54	-0.43
Driver's license holding [D]	-2.63	-1.75	-0.21	-0.15
Number of household members	-1.69	-2.23	-0.25	-0.37
Number of motor vehicles	1.49	1.71	0.06	0.08
Number of telecommunications connections	-0.27	-0.73	0.46	1.42
Family with dependent children [D]	3.34	2.14	1.56	1.12
Household income [x 1,000 DM]	0.44	1.43	-0.15	-0.55
Worker [D]	0.61	0.25	3.05	1.41
Non-worker [D]	-0.16	-0.06	0.35	0.16
Inner city [D]	4.61	2.00	2.99	1.46
Suburbs [D]	5.48	2.46	1.53	0.77
Karlsruhe [D]	-2.74	-2.78	-0.12	-0.13
Duration of residence (years)	0.01	0.28	0.00	-0.08
Saturday [D]	-1.10	-1.43	2.79	4.79
Number of observations	1692		1692	
Mean of dependent variable value	5.407		3.767	
SD of dependent variable	16.08		12.66	
R^2	0.027		0.051	
Degrees of Freedom	(20, 1671)		(20, 1671)	
F	2.31		4.49	
Var[α]	10.69		11.29	
Var[ε]	180.99		111.14	

On Saturdays individuals tend to have larger I_C than on Sundays (Table 4.4). This is probably due to the fact that stores are closed in Germany on Sundays. The presence of dependent children and automobile availability positively contribute to I_H on weekend days (significant at $\alpha = 10$ %). Likewise residents of inner city and suburbs tend to have larger I_H. Household size, on the other hand, negatively influences I_H.

In general, individuals who live in Karlsruhe tend to have a centroid closer to the home location. Judging from the average values of I_C and I_H, the centroid of activity locations tends to be farther away from home, and activities are more spread or/and more activities are pursued, by commuters than by non-workers, and on weekend days than weekdays.

4.5 Decomposing the Variation

To probe further into the nature of day-to-day variations in I_H and I_C, their variances are decomposed into systematic variations and random variations, which are respectively further decomposed into within-person variances and between-person variances, and into individual-specific error variances and white noise. The statistically decomposing formula can be seen on Appendix B. Results can be seen in Table 4.5.

Of the estimated total sum of squares (SST), the regression sum of squares (SSR) accounts for up to 29.0%, and the rest is the error sum of squares (SSE). This highest percentage is found for I_H of commuters on weekdays. This is followed by 23.2% for I_C, also for commuters on weekdays. The fraction of SSR in SST is small in the models for non-workers on weekdays (6.3% for I_H and 7.8% for I_C) and in the models for weekend days (2.7% for I_H and 5.1% for I_C).

Of the SSR for I_H, within-person variance accounts for 19.1% in case of commuters and 3.2% for non-workers on weekdays, and 4.1% for all individuals on weekend days; the rest is between-person variance. The corresponding values for I_C are 26.1%, 2.1% and 22.7%, respectively. SSR represents that portion of variance that is systematically accounted for by the regression model. The results therefore indicate that much of the systematic variations in second moments are between-person variations, and day-to-day, within-person variations account for only small proportions. Yet it is noteworthy that larger portions of systematic variations, in both I_H and I_C, are within-person variations for commuters on weekdays. Another case is I_C for all individuals on weekend days. For non-workers, on the other hand, only very small portions of systematic variations in second moments are within-person variations, and most are between-person variations.

The explanatory variables in the commuter models for weekdays that are associated with day-to-day, within-person variations are the day-of-the-week dummies, work/school duration, and the number of work trips. Day of the week and work schedule appear to be the primary factors that account for systematic day-to-day variations in commuters' action spaces.

For workers on weekdays, the heterogeneity term, or, the variance of the individual-specific error term, accounts for 62.3% of the SSE for I_H, and 5.7% for I_C. The rest is white noise. That heterogeneity term accounts for a substantial proportion of the total SSE for commuters on weekdays is quite noteworthy. On the other hand, white noise is the dominant component of the total SSE for non-workers and all individuals on weekend days. On weekend days, only 3.0% and 7.2% of the SSE for I_H and I_C, respectively, are attributable to the heterogeneity term.

TABLE 4.5 Analysis of Variance of the Second Moment of Activity Locations

a. Workers and Students on Weekdays

		I_H			I_C		
		SS	%		SS	%	
SSR	Within-person	61,358	19.1	5.56	41,290	26.1	6.0
	Between-person	259,126	80.9	23.5	116,756	73.9	17.1
	Subtotal	320,485	100	29.0	158,046	100	23.2
SSE	Individual-specific error	488,130	62.3	44.2	29,709	5.7	4.4
	White noise	295,161	37.7	26.7	494,761	94.3	72.5
	Subtotal	783,291	100	71.0	524,470	100	76.8
	Total	1,103,776		100	682,517		100

b. Non-Workers on Weekdays

		I_H			I_C		
		SS	%		SS	%	
SSR	Within-person	685	3.2	0.2	466	2.1	0.2
	Between-person	20,728	96.8	6.1	21,654	97.9	7.6
	Subtotal	21,413	100	6.3	22,120	100	7.8
SSE	Individual-specific error	26,274	8.3	7.8	16,714	6.4	5.9
	White noise	290,912	91.7	85.9	246,378	93.6	86.4
	Subtotal	317,186	100	93.7	263,092	100	92.2
	Total	338,599		100	285,213		100

c. Weekend Days

		I_H			I_C		
		SS	%		SS	%	
SSR	Within-person	481	4.1	0.1	3,116	22.7	1.1
	Between-person	11,336	95.9	2.6	10,634	77.3	3.9
	Subtotal	11,817	100	2.7	13,750	100	5.1
SSE	Individual-specific error	12,655	3.0	2.9	18,538	7.2	6.8
	White noise	412,832	97.0	94.4	238,871	92.8	88.1
	Subtotal	425,488	100	97.3	257,409	100	94.9
	Total	437,304		100	271,159		100

Note: SS = sum of squares; SSR = the regression sum of squares; SSE = the error sum of squares

These results show that, on weekdays, commuters have more stable and more predictable activity space than do non-workers. As noted earlier, it is reasonable to assume that, for commuters, activity locations on weekdays are influenced by the location of the work place or school to which they commute. This leads to a stable second moment of the centroid of activity locations (I_H), which is strongly influenced by the distance between the home and work locations as evidenced by the very significant coefficient of commute distance shown in Table 4.2. The result that the heterogeneity term is a dominant component of the variance of I_H on weekdays suggests that commute distance alone does not entirely explain regularity in I_H for each commuter. Probing into omitted variables that are now represented by the individual-specific error term remains as a future research task.

This is not at all the case for I_C of commuters on weekdays, non-workers' I_H and I_C, or I_H and I_C for all individuals on weekend days. The error sum of squares is dominated by white noise in these cases. The results constitute a piece of evidence that non-workers' travel and weekend travel are more random and less recurrent.

4.6 Summary

Using the *Mobidrive* data set obtained from a six-week travel diary survey in Karlsruhe and Halle, Germany, this chapter has examined the characteristics of action space and its day-to-day variation based on the representation of its extension by the second moment of activity locations it contains. The study of this chapter has shown that the employment status, residence location, out-of-home work/school duration and day of the week have significant influences on the stability of second moments of activities locations. Individuals with out-of-home work/school commitments tend to have more stable second moments than those without them. The study of this chapter has also shown that the second moments tend to take on larger values on Fridays and Saturdays.

The statistical analyses of the variation of the second moments have revealed that the centroid of activity locations and the number or/and spread of activity locations of workers and students tend to be stable on weekdays. Unobserved heterogeneity across individuals is a major component that accounts for the variability of their centroid locations on weekdays. Even after commute distance is accounted for, there are yet other unobserved factors whose effects are fixed over time for each individual but vary across individuals. On weekend days, individuals have travel patterns with more variations within each individual as well as across individuals, and unobserved heterogeneity plays only minor roles.

Patterns of variations in action space found in this study are consistent with variations in activity engagement and constraints governing it, theoretically postulated between weekdays and weekend days and also between workers/students and non-workers. On weekdays, when activities tend to be obligatory and routine, activity locations tend to be fixed and action space tends to be recurrent. On weekend days, when the activities tend to be more discretionary, activity locations are more variable and action space tends to be random and non-recurrent. The findings of this chapter thus support the hypotheses of the study on activity engagement and the spatial extension of action space.

With the understanding that the workers' action space tend to be stable from day-to-day, it is possible to predict how the workers will move in a given spatial condition, which enables the analysis of movement variability of workers and subsequently its impact to the travel pattern and transportation network. Such knowledge certainly has direct implications for urban and transport management. Moreover, with the understanding variability of individual movement in space, we will be able to assess the efficiency of transportation and urban infrastructure such as bus station location and service coverage area and then identify who would gain the most benefit of the systems and conversely who would suffer the lack of accessibility (social exclusion), which can be used to achieve a more balanced transportation systems. Moreover, we could also address some urban planning issues, e.g. the impact of the locations of office, residential as well as commercial areas.

The results in this chapter show that, in the short term, the out-of-home activity orientation and the commitment influence the extension of action space. It is also shown that a substantial portion of the variations in their action spaces is due to unexplained differences across individuals that remain stable over time for each individual (unobserved heterogeneity). On the other hand, random factors have dominant influences on non-workers' weekday action spaces and all individuals' weekend action spaces.

However, with the emerging era of motorization and suburbanization in metropolitan regions in last three decades, the travel constraints over time, as well as the urban form in many metropolitan areas have been changes. This implies substantial changes in the physical and social environment for trip making, which, in the end, imply changes in the needs for, resources available for, and constraints imposed on, travel. The changes of individual's action space over a long-time span, as far as the author is aware, have never been examined before.

In Chapter 6, utilizing the concept of second moment of activity locations, the changes of individual's action space over long period is examined. However, before analyzing the changes of individual action space over long periods, the changes and the stability of individual's activity and travel behavior during that period is examined. This is conducted in Chapter 5.

Chapter 5
The Temporal Changes of Relationships Underlying Individual Travel Behavior

In this chapter, using the sub-samples of Osaka metropolitan area person-trip data, the stability of urban travelers' activity and travel patterns during the period when the urban area underwent substantial changes are examined. Based on the examination, general principles that may govern changes in travelers' activity and travel patterns are inferred. The simultaneous equations model systems of urban travel are developed and a statistical approach is taken in order to test the stability of a system of models that describes pertinent aspects of activity and travel patterns.

The next section offers a brief description of the individual behavior changes in long term period. After that, the socio-economic changes in the Osaka metropolitan area over time as well as the travel data that is used in this study is described. It followed by section that presents the approach that adopted in this study in order to examine behavioral stability, discusses the hypotheses behind the development of the model system, and describes the model system itself. After that, the estimation results of the model system are discussed and the stability comparison of the model system is described. Summary is presented in the last part of the chapter.

5.1 The Changes of Individual Behavior in Long Term Period

In the second half of the 20^{th} century, most metropolitan areas of industrialized countries underwent substantial changes. However, how the individual composes their travel pattern and how the travel parameters are changing over time are still largely unknown.

With the emerging era of motorization and suburbanization in metropolitan areas in the last three decades, the constraints travel over time, as well as the urban form in many metropolitan areas, has changed. For example, vehicle ownership has increased rapidly in industrialized countries after World War II. Suburbanization progressed and metropolitan areas expanded geographically in the same period, resulting in new spatial distributions of residences and jobs. This implies substantial changes in the physical environment for trip making. Social changes are also numerous. More women are now employed, while household size is shrinking. Various commodities, appliances and services have been invented to reduce the time required for domestic chores such as cleaning, cooking and yard work. Household income has in general increased, in part because of the increased number of two-worker households. All these changes imply changes in the needs for, resources available for, and constraints imposed on, travel. See Cohen and Kocis (1980), Kollo and Purvis (1984), Levinson and Kumar (1994), Cervero (1986), Roberts (1986), and van Beek et al. (1986), for discussion about the impact of motorization and suburbanization to the way people travel.

Indeed, the changes in specific indices of activity and travel behavior (e.g., the number of trips, or travel time expenditure) have been often examined, most typically using cross-sectional data from multiple regions or repeated cross-sectional data from a region. Little is known, however, as to how urban residents' adaptations to the vast changes in their travel environments have modified their time use and travel patterns as a whole (see chapter 2 for literature review of stability and transferability of travel behavior). Analyzing the individual travel behavior without treating the causal mechanisms underlying activity engagement and travel as wholly and undervalue the individual adaptation processes over time could lead to bias descriptions and produce overestimated results. Further, analyzing the invariants in their activity and travel patterns through the period when urban area underwent substantial changes, and inferring the general principle that may govern changes in urban residents' activity and travel patterns are needed to understand how the individual travel behavior change overtime.

It can be anticipated that workers and non-workers are affected differently by these changes. The obligation commitments as well as commute mode will act as the constraints as well as the direction in the way workers change their patterns. The flexibility in auto travel allows the auto commuter[7] to adapt to changes in the travel environment in many different ways, e.g., changing routes, destinations, departure times, adjusting trip chaining patterns, trading-off among the trip frequency, activity duration, and trip length, or diversifying activity locations. On the other hand, transit commuters (primarily rail commuters) are more likely to visit non-work opportunities that are in the vicinity of transit stops on their commute routes, such as railroad stations. Changes of land uses around transit stops will affect their travel patterns significantly; transit commuters' accessibility to opportunities is determined by the accessibility that transit stops offer, which in turn is dependent on the land use developments around the stops and the transit level of service. Because public transit tends to serve masses of demand, large numbers of transit commuters tend to be faced with similar sets of opportunities. One may then conjecture that their travel patterns are relatively homogenous compared with those of auto commuters. Moreover, because transit commuters' travel patterns are constrained by transit networks and schedules, changes in their travel patterns are governed by transit supply characteristics to some extent. For these two reasons, transit

[7] A commuter is defined in this study as a worker who made at least one work trip on the survey day. A worker who did not made any work trip on the survey day is excluded from the analysis.The non-worker traveler is defined as a non-commuters.

commuters are expected to exhibit similar patterns of changes when a change takes place in the travel environment.

The ultimate objective of this chapter is to identify inherent tendencies of urban travel, in particular, whether they tend to expand, contract, or remain stable, and which aspects of travel exhibit these tendencies. This is based on the belief that a better understanding of urban travel demand, and therefore better quantitative representation of it, can be obtained through this endeavor. Examined in this study is the stability of urban travelers' activity and travel patterns during the period when the urban area underwent substantial changes. Based on the examination, general principles that may govern changes in travelers' activity and travel patterns are inferred. To these ends, simultaneous equations model systems of urban travel are developed and a statistical approach is taken in order to test the stability of a system of models that describes pertinent aspects of activity and travel patterns.

This analysis presented in this chapter is based on the sub-sample data from conventional large-scale household travel surveys conducted in the Osaka metropolitan area of Japan in 1980, 1990 and 2000, with sampling rates of 2.4% to 3.0% (see chapter 3 for the description of the database). In this study, the travel data have been supplemented with land use and network data in this study.

5.2 Changes in the Osaka Metropolitan Area

The Osaka metropolitan area is the second largest in Japan, after the Tokyo metropolis, with three core cities of Osaka, Kyoto, and Kobe. Osaka is the largest among the three and is the center of commerce in the Kansai Area; Kyoto was the ancient capitol of Japan established in 794; and Kobe is the maritime center of the area. For more detail information about the Osaka metropolitan area, please see Chapter 3.

Changes in socio-economics and accessibility

At the metropolitan level, the residential population in the Osaka metropolitan area has steadily increased through 2000, although the rate of growth has visibly declined. Based on the analysis of household travel survey date from 1970, 1980, 1990 and 2000, Fukui (2003) shows how the residential population in the Osaka metropolitan area has decentralized; the number of younger residents has been increasing in the suburbs, while the populations are aging in older neighborhoods closer to the nuclei of the metropolis. The total number of employees in the metropolitan area peaked in 1991, when the "bubble" economy of Japan reached its peak, then started to decrease. A trend of decentralization is also found in employment. Employment has increased in the suburbs, both in secondary and tertiary industries, while it is declining in central cities.

The average number of vehicles per household in the Osaka metropolitan area increased from 0.41 in 1970 to 0.66 in 1980, 0.88 in 1990, and to 0.97 in 2000. The area, which is densely populated and well-served by public transit, has had a lower rate of vehicle ownership than the nationwide average, which was 1.12 vehicles per household in 2000. The older parts of the metropolitan area, including commercial centers and mixed commercial and residential areas, have very slow rates of motorization. Newly developed suburbs in general show higher levels and faster growth rates of vehicle ownership. On the other hand, mode use has practically unchanged among commercial area residents, and the fraction of auto trips has increased only slightly in old suburbs. Similar tendencies are found with mixed commercial/residential areas. An increase in the fraction of auto trips and a decline in the share of public transit are noticeable in new suburbs, and auto trips are starting to dominate in newly urbanizing areas (Kitamura et al., 2003).

Along with the trends of decentralization and motorization, transportation networks have also changed over time. Kitamura et al. (2003) note that the accessibility indices by auto are roughly twice as large as those by rail.[8] Despite the well-developed rail networks in the area, the automobile provides better accessibility to both population and employment. It is also notable that, despite the trend of decentralization, accessibility indices, when averaged over the municipalities, increased between 1980 and 2000. It may be inferred that the decentralization in the Osaka metropolitan area has not adversely affected the mobility of its residents.

Other characteristics of changes in the Osaka metropolitan area include (Kitamura et al., 2003):

- The mean commute trip duration is quite stable at 35.8 to 35.9 minutes between 1980 and 2000. But trip durations for non-work purposes are increasing.
- The use of rail and bus has declined, especially for work and school trips. The number of non-work trips by rail is increasing, however.
- These changes have led to changes in the total amount of time spent for traveling from 54.1 minutes in 1970 to 60.9 minutes in 2000, an increase by 12.5%. Changes in travel time expenditure are most noticeable for the residents of new suburbs (an increase of 16.8%), emerging suburbs (12.6%), and unurbanized areas (12.5%). The mean travel time expenditure is stable in autonomous cities, mixed commercial cities and commercial cities.

For more discussion about the changes in the Osaka metropolitan area between 1970 and 2000, see Fukui (2003) and Kitamura et al. (2003).

Profiles of urban traveler in the study area

The profiles of urban travelers in the Osaka metropolitan area are shown in Table 5.1. Auto commuters are defined as those who used the automobile in any part of their commute trips to work on the survey day. Likewise transit commuters are defined as those who commuted to work using public transit (mostly bus, rail and taxi) but without using the automobile. Thus those who made park-and-ride trips to work, for example, are classified as auto commuters. Mode use in the commute trip from work to home is not considered in this classification.

The analysis focused on adult travelers; school students were excluded. Only those commuters who had closed travel patterns (i.e., those that started from, and ended at, the home base) and commuted by auto or public transit are included in the analysis of this study; those who commuted by non-motorized modes (e.g., on foot or by bicycle) are excluded. If multiple modes are used in a commute trip, its mode is defined as auto if the automobile is used at all; otherwise it is defined as public transit.

[8] Accessibility indices are evaluated residential population, total employment and retail employment as measures of attraction. The indices are measured based on gravity principle as defined in Equation 5.2 in this chapter.

The sample profiles indicate that non-worker travelers in the Osaka metropolitan area are predominantly adult females. In contrast, auto-commuters are predominantly males in the 25 – 54 age bracket. The transit commuters have more balanced age and gender distributions. The number of travelers who have dependent child is continuously decreasing. The driver license ownership level is increasing. Mixed commercial/residential areas are over-represented as transit commuters' residence areas, while autonomous areas are over-represented among auto commuters.

For the models analysis that follows, estimation sample are drawn from the original data files randomly at the rate of approximately 10%.

The travel and activity behaviors of urban traveler in the study area

The urban travelers' characteristics in the 1980, 1990 and 2000 data sets are summarized in Table 5.2. From 1980 to 2000, generally, all travelers are constantly increasing their activity and travel engagements and make their travel patterns more efficient with more visits per trip chain. However, although commuters' number of non-work visits increased, time expenditures for non-work activities consistently decreased. It seems that the loose constraint of non-worker travelers' activity has allowed them to expand their activity and travel patterns constantly. On the other hand, the work and commuting constraints encourage the commuters to trade-off their expenditure time for non-work activity with number of non-work visits.

Auto commuters tended to make simple commutes of home-work-home more frequently than did transit commuters. Transit commuters, on the other hand, made more trips, more trip chains, more stops for non-work activities, more effective trip patterns, spent more time for non-work activities, and had longer commute distances than did auto commuters. The table shows that transit commuters were more mobile and had higher levels of activity engagement than did auto commuters in the study area consistently in the 20-year period between 1980 and 2000. Interestingly, the transit commuters have less work duration than auto commuters in 20-year period. However, it has been confirmed that this tendency is not caused by the differences of users' gender (more women were using transit than auto, see Table 5.1).

The results here run entirely counter to the common belief that auto travelers are more mobile and chain trips more often to combine more visits into a trip chain (e.g., Strathman and Dueker, 1995). In particular, the finding that auto commuters are more likely to make simple home-work-home commutes may be quite counterintuitive. This is presumably due to the travel environment created by the well developed transit networks and dense land use in the study area. In Japanese urban areas, including the Osaka metropolitan area, transit terminals provide superb access to a large number of opportunities which evidently encourages transit commuters to engage in more activities and pursue complex commutes with non-work visits. In this sense, the common belief that public transit is less suitable for trip chaining than the automobile may not apply in metropolitan areas of Japan. The tabulation here thus offers evidence that activity engagement and travel patterns are substantially influenced by transportation networks and land use developments.

TABLE 5.1 Profiles of Urban Traveler in the Osaka Metropolitan Area

Individual and Household Parameters	Non-workers			Auto Commuters			Transit Commuters		
	1980	1990	2000	1980	1990	2000	1980	1990	2000
Male [D]	7.0%	11.3%	20.4%	83.1%	79.8%	72.6%	57.6%	51.5%	50.5%
Lower than or 24 years old [D]	3.7%	2.7%	2.6%	11.5%	12.7%	8.5%	15.7%	17.0%	12.7%
25 – 34 Years old [D]	28.9%	16.8%	14.5%	33.0%	22.7%	26.4%	25.2%	19.3%	26.1%
35 – 44 Years old [D]	24.0%	21.2%	12.3%	30.8%	29.2%	22.6%	24.8%	23.8%	19.0%
45 – 54 Years old [D]	16.2%	17.7%	13.8%	18.0%	23.3%	24.2%	21.3%	23.8%	23.0%
55 – 64 Years old [D]	12.8%	19.3%	21.1%	5.3%	10.3%	14.7%	9.7%	13.0%	15.3%
65 Years old or over [D]	14.4%	22.4%	35.7%	1.3%	1.7%	3.5%	3.2%	3.0%	3.9%
Number of household members	3.28	3.08	2.89	3.45	3.40	3.50	3.14	3.12	3.12
Family with dependent children [D]	48.8%	37.8%	29.8%	49.7%	43.7%	42.0%	40.2%	35.8%	30.2%
Number of cars per adult household member	0.30	0.33	0.34	0.57	0.58	0.62	0.21	0.30	0.35
Driver's license holding [D]	14.1%	28.4%	42.2%	85.5%	96.5%	97.6%	35.0%	53.0%	68.1%
Resides in commercial area [D]	2.8%	2.9%	2.8%	1.4%	1.8%	1.2%	3.2%	3.8%	4.1%
Resides in mixed commercial/residential area [D]	26.6%	27.0%	31.4%	18.6%	18.5%	20.0%	29.3%	31.1%	37.0%
Resides in autonomous city [D]	5.8%	8.5%	4.9%	13.1%	14.4%	11.9%	4.1%	7.0%	2.7%
Resides in suburbs area [D]	63.9%	61.4%	60.3%	64.8%	65.0%	65.7%	62.8%	57.9%	55.9%
Resides in un-urbanized Side [D]	0.9%	0.2%	0.6%	2.1%	0.4%	1.2%	0.6%	0.2%	0.3%

[D] indicates a 0-1 dummy variable.

TABLE 5.2 Travel Characteristics of Urban Traveler in the Osaka Metropolitan Area

Travel Parameters	Non-workers			Auto Commuters			Transit Commuters		
	1980	1990	2000	1980	1990	2000	1980	1990	2000
Total number of trips / day	2.56	2.62	2.81	2.35	2.32	2.44	2.57	2.50	2.55
Number of work trips / day[9]				1.07	1.11	1.12	1.08	1.15	1.13
Percentage of workers who made simple commute[10]				81.9%	82.8%	77.8%	73.6%	74.9%	72.4%
Number of non-work visits / day	1.36	1.43	1.59	0.17	0.17	0.25	0.30	0.29	0.33
Percentage of workers who made non-work visits	100%	100%	100%	14.78%	14.44%	18.80%	24.41%	23.58%	25.69%
Time expenditure for all activities (min)	91.84	108.97	125.90	571.85	591.91	580.56	554.08	557.20	553.89
Time expenditure for work activities (min)				544.81	567.12	557.05	505.88	515.23	516.31
Time expenditure for non-work activities (min)	91.80	108.97	125.90	27.05	24.79	23.51	48.20	41.97	37.58
Number of visits / day	1.36	1.43	1.59	1.24	1.28	1.37	1.38	1.43	1.47
Number of trip chains / day	1.20	1.19	1.22	1.11	1.04	1.07	1.19	1.07	1.09
Average number of visits / trip chain	1.15	1.21	1.34	1.12	1.23	1.29	1.16	1.36	1.36
Total travel time (min)	35.91	41.03	45.50	54.51	61.59	61.13	71.66	74.72	68.55
Time for commute and work purpose trips (min)				48.97	57.03	55.67	64.54	68.11	63.09
One-way commute distance (km)				5.82	6.65	7.01	8.44	7.84	8.41

[9] "Work trips" refer to those trips made to engage in work activities, and they are not necessarily made from the home base. "Non-work trips" are those made to engage in out-of-home non-work activities.

[10] A commuter is said to have made a "simple commute" if he/she made one commute trip to work, then one trip back to home, and did not introduce any non-work stops on the way to or back from work on the survey day. Otherwise, he/she is said to have made a "complex commute."

5.3 The Development of Mechanism Underlying Travel and Activity Engagements

The model system of activities and travel is developed in this study taking into consideration all the pertinent elements that influence behavior. The model system includes as endogenous variables: total expenditure time for non-work activities, number of non-work visits, number of trip chains, and total travel time. The model system embodies the causal structure postulated for these variables. The model system will be different for workers and non-workers.

Model system for non-workers

It can be reasonably assumed that the amount of time available for out-of-home activities and travel is pre-determined for each individual. This amount of time is allocated to activities and travel. In activity decision, one must consider how much time each activity will take to pursue in a satisfactory or meaningful manner. One must also consider potential locations where the activity can be pursued; some activities can be engaged in at any place (e.g., calling a friend by the cellular phone), some at a set of alternative locations (e.g., grocery shopping), and some at a specific location (e.g., visiting a friend who is hospitalized). Visiting a location requires traveling, which of course requires a certain amount of time. Thus, the number of visits and their locations influence the amount of time available for activities. At the same time, the amount of time required for activities influences the number and locations of visits to be made.

The visits must be organized into trip chains and this will determine the origin and destination of each trip to be made, and hence the amount of time required to travel, given the mode of travel. The time required to travel must be traded off with the time for activities. Thus, activity time is one of the factors that influence trip planning, while travel time is a factor in activity planning. If there is a desire to reduce travel time, a faster mode may be chosen, or different ways of combining visits into chains may be attempted. Alternatively, one might choose closer locations to visit, or reduce activity durations instead of reducing travel time (Kitamura et al., 1998; Dijst and Vidakovic, 2000).

It is unclear how individuals make this complex decision. In modeling these relationships, it seems inevitable to postulate some decision mechanism and to assume that it can be applied to all situations. It is unrealistic to assume that there is a single decision mechanism that applies to all individuals, or that a given individual will deploy the same mechanism in all situations. Indeed, numerous mechanisms can exist for this complex a decision problem. Yet, constructing structural relations is extremely difficult, if not impossible, without this simplifying assumption.

In formulating a simplified decision mechanism, it is postulated that, given a time budget, activity time is first determined, then the number of visits is chosen. The visits will then be organized into trip chains, which will determine the number of trips. The number of chains and the number of trips together determine total travel time expenditure. The basic structure of the model system for non-worker travelers can be assumed as in Figure 5.1.

The assumption that activity time is determined before the number of visits is based on the results in Senbil and Kitamura (2003) where alternative structural equations models are estimated to examine whether activity time determines the number of visits or the number of visits determines activity time. The results indicated that the former causal relation is predominant.

Note that the travel time budget as the upper bound of travel time expenditure, governs the travel decisions represented by the model equations. Attempts to estimate travel time budges based on travel time expenditures using stochastic frontier models, however, were unsuccessful and travel time budgets are not incorporated into the analysis that follows.

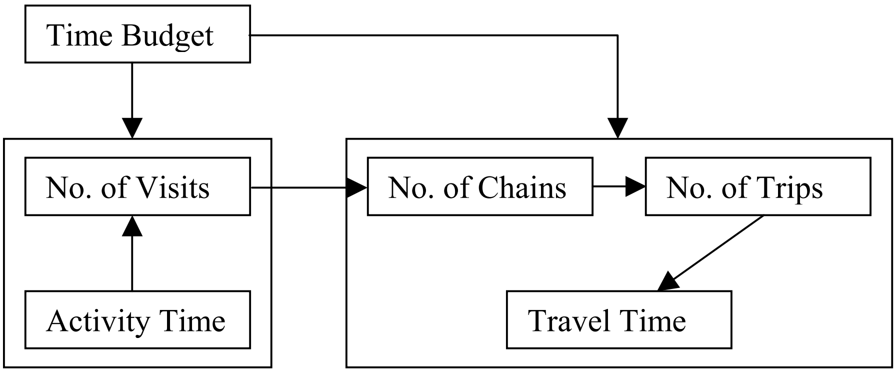


FIGURE 5.1 Relations among Activities and Travel for Non-Work Travelers

Letting

t_{NW} = total out-of-home, non-work activity time,
v_{NW} = the number of non-work visits,
n_C = the number of trip chains,
n_T = the number of trips (= $v_{NW} + n_C$), and
t_T = total travel time.

Note that non-workers are assumed to engage in no work activities and make no work trips. These endogenous variables are expressed in the simultaneous equations model system as

$$\begin{cases} t_{NW} = f_{t_{NW}}(R,W) \\ v_{NW} = f_{v_{NW}}(t_{NW},R,W) \\ n_C = f_{n_C}(v_{NW},R,W) \\ n_T = v + n_C \\ t_T = f_{t_T}(n_T,R,W) \end{cases} \tag{5.1}$$

Where R is the vector of variables representing the characteristics of the residence areas, including accessibility indices, and W is the vector of individual and household attributes.

Note the recursive structure which embodies the causal relationships shown in Figure 5.1, i.e., t_{NW} is first determined, v_{NW} is next determined given t_{NW}, then n_C given v_{NW}, then finally t_T given n_T (= $n_C + v_{NW}$).

The vectors of explanatory variables, R and W, contain: residential area type[11]; accessibility indices to population, employment, and retail establishments, respectively by auto and by rail; and demographic and socio-economic attributes of the individual and household. The accessibility index by activity and mode is defined as

$$I_i^{mp} = \sum_j \frac{A_j^p}{\left(t_{ij}^m\right)^2} \tag{5.2}$$

where

I_i^{mp} = the accessibility index at zone i for activity p by mode m,

A_j^p = the attraction measure of zone j for activity p,

t_{ij}^m = the mean travel time between zones i and j by mode m,

and m = auto, or rail; and p = work, social, or shopping (the number of employees, residential population, and the number of retail establishments are used as the attraction measures, respectively).

Returning to the simultaneous equation system of Equation (5.1), it can be seen that endogenous variables appear on the right-hand side of the equations for v_{NW}, n_C and t_T. This could potentially lead to inconsistent estimation. In order to obtain consistent estimates, a two-stage procedure is adopted in this study. In the first stage, ordinary least-square regression is applied to the respective model equations, which are formulated to have the following specific forms with a normal error term introduced into each:

$$\begin{cases} t_{NW} = \theta_{t_{NW}}{}' X_{t_{NW}} + \varepsilon_{t_{NW}} \\ v_{NW} = t_{NW}(\theta_{v_{NW}}{}' X_{v_{NW}}) + \varepsilon_{v_{NW}} \\ n_C = v_{NW}(\theta_{n_C}{}' X_{n_C}) + \varepsilon_{n_C} \\ t_T = (v_{NW} + n_C)(\theta_{t_T}{}' X_{t_T}) + \varepsilon_{t_T} \end{cases} \tag{5.3}$$

where $\theta_{t_{NW}}$, $\theta_{v_{NW}}$, θ_{n_C}, and θ_{t_T} are vectors of coefficients, $X_{t_{NW}}$, $X_{v_{NW}}$, X_{n_C}, and X_{t_T} are vectors of explanatory variables, " ' " indicates the transposition operation, and $\varepsilon_{t_{NW}}$, $\varepsilon_{v_{NW}}$, ε_{n_C}, and ε_{t_T} are normal random error terms which are assumed to be mutually independent and serially uncorrelated. Note the recursive structure, where v_{NW} is determined given t_{NW}, then n_C given v_{NW}, etc. Also note that n_T is based on the identity that it is the sum of the number of visits and the number of trip chains. The term, $\theta_{v_{NW}}{}' X_{v_{NW}}$, represents the mean number of visits per unit out-of-home activity time, $\theta_{n_C}{}' X_{n_C}$ the mean number of trip chains per visit, and $\theta_{t_T}{}' X_{t_T}$ the mean trip duration. Thus, each equation in the model system offers a clear interpretation. The model structure at the same time facilitates the determination of the source of instability. For example, the model system makes it possible to determine whether a change in total travel time expenditure is due to a change in out-of-home activity engagement, in trip chaining, or in mean trip length.

[11] The residential type that are adopted in this study are based on the urban area classification scheme by Fukui (2003): commercial area, mixed area, autonomous area, suburbs area, and un-urbanized area.

Based on the results of the first-stage, the following instrument variables are defined:

$$\begin{cases} \hat{t}_{NW} = \hat{\theta}_{t_{NW}}' X_{t_{NW}} \\ \hat{v}_{NW} = \hat{t}_{NW} (\hat{\theta}_{v_{NW}}' X_{v_{NW}}) \\ \hat{n}_C = \hat{v}_{NW} (\hat{\theta}_{n_C}' X_{n_C}) \end{cases} \tag{5.4}$$

where $\hat{\theta}_{t_{NW}}$, $\hat{\theta}_{v_{NW}}$, and $\hat{\theta}_{n_C}$ are vectors of coefficient estimates from the first stage. In the second stage, the simultaneous equations system of Equation (5.3) is estimated again while applying these instrument variables, i.e.,

$$\begin{cases} t_{NW} = \theta_{t_{NW}}' X_{t_{NW}} + \varepsilon_{t_{NW}} \\ v_{NW} = \hat{t}_{NW} (\theta_{v_{NW}}' X_{v_{NW}}) + \varepsilon_{v_{NW}} \\ n_C = \hat{v}_{NW} (\theta_{n_C}' X_{n_C}) + \varepsilon_{n_C} \\ t_T = (\hat{v}_{NW} + \hat{n}_C)(\theta_{t_T}' X_{t_T}) + \varepsilon_{t_T} \end{cases} \tag{5.3'}$$

In this study, no iteration is performed between Equations (5.3') and (5.4) to attain convergence.

Model system for commuters

The basic structure of the model system for commuters is illustrated in Figure 5.2. The model system for commuters has been developed with the same conceptual framework as the one for non-workers. Commute trips are introduced into this model system to formulate a system for workers.

A typical worker commutes to his workplace and has obligations to work for a certain number of hours each day. The duration of commute trips to and from work and total work duration directly influence the amount of discretionary time that can be allocated to non-work activities. At the same time, commuting brings the worker closer to opportunities along the commute route and around the work location. These opportunities can be visited with little extra travel time over the time spent for commuting to and from work. This enhanced accessibility may imply that a worker with a longer commute tends to pursue activities more frequently and at more locations. Then commute time would positively influence non-work activity time, offsetting, at least partially, its negative effect on time availability. One would also expect that a high level of accessibility at the work location will prompt more frequent activity engagement and will positively contribute to the amount of non-work activity time. This would be the case with the home location as well. These factors therefore enter the model system as explanatory variables.

Total trip time can be viewed as a function of the number of trips, and is influenced by home and work area characteristics as represented by accessibility indices and other area indicators. Note that the total trip time is approximately twice the one-way commute trip duration if the worker has the simple travel pattern of home-work-home.

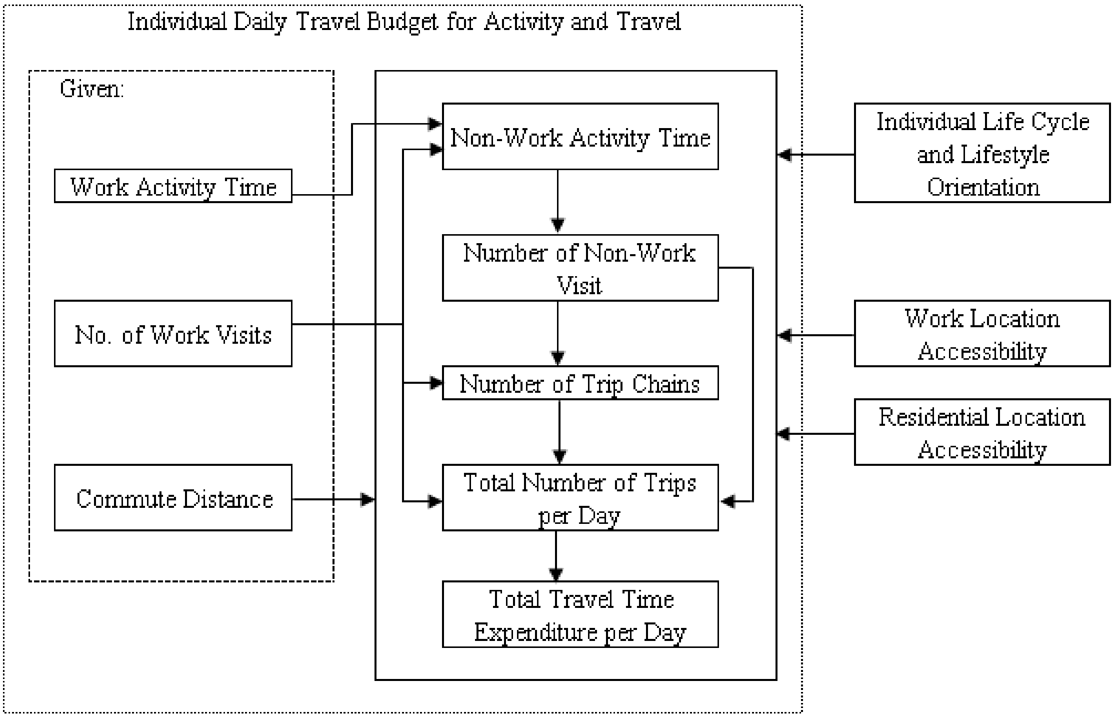


FIGURE 5.2 Relations among Activities and Travel for Commuters

Let the endogenous variables of the model system be

t_{NW} = total out-of-home, non-work activity time,
v_{NW} = the number of visits (stops) for non-work activities,
n_C = the number of trip chains,
n_T = the number of trips, and
t_T = total trip time,

and let

d_X = one-way commute distance,
t_W = total out-of-home work duration,
v_W = the number of visits for work activities, and
v = $v_{NW} + v_W$; the total number of visits.

Then the model system may be formulated in general form as

$$\begin{cases} t_{NW} = f_{t_{NW}}(d_X, t_W, v_W, R, W) \\ v_{NW} = f_{v_{NW}}(t_{NW}, d_X, R, W) \\ n_C = f_{n_C}(v_{NW}, v_W, d_X, R, W) \\ n_T = v + n_C = v_W + v_{NW} + n_C \\ t_T = f_{t_T}(n_T, d_X, R, W) \end{cases} \quad (5.5)$$

Where

R= the vector of variables representing the residence and work areas, including accessibility indices, and
W = the vector of individual and household attributes.

The endogenous variables are assumed to form a recursive structure, i.e., v_{NW} is determined given t_{NW}, then n_C given v_{NW}, n_T given n_C and v_{NW}, and finally t_T given n_T. Note that the number of trips equals the number of work and non-work visits plus the number of trip chains. Total travel time is viewed as a function of the number of trips, and is expected to be influenced by home and work area characteristics as represented by accessibility indices and other area indicators. Commute distance, d_X, out-of-home work duration, t_W, and the number of work visits, v_W, are assumed to be pre-determined in this study.

The specific forms of the respective models as adopted for estimation are as follows

$$\begin{cases} y^* = \beta_y ' X_y + \xi_y \\ t_{NW} = \begin{cases} \beta_{t_{NW}} ' X_{t_{NW}} + \xi_{t_{NW}} & \text{if } y^* > y_0 \\ 0 & \text{otherwise} \end{cases} \\ v_{NW} = \begin{cases} t_{NW}(\beta_{v_{NW}} ' X_{v_{NW}}) + \xi_{v_{NW}} & \text{if } y^* > y_0 \\ 0 & \text{otherwise} \end{cases} \\ n_C = (v_W + v_{NW})(\beta_{n_C} ' X_{n_C}) + \xi_{n_C} \\ t_T = \begin{cases} n_C(\beta_{t_T}^{(1)} ' X_{t_T}^{(1)}) + \xi_{t_T}^{(1)} & \text{if } v_{NW} = 0 \text{ and } v_W = 1 \\ (v_W + v_{NW} + n_C)(\beta_{t_T}^{(2)} ' X_{t_T}^{(2)}) + \xi_{t_T}^{(2)} & \text{otherwise} \end{cases} \end{cases} \tag{5.6}$$

where y^* is a latent variable, y_0 is a threshold, $\beta_y, \beta_{t_{NW}}$, $\beta_{v_{NW}}$, β_{n_C} and $\beta_{t_T}^{(l)}$, l = 1, 2 , are vectors of coefficients, $X_y, X_{t_{NW}}$, $X_{v_{NW}}$, X_{n_C} and $X_{t_T}^{(l)}$ are vectors of explanatory variables (which may include d_X, t_W, and v_W), "'" denotes the transposition operation, and ξ_y, $\xi_{t_{NW}}$, $\xi_{v_{NW}}$, ξ_{n_C} and $\xi_{t_T}^{(l)}$ are normal random error terms. The latent variable, y^*, constitutes a binary probit model of non-work activity engagement. The term, $\beta_{v_{NW}} ' X_{v_{NW}}$, represents the mean number of non-work visits per unit out-of-home, non-work activity time, $\beta_{n_C} ' X_{n_C}$ the mean number of trip chains per visit (both work and non-work), $\beta_{t_T}^{(1)} ' X_{t_T}^{(1)}$ a mean trip duration for individuals with simple commutes, and $\beta_{t_T}^{(2)} ' X_{t_T}^{(2)}$ a mean trip duration for individuals with complex commutes.

As non-worker's model system, the model system of Equation (5.5), it can be seen that endogenous variables appear on the right hand-side of the equation for v_{NW}, n_C and t_T. This could potentially lead to inconsistent estimation. In order to obtain consistent estimates, a two-stage procedure is adopted in this model system as well. In the first stage, ordinary least-square regression is applied to the respective model equations, and in the second stage, the endogenous variables on the right-hand side are replaced by instrumental variables, which are predicted values of the respective endogenous variables obtained from the corresponding models estimated in the first stage.

Moreover, as Table 5.2 has shown, the fraction of commuters who engaged in non-work activities is relatively small. Time expenditure for non-work activities (t_{NW}) and the number of non-work visits (v_{NW}) take on values of 0 for those who did not engage in non-work activities. Although this may be represented by a pair of Tobit models with truncation at 0, applied to

t_{NW} and v_{NW} respectively, this would not guarantee that t_{NW} and v_{NW} are both 0 when non-work activities are not pursued. The probit model of non-work activity engagement is therefore introduced and the coefficients of models for t_{NW} and v_{NW} are estimated using only those cases where they are positive (about 20% of the sample used for model estimation here). To eliminate selectivity bias that would be caused by this and to obtain consistent parameter estimates, a selectivity bias correction term is introduced into the model equations for t_{NW} and v_{NW} (Maddala, 1983; Washington et. al, 2003). Inverse Mill's ratios prepared from the binary probit model of non-work activity engagement are used as the correction terms. The results of binary probit model describe in Appendix C.1.

The models in Equations 5.6 of formulation become:

$$\begin{cases} t_{NW} = \begin{cases} \beta'_{t_{NW}} X_{t_{NW}} + \alpha_{t_{NW}} \lambda_i + \xi_{t_{NW}}, & \text{if } t_{NW} > 0 \\ 0 & \text{otherwise} \end{cases} \\ v_{NW} = \begin{cases} t_{NW} \left(\beta'_{v_{NW}} X_{v_{NW}} + \alpha_{v_{NW}} \lambda_i \right) + \xi_{v_{NW}}, & \text{if } t_{NW} > 0 \\ 0 & \text{otherwise} \end{cases} \\ n_C = v\left(\beta'_{n_C}{}' X_{n_C} \right) + \varepsilon_{n_C} = \left(v_{NW} + v_W \right)\left(\beta'_{n_C} X_{n_C} \right) + \xi_{n_C} \\ t_T = \begin{cases} n_C \left(\beta'^{(1)}_{t_T} X^{(1)}_{t_T} \right) + \xi_{t_T} & \text{if } v_{NW} = 0 \text{ and } v_W = 1 \\ \left(v + n_C \right)\left(\beta'^{(2)}_{t_T} X^{(2)}_{t_T} \right) + \xi_{t_T} & \text{if } v_{NW} > 0 \text{ and } v_W \geq 1 \text{ or if } v_{NW} = 0 \text{ and } v_W > 1 \end{cases} \end{cases} \tag{5.6'}$$

where λ_i is the selectivity correction error term for individual i and $\alpha_{t_{NW}}$ and $\alpha_{v_{NW}}$ are vectors of selectivity correction error term coefficients. Based on the results of the first-stage (Equation 5.6'), the following instrument variables are defined:

$$\begin{cases} \text{for } t_{NW} > 0, \hat{t}_{NW} = \hat{\beta}'_{t_{NW}} X_{t_{NW}} + \hat{\alpha}_{t_{NW}} \lambda_i \\ \text{for } t_{NW} > 0, \hat{v}_{NW} = \hat{t}_{NW} \left(\hat{\beta}'_{v_{NW}} X_{v_{NW}} + \hat{\alpha}_{v_{NW}} \lambda_i \right) \\ \hat{n}_C = \left(\hat{v}_{NW} + v_W \right)\left(\hat{\beta}'_{n_C} X_{n_C} \right) \end{cases} \tag{5.7}$$

where $\hat{\beta}_{t_{NW}}$, $\hat{\beta}_{v_{NW}}$, $\hat{\beta}_{n_C}$, $\hat{\alpha}_{t_{NW}}$, and $\hat{\alpha}_{v_{NW}}$ are vectors of coefficients estimates from the first stage.

In the second stage, the simultaneous equation system of equation (5.6') is estimated again while applying these instrument variables, i.e.:

$$\begin{cases} t_{NW} = \begin{cases} \beta'_{t_{NW}} X_{t_{NW}} + \alpha_{t_{NW}} \lambda_i + \xi_{t_{NW}}, & \text{if } t_{NW} > 0 \\ 0 & \text{otherwise} \end{cases} \\ v_{NW} = \begin{cases} \hat{t}_{NW} \left(\beta'_{v_{NW}} X_{v_{NW}} + \alpha_{v_{NW}} \lambda_i \right) + \xi_{v_{NW}}, & \text{if } t_{NW} > 0 \\ 0 & \text{otherwise} \end{cases} \\ n_C = \left(\hat{v}_{NW} + v_W \right)\left(\beta'_{n_C} X_{n_C} \right) + \xi_{n_C} \\ t_T = \begin{cases} \hat{n}_C \left(\beta'^{(1)}_{t_T} X^{(1)}_{t_T} \right) + \xi_{t_T} & \text{if } v_{NW} = 0 \text{ and } v_W = 1 \\ \left(\hat{v}_{NW} + v_W + \hat{n}_C \right)\left(\beta'^{(2)}_{t_T} X^{(2)}_{t_T} \right) + \xi_{t_T} & \text{if } v_{NW} > 0 \text{ and } v_W \geq 1 \text{ or if } v_{NW} = 0 \text{ and } v_W > 1 \end{cases} \end{cases} \tag{5.8}$$

The model system is estimated for auto commuters and transit commuters separately. The characteristics of commute trip mode choice in the study area are examined by developing a nested logit model of trip making and commute mode choice which indicates the probability that a commuter will use the automobile. However, since the commuters' trip making generation as well as mode choice behavior is not the scope of this chapter, the discussion of the results of the nested logit model, as well as its stability test, are described in Appendix C.2. A brief summary of estimation results is presented below.

The coefficient estimates offer an expected indication that male workers use the automobile for commuting with larger probabilities than do their female counterparts. In addition, both the number of automobiles per adult household member and driver's license holding positively influence automobile use for commuting consistently over the years. Also, there is a clear indication that work zone accessibility to retail opportunities negatively affects auto use for commuting; a worker commuting to a more commercialized area tends not to use the automobile. The presence of children encourages workers to use the automobile to commute, possibly because commuting by auto makes it easier to make chauffeuring and other non-work trips that the presence of children generates.

Behavioral hypotheses

As the more available opportunities for activity engagement as well as better accessibility that is provided, the individual activity and travel engagements will continuously expand. However, the changes are expected to be different between workers and non-workers. The loose constraint of out-of-home activity and travel allow the non-workers to expand their activity and travel engagements without any restraints. On the other hand, workers' expanding pattern will be highly influenced by their working environment as well as their commuting conditions.

The duration of commute trips to and from work and the total work duration directly influence the amount of discretionary time that can be allocated to non-work activities. At the same time, commuting brings the worker closer to non-work opportunities along the commute route and around the work location. These opportunities can be reached with little extra travel time beyond that spent for commuting to and from work. This enhanced accessibility may imply that a worker with a longer commute tends to pursue activities more frequently and at more locations. Then, commute time would positively influence non-work activity time, offsetting, at least partially, its negative effect on time availability. One would also expect that a high level of accessibility at the work location will prompt more frequent activity engagement and will positively contribute to the amount of non-work activity time. This would be the case with the home location as well.

Visits to pursue out-of-home activities are organized into trip chains that determine the origin, destination and sequence of each trip to be made, and hence the amount of time required to travel, given the mode of travel. One would expect that a worker with a longer commute tends to visit locations on the way to or from work, i.e., more trip chaining or fewer trip chains given the number of visits. A worker with a shorter commute, on the other hand, may tend to make a separate home-based trip chain after work because he is subjected to looser time constraints. Accessibility, either at the work location or home base, is expected to encourage trip chaining because higher accessibility implies more opportunities in close proximity, which will prompt the traveler to combine more visits and trips into fewer chains.

The effects of commuting on travel are expected to be different between auto commuters and transit commuters. For auto commuters, the commute time could positively influence the number of visits. It can also be postulated that the number of visits will be positively influenced by the accessibility to opportunities at the work location as well as at the home base. An auto commuter is more likely to visit more locations for non-work activities because the automobile is more suited for chained trips. Indeed, it has been often observed that auto users tend to chain trips, combining more visits into one trip chain. A competing hypothesis is that a transit commuter (primarily rail commuters in the study area) is more likely to visit more non-work locations because railroad stations, especially terminals, provide superb access to a number of non-work opportunities in Japanese urban areas, including the Osaka metropolitan area. In fact the results of marginal tabulation presented in Table 5.2 have indicated that transit commuters are more likely to pursue non-work activities and chain trips than auto commuters in the study area. This is examined further while taking person attributes and other contributing factors into account.

The illustration of the hypotheses between commuters' activities and travel parameters can be seen at Figure 5.3.

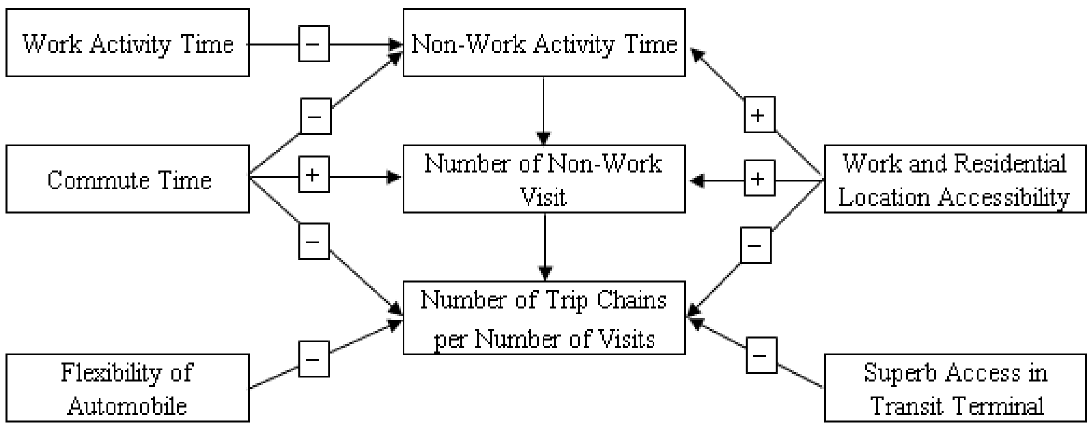


FIGURE 5.3 Behavioral Hypotheses among Commuters' Activities and Travel Parameters

5.4 Analysis with the Simultaneous Equations Model Systems

Results of estimating the simultaneous equations model system offer many insights into urban residents' travel and activity engagement, and reveal certain differences between non-worker and commuter as well as between auto and transit commuters.

Estimation results

The simultaneous equations model system for time expenditure for non-work activities (t_{NW}), number of non-work visits (v_{NW}), number of trip chains (n_C), and total travel time expenditure

(t_T) is estimated separately for non-workers, auto commuters and transit commuters based on sub-samples from the data sets. Coefficient estimates and goodness-of-fit statistics are presented in Appendices D, E and F for non-workers, auto commuters and transit commuters, respectively. Generally, since non-workers' activities are more discretionary than commuters, non-workers models have lower the coefficient of determination (R^2) than commuters'. Salient results are as follows.

Time Expenditure for Non-work Activities (t_{NW}): Non-workers' time expenditure for activities are highly influence by the trip modes. Non-worker transit users are spending more time for out-of-home activities than auto users and non-motorized users.

For both auto and transit commuters, work duration has significant negative influences on time expenditure for non-work activities (but not for auto commuters' model of 1980). The coefficient estimates for auto commuters indicate that an increase of work duration by a minute implied a decrease of non-work activity time by 0.05 minute in 1980, 0.13 minute in 1990 and 0.22 minute in 2000. Corresponding values for transit commuters are: 0.84 minute in 1980, 0.28 minute in 1990 and 0.53 minute in 2000.

Estimation results show males tend to spend more time on non-work activities than do females. The presence of dependent children reduces the commuters' available expenditure time for non-work activities. On the contrary, since non-workers have loose time constraint to engage in activities, there is no significant influence of dependent children to their expenditure time for activities. There are indications that older commuters, especially transit commuters, tend to spend less time on non-work activities.

No clear effects are evident of driver's license holding, commute trip distance or residence and workplace accessibility.

The coefficients of selectivity correction error term parameter have significant negative influence on time expenditure for non-work activities. The significance of selectivity correction parameter shows a strong indication that the sample selectivity is playing a role because the hypothesis of no selectivity bias is rejected with over 99% confidence as indicated by the t statistics. The implication is that the model is seriously misspecified when the selectivity bias term is omitted (Washington et. al, 2003). The negative value means that, without using the selectivity correction error term, the model will provide higher estimation of expenditure time for non-work activities than condition where the sample is not in truncated condition.

Number of Non-Work Visits (v_{NW}): As Eq. (5.3) and Eq. (5.5) indicate, the model predicts the number of non-work visits given the amount of time spent for non-work activities, and a model coefficient indicates the effect of a unit change in the explanatory variable value on the number of non-work visits *per* unit time allocated to non-work activities.

Non-workers model show that, among non-workers, transit users tend to have fewer non-work visits per unit non-work activity time compared with auto and non-motorized non-workers, i.e., transit non-workers tend to have a longer average duration per visit.

There are indications that older non-workers tend to have fewer non-work visits per unit non-work activity time. Male non-workers and transit commuters tend to have fewer non-work visits per unit non-work activity time compared with their counterpart, i.e., male tend to have a longer average duration per visit.

The number of transit commuters' non-work visits is negatively influenced by the number of household members and by the number of automobiles available per adult household member. This may be a result of intra-household task allocation; fewer household tasks are assigned to a transit commuter in a household with more automobiles or with more members because the tasks can be performed by other members, possibly using a household automobile. The ownership of driver license increases non-workers' number of visits and the availability of automobile reduces it. The presence of dependent children, on the other hand, positively contributes to transit commuters' non-work visits.

The availability of opportunities around a home location, which is presented by residential area type, influence the transit commuters' (except in 1990 model) and non-workers' number of non-work visits. Transit commuters who reside in satellite cities tend to have more non-work visits than those in the other areas. On the other hand, transit commuters who reside in un-urbanized area tend to have fewer non-work visits than those in the other areas.

In every model estimated, the coefficient of determination (R^2) is much smaller than that of the corresponding model for time expenditure for non-work activities. Most of all variables in auto commuters' model are not significant.

The selectivity bias term is not significant, especially for transit commuters. It shows that the number of non-work visits model of the selected sample ($t_{NW} > 0$) has already represents the sample's population and does not need selectivity bias correction error term to improve the result of commuters' model.

Number of Trip Chains (n_C): The model predicts the number of trip chain per visit. Thus a larger coefficient estimate implies more trip chains and therefore less combining of trips, given the total number of visits.

Given the number of visits, non-workers who use transit as their trip mode tend to have fewer trip chains than auto and non-motorized non-workers.

The presence of dependent children has a significant positive influence on the number of trip chains consistently for both non-workers and commuters, except for the 1980 model for auto commuters. The number of trip chains for auto users is positively influenced by the number of household members. Given the number of visits, commuters from larger households tend to have more trip chains, each having fewer visits. It may be the case that intra-household interactions in larger households tend to inhibit trip chaining, e.g., one returns home from work first to join household members before engaging in a social activity, instead of directly traveling from work to the social activity.

The number of cars per adult household member has opposite influences on the number of trip chains between commuters and non-workers. The commonly held belief that the automobile is more suitable to trip chaining and auto drivers are more likely to combine visits into multi-visit trip chains works only in non-workers travel pattern. This result, which is consistent with those of Table 5.2, suggests that, given the number of total visits, auto commuters tend to have more trip chains with a fewer average number of visits per trip chain.

This, however, may be unique to dense and mixed land use developments in Japanese urban areas where commercial establishments concentrated around rail stations offer excellent opportunities for chained non-work activity engagement (see Kondo and Nishii, 1992).

The coefficient estimates of commute distance are significantly negative, indicating that those with longer commutes tend to combine a given number of visits into fewer trip chains. This may be an indication that commuting brings commuters closer to opportunities, prompting chained activity engagement. At the same time, it can be interpreted as an indication that the limited time availability resulting from a longer commute encourages the commuter to adopt an efficient travel pattern with more trip chaining.

Male commuters tend to have fewer trip chains per visit, but not in model of 1980. The availability of opportunities around home location, which presented by residential area type, has significant influence to the number of trip chain as well, e.g. non-workers who reside in central area (CBD) tend to have more trip chains per visits.

Total Travel Time (t_T): The model predicts the total time expenditure for travel in a given day. Thus a larger coefficient estimate implies more time spent for travel, given the total number of visits and trip chains in a given day.

For both commuters and non-workers, given the number of visits and trip chains, male travelers tend to have more travel time than their female counterparts.

Non-workers' total travel time is negatively influenced by the number of household members and by the number of automobiles available per adult household member and is positively influenced by the ownership of driver license. This may be a result of intra-household task allocation; fewer household tasks are assigned to each member in a household with more automobiles or with more members because the tasks can be performed by other members, possibly using a household automobile.

Given the number of visits and trip chains, non-workers who use transit as their trip mode tend to spend more time to travel than auto and non-motorized non-workers.

Especially for Simple Commuters ($t_{T\ SIMPLE}$): Commute distance has predominant positive influences on total travel time expenditure, for both auto commuters and transit commuters, for the obvious reason that commute distance is roughly proportional to commute time.[12] High accessibility from workplace to population positively influences total travel time expenditure, while car availability have negative influences. The presence of dependent children negatively influences transit commuters' total travel time expenditures, while the number of household members negatively influences auto commuters' total travel time expenditures. Male transit commuters tend to have larger total travel time expenditures.

Especially for Complex Commuters ($t_{T\ COMPLEX}$): Interestingly, the model for complex commutes tends to have similar significant coefficients as the model for simple commutes, with slightly weaker statistical indications. This suggests that commuters' total travel time is determined largely by the commute trip time between home and work, and engagement in non-work activities does not influence it substantially.

[12] Recall that commute distance (d_X) is considered to be pre-determined.

5.5 The Stability of Urban Residents' Activity and Travel

Differences in the coefficient vectors and the stability of activity and travel patterns are examined with the model system while applying the following methods:

1. by statistically testing the hypothesis that the model coefficients have not changed their values over the years as a whole by applying *F*-test,
2. by predicting the values of the endogenous variables using the coefficient estimates from 1980, 1990 and 2000, on data from 1980, 1990 and 2000, and
3. by predicting the values of the endogenous variables on the data from 1980, 1990 and 2000, using the coefficient estimates from 1980, 1990, and 2000.

The first method offers statistical indications of behavioral stability as represented by the model coefficients. Let Ψ_y be the coefficient vector for year *y*. The hypothesis tested in the first method is

$$\mathrm{H}_0: \ \Psi_y = \Psi_{y'}, \quad y, y' = 1980,\ 1990,\ 2000, \quad y \neq y'.$$

Estimates of the coefficient vectors, $\hat{\Psi}_y$, y = 1980, 1990, 2000, are used in the test. This method offers statistical indications of behavioral stability as represented by the model coefficients.

The second method indicates structural change in behavior over time as reflected in the value of the endogenous variable. Let a model equation in the model system be denoted by $\bar{q} = g(\bar{X}_y : \Psi_{y'})$, where $\bar{q}$ is the endogenous variable, $\bar{X}_y$ is the vector of mean explanatory variable values for year *y*. Let

$$\bar{q}_{y:80} = g(\bar{X}_y : \Psi_{1980}),\ \bar{q}_{y:90} = g(\bar{X}_y : \Psi_{1990}),\ \bar{q}_{y:00} = g(\bar{X}_y : \Psi_{2000})$$

for *y* = 1980, 1990 and 2000. In this methods, the equality among $\bar{q}_{y:80}$, $\bar{q}_{y:90}$ and $\bar{q}_{y:00}$ is inspected. It shows how the behavior of an urban resident of a given set of attributes, living in a certain area and having a certain level of accessibility, has changed over time due to structural change as represented by the change in Ψ_y.

The third method, on the other hand, indicates how changes in the characteristics of urban area and residents have prompted changes in behavior. Let

$$\bar{q}_{80:y} = g(\bar{X}_{1980} : \Psi_y),\ \bar{q}_{90:y} = g(\bar{X}_{1990} : \Psi_y),\ \bar{q}_{00:y} = g(\bar{X}_{2000} : \Psi_y)$$

for *y* = 1980, 1990 and 2000. The equality among $\bar{q}_{80:y}$, $\bar{q}_{90:y}$ and $\bar{q}_{00:y}$ is inspected here.

As an additional, the pair wise comparison of the model's parameters also provided in order to describe the stability of each parameter of the model.

Results of *F*-test (Table 5.3) indicate that the model coefficients are highly unstable and are not transferable over time for both non-workers and commuters.

TABLE 5.3 Temporal Stability of Model Coefficients for Urban Residents

a. Results of *F*-tests: Non-workers

	1980, 1990 vs. 2000	1990 vs. 2000	1980 vs. 2000	1980 vs. 1990
t_{NW}	4.13 ** (36, 17381)	1.31 (18, 12059)	7.35 ** (18, 11995)	3.69 ** (18, 10708)
n_{nwv}	7.87 ** (36, 17381)	6.31 ** (18, 12059)	10.95 ** (18, 11995)	6.61 ** (18, 10708)
n_C	3.85 ** (36, 17381)	3.96 ** (18, 12059)	4.21 ** (18, 11995)	3.42 ** (18, 10708)
t_T	10.17 ** (36, 17381)	2.28 * (18, 12059)	10.87 ** (18, 11995)	15.82 ** (18, 10708)

(n, d): degrees of freedom (numerator, denominator)
* = significantly different at α = 0.05 , ** = significantly different at α = 0.01

b. Results of *F*-tests: Auto Commuters

	1980, 1990 vs. 2000	1990 vs. 2000	1980 vs. 2000	1980 vs. 1990
t_{NW}	4.02 ** (42, 1652)	3.01 ** (21, 1197)	5.43 ** (21, 1155)	3.62 ** (21, 952)
n_{nwv}	1.15 (38, 1652)	1.22 (19, 1197)	1.47 (19, 1155)	0.51 (19, 952)
n_C	28.02 ** (36, 9964)	3.09 ** (18, 7071)	30.83 ** (18, 6452)	53.08 ** (18, 6405)
$t_{T\ SIMPLE}$	5.56 ** (36, 8018)	5.76 ** (18, 5674)	4.23 ** (18, 5094)	3.58 ** (18, 5268)
$t_{T\ COMPLEX}$	1.98 * (36, 1946)	1.92 * (18, 1397)	2.27 * (18, 1358)	0.73 (18, 1137)

(n, d): degrees of freedom (numerator, denominator)
* = significantly different at α = 0.05 , ** = significantly different at α = 0.01

c. Results of F-tests: Transit Commuters

	1980, 1990 vs. 2000	1990 vs. 2000	1980 vs. 2000	1980 vs. 1990
t_{NW}	8.49 ** (42, 4675)	2.87 ** (21, 3184)	9.72 ** (21, 3097)	10.84 ** (21, 3069)
n_{nwv}	2.46 ** (38, 4675)	3.17 ** (19, 3184)	2.68 ** (19, 3097)	0.88 (19, 3069)
n_C	109.73 ** (36, 19214)	5.76 ** (18, 12907)	127.84 ** (18, 12441)	178.68 ** (18, 13080)
$t_{T\ SIMPLE}$	15.25 ** (36, 14182)	18.35 ** (18, 9476)	9.95 ** (18, 9096)	17.05 ** (18, 9792)
$t_{T\ COMPLEX}$	4.39 ** (36, 5032)	5.25 ** (18, 3431)	5.38 ** (18, 3345)	2.35 * (18, 3288)

(n, d): degrees of freedom (numerator, denominator)
* = significantly different at α = 0.05 , ** = significantly different at α = 0.01

Table 5.3 indicates that, except for auto commuters' models of non-work visits (v_{NW}) and auto commuters' models total travel time expenditure for complex commuters ($t_{T\ COMPLEX}$), the models of out-of-home activity time (t_{NW}), number of non-work visits (v_{NW}), number of trip chains (n_C) and several models of total travel time expenditure (t_T) are not stable between any combinations of years. Most of the differences in model coefficient vectors are significant at $\alpha = 0.01$. The pair-wise test of model coefficients (shown on Appendix G) also indicates that most of the models' coefficients, especially for transit commuters' and non-workers', are not stable between any combinations of years.

The auto commuters' models of number of non-work visits (v_{NW}) seems to be stable and transferable presumably because of the model is under-specified; v_{NW} model, have very low coefficient of determination (R^2) and less significant variables. The models that have a better specification, in the sense that have more significant variables (i.e. t_{NW} and n_C) with better coefficient of determination, are not transferable over periods (Badoe and Miller, 1995). This result proves that the rapid changing of travel environment shapes the individual's socio and demographic conditions dynamically, which make the behavior continuously evolving and not transferable.

Although both are unstable, the auto commuters offer smaller F-values between periods than do transit commuters; auto commuters have more stable patterns over time than do transit commuters. Presumably, workers who use private automobiles for their daily commutes are less affected by changes in the travel environment over time because of the flexibility the automobiles offer which makes their travel more independent of the travel environment. On the other hand, transit commuters whose travel is bounded by the service offered by public transit tend to show travel patterns that change as transit service level and travel environment changes.

To separate the effects of variations in coefficient vectors and those in explanatory variable values on the four indices of activity and travel, the 1980, 1990 and 2000 mean explanatory variable values are input to the respective models to compute index values with the estimated 1980, 1990 and 2000 coefficient vectors. The results are summarized in Table 5.4 for non-workers, Table 5.5 for auto commuters and Table 5.6 for transit commuters

Section b of Table 5.4, Table 5.5 and Table 5.6 shows the impact of changes in mean explanatory variable values under the three coefficient vectors. In other words, it shows the impact of changes in the demographic, socio-economic and accessibility variables by themselves without any changes in the structural relationships underlying activity engagement and travel. Section c of the tables shows the impact of changes in mean coefficient vectors values, i.e., it shows the impact of changes in the structural relationships by themselves without any changes in the demographic, socio-economic and accessibility variables.

TABLE 5.4 Travel Indices Produced with 1980, 1990, 2000 Coefficient Vectors at 1980, 1990, 2000 Mean Explanatory Variable Values for Non-Workers

a. Travel Index Values

	Coefficient Vector											
	t_{NW}			v_{NW}			n_C			t_T		
Data	1980	1990	2000	1980	1990	2000	1980	1990	2000	1980	1990	2000
1980	89.6	105.5	113.5	1.362	1.200	1.332	1.203	1.177	1.188	34.9	39.3	41.0
1990	97.0	111.4	118.7	1.437	1.445	1.508	1.198	1.204	1.204	35.1	41.4	42.9
2000	105.4	122.4	127.1	1.523	1.513	1.584	1.207	1.192	1.216	39.9	45.7	46.1

b. Change in Travel Indices due to Change in Explanatory Variable Values (value with 1980 data = 100)

	Coefficient Vector											
	t_{NW}			v_{NW}			n_C			t_T		
Data	1980	1990	2000	1980	1990	2000	1980	1990	2000	1980	1990	2000
1980	100	100	100	100	100	100	100	100	100	100	100	100
1990	108.2	105.6	104.6	105.5	120.5	113.3	99.6	102.3	101.3	100.5	105.3	104.5
2000	117.6	116.0	111.9	111.8	126.1	119.0	100.4	101.2	102.3	114.2	116.4	112.4

c. Change in Travel Indices due to Change in Coefficient Vector (value with 1980 coefficient vector = 100)

	Coefficient Vector											
	t_{NW}			v_{NW}			n_C			t_T		
Data	1980	1990	2000	1980	1990	2000	1980	1990	2000	1980	1990	2000
1980	100	117.7	126.7	100	88.1	97.8	100	97.9	98.8	100	112.5	117.5
1990	100	114.9	122.4	100	100.6	105.0	100	100.5	100.5	100	117.8	122.2
2000	100	116.1	120.6	100	99.3	104.0	100	98.7	100.7	100	114.6	115.5

TABLE 5.5 Travel Indices Produced with 1980, 1990, 2000 Coefficient Vectors at 1980, 1990, 2000 Mean Explanatory Variable Values for Auto Commuters

a. Travel Index Values

	Coefficient Vector														
	t_{NW}			v_{NW}			n_C			$t_{T\ SIMPLE}$			$t_{T\ COMPLEX}$		
Data	1980	1990	2000	1980	1990	2000	1980	1990	2000	1980	1990	2000	1980	1990	2000
1980	170.4	193.8	149.0	1.156	1.193	1.259	1.109	1.037	1.043	49.6	54.8	51.6	67.3	69.9	69.5
1990	144.5	172.7	145.5	1.145	1.185	1.253	1.112	1.041	1.048	53.1	56.6	54.4	71.8	76.1	74.4
2000	114.1	147.7	115.4	1.169	1.191	1.290	1.160	1.055	1.070	56.7	62.2	56.2	71.5	75.4	72.4

b. Change in Travel Indices due to Change in Explanatory Variable Values (value with 1980 data = 100)

	Coefficient Vector														
	t_{NW}			v_{NW}			n_C			$t_{T\ SIMPLE}$			$t_{T\ COMPLEX}$		
Data	1980	1990	2000	1980	1990	2000	1980	1990	2000	1980	1990	2000	1980	1990	2000
1980	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
1990	84.8	89.1	97.7	99.1	99.3	99.6	100.2	100.4	100.5	107.1	103.4	105.5	106.7	108.8	107.1
2000	66.9	76.2	77.5	101.2	99.8	102.5	104.6	101.8	102.6	114.4	113.5	109.0	106.2	107.9	104.2

c. Change in Travel Indices due to Change in Coefficient Vector (value with 1980 coefficient vector = 100)

	Coefficient Vector														
	t_{NW}			v_{NW}			n_C			$t_{T\ SIMPLE}$			$t_{T\ COMPLEX}$		
Data	1980	1990	2000	1980	1990	2000	1980	1990	2000	1980	1990	2000	1980	1990	2000
1980	100	113.7	87.4	100	103.2	108.9	100	93.5	94.0	100	110.5	104.1	100	103.9	103.2
1990	100	119.5	100.7	100	103.5	109.4	100	93.6	94.3	100	106.7	102.5	100	105.9	103.6
2000	100	129.5	101.2	100	101.8	110.3	100	91.0	92.3	100	109.6	99.2	100	105.5	101.3

TABLE 5.6 Travel Indices Produced with 1980, 1990, 2000 Coefficient Vectors at 1980, 1990, 2000 Mean Explanatory Variable Values for Transit Commuters

a. Travel Index Values

	Coefficient Vector														
	t_{NW}			v_{NW}			n_C			$t_{T\ SIMPLE}$			$t_{T\ COMPLEX}$		
Data	1980	1990	2000	1980	1990	2000	1980	1990	2000	1980	1990	2000	1980	1990	2000
1980	193.6	180.7	161.3	1.223	1.262	1.343	1.179	1.058	1.063	68.1	76.0	65.7	81.6	91.2	83.0
1990	169.0	177.9	166.5	1.206	1.210	1.330	1.218	1.068	1.082	64.4	71.3	62.0	76.9	86.1	78.0
2000	130.3	147.6	144.5	1.216	1.221	1.327	1.294	1.072	1.088	65.4	75.5	65.5	75.9	89.6	74.6

b. Change in Travel Indices due to Change in Explanatory Variable Values (value with 1980 data = 100)

	Coefficient Vector														
	t_{NW}			v_{NW}			n_C			$t_{T\ SIMPLE}$			$t_{T\ COMPLEX}$		
Data	1980	1990	2000	1980	1990	2000	1980	1990	2000	1980	1990	2000	1980	1990	2000
1980	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
1990	87.3	98.5	103.2	98.6	95.9	99.0	103.3	101.0	101.8	94.6	93.8	94.3	94.3	94.5	94.0
2000	67.3	81.7	89.6	99.5	96.8	98.8	109.7	101.3	102.4	96.1	99.3	99.7	93.0	98.2	89.9

c. Change in Travel Indices due to Change in Coefficient Vector (value with 1980 coefficient vector = 100)

	Coefficient Vector														
	t_{NW}			v_{NW}			n_C			$t_{T\ SIMPLE}$			$t_{T\ COMPLEX}$		
Data	1980	1990	2000	1980	1990	2000	1980	1990	2000	1980	1990	2000	1980	1990	2000
1980	100	93.3	83.3	100	103.2	109.9	100	89.7	90.2	100	111.6	96.5	100	111.8	101.8
1990	100	105.3	98.5	100	100.4	110.3	100	87.7	88.8	100	110.6	96.2	100	112.0	101.4
2000	100	113.2	110.9	100	100.4	109.1	100	82.8	84.1	100	115.3	100.1	100	118.1	98.4

Table 5.4 for non-workers indicates the following.

- The diagonal elements of section a of the table indicate that, from 1980 to 2000, all of non-workers' travel and activity indices have been constantly increase.
- Section b shows that the expenditure time for non-work activity (t_{NW}), number of non-work visits (v_{NW}), number of trip chains (n_C) and travel time expenditure (t_T) increased consistently from 1980 to 2000 due to changes in the demographic, socio-economic and accessibility variables. However, the increasing rates differ for each index. The time expenditure for non-work activity increased more than 10% under any of the three coefficient vectors. It may be inferred that demographic, socio-economic and accessibilities indices changes between 1980 and 2000 by themselves induced an increase of over 10% in time expenditure for non-work activity. They have also resulted more than 11 % increases in number of non-work visits, at least 12 % increases in total travel time expenditure, and slight increases in number of trip chains.
- The coefficient vectors also have changed over time in the direction of increasing the values of the respective travel indices (see section c). Regardless of the year of the data, the values of the respective travel indices increase with the year of the coefficient vector. The rate of increase is more than 20% for t_{NW}, up to 5% for v_{NW}, over 15% for t_T and relative stable for n_C. The estimated coefficient vectors embody the tendencies that the aspects of activity and travel represented by the four indices have been increasing between 1980 and 2000; the levels of out-of-home activity engagement and travel would have expanded during the two decades even when no changes had taken place in demographic and socio-economic characteristics in the study area. For example, even if vehicle ownership and driver's license holding had not increased between 1980 and 2000, activity engagement and travel would still have expanded.

Table 5.5 for auto commuters indicates the following.

- The diagonal elements of Section a of the table indicate that the time spent for non-work activities has continuously decreased. On the other hand, the number of non-work visits has constantly increased.
- Section b shows that the number of trip chains and travel time expenditure have increased consistently from 1980 to 2000 due to changes in the demographic, socio-economic and accessibility variables. The total travel time for simple commuters increased around 10% under any of the three coefficient vectors. In other words, changes in demographics, socio-economics and accessibilities indices between 1980 and 2000 by themselves have induced an increase of over 10% in total travel time expenditure. Similar tendencies can be found for complex commuters, but to lesser extents. The results also show that, despite the changes in demographics, socio-economics and accessibilities indices, the number of non-work visits has tended to be stable and the time expenditure for non-work activities has decreased by 30 % between 1980 and 2000.
- Although there are some irregularities, section c shows that the number of non-work visits as well as time expenditure for non-work activities and total travel time have tended to increase with coefficient vectors of later years. The levels of out-of-home activity engagement and travel would have expanded due to changes in the structural relationships, even when no changes had taken place in demographics, socio-economics and accessibility indices in the study area.

For the transit commuters, Table 5.6 offers the following.

- The diagonal elements of Section a indicate that the time expenditure for non-work activities has constantly decreased between 1980 and 2000.

- Section b shows that the number of trip chains increased by about 4% and the time expenditure for non-work activities decreased by about 20% between 1980 and 2000 due to changes in the mean explanatory variable values, under any of the three coefficient vectors. For the other indices of activity engagement and travel, however, no consistent tendencies can be observed, although their values tend to decrease in 1990 and increase again in 2000.
- The time expenditure indices (t_{NW} and t_T) increased in 1990 and decreased in 2000 as the coefficient vectors change their values over time (Section c). In contrast, the number of trip chains decreased in 1990 and increased in 2000. The number of non-work visits consistently increased over the study period due to changes in the structural relationships.

The analysis has shown that, in the last 20 years, urban travelers have continuously expanded their activity and travel engagements. As the hypothesis of the study, with the more available opportunities for activity engagement as well as the better accessibility that provided, the individual activity and travel engagements will be continuously expanding.

However, while non-workers are able to expand their activity and travel engagements constantly, the workers' expansion rates are highly limited by their working and travel environment conditions. In the last 20 years, the commuters has continuously reduced their expenditure time for non-work activities and developed effective travel pattern with pursuing a constant increase in the number of non-work visits. The commuters' total travel time only increased slightly. The irregular patterns that occur in a commuters' expansion pattern are presumed to be caused by the burst of economic conditions in the Osaka metropolitan area in early 1990 and followed by the Asian economic crisis in the late 1990. Considering the fact that Japanese economy contracted between 1990 and 2000, the expansion in travel indicated in this analysis is noteworthy.

The statistical results in Tables 5.4 – 5.6 show that the structural relationships underlying urban travelers' activity and travel have not been stable over time.

Comparing the results for commuters, the auto commuters' structural relationships have changed to expand their out-of-home activity and travel. It is also clear that for auto commuters, the structural relationships have changed to expand their out-of-home activity and travel. This tendency, combined with changes in individual and household attributes which also contributed to the expansion of activity and travel, has produced the increases in the number of visits for non-work activities, number of trip chains, and total travel time expenditure. On the other hand, while also exhibiting tendencies to expand the activity engagement, transit commuters' total travel time expenditure tend to be stable over time. Both types of commuters have tended to make their trip patterns more effective over the 20-year period by making more non-work visits with less time spent for activities and with fewer trip chains.

5.6 Summary

Using the results of household travel surveys conducted in 1980, 1990 and 2000 in the Osaka metropolitan area of Japan, supplemented with demographic, land use, and network data, this study has attempted to examine how changes over time in demographic and socio-economic attributes and in the travel environment in the region have impacted urban travelers' activity-travel patterns. The study has adopted a holistic approach by exploring the stability in structural relationships underlying several of the most pertinent indices of activity engagement and travel, using structural equations model systems.

The study has shown that the urban residents have expanded their travel and activities engagement over the 20–year period in the Osaka metropolitan area. The structural relationships underlying their activity-travel patterns were not stable over time, and non-workers, auto commuters and transit commuters exhibit different tendencies of change.

Since non-workers are not constrained by out-of-home commitments and their daily activities are only influenced by their in-home conditions, in the last 20 years, non-workers are able to expand their activity and travel engagements constantly. On the other hand, commuters' ability to expand their activity and travel patterns is constrained and influenced by their work conditions as well as their travel environments.

Auto commuters, who have larger extents of flexibility in adapting to changes in the travel environment, have consistently increased the number of non-work visits, trip chains and total travel time. Throughout the period of economic boom between 1980 and 1990, then the contraction of economy between 1990 and 2000, they expanded their travel and activity engagement. On the other hand, transit commuters, who do not have the same level of flexibility in arranging their travel patterns as auto commuters, tended to have stable total travel time. They nonetheless show the tendency to expand non-work activity engagement over the period. Both types of commuters have constantly developed their trip patterns to be more effective over the 20-year period by making more non-work visits with less time spent for activity and with fewer trip chains.

The statistical test of this study has revealed that only under-specified models are transferable over periods. None of the models that were developed in this study and fit well to the data from a period turned out to be transferable to another period. Salient associations in observed travel relationships do not seem to be stable over time. The structural relationships underlying travel may be inherently transient. The rapid changes to the travel environment shape the individual's socio and demographic conditions dynamically, which makes the behavior continuously evolving and not transferable over time.

This chapter has shown that, in long term period, the individual behavior is not transferable. The pattern changes between individuals are different. The incremental rate for each travel and activity indices are different. These findings proved that, ignoring the individual adaptation processes in travel and activity over time as well as analyzing the travel processes separately will lead to bias descriptions as well as overestimated results which may result in inappropriate policy and planning decisions.

Moreover, this results show that, in the Osaka metropolitan area, the urban residents have expanded their travel and activities engagement over the 20–year period. The structural relationships underlying their activity-travel patterns were not stable over time. However, though individual's activity and travel parameters are expanding, the changes of their action space are largely unknown

In Chapter 6, with the concept of second moment of activity locations developed in Chapter 4, the changes of individual's action space in the Osaka metropolitan area over long period are examined. It is expected that, since the urban residents in the Osaka metropolitan area have expanded their travel and activities engagement over the 20–year period, their action space will expand as well.

Chapter 6
The Changes of Individual Action Space for a Long Time Span

With the concept of second moment that developed in Chapter 4 and using the sub-sample of the Osaka metropolitan area person-trip data, this chapter examines the changes and stability of individual's action space over a long span period. The aim is to determine empirically whether there exist invariants in urban residents' activity space through the period when the urban area underwent substantial changes; and to infer general principles that govern changes in urban residents' action space. Using tobit models, the model systems of action space indices are developed and a statistical approach is taken in order to test the stability of the model systems.

The next section offers a brief overview about the changes of action space overtime, the further development of the concept of second moments of activity locations as well as the model systems and the behavioral hypotheses. After that, the description of the used samples and the descriptive statistics of the second moment values are presented. The result of model estimation is discussed and the stability analysis of the individuals' action space is presented. The chapter is concluded with a summary of results.

6.1 The Changes of Action Space over Long Period

The era of full-fledged motorization and over-populated city centers prompted the process of rapid suburbanization after World War II. The trend of motorization and suburbanization has greatly affected the way people travel (e.g. Cohen and Kocis, 1980; Kollo and Purvis, 1984; Levinson and Kumar, 1994). In particular, the greater separation of job and residence that resulted in the early stage of suburbanization, when only residences moved out to the suburbs, made commute trips more substantial elements of daily travel.

Motorization and suburbanization trends have produced urban forms with spread-out opportunities and less essential city centers. Activity locations of suburban residents, including commuters, has shift away from city center towards places that are more accessible for them. These changes have induced changes in the way trips are made; changes in trip destinations caused by changes in accessibility may prompt changes in travel mode or patterns of trip chaining, for example.[13]

In addition to motorization and suburbanization that have fundamentally changed the travel environment of metropolitan residents, the demographic and socio-economic composition has changed substantially in many areas (e.g., Cervero, 1986; Roberts, 1986; van Beek et al., 1986; Fukui, 2003; Kitamura et al., 2003). For example, the fraction of women in the labor force has increased substantially, while the household size has decreased, and the population has been aging in metropolitan areas of many developed countries

Although in last three decades the constraints travel over time, as well as the urban form in many metropolitan areas has significantly changed, how the individual's action space change over a long-time span is largely unknown. This chapter examines the changes and stability of individual's action space over a long span period. The aim is to determine empirically whether there exist invariants in urban residents' activity space through the period when the urban area underwent substantial changes; and to infer general principles that govern changes in urban residents' action space.

The action space in this study is analyzed based on the representation of the extension of action space by the second moment of activity locations it contains (see Chapter 4 for more description about the concept of second moment). The data are using the sub-sample of conventional large-scale household travel surveys conducted in the Osaka metropolitan area of Japan (see Chapter 3).

6.2 Modeling the System of the Second Moments

In this study, the action space of an individual is represented by the second moment of the out-of-home activity locations it contains (see Chapter 4). However, in order to distinguish the simple trip makers from complex trip ones[14] according to the different behavior and adaptation processes over time, the relationship between second moment indices is further developed.

The Relationships of I_H and I_C.

The relationships of individual's I_H and I_C value are assumed to be different between workers and non-workers as well as between simple trip makers and complex trip makers. Simple trip makers' (N = 1, see Figure 4.1) moment value only depends on $I_H = L^2$ and $I_C = 0$. On the other hand, complex trip makers have I_C and I_H values that correlated each other. The

[13] A trip chain is defined in this study as a series of trips that starts, and ends, at the home base in which one or more destinations are visited.

[14] Simple-trip makers refer to individuals who make exactly two trips to one out-of-home activity location on a given day; their I_C equals 0. Complex-trip makers are those who make more than two trips on a given day, visiting more than one out-of-home activity location.

correlation of those two indices is presumed to depend on their pegs of commitment locations as well as on their daily routine activities (i.e. worker, student or non-worker) (Pred, 1977).

It is evident that individual's action space is defined primarily by their residential and obligation locations and other activities are located around those two locations (Pred, 1977; Cullen & Godson, 1975; Golledge and Stimpson, 1997). Since to the obligations locations tend to be fixed and individual's non-work activity locations lie between obligation and residential locations, the daily individual's travel area orientation would not vary over time.

I_H, as the representation of distance from activity's center location to home locations, can be assumed as a representation of daily individual's travel area orientation that tends to be fixed. With a six-week continuous travel diary data, the results in Chapter 4 have showed that the within-person variation of I_H value tends to be stable in weekdays.

Moreover, it is reasonable to assume that individual with obligatory trip pattern (like worker and student) decides his or her travel area orientation first before deciding the location of his non-work activity locations based on his available resources (e.g. time left to engage in non-work activity, available mode, etc.). The I_H values will be influenced by commute distance and will not be influenced by values of I_C – workers will travel and make activity engagement at their orientation area (i.e. work location), either they will make non-work activity engagement or not. The I_C value is influenced by the obligation engagement parameters (e.g. working duration and number of work trips, etc.) and commute distance (Nishi and Kondo, 1992). Longer work duration will reduce the available time for non-work activity engagements. On the other hand, a higher number of work trips will increase worker's I_C values as well as the opportunities to make non-work activity engagements.

On the contrary, the non-workers do not have any fix obligatory locations and their action space is only defined primarily by their residential location. Indeed, non-workers have favorite places in pursuing their activity engagements. However, it would not as fixed as obligatory locations. Their decision on how far they will travel from home (I_H) will be influenced by the spread of the activity locations (I_C). Simultaneously, since individual has limited time for out-of-home travel and activities, the spread of activity locations (I_C) will be influenced by how far they have been traveled from home (I_H).

Let the endogenous variables of the model be:

d_x = one-way commute distance,
m_x = fraction of chosen mode in a given day
t_w = work duration
v_w = the number of visits (stops) for work activities.

The model may be formulated in general form as:

Simple trip workers: $I_{H_W} = f_{I_{H_W}}\left(d_x, m_C, R, W\right)$

Simple trip non-workers: $I_{H_{NW}} = f_{I_{H_{NW}}}\left(m_x, R, W\right)$

Complex trip workers: (6.1)

$$I_{H_W} = f_{I_{H_W}}\left(d_x, m_x, R, W\right) \;\&\; I_{C_W} = f_{I_{C_W}}\left(d_x, m_x, t_w, v_w, R, W, I_{H_W}\right)$$

Complex trip non-workers:

$$I_{H_{NW}} = f_{I_{H_{NW}}}\left(I_{C_{NW}}, m_x, R, W\right) \;\&\; I_{C_{NW}} = f_{I_{C_{NW}}}\left(I_{H_{NW}}, m_x, R, W\right)$$

where: I_{H_W} = I_H for worker, $I_{H_{NW}}$ = I_H for non-worker,

I_{C_W} = I_H for worker, $I_{C_{NW}}$ = I_H for non-worker,

R = the vector of variables representing the residence and work areas, including accessibility indices, and

W = the vector of individual and household attributes.

The distance from the residence location to the center of the metropolitan area will be added as an additional explanatory variable to examine the effect of regional activity center toward individual's action space. In the 1970s, the UMOT Project (Unified Mechanism of Travel) showed that the activity space has propensity to be oriented to main agglomeration center (Zahavi, 1979; Beckman, Golob, and Zahavi, 1983).

The simple trip pattern is examined by a general Tobit model of I_H value greater than zero[15]. The general form of the Tobit model for individual with a simple trip pattern is:

$$y_i^* = \beta' x_i + \varepsilon_i, \varepsilon_i \approx N\left[0, \sigma^2\right] \qquad (6.2)$$

if $y_i^* \leq 0$ then $y_i = 0$; if $y_i^* > 0$ then $y_i = y_i^* = \beta' x_i + \varepsilon_i$

For the complex trip workers, it is presumed that individual will decide their orientation first (I_H) followed by their non-obligations activities (I_C), which is conditioned by given I_H. The specific functional forms for complex trip workers are:

$$I_{H_W} = \begin{cases} I_{H_W}^* = \beta_{H_W}' X_{H_W} + \varepsilon_{H_W}, & if\ I_{H_W}^* > 0 \\ 0, & if\ I_{H_W}^* \leq 0 \end{cases} \qquad (6.3)$$

$$I_{C_W} = \begin{cases} I_{C_W}^* = \hat{I}_{H_W}\left(\beta_{C_W}' X_{C_W}\right) + \varepsilon_{C_W}, & if\ I_{C_W}^* > 0 \\ 0, & if\ I_{C_W}^* \leq 0 \end{cases}$$

As for non-worker, the distance of the activities' centroid from home (I_H) is influenced by the spread of activity locations (I_C) and simultaneously, the I_C value is influenced by given I_H values. The specific functional forms for complex trip non-workers are:

$$I_{H_{NW}} = \begin{cases} I_{H_{NW}}^* = \beta_{H_{NW}}'\left(X_{H_{NW}} + I_{C_{NW}}\right) + \varepsilon_{H_{NW}}, & if\ I_{H_{NW}}^* > 0 \\ 0, & if\ I_{H_{NW}}^* \leq 0 \end{cases} \qquad (6.4)$$

$$I_{C_{NW}} = \begin{cases} I_{C_{NW}}^* = \beta_{C_{NW}}'\left(X_{C_{NW}} + \hat{I}_{H_{NW}}\right) + \varepsilon_{C_{NW}}, & if\ I_{C_{NW}}^* > 0 \\ 0, & if\ I_{C_{NW}}^* \leq 0 \end{cases}$$

15 Since the data collected based on zonal based systems and the analysis will focus only for traveler, I_H is 0 if the activity location is within the same municipality as residence. I_H is greater than 0 if the activity location is outside the home municipality. More detail explanations about the data and limitations are provided in Section 6.3.

Behavioral Hypotheses

The individual's action space will be expanding over time. Since the individual's travel and activity engagements in the study area have been expanding over time (see Chapter 5 results), the individual's action space will be expanding as well.

High dense and well developed transit network and superb access that are provided by terminals in Osaka metropolitan areas allow transit users[16] to reach long distance locations conveniently while at the same time they are still able to access superb opportunities in transit terminals. This condition provides transit users with a wider reachable locations in a given time than other modes' users.

Since an individual action space is primarily defined by home locations and their routine engagement locations (e.g. work office) and both locations tend to be fixed for a long period, either in a simple pattern or in a complex pattern, workers will have more stable action space indices than non-workers.

The individual's action space is a representative of individual's travel and activity engagements in space. The changes in activity engagements pattern and travel environments over time will influence the individual action space as well.

6.3 Description and Distribution of the Second Moments Values

Estimation and Limitation of Sample

The samples are drawn from the original data files randomly at the rate of approximately 10%. In order to eliminate extreme second moment values that are difficult to analyze meaningfully, the analysis only includes intra-regional trip makers. The intra-regional trip maker is defined as individuals whose trips on the survey day are all contained inside the study area, the Osaka metropolitan area. Individuals who did not make a trip at all, or who made trips to outside the study area, are excluded from the analysis.

The analysis focused on working-age adults; students and old age people (more than 65 years old) are excluded from the sample. Workers are defined as individuals who made at least one work trip on a given day. Workers that did not make a work trip on a given day are excluded. Profiles of the estimation sample are shown in Appendix H. The profiles show that number of car ownership per adult household members, driving license ownership and accessibility indices have steadily increased from 1980 to 2000. On the other hand, the presence of dependent children has continuously decreased from 1980 to 2000. The trip and activity engagement rates of the sample intra-region traveler in the Osaka Metropolitan Area are shown in Table 6.1.

In the household travel survey, the respondent's activity locations are recorded using a geographical zone system, which is rather coarse. This creates a problem that many activity locations lay in the same zone as the respondent's zone of residence. In this case it is difficult to determine I_H or I_C based on the information available in the data set. Although the trip

[16] Most of transit users in the Osaka metropolitan area are rail users.

length can be estimated based on the reported duration of the trip and the travel mode used, this will not offer sufficient information on activity location to determine I_H and I_C.

The approach taken in this study is to compute second moments of activity locations using the coordinates of the centroids of the zones to which activity locations fall. This of course is an approximation, and a more precise evaluation of second moments would have been possible had activity locations been geo-coded using a coordinate system. If all activity locations of a respondent lie in his residence zone, then I_H and I_C are both set to zero. If his activity locations all happen to lie in the same zone as the centroid of his activity locations, then I_C is set equal to 0. Those respondents with a zero I_H or I_C form their own categories as can be seen in the analysis presented below.

TABLE 6.1 Activity and Engagements Rates of Intra-region Travelers in the Osaka Metropolitan Area

Activity and Engagements Rates	1980	1990	2000
Total number of trips per day	2.55	2.50	2.62
Total number of activity locations per day	1.35	1.39	1.49
Percent of simple-trip makers	72.5%	73.8%	68.3%
Average of Car Trip Fraction in One Day Trip Pattern	0.26	0.34	0.37
Average of Transit Trip Fraction in One Day Trip Pattern	0.28	0.28	0.26
Average of Non-Motorized Trip Fraction in One Day Trip Pattern	0.46	0.38	0.37
Average of I_H Value	73.38	86.65	106.96
Average of I_C Value	1.01	1.37	2.21
Percent of individuals whose activity centroids were outside home municipalities ($I_H > 0$)	44.7%	49.3%	52.6%
Percent of individuals who pursued activities in multiple municipalities ($I_C > 0$)	2.54%	2.52%	3.48%
Percent of Individual who make commute trip[17]	65.5%	69.2%	65.7%
The average commute distance	6.14	6.81	7.75

Table 6.1 shows that residents of the Osaka metropolitan area have expanded their travel and also their action space in the last 20 years. The number of trips per day and the number of activity locations per day are increasing and the fraction of simple-trip makers is decreasing from 1980 to 2000. Other indices of travel, fraction of travelers to outside the home municipality, fraction of travelers who pursued activities in multiple municipalities and second moment values, indicate expansion of travel. In particular, the total second moment has increased by 48% between 1980 and 2000. It can also be seen that the fraction of trips by auto has steadily increased, and that of non-motorized trips has decreased over the two decades.

Note that the fluctuation in the number of trips, the fraction of simple-trip makers, and the fraction of commuters are presumably because of the fluctuation of work activity conditions (number of work trips and work duration) due to the burst of the economic bubble in the early 1990 and the economic recession that followed. For the discussion of the temporal changes of workers and commuters' travel behavior in the Osaka metropolitan area, see Chapter 5.

[17] A commuter is defined in this study as a worker who made at least one work trip on the survey day. Commuting activity is a serial trips pattern from home to work location or from work location to home.

The increase in I_H implies that individuals have been engaging in activities at locations that are increasingly farther from home. And the increase in I_C shows that individuals have been pursuing activities at increasingly diverse locations. Consistent with this, the fraction of respondents who engaged in activities outside their home municipalities is increasing, and so are the respondents who pursued activities in multiple municipalities. Note that the increases in second moments are not simply due to the increased number of activities. The number of activities increased only by 10.4% from 1.35 in 1980 to 1.49 in 2000, while I_H increased by 45.8% and I_C by 119% in the same period. From 1980 to 2000, although the number of commuters tends to be steady, the commute distance has increased by 26%.

Description of Second Moment Values (I_H and I_C values)

The descriptive analysis of second moment values based on work engagement status, residential area[18], car and driving license availability, and the fraction of chosen trip modes can be seen on Appendix I. The salient results are summarized below.

Individual action space indices, both I_H and I_C, have steadily expanded from 1980 to 2000, as well as the fraction of individuals who engage their activity outside of their home municipals and spread their activity locations across municipals.

Commuting makes workers' action space more expansive than non-workers'. Since the complex commuters engaged in their non-work activities at locations that lie between workplace and home (Pred, 1977; Cullen & Godson, 1975; Golledge and Stimpson, 1997; etc.), simple commuters have higher I_H values than complex commuters. On the contrary, as a loose time constraint travelers, complex non-workers have more expansive action space than simple non-workers.

Suburbs and un-urbanized areas' residents have the most expansive action space and mixed area residents have the less expansive action space compared to other residential areas. The autonomous area's residents have the less out-of-home-municipal engagement rates compared to others. The high accessibility of many opportunities allows mixed area residents to have high out-of-home-municipal engagement rates with less I_H values. On the other hand, the self-provision of opportunities in autonomous area allows its residents to fulfill their necessity engagements inside their home municipality.

The higher number of automobiles among adult household members reduces intra-household sharing trips, allows individual to make their own trips and reduces each individual's I_H value.

The license ownership doubles individual's action space indices values. However, this does not mean that automobile users have higher action space values than other modes. Our data shows that 42.2%, 43.2% and 46.5 % of driving license holders, in 1980, 1990, and 2000, respectively, did not choose automobile as their travel mode.

[18] The urban area classifications that are adopted in this study are based on the urban area classification scheme by Fukui (2003): commercial area, mixed area, autonomous area, suburbs area, and un-urbanized area.

Transit users have superior I_H values than automobile users, while their I_C values are relatively the same. Individuals who use transit for all their trips in the given day have I_H values 2 - 3 times larger than individuals who use automobile for all their trips.

Higher rate of transit usage in given daily trip produces higher I_H values, especially for simple trip makers. On the contrary, the higher rate of automobile usage by individuals produces lower I_H values. Moreover, the complex trip makers' who use transit for all their trips on the observed day have widespread activity locations with superior out-of-home-municipal engagement rates and across-municipalities engagement rates than other modes. The combination of transit mode with other modes (non-motorized or automobile) will expand the action space significantly. This shows that the commonly held belief that public transit is not suited for trip chaining does not applied in Osaka metropolitan area. Highly dense and well developed of transit network and the superb access that are provided by terminal in Osaka metropolitan areas allow the transit users to reach long distance locations conveniently while at the same time, they are still able to access superb opportunities in transit terminals. These conditions allow transit users to have superior action space than other modes users.

The individuals who depend on non-motorized mode (walk/bicycle) have very small action space (under walk/bicycle distance) and very low out-of-home-municipality activity engagements. In addition, the older individual has smaller I_H values than younger ones.

6.4 Estimation Results

Simple Trip Makers

The result of estimation of the Tobit model for I_H of simple trip makers are showed on Appendix J, both for workers and non-workers. The salient results are summarized below.

For both workers and non-workers, the male simple trip makers have higher I_H value than their female counterparts. The involvements of non-motorized trips in individual's daily trip pattern limits the simple trip makers' trip distance, presumably under walk/cycling distance and reduces the probability of out-of-home-municipal engagement as well as the I_H values. On the other hand, the usage of transit increases the out-of-home-municipal engagement as well as the I_H values of simple trip non-workers. The superb transit access in Osaka metropolitan area allows transit travelers to reach more opportunities compared to auto users. However, the transit usage factors did not influence the simple trip workers' I_H values statistically. Since the simple trip worker only made one commute trip in a given day, the commute distance dominantly influences the I_H values of simple trip workers; either they use auto or transit as their trip mode.

The self-provision of opportunities in autonomous areas allows a simple trip worker to engage their out-of-home-engagements inside their home municipalities and to have less I_H value than other areas' simple trip workers. On the other hand, the characteristics of commercial and mixed residential areas which have mixed opportunities and high accessibilities across areas, encourage the simple trip workers to engage in activity outside their home municipality and to have higher I_H values than other areas' simple trip workers. However, the coefficients of 1990 model are not significant (either at α=0.05 or α=0.10).

Complex Trip Makers

The estimation result of the Tobit model for action space indices of complex trip makers are shown in Appendix K, both for workers and non-workers. The salient results are as follows.

Since the workers' action space is defined by home and work location, the I_H value is dominantly influenced by commute distance. Moreover, since workers only have limited available time for out-of-home engagements and travel, higher commute distances will reduce the spread of activity locations (I_C values). Male workers, in particular, travel farther from home but with less spread than their female counterparts. However, the statistical indices are weak in the 2000 model. The age dummy variable is not a significant parameter in the model.

On the contrary, since non-workers tends to have loose constraints on out-of-home time expenditure, non-workers' I_H values have positive correlation with I_C values. This means that the farther non-workers travel from home location, the more diverse their activity locations will be. While they make out-of-home-municipal engagements, non-workers maximize their engagements pattern positively correlated with their traveled distance from home. This result supports Dijst and Vidakovic (2000) hypothesis, that "given the length of the available interval, individual try to maximize their reach by increasing travel time given acceptable duration's of visit".

Higher residential accessibility to the population center as well as to the metropolitan center provides workers with more activity opportunities and increases the spread of activity locations, especially for mixed area workers. On the contrary, the residential accessibilities to the population center and to the metropolitan center negatively affect the spread of non-workers' activity locations. Closer distance to the population centers and metropolitan center makes the residential area denser and more opportunities are available. This will allow the non-workers to have more engagement probability inside their home areas and make their activity locations less spread.

These results show that commuting activity brings commuters close to the opportunities and encourages commuters to engage in more activities. On the other hand, non-commuters will try to fulfill their necessities as much as possible in their home area, like autonomous non-workers. But, once the non-commuters have to make outside-home-municipality activity engagement, they will maximize gain from the travel pattern as much as possible. However, few of the accessibility indices are significant in three time points.

For both workers and non-workers, the non-motorized trips, like walking and cycling, move the centroid of activity locations closer to home locations and reduce the spread of activity locations. On the contrary, superb access that is provided by terminals increases the spread of activity locations as well as the activity centroid distance from home.

Higher number of work trips increases the spread of activity locations. However, the work duration, commute with car as well as car availability is not constantly significant in three time points.

Interestingly, either for complex or simple trip makers, the individual and household socio-economic variables are relatively insignificant over periods of time.

6.5 The Stability and the Changes of Action Space Indices

Same with the approach that adopted in Chapter 5, the differences in the coefficient vectors and the stability of action space indices are examined in the model system while applying the following four methods:

1. testing the hypothesis that the model coefficients have not changed over the years as by applying likelihood ratio test,
2. testing the hypothesis that the model coefficients have not changed over the years by applying pair-wise comparison
3. predicting the values of the endogenous variables using the coefficient estimates from 1980, 1990 and 2000, on data from 1980, 1990 and 2000, and
4. predicting the values of the endogenous variables on the data from 1980, 1990 and 2000, using the coefficient estimates from 1980, 1990, and 2000.

The first and second methods offer statistical indications of behavioral stability as represented by the model coefficients. The third method indicates structural change in behavior over time; it shows how the behavior of a commuter with certain attributes, living in a certain area and having a certain level of accessibility, has changed over time. The fourth method, on the other hand, indicates how changes in the characteristics of commuters have prompted changes in behavior (see Chapter 5 for more detail explanation of the methods).

TABLE 6.2 Stability of Action Space Indices for Simple and Complex Trip Makers

a. Stability of Simple Trip Makers

Year Data	Worker's I_H		Non-Worker's I_H	
	χ^2	df	χ^2	df
1980 vs 1990	1011	20	53.9	18
1980 vs 2000	8789	20	132	18
1990 vs 2000	125	20	67.4	18
1980 vs 1990 vs 2000	12980	40	171	36

The critical values of χ^2 at $\alpha = 0.05$ is 28.9 (df = 18), 31.4 (df = 20), 51 (df = 36) and 55.8 (df = 40)

b. Stability of Complex Trip Makers

Year Data	Worker				Non-Worker			
	I_H		I_C		I_H		I_C	
	χ^2	df	χ^2	df	χ^2	df	χ^2	df
1980 vs 1990	68.5	12	38.7	22	109	19	42	19
1980 vs 2000	3049	12	-	22	69.4	19	119	19
1990 vs 2000	178	12	51.1	22	50.2	19	65	19
1980 vs 1990 vs 2000	4215	24	-	44	139	38	189	38

The critical values of χ^2 at $\alpha = 0.05$ is 21 (df = 12), 30.1 (df=19), 33.9 (df = 22), 36.4 (df =24), 53.4 (df = 38) and 60.5 (df = 44)

- : because of the indices are calculated based on zones, I_C values are not performing well. No proper likelihood test value was obtained

The results of likelihood ratio tests (Table 6.2) indicate that the model coefficients are not stable between any pairs of years prompting a conclusion that individual action space indices are not stable between 1980 and 2000 in the Osaka metropolitan area. The pair-wise tests of individual coefficients (shown on Appendix L) also indicate that the models are not stable between any combinations of years for both simple and complex trip makers.

To separate the effects of variations in coefficient vectors and those in explanatory variable values on the action space indices, the 1980, 1990 and 2000 mean explanatory variable values are input to the respective model to compute index values with the estimated 1980, 1990 and 2000 coefficient vectors. The results are summarized in Table 6.3 for simple trip makers and Table 6.4 for complex trip makers.

TABLE 6.3 Action Space Indices Produced with 1980, 1990, 2000 Coefficient Vectors at 1980, 1990, 2000 Mean Explanatory Variable Values for Simple Trip Makers

a. Action Space Index Values

Data	Coefficient Vector					
	$I_{H\ WORKER}$			$I_{H\ NON\ WORKER}$		
	1980	1990	2000	1980	1990	2000
1980	155.6	127.1	133.5	20.6	24.3	76.5
1990	176.6	147.3	155.5	18.9	31.3	76.5
2000	199.4	180.5	183.3	22.3	37.4	47.4

b. Change in Action Space Indices due to Change in Explanatory Variable Values (value with 1980 data = 100)

Data	Coefficient Vector					
	$I_{H\ WORKER}$			$I_{H\ NON\ WORKER}$		
	1980	1990	2000	1980	1990	2000
1980	100	100	100	100	100	100
1990	113.4	115.9	116.5	91.4	129.0	100.0
2000	128.1	142.0	137.3	107.8	154.1	61.9

c. Change in Action Space Indices due to Change in Coefficient Vector (value with 1980 coefficient vector = 100)

Data	Coefficient Vector					
	$I_{H\ WORKER}$			$I_{H\ NON\ WORKER}$		
	1980	1990	2000	1980	1990	2000
1980	100	81.7	85.8	100	117.5	370.6
1990	100	83.4	88.1	100	165.9	405.5
2000	100	90.5	91.9	100	167.9	212.9

TABLE 6.4 Action Space Indices Produced with 1980, 1990, 2000 Coefficient Vectors at 1980, 1990, 2000 Mean Explanatory Variable Values for Complex Trip Makers

a. Action Space Index Values

Data	Coefficient Vector											
	$I_{H\ WORKER}$			$I_{C\ WORKER}$			$I_{H\ NON\ WORKER}$			$I_{C\ NON\ WORKER}$		
	1980	1990	2000	1980	1990	2000	1980	1990	2000	1980	1990	2000
1980	90.6	98.0	101.0	7.0	6.2	19.8	27.8	23.9	79.9	1.7	4.7	-20.5*
1990	91.5	99.6	104.0	6.6	9.3	15.6	40.6	41.9	86.9	-6.5*	2.9	28.7
2000	123.5	114.9	138.9	25.2	23.9	9.7	30.7	125.4	47.2	-71.3*	-73.3*	7.4

b. Change in Action Space Indices due to Change in Explanatory Variable Values (value with 1980 data = 100)

Data	Coefficient Vector											
	$I_{H\ WORKER}$			$I_{C\ WORKER}$			$I_{H\ NON\ WORKER}$			$I_{C\ NON\ WORKER}$		
	1980	1990	2000	1980	1990	2000	1980	1990	2000	1980	1990	2000
1980	100	100	100	100	100	100	100	100	100	100	100	100
1990	101.0	101.6	103.0	94.3	150.9	79.0	146.1	174.9	108.8	-480.9*	60.8	340.3
2000	136.4	117.3	137.4	362.2	387.5	49.0	110.3	524.1	59.1	-4294.2*	-1657.6*	236.3

c. Change in Action Space Indices due to Change in Coefficient Vector (value with 1980 coefficient vector = 100)

Data	Coefficient Vector											
	$I_{H\ WORKER}$			$I_{C\ WORKER}$			$I_{H\ NON\ WORKER}$			$I_{C\ NON\ WORKER}$		
	1980	1990	2000	1980	1990	2000	1980	1990	2000	1980	1990	2000
1980	100	108.2	111.5	100	88.6	283.8	100	86.0	287.4	100	276.7	-1302.8*
1990	100	108.8	113.7	100	141.7	237.6	100	103.1	214.0	100	244.2	643.1
2000	100	93.0	112.4	100	94.8	38.4	100	408.8	154.0	100	97.2	210.4

* : zone based analysis makes intra-zone trips are unnoticeable and abrupt change on the activity and travel indices between observed years

Section b of Tables 6.3 and 6.4 shows the impact of changes in mean explanatory variable values under the three coefficient vectors. In other words, it shows the impact of changes in the demographic, socio-economic and accessibility variables by themselves without any changes in the structural relationships underlying activity engagement and travel. Section c of the tables shows the impact of changes in mean coefficient vectors values, i.e., it shows the impact of changes in the structural relationships by themselves without any changes in the demographic, socio-economic and accessibility variables.

From Table 6.3, the simple trip makers' comparisons of indices show:

- The diagonal elements of section a of Table 6.3 indicates that the I_H value of simple trip makers has continuously expanded in the last 20 years.
- Section b of Table 6.3 shows that, workers' I_H value has steadily increased from 1980 to 2000. The workers' I_H value is increased around 30 - 40% due to changes in mean explanatory variable values under any of the three coefficient vectors. It may be inferred that demographic, socio-economic and accessibilities indices changes between 1980 and 2000 have by themselves induced over 30 - 40% increases of activity centroid distance from home location of simple trip workers. The I_H non-worker tended to increase as well; however, the patterns are unclear.
- The coefficient vectors of non-workers' I_H steadily increase the values of the travel indices (see section c). This means that the non-workers' action space has expanded due to changes in the actions space indices, even when no changes have taken place in individual's demographic, socio-economic characteristics and accessibility indices in the study area.

  On the other hand, the coefficient vectors of workers' I_H reduce the values of the travel indices in 1990 and increase the indices in 2000. This fluctuation pattern is presumably due to the vigor of economic condition in that period. The burst of the economic bubble in the early 90's and the economic recession that followed have fluctuated workers' activity and travel engagement conditions as well their action space (see Chapter 5).

From Table 6.4, the complex trip makers' comparisons of indices show:

- The diagonal elements of section a of Table 6.4 indicates that all action space indices of complex trip makers were continuously expanded.
- Section b of Table 6.4 shows that, workers' I_H value has steadily increased from 1980 to 2000. The changes of demographic, socio-economic and accessibilities indices between 1980 and 2000 have by themselves induced over 17 - 38% increase of activity centroid distance from home of complex trip workers.

  The irregular patterns due to negative values of workers' I_C, non-workers' I_H and I_C are presumably caused by roughness of zoning system (based on districts or municipalities) that used in the data collection. Most of the sample does not engage in across-municipalities activity (only 12% among workers and 5% among non-workers who have $I_C > 0$ and 80% of non-worker travelers have $I_H = 0$). The intra zone trip as well as its expansion over period is imperceptible. However, the workers' I_C value, as well as non-workers' indices, still shows an expansion trend.
- Section c shows that most of all action space indices' coefficient vectors steadily increase the values of the travel indices (see section c). This means that the complex trip makers' action space has expanded due to changes in the actions space indices relationships by themselves, even when no changes have taken place in individual's demographic, socio-economic characteristics and accessibility indices in the study area.

Overall, despite some unclear patterns due to the roughness of the zoning system, the statistical analyses have showed that the changes to socio-economic and demographic conditions in the last 20 years, as well as the changing of action space indices relationship themselves, have encouraged the individual to constantly expand their spatial movement in space.

6.6 Summary

Using the results of household travel surveys conducted in 1980, 1990 and 2000 in the Osaka metropolitan area of Japan, supplemented with demographic, land use, and network data, this study has examined how the temporal changes of travel environment and socio demographic conditions have impacted individual's action space. It shows that individual action space has steadily expanded from 1980 to 2000, as well as the fraction of individual who engage their activity to outside their home municipals and spread their activity locations across municipals. However, the individual action space indices have been unstable over time.

The distribution analysis of the action space indices has shown that, in the last 20 years, the limitation of available time for out-of-home engagements and travel encourages worker to trade-off their travel distance from home with the spread of their activity locations. The common belief that public transit is not suited for trip chaining has not been proven in an area that provides superb opportunities access like Osaka metropolitan area. The study has shown that transit users have superior action space than other mode users. The superb transit accessibility between cities/areas allows the transit users to reach long distance locations conveniently, while at the same time they are still able to access superb opportunities in transit terminals.

Since the individual's action space is continuously expanding and its indices are not stable over time, the failure in adopting the expansion of individual's ability movement in space over time will lead to a biased descriptions in predicting the individual movement under space and time constraints and will lead to ineffective infrastructure design as well as fruitless transportation system management.

Chapter 7
Conclusion

Using the *Mobidrive* dataset, a six-week continuous travel diary, and person-trip data of the Osaka metropolitan area, this study has attempted to analyze the individual's behavior variability based on the variability and the changes of their spatial movement over time.

This study examined the variability and stability as well as the changes of individual spatial movement over time. It also takes into account individual's intra-personal and inter-personal variability. Moreover, the study includes individual heterogeneity in the analysis, and, as far as the author is aware, this is the first study that takes these factors into account. This study also expands the variability analysis into a longer period, which is also considered novel for this kind of analysis. In order to achieve the later aim, it is necessary to understand how individual travel behavior changes over time.

Pertaining to this long-term analysis, the study to understand the mechanisms underlying activity engagement and travel as a whole process over long period, the stability of activity engagement and travel, whether there exist invariants in urban residents' activity-travel patterns through the period when urban area underwent substantial changes and to infer general principles that may govern changes in urban residents' activity-travel patterns, is a unique and important contribution.

Day-to-day variability in the individual action space

Using the *Mobidrive* data set obtained from a six-week travel diary survey in Karlsruhe and Halle, Germany, this study has examined the characteristics of action space and its day-to-day variation based on the notion of the second moment of the out-of-home activity locations it contains. This study has shown that the employment status, residence location, out-of-home work/school duration and day of the week, have significant influences on the stability of second moments of activities locations. For example, people living in the inner-city area, the area that lies between the central of commercial area and the suburbs, tend to be more mobile and have larger action space than other areas since the area they live offers mixed opportunities for various activities. Individuals with out-of-home work/school commitments tend to have more stable second moments than those without them. The result shows that the second moments tend to take on larger values on Fridays and Saturdays.

The results also support the notion that individuals' action spaces are defined primarily by their residential and work locations and other activities located around these two locations. It also shows that, on weekdays, commuters (i.e. workers and students) have more stable and more predictable activity space than non-commuters (i.e. non-workers). Specifically, the statistical analyses of the variation of the second moments have revealed that the centroid of activity locations and the number or/and spread of activity locations of workers and students tend to be stable on weekdays. Unobserved heterogeneity across individuals is a major component that accounts for the variability of their centroid locations on weekdays. Even after commute distance is accounted for, there are yet other unobserved factors whose effects are fixed over time for each individual but vary across individuals. On weekend days, travel patterns vary more within an individual as well as across individuals while unobserved heterogeneity plays only minor roles.

Patterns of variations in action space found in this study are consistent with variations in activity engagement and constraints governing it, as theoretically postulated between weekdays and weekend days and also between workers/students and non-workers. On weekdays, when activities tend to be obligatory and routine, activity locations tend to be fixed and action space tends to be recurrent. On weekends, when the activities tend to be more discretionary, activity locations are more variable and the action space tends to be random and non-recurrent. The empirical findings in this study thus support the hypotheses on activity engagement and the spatial extension of action space.

With the understanding of the day-to-day variability of individual action space, it is possible to predict how far the individual will be able to move over a given spatial condition, which enables the analysis of movement variability of individual, and subsequently its impact to the travel pattern and transportation network. Such knowledge certainly has direct implications for urban and transport management. With the understanding of variability of individual movement in space, we will be able to assess the efficiency of transportation and urban infrastructure, such as bus station location and service coverage area, and then identify who would gain the most benefit from the system, and, conversely, who would suffer lack of accessibility (social exclusion), which can be used to achieve a more balance transportation system. Moreover, we could also address some urban planning issues, e.g. the impact of the locations of office, residential as well as commercial areas. All of these potential contributions can help governments, planners and operators to achieve sustainable transportation and urban planning.

Temporal changes of relationships underlying individual travel behavior

In order to understand the changes of individual spatial movement over a long period, it is necessary to understand the changes of individual travel and activity behavior as well as the changes of relationships that underlying the travel behavior over that period.

Using the household travel surveys conducted in 1980, 1990 and 2000 in the Osaka metropolitan area of Japan, supplemented with demographic, land use, and network data, this study examined how changes over time in demographic and socio-economic attributes and in the travel environment within the region have impacted commuters' activity-travel patterns. This is conducted by using a holistic approach by exploring the stability in structural relationships underlying several of the most pertinent indices of activity engagement and travel, using structural equations model systems.

The study has shown that the urban residents have expanded their travel and activities engagement over the 20–year period. More available opportunities as well as better accessibility condition have encouraged individuals to make more travel and activity engagements. The structural relationships underlying their activity-travel patterns were not stable over time, and non-workers, auto commuters and transit commuters exhibit different tendencies of change.

For the non-workers, the study shows that they are able to expand their activity and travel engagements constantly. This is reasonable because they are not constrained by out-of-home commitments and their daily activities are only influenced by their in-home conditions. On the other hand, the commuters' expansion patterns highly depend on their commitment conditions as well as their travel environments.

There are also differences in the expansion pattern of activity and travel engagements between commuters themselves. Auto commuters, who have higher flexibility in adopting to changes in the travel environment, consistently increased the number of non-work visits, trip chains and total travel time, and under the economic boom between 1980 and 1990, then the contraction of economy between 1990 and 2000, they consistently expanded their travel and activities engagement. Meanwhile, the transit commuters, who do not have the flexibility in arranging their travel patterns that is offered by the automobile, while they have a tendency to expand the activity engagement as well, tend to have stable total travel time. Both commuters have also constantly developed their trip patterns to be more effective over the 20-year period by making more non-work visits with less expenditure time for non-work activity and fewer trip chains.

The stability test has revealed that only an under-specified model is transferable over time periods. The rapid changes to the travel environment shapes the individual's socio and demographic conditions dynamically, which makes the behavior continuously evolving and not transferable.

The difference in change pattern between individuals as well as the lack of transferability of the behavior over time will make ignoring the individual adaptation processes in travel and activity bias results and consequently inappropriate policy and planning decisions. Moreover, with analyzing the individual travel behavior as a whole, we would be able to understand the relationships between travel parameters as well as the reasons that underlying it. Analyzing the changes of individual travel behavior based on one certain parameter may also lead to the biased results.

For example, in analyzing the impact of the usage of rail transport to the non-workers' travel patterns in the last 20 years, the results have shown that although the non-workers who use transit as their mode have fewer non-work visits per unit non-work activity time compared to auto and non-motorized non-workers, they tend to have a longer average duration per visit. And given the number of visits, they tend to have fewer trip chains than auto and non-motorized non-workers. Given the number of visits and trip chains, they tend to spend more travel time than auto and non-motorized non-workers. This leads to the conclusion that, although the non-workers who use transit tend to have less non-work visits than non-workers who use automobile or non-motorized mode, the dense rail network in the Osaka metropolitan area, and superb opportunities in main terminals, have allowed them to have longer activity time engagements, with more efficient travel patterns and superior reachable distance.

The changes of individual action space for a long time span

Using the household travel surveys conducted in 1980, 1990 and 2000 in the Osaka metropolitan area of Japan, supplemented with demographic, land use, and network data, this study has examined how the temporal changes to the travel environment and socio demographic conditions have impacted individual's action space.

The study has shown that individual action space has steadily expanded from 1980 to 2000, and so has the fraction of individuals who engage their activity outside their home municipals and spread their activity locations across municipals. The individual's desires to engage in more activity and travel due to more available opportunities and better accessibility lies behind these continued expansions.

However, the individual action space indices have been not stable over time. Since the individual's action space is continuously expanding and its indices are not stable over time, failure to adopt these changes will lead to bias in prediction of the individual movement area which would generate ineffective infrastructure design and fruitless transportation system management.

The distribution analysis of the action space indices has shown that, in the last 20 years, the limitation of available time for out-of-home engagements and travel makes workers trade-off their travel distance from home with the spread of their activity locations. The common belief that public transit is not suited for trip chaining is not proved in an area that provides superb opportunities access, like the Osaka metropolitan area. The study has shown that transit users have superior action space than other mode users. The superb transit accessibility between cities/areas allows the transit users to reach long distance locations conveniently, and, at the same time, they are still able to access superb opportunities in transit terminals.

In regional planning issues in the a longer term, understanding the changes of individual's ability to move in space and time will help the prediction of migration trend due to changes in residential and work locations. Since the individual's action space is continuously expanding and its indices are not stable over time, the failure in adopting the expansion of individual's ability movement in space over time will lead to a biased descriptions in predicting the individual movement under space and time constraints and will lead to ineffective infrastructure design as well as fruitless transportation system management.

General conclusion

This study has proved that it is necessary to adopt the variability and the changes of individual behavior into the urban and transportation planning process. Failing to adopt the variability and the changes of the behavior will lead to inefficient transport planning and management. Moreover, it potentially creates a social exclusion and redundant transportation supply in the community. Adopting the variability as well as the stability of the behavior enables a more efficient, sustainable and livable system design.

Direction of further research that arise from the thesis

In day-to-day variability of individual's action space analysis, the statistical analyses of the variation of the second moments have revealed that the unobserved heterogeneity across individuals is a major component that accounts for the variability of their centroid locations on weekdays. However, even after commute distance is accounted for, there are yet other unobserved factors whose effects are fixed over time for each individual but vary across individuals. Since the individual's action space largely depends on the activity locations in space, it is possible that the omitted individual's unique variables that are represented by individual-specific error terms are due to the available engagement opportunity as well as the available accessibility in space which is unique for each individual.

Moreover, in this study, the analyses between individual's activity engagement and travel patterns and individual's action space are carried out separately. The available opportunities for each individual and their familiarity to the opportunity (knowledge map) are not accounted in the analysis. How the individual varies their activity locations among available opportunities as well as its relationship with individual travel pattern is largely unknown.

Analyzing the individual's action space with individual's activity engagement and travel pattern under one holistic approach will provide a significant breakthrough in individual travel behavior analysis. Moreover, integrating the individual's mental map and preferences diversification with the available opportunities and network conditions in analyzing the individual action space will give significant contribution to understand the individual spatial movement behavior.

This study has yet accounted the individual time budget in analyzing the changes of individual activity engagement and travel pattern. Theoretically, the individual time budget for travel and activity is the maximum time that an individual would be able to spend to engage in activity and travel. Understanding the limit of the individual time budget as well as how individual allocates their available time to activity and travel will provide significant contribution to the travel behavior research generally.

REFERENCES

Adler, T.J. and M. Ben-Akiva (1979) A theoretical and empirical model of trip chaining behavior. *Transportation Research*, **13**, 253 – 257.

Arentze, T., A. Borgers, F. Hofman, S. Fujii, C. Joh, A. Kikuchi, R. Kitamura, H. Timmermans and P. van der Waerden (2001) Rule-based versus utility-maximizing models of activity-travel patterns: A comparison of empirical performance. In D. Hensher (ed.) *Travel Behaviour Research: The Leading Edge*, Elsevier Science, Oxford, pp. 569-583.

Atherton, T.J. and M.E. Ben-Akiva (1976) Transferability and updating of disaggregate travel-demand models. *Transportation Research Record*, **895**, 12-18.

Axhausen, K.W. and T. Gärling (1992) Activity-based approaches to travel analysis: Conceptual frameworks, models, and research problems. *Transport Reviews*, **12**(4), 323-341.

Axhausen, K.W., A. Zimmermann, S. Schönfelder, G. Rindsfüser and T. Haupt (2002) Observing the rhythms of daily life: A six-week travel diary, *Transportation*, **29**(2) 95-124.

Badoe, D.A. and E.J. Miller (1995) Analysis of the temporal transferability of disaggregate work trip mode choice models. *Transportation Research Record*, **1493**, 1-11.

Beckmann, M.J., T.F. Golob and Y. Zahavi (1983a) Travel probability fields and urban spatial structures: 1. Theory, *Environmental and Planning A*, **15**, 593–606.

Beckmann, M.J., T.F. Golob and Y. Zahavi (1983b) Travel probability fields and urban spatial structures: 2. Empirical test, *Environmental and Planning A*, **15**, 727 – 728.

Brög W. (1980) Latest empirical findings of individual travel behavior as a tool for establishing better policy – sensitive planning model. Presented in 2nd World Conference on Transport Research, London, England.

Brög W. and E. Erl (1983) Application of a model of individual behavior (situational approach) to explain household activity patterns in an urban area and to forecast behavioral changes. In S. Carpenter and P. Jones (eds.) *Recent Advances in Travel Demand Analysis, Gower Publishing*, Aldershot, England, pp. 117 - 136.

Burns, L.D. (1979) *Transportation, Temporal, and Spatial Components of Accessibility*. D.C. Heath, Lexington, Massachusetts.

Cervero, R. (1986) Intrametropolitan trends in sunbelt and western cities: Transportation implications. *Transportation Research Record*, **1067**, 20-27.

Chapin, F.S. Jr. (1974) *Human Activity Patterns in the City*, John Willey and Sons, New York.

Cohen, G.S. and M.A. Kocis (1980) Components of change in urban travel. *Transportation Research Record*, **775**, 42-47.

Cullen, I. (1978) The treatment of time in the explanation of spatial behavior. In T. Carlstein, D. Parkes, and N. Thrift (eds.) *Human Activity and Time Geography*, 2 (Timing Space and Spacing Time), New York, Willey, pp. 27 – 38.

Cullen, I. and V. Godson (1975) Urban networks: the structure of activity patterns. *Progress in Planning*, **4** (1). 1 – 96.

Damm, D. (1983) Theory and empirical results: A comparison of recent activity-based research. In S. Carpenter and P. Jones (eds.) *Recent Advances in Travel Demand Analysis, Gower Publishing*, Aldershot, England, pp. 3-33.

Dangschat J., W. Droth, J. Friedrichs, and K. Kiehl (1982) Action space of urban residents: An empirical study in the region of Hamburg, *Environmental and Planning A*, **14**, 1155-1174.

Dijst, M. (1999) Two-earner families and their action spaces: A case study of two Dutch communities, *GeoJournal*, **4**(3), 195-206.

Dijst, M. and V. Vidakovic (2000) Travel time ratio: The key factor of spatial research, *Transportation*, **27**, 179-199.

Djist, M. and V. Vidakovic (1997) Individual action space in the city. In D.F. Ettema and H.J.P. Timmermans (eds) *Activity-based Approaches to Travel Analysis*, Pergamon Press, Oxford, pp. 117-134.

Elmi, A.M., D.A. Badoe and E.J. Miller (1999) Transferability analysis of work-trip-distribution models. *Transportation Research Record*, **1676**, 169-176.

Ettema, D., A. Borgers and H. Timmermans (1995). SMASH (Simulation Model of Activity Scheduling Heuristics): Empirical Test and Simulation Issues. Paper for the conference "Activity based approaches: activity scheduling and the analysis of activity patterns", Eindhoven, The Netherlands, 1995.

Ettema, D.F. and H.J.P. Timmermans (1997) Theories and models of activity patterns. In D.F. Ettema and H.J.P. Timmermans (eds.) *Activity-based Approaches to Travel Analysis*, Pergamon Press, Oxford, pp. 1-36.

Fujiwara, A. and Y. Sugie (1997) Temporal stability of stated preference data. In P. Stopher and M. Lee-Gosselin (eds.) *Understanding Travel Behaviour in an Era of Change*, Elsevier Science, Oxford, pp. 257-277.

Fukui, K. (2003) Longitudinal Analysis of Travel Behavior Change Using Dynamic Urban Area Classification. MS thesis, Department of Civil Engineering Systems, Kyoto University, Kyoto, February.

Golledge, R. (1970) Some equilibrium models of consumer behavior. *Economic Geography*, **46**, 417 – 424.

Golledge, R.G. and R.J. Stimson (1997) *Spatial Behavior*, The Guilford Press, New York and London.

Hanson, S. (1980) Spatial diversification and multipurpose travel: implications for choice theory. *Geographical Analysis*, **12**, 245 – 257.

Hanson, S. and J.O. Huff (1982) Assessing day-to-day variability in complex travel patterns. *Transportation Research Record*, **891**, 18-24.

Hanson, S. and J.O. Huff (1986) Classification issues in the analysis of complex travel behavior. *Transportation*, **13**, 271 – 293.

Hanson, S. and J.O. Huff (1988) Repetition and day-to-day variability in individual travel patterns: Implications for classification. In R.G. Golledge and H. Timmermans (eds.) *Behavioural Modelling in Geography and Planning*, Croom Helm, London, 368-398.

Hanson, S. and J.O. Huff (1988) Systematic variability in repetitious travel, *Transportation*, **15**, 111 – 135.

Hay, A.M. and R.J. Johnston (1979) Search and the choice of shopping centre: two models of variability in destination selection. *Environmental and Planning A*, **11**, 791 – 804.

Herz, R. (1983) Stability, variability and flexibility in everyday behaviour. In S. Carpenter and P. Jones (eds.) *Recent Advances in Travel Demand Analysis, Gower Publishing*, Aldershot, England, pp. 385 - 400.

Horton, F. und D.R. Reynolds (1971) Effects of urban spatial structure on individual behaviour, *Economic Geography*, **47**, 36-48.

Horton, F.E. and W.E. Wagner (1969) A Markovian analysis of urban travel behavior: Pattern response by socioeconomic-occupational groups. *Highway Research Record*, **283**, 19-29.

Huff, J.O. and S. Hanson (1986) Repetition and variability in urban travel. *Geographical Analysis*, **18**, 97 – 114.

Huff, J.O. and S. Hanson (1990) Measurement of habitual behaviour: Examining systematic variability in repetitive travel. In P. Jones (ed.) *Developments in Dynamic and Activity-based Approaches to Travel Analysis*, Gower, Aldershot, pp. 229-249.

Hupkes, G. (1977) Gesgeven of afremmen: toekmstscenario's voor ons vervoerssysteem. Deventer/Antwerpen: Kluwer.

Hägerstrand, T. (1970) What about people in regional science? *Papers of the Regional Science Association*, **24**, 7-21.

Joh, C.-H., T.A. Arentze and H.P. Timmermans (2001a) Pattern recognition in complex activity travel patterns: comparison of Euclidean distance, signal-processing theoretical, and multidimensional sequence alignment methods. *Transportation Research Record*, **1752**, 16-31.

Joh, C.-H., T.A. Arentze and H.P. Timmermans (2001b) A position-sensitive sequence-alignment method illustrated for space – time activity-diary data. *Environment and Planning A*, **33**, 313 – 338.

Jones, P. and M. Clark (1988) The significance and measurement of variability in travel behavior. *Transportation*, **15**, 65 – 87.

Jones, P., F. Koppelman and J.P. Orfueil (1990) Activity analysis: State-of-the-art and future directions. In P. Jones (ed.) *Developments in Dynamic and Activity-Based Approaches to Travel Analysis*, Gower Publishing, Aldershot.

Jones, P.M., M.C. Dix, M.I. Clarke, and I.G. Heggie (1983) *Understanding Travel Behaviour*. Gower Publishing, Aldershot, England.

Kansky, K.J. (1967) Travel patterns of urban residents. *Transportation Science*, **1**, 261-285.

Karasmaa, N. and M. Pursula (1997) Empirical studies of transferability of Helsinki metropolitan area travel forecasting models, *Transportation Research Record*, **1607**, 38-44.

Kasturirangan, K., R.M. Pendyala, and F.S. Koppelman (2002) History dependency in daily activity participation and time allocation for commuters. *Transportation Research Record*, **1807**, 129 – 136.

Kei-Han-Shin Metropolitan Area Transportation Planning Commission (undated) Current State of Osaka Metropolitan Area as Indicated by Its Residents' Movement. Osaka.

Kinki Regional Development Bureau's Websites (http://www.kkr.mlit.go.jp/en/index.html)

Kitamura R. and T. van der Horn (1987) Regularity and irreversibility of weekly travel behavior. *Transportation*, **14**, 227 – 251.

Kitamura R., Yamamoto, T., Susilo, Y.O. and Axhausen, K.W. (2004) On the day-to-day variability of prisms vertex location. Presented at 83rd Annual Meeting of Transportation Research Board, Washington D.C., USA. Revised version published at Transportation Research A (*in press*).

Kitamura, R. (1983) A sequential, history dependent approach to trip-chaining behavior. *Transportation Research Record*, **944**, 13-22.

Kitamura, R. (1988a) An analysis of weekly activity patterns and travel expenditure. In R.G. Golledge and H.J.P. Timmermans (eds.), *Behavioral Modeling Approaches in Geography and Planning*, Croom Helm, London, pp. 399-423

Kitamura, R. (1988b) An evaluation of activity-based travel analysis. *Transportation*, **15**, 9-34.
Kitamura, R. and M. Kermanshah (1983) Identifying time and history dependences of activity choice. *Transportation Research Record*, **944**, 22 – 30.
Kitamura, R. and M. Kermanshah (1984) A sequential model of interdependent activity and destination choice. *Transportation Research Record*, **987**, 81 – 89.
Kitamura, R. and T. van der Hoorn (1987) Regularity and irreversibility of weekly travel behavior. *Transportation*, **14**, pp. 227-251.
Kitamura, R. and Y.O. Susilo (2003) Trends in Travel: A Study of Changes in Structural Relationships Underlying Travel. Paper presented at the 8th Conference of Hong Kong Society for Transport Studies, Hong Kong, December.
Kitamura, R. and Y.O. Susilo (2005) Is travel demand is insatiable? A study of changes in structural relationships underlying travel. *Transportmetrica*, **1**(1), 23 - 45.
Kitamura, R., C. Chen and R. Narayanan (1998) The effects of time of day, activity duration and home location on travelers' destination choice behavior. *Transportation Research Record*, **1645**, 76-81.
Kitamura, R., L.P. Kostyniuk and M.J. Uyeno (1981) Basic properties of urban time-space paths: Empirical tests. *Transportation Research Record*, **794**, 8-19.
Kitamura, R., S. Fujii and E.I. Pas (1997) Time-use data, analysis and modeling: Toward the next generation of transportation planning methodologies. *Transport Policy*, **4**(4), 225-235.
Kitamura, R., Y.O. Susilo, K. Fukui, J. Murakami and K. Kishino (2003) The invariants of travel behavior: the case of Kyoto-Osaka-Kobe metropolitan area of Japan, 1970-2000. Paper presented at the 10th Conference of the International Association for Travel Behaviour Research, Lucerne, August.
Kollo, H.P.H. and C.L. Purvis (1984) Changes in regional travel characteristics in the San Francisco Bay Area: 1960-1981. *Transportation Research Record*, **987**, 57-66.
Koppelman, F.S. and C.G. Wilmot (1982) Transferability analysis of disaggregate choice models. *Transportation Research Record*, **895**, 18-24.
Koppelman, F.S. and E.I. Pas (1984) Estimation of disaggregate regression models of person trip generation with multiday data. In J. Volmuller and R. Hamerslag (Eds.) Proceedings of the 9th International Symposium on Transportation and Traffic Thoery. VNU Science Press, Utrecht, The Netherlands, pp. 513 – 531.
Koppelman, F.S. and E.I. Pas (1985) Travel-activity behavior in time and space: methods for representation analysis. In P. Nijkamp, H. Leitner and N. Wrigley (Eds.) *Measuring Umeasurable*. Martinus Nijhoff, Dordrecht, The Netherlands, pp. 587 – 627.
Kostyniuk, L.P. and R. Kitamura (1984) Trip chains and activity sequences: Test of temporal stability. *Transportation Research Record*, **987**, 29-39.
Kundera, M. (1984) *The Unbearable Lightness of Being*, Harper & Row, New York.
Kwan, M.P. (2003), Accessibility in Space and Time: A GIS Approach, *CSISS Workshop Material*, downloaded from: http://facweb.arch.ohio-state.edu/sgordon/courses2/crp607/Kwan_607%20App.pdf
Lenntorp, B. (1976) Paths in Space-Time Environment: A Time Geographic Study of Possibilities of Individuals, The Royal University of Lund, Department of Geography, Lund (Lund Studies in Geography, B, Human Geography, 44).
Levinson, D.M. (1998) Accessibility and the journey to work. *Journal of Transport Geography*, **6**(1), 11-21.
Levinson, D.M. and A. Kumar (1994) The rational locator: Why travel times have remained stable. *Journal of the American Planning Association*, **60**(3), 319-331.

Lipps O (2000) Modellierung der individuellen verhaltensvariationen bei der verkehrsentstehung, PhD thesis at the Fakultät Bauingeniuer und Vermessungswesen, Universität Karlsruhe, Karlsruhe.

Ma, J. and K.G. Goulias (1997) An analysis of activity and travel patterns in the Puget Sound Transportation Panel, In D.E. Ettema and H.J.P. Timmermans (eds.) *Activity-based Approaches to Travel Analysis*, Elsevier Science, Oxford, pp. 189-207.

Maddala, G.S. (1983) *Limited-dependent and Qualitative Variables in Econometrics*. Cambridge University Press, Cambridge.

Marble, D.F. and S.R. Bowbly (1968) Shopping alternatives and recurrent travel patterns. In F. Horton (eds.) *Geographic Studies of Urban Transportation and Network Analysis*, Northwestern University Press, Evanston, IL.

Marble, D.F., P.O. Hanson and S. Hanson (1972) Field Operations and Questionnaires, Household Travel Behavior, Study 1, Department of Human Geography, State University of New York at Buffalo, Buffalo.

Meier, R. (1959) Measuring social and cultural change in urban regions. *Journal of the American Institute of Planners*, **25**, 180 – 190.

Miller, H.J. (2005) What about people in geographic information science? In P. Fisher and D. Unwin (ed.) *Re-Presenting Geographic Information Systems*, John Wiley, New York, (*in press*).

Mokhtarian, P. L. and Salomon, I. (2001) How derived is the demand for travel?: Some conceptual and measurement considerations. *Transportation Research A*, **35**(8), 695-719.

Mokhtarian, P.L. and C. Chen (2004) TTB or not TTB, that is the question: A review and analysis of the empirical literature on travel time (and money) budgets. *Transportation Research A*, **38**, pp. 643 - 675.

Monzon, J., K.G. Goulias and R. Kitamura (1989) Trip generation models for infrequent trips. *Transportation Research Record*, **1220**, pp. 40-46.

Nishii, K. and Kondo, K. (1992) Trip Linkages of Urban Railway Commuters Under Time-Space Constraints: Some Empirical Observations. *Transportation Research B*, **26**(1), pp. 33-44.

Oppenheim, N. (1975) A typological approach to individual urban travel behavior prediction. *Environment and Planning A*, **7**, 141-152.

PTV AG, B. Fell, S. Schönfelder and K.W. Axhausen (2000) Mobidrive questionnaire, *Arbeitsberichte Verkehr- und Raumplanung*, **52**, Institut für Verkehrsplanung und Transportsysteme, ETH Zürich, Zürich.

Pas, E.I. (1983) A flexible and integrated methodology for analytical classification of daily travel behavior. *Transportation Science*, **17**, 405-249.

Pas, E.I. (1984) The effect of selected sociodemographic characteristics on daily travel-activity behavior. *Environment and Planning A*, **16**, 571 – 581.

Pas, E.I. (1986) Multiday samples, parameter estimation precision, and data collection costs for least squares regression trip-generation models. *Environment and Planning A*, **18**, 73 – 87.

Pas, E.I. (1987) Intrapersonal variability and model of goodness-of-fit. *Transportation Research A*, **21**, 431 – 438.

Pas, E.I. (1988) Weekly travel-activity behavior. *Transportation*, **15**, 89-109

Pas, E.I. and F.S. Koppelman (1985) Analysis of multiday travel-activity patterns. Paper presented at the 64th Annual Meeting of the Transportation Research Board, Washington, D.C.

Pas, E.I. and F.S. Koppelman (1986) An examination of the determinants of day-to-day variability in individuals' travel behavior. *Transportation*, **13**, 183 – 200.
Pas, E.I. and S. Sundar (1994) Intrapersonal variability in daily urban travel behavior: some additional evidence, *Transportation*, **24**, 1 – 16.
Pred, A. (1977) The choreography of existence: Comments on Hagerstrand's time-geography and its usefulness. *Economic Geography*, **53**, 207-21.
Prevedouros, P.D. and J.L. Schofer (1989) Suburban transport behavior as a factor in congestion. *Transportation Research Record*, **1237**, 47-58.
Recker W.W., M.G. McNally and G.S. Roots (1985) Travel/activity analysis: pattern recognition, classification and interpretation. Transportation Research A, **19**, 179 – 196..
Recker W.W., M.G. McNally and G.S. Roots (1986) A model of complex travel behavior part 1 – theoretical development. Transportation Research A, 20, 307 – 318.
Roberts, R.A. (1986) Analysis of demographic trends and travel patterns: Implications for the future of the Portland transit market. *Transportation Research Record*, **1067**, 1-8.
Schlich, R. and K.W. Axhausen (2003) Habitual Travel Behaviour: Evidence from a six-week travel diary. *Transportation*, **30**, 13-36.
Schönfelder, S. and K.W. Axhausen (2001) Mobidrive – Längsschnitterhebungen zum individuellen verkehrsverhalten: perspektiven für raum-zeitliche analysen, paper presented at CORP 2001, February 2001, Wien.
Schönfelder, S. and K.W. Axhausen (2002) Measuring the size and structure of human activity spaces – the longitudinal perspective, *Arbeitsberichte Verkehr- und Raumplanung*, **135**, Institut für Verkehrsplanung und Transportsysteme, ETH Zürich, Zürich.
Schönfelder, S. and K.W. Axhausen (2002) On the variability of human activity spaces, *Arbeitsberichte Verkehr- und Raumplanung*, **151**, Institut für Verkehrsplanung und Transportsysteme, ETH Zürich, Zürich.
Schönfelder, S. and K.W. Axhausen (2003) Activity spaces: Measures of social exclusion?, *Transport Policy*, **10** (4), 273 – 286.
Schönfelder, S., R. Schlich, A. König, A. Aschwanden, A. Kaufmann, D. Horisberger and K.W. Axhausen (2002) Mobidrive: Data format guide part A: Basic survey details, data processing and imputation, *Arbeitsberichte Verkehr- und Raumplanung*, **116a**, Institut für Verkehrsplanung und Transportsysteme, ETH Zürich, Zürich.
Schönfelder, S., R. Schlich, A. König, A. Aschwanden, A. Kaufmann, D. Horisberger and K.W. Axhausen (2002) Mobidrive: Data format guide part B: Variables, *Arbeitsberichte Verkehr- und Raumplanung*, **116b**, Institut für Verkehrsplanung und Transportsysteme, ETH Zürich, Zürich.
Scott, D.M. and M.W. Horner (2005) Does urban form contribute to social exclusion? An exploratory spatial data analysis. 84th Annual Meeting Transport Research Board CD ROM, Washington, DC.
Senbil, M. and R. Kitamura (2003) Simultaneous relationships between telecommunications and activities. Paper presented at the 10th International Conference on Travel Behaviour Research, Lucerne, August.
Smith, T.R. (1978) Uncertainty, diversification, and mental maps in spatial choice problems. *Geographical Analysis*, **10**, 120 – 141.
Srivastava G. and S. Schönfelder (2003) On the temporal variation of human activity spaces, *Arbeitsberichte Verkehr- und Raumplanung*, **196**, Institut für Verkehrsplanung und Transportsysteme, ETH Zürich, Zürich.

Strathman JG & Dueker KJ (1995) Understanding trip chaining. *Special Reports on Trip and Vehicle Attributes*, 1990 NPTS Report Series, US Department of Transportation, February.
Supernak, J. (1982) Travel-time budget: A critique. *Transportation Research Record*, **879**, 15-25.
Supernak, J. (1984) Travel regularities and their interpretations: A discussion paper. *Transportation Research Record*, **987**, 48-57.
Supernak, J. and D. Schoendorfer (1985) Automobile availability and its application in transportation studies. *Transportation Research Record*, **1037**, 73-81.
Supernak, J., A. Talvitie and A. DeJohn (1983) Person-category trip-generation model. *Transportation Research Record*, **944**, 74-83.
Supernak, J.C. (1987) A method for estimating long-term changes in time-of-day travel demand, *Transportation Research Record*, **1138**, 18-26.
Susilo, Y.O. and Kitamura R. (2003) An analysis of the impact of land use and accessibility on individual travel patterns over time. Presented at 9th International Symposium for Students and Young Researchers on Transportation and Infrastructure Planning Conference, Bangkok, Thailand.
Susilo, Y.O. and Kitamura R. (2004) An analysis of individual action space: A preliminary exploration of Six Weeks Mobidrive Travel Diary Data. Presented at 7th Indonesian National Symposium of Inter-University Transportation Study Forum, Bandung, Indonesia.
Susilo, Y.O. and Kitamura R. (2005) An analysis of the day-to-day variability in the individual's action space: An exploration of the six-week Mobidrive travel diary data. Presented at 83rd Annual Meeting of Transportation Research Board, Washington D.C., USA. Revised version published at Transport Research Record (*in press*).
Szalai, A. (ed.) (1972) *The Use of Time*, Mouton, The Hague.
Timmermans, H., P. van der Waerden, M. Alves, J. Polak, S. Ellis, A.S. Harvey, S. Kurose and R. Zandee (2003) Spatial context and the complexity of daily travel patterns: An international comparison. *Journal of Transport Geography*, **11**, 37-46.
Van Beek, P., N. Kalfs and U. Blom (1986) Gender differences in activities and mobility in the Netherlands, 1975 to 1990. *Transportation Research Record*, **1607**, 134-138.
Washington, S.P., M.G. Karlaftis and F.L. Mannering (2003) *Statistical and Econometric Methods for Transportation Data Analysis*, Chapman and Hall/CRC.
Wikipedia Encyclopedia (http://www.wikipedia.org)
Wilson WC (1998) Activity pattern analysis by mans of sequence-alignment methods. *Environment and Planning A*, **30**, 1017 – 1038.
Yunker, K.R. (1976) Tests of the temporal stability of travel simulation models in Southeastern Wisconsin. *Transportation Research Record*, **610**, 1-5.
Zahavi, Y. (1979) *The UMOT Project* report DOT-RSPA-DPB-20-79-3, US Department of Transportation, Washington, D.C.
Zahavi, Y. and A. Talvitie (1980) Regularities in travel time and money expenditures. *Transportation Research Record*, **750**, 13-19.
Zahavi, Y. and J.M. Ryan (1980) Stability of travel components over time. *Transportation Research Record*, **750**, 19-26.

LIST OF APPENDICES

APPENDIX A:
Contents of The *Mobidrive* Main Survey Forms

(source: Axhausen et al., 2002)

TABLE A.1 Contents of the Household Questionnaire

Item	Coding and Comments
Number of residents	(Excluding family members who only visit occasionally)
Number of family members residing elsewhere	
Number of dogs	
Composition of vehicle fleet	Number of cars, bicycles, motorized cycles, small motorcycles, motorcycles, trucks, other (please specify)
Household membership in a car sharing organization	Yes, no
Permission to use vehicles of other households and frequency of use	Yes, no; about daily, more then once a week, once a week, twice or trice a month, once a month, less than once a month
Private parking space in a garage	Number, for up to three: (below building, below building elsewhere, garage on the lot, garage elsewhere); distance [m or min], monthly rent or purchase price
Other private parking spaces	Number, for up to three: type (yard, driveway, marked space, covered space, on public right-of-way); distance [m or min], monthly rent or purchase price
Distance to the closest bus stop	[m or min]
Distance to the closest tram stop	[m or min]
Distance to the closest heavy rail station	[m or min]
Size of accommodation	[m^2]
Type of accommodation	Apartment (in building of 7 or more), apartment (in building of up to 6), free standing single family home, duplex, terrace, flat within single family home
Ownership status	Owned, rented
Type of subsidy for accommodation	None, company housing, subsidized housing
Year of construction of accommodation	
Year of move	
Costs (rent of mortgage)	[DM] (excluding service charges, heating, electricity etc.)
Additional costs of housing	[DM]
Presence of	One balcony, multiple balconies, terrace, terrace, rooftop terrace, basement, attic, laundry room, drying room, garden, other (please specify)
Size of garden	[m^2]
Telecommunication resources	Number of land lines, mobile phones, fax machines, private email addresses, work-related email addresses
Monthly household income net after taxes and social security payments	- 1000, 1000 – 1799, 1800 – 2499, 2500 – 2999, 3000 – 3999, 4000 – 4999, 5000 – 7499, 7500 DM and more

TABLE A.2 Contents of the Person Questionnaire

Item	Coding and Comments
Given name	Abbreviations were possible
Sex	Female, male
Relation to other household members	Spouse/partner, parent, child, other (please specify)
Currently married	Yes, no
Types of education completed	None, primary school, minimum required years of schooling, intermediate exam, subject limited baccalaureate, baccalaureate, East German baccalaureate, apprenticeship, craft master, 3 year degree, university degree (sciences/engineering or other), other (please specify)
Status	Pupil, student, homemaker, part time employed, full time employed, self employed, in retirement, supporting family member, unemployed
Number of employers	
Number of work locations	
Number of working hours	[/week]
Address of work location	Street address of most frequently visited work location
Duration of employment	Starting years with different employers
Profession	Open
In education/further education	Yes, no
Number of qualification sought	
Number of hours in education	[/week]
Name and addresses of schools	
Presence of fixed time commitments	Yes, no
Type of fixed commitments	Clubs, civic, political, charitable, self improvement, care of family or friends, other (please specify) (tick all which apply)
Number of fixed commitments	[/week]
Number of hours spent on those	[/week]
Day of week and location of those	
License ownership	Yes, no
Type of licenses	Motorized bicycle, small motorcycle, motorcycle, car, truck, coach
Ownership of heavy rail discount card	Yes, no
Ownership of heavy rail season ticket	Yes, no and type (open) and area of validity
Ownership of local public transport season ticket	Yes, no and type (monthly, academic term, senior, pupil, other (please specify)) and area of validity
Nationality	German, other (please specify)

TABLE A.3 Contents of the Vehicle Questionnaire

Item	Coding and Comments
Type of vehicle	Bicycle, motorized bicycle, small motorcycle, motorcycle, car, truck, other (Please specify
Producer	Open (motor vehicles only)
Year of production	(motor vehicles only)
Year of purchase	(motor vehicles only)
Power	[PS] (motor vehicles only)
Motor size	[ccm] (motor vehicles only)
Type of fuel	Gasoline, diesel, other (please specify) (motor vehicles only)
Current odometer reading	[km] (motor vehicles only)
Type of bicycle	Mountain bike, racing bike, city bike, children's bike, other (bicycles only)
Age of bicycle	Less than two years, more than two years (bicycles only)
Mileage with the vehicle during the last twelve months	[km]
Owner of the vehicle	Personal (name, if household member); employer (name of the household member employed); other (please specify)
Main user of the vehicle	Name of household member
Other users	Names of household members
Most frequently used parking space	Yard, driveway, marked space, curb, garage, covered parking space, bicycle shed, basement, other (please specify)
Distance from parking space to home	[m or min]

APPENDIX B:
The Formula in Decomposing of the Variability

Calculation Steps:

Let, Y_{it} = observed value and $\hat{Y}_{it}$ = predicted value
i = individual indices, t = observed day indices,
For i = 1, …, N and t = 1, …, T_i :
N = number of observed individual = 257 person
T_i = number of observed days for each person
Total number of observed days = 6439 days and average observed day / person, T = 25.05 observed days / person

Let,

$$\bar{\hat{Y}}_i = \frac{1}{T_i}\sum_t \hat{Y}_{it} \quad \text{and} \quad \bar{\bar{Y}} = \frac{1}{N}\sum_i \left(\frac{1}{T_i}\sum_t \hat{Y}_{it}\right)$$

Total Sum of Squares, SST = $\sum_i \sum_t \left(Y_{it} - \bar{\bar{Y}}\right)^2$

Systematic Variance:

- Total Regression Sum of Squares, SSR = $\sum_i \sum_t \left(\hat{Y}_{it} - \bar{\bar{Y}}\right)^2$
- Within-persons variations, SSR_i = $\sum_t \left(\hat{Y}_{it} - \bar{\hat{Y}}_i\right)^2$, with i = 1, … N

  Within-persons variations total = $\sum_i \sum_t \left(\hat{Y}_{it} - \bar{\hat{Y}}_i\right)^2$
- Between persons variations = $\sum_i T_i \left(\bar{\hat{Y}}_i - \bar{\bar{Y}}\right)^2$

Random Variance:

The variance of white noise for each person: $\hat{\sigma}^2_{2\varepsilon_i} = \text{var}\left(\hat{\varepsilon}_{it}\right) = \text{var}\left(Y_{it} - \hat{Y}_{it}\right)$

Assuming $\sum_{t=1}^{T} \hat{\varepsilon}_{it} = 0$, the individual specific error component for each person: $\hat{\alpha}_i = \frac{1}{T_i}\sum_t \left(Y_{it} - \hat{Y}_{it}\right)$

- Individual Specific Error Component = $NT\ \text{var}\,\alpha_i$
- White noise, random error = $\sum_i T_i \ . \ \sigma^2_{\varepsilon_i}$

R-square values: $R^2 = \frac{SSR}{SST}$

APPENDIX C:
Supplementary Models in Analyzing the Temporal Changes of Relationships Underlying Individual Travel Behavior

C.1 Binary Probit Model of Non-Work Activity Engagement for Commuters

To eliminate the selectivity bias that would be occur in Equation 5.6 due to the truncated sample condition, a selectivity bias correction term is introduced into the model equations for t_{NW} and v_{NW} (Maddala, 1983; Washington et. al, 2003). Inverse Mill's ratios prepared from the binary probit model of non-work activity engagement are used as the correction terms.

The outcome of the binary probit model of non-work activity engagement for commuters is as follow.

TABLE C.1 Binary Probit Model of Non-Work Activity Engagement for Auto Commuters

	1980		1990		2000	
	Coeff.	t	Coeff.	t	Coeff.	t
Constant	2.46	7.12	0.47	0.94	0.81	2.41
Male [D]	-0.29	-3.32	-0.45	-6.09	-0.51	-8.44
25 - 34 Years Old [D]	0.02	0.19	0.18	1.58	0.17	1.32
35 - 44 Years Old [D]	-0.03	-0.24	-0.001	-0.01	0.29	2.20
45 - 54 Years Old [D]	-0.32	-2.19	-0.05	-0.38	0.15	1.18
55 - 64 Years Old [D]	-0.07	-0.41	-0.18	-1.21	0.07	0.51
65 Years Old or Over [D]	-0.68	-2.28	-0.39	-1.32	-0.32	-1.66
Number of Household Members	-0.03	-1.04	-0.05	-1.54	-0.07	-2.97
Household with Dependent Child [D]	0.07	0.77	0.13	1.50	0.23	3.15
Number of Cars per Adult Household Member	-0.17	-1.29	-0.05	-0.42	-0.04	-0.35
Driver's License Holding [D]	-0.03	-0.28	0.10	0.58	-0.24	-1.56
Resides in Commercial Area [D]	-0.18	-0.39	-0.05	-0.10	-0.19	-0.53
Resides in Mixed Commercial/Residential Area [D]	-0.34	-1.40	-0.13	-0.31	-0.07	-0.30
Resides in Autonomous Area [D]	-0.31	-1.60	-0.04	-0.12	0.04	0.19
Resides in Satellites Area [D]	-0.25	-1.25	-0.14	-0.36	0.03	0.16
Residence Zone Accessibility to Population	0.06	0.94	0.00	0.01	-0.0010	-0.08
Work Zone Accessibility to Population	-0.02	-0.28	0.04	0.69	-0.0011	-0.09
Work Activity Time (min)	-0.01	-23.88	-0.004	-18.09	-0.003	-16.30
Number of Work Trip / Day	0.24	3.03	0.74	10.01	0.55	9.61
Work One-way Commute Distance	-0.02	-2.97	-0.004	-0.83	-0.01	-2.42
N	2893		3512		3559	
L(0)	-1258.82		-1431.86		-1764.45	
L(β)	-835.38		-979.74		-1364.41	
Degrees of Freedom	19		19		19	
Chi square	846.9		904.2		800.1	

TABLE C.2 Binary Probit Model of Non-Work Activity Engagement for Transit Commuters

	1980		1990		2000	
	Coeff.	t	Coeff.	t	Coeff.	t
Constant	2.33	9.49	0.49	1.33	0.56	1.33
Male [D]	-0.18	-3.77	-0.27	-5.65	-0.48	-10.28
25 - 34 Years Old [D]	-0.05	-0.66	0.15	2.13	0.08	0.97
35 - 44 Years Old [D]	-0.11	-1.48	0.042	0.58	0.10	1.11
45 - 54 Years Old [D]	-0.17	-2.33	-0.01	-0.20	0.13	1.67
55 - 64 Years Old [D]	-0.42	-4.78	-0.23	-2.82	0.04	0.49
65 Years Old or Over [D]	-0.71	-5.10	-0.82	-5.84	-0.25	-2.02
Number of Household Members	-0.08	-4.37	-0.11	-5.80	-0.12	-6.78
Household with Dependent Child [D]	0.04	0.71	0.11	2.02	0.19	3.25
Number of Cars per Adult Household Member	-0.30	-4.07	-0.25	-3.63	-0.06	-0.90
Driver's License Holding [D]	0.05	0.90	0.07	1.39	0.18	3.76
Resides in Commercial Area [D]	-0.26	-1.03	0.041	0.12	0.23	0.56
Resides in Mixed Commercial/Residential Area [D]	-0.14	-0.65	0.14	0.41	0.23	0.59
Resides in Autonomous Area [D]	-0.15	-0.70	0.07	0.22	-0.10	-0.24
Resides in Satellites Area [D]	-0.14	-0.70	0.06	0.18	0.18	0.47
Residence Zone Accessibility to Population	0.01	0.17	0.01	0.38	0.0001	0.01
Work Zone Accessibility to Population	0.004	0.13	0.003	0.09	-0.0017	-0.20
Work Activity Time (min)	-0.01	-38.85	-0.004	-26.22	-0.004	-25.18
Number of Work Trip / Day	0.39	6.71	0.88	16.78	0.73	14.39
Work One-way Commute Distance	-0.01	-2.46	-0.007	-2.32	-0.01	-3.48
N	6307		6773		6134	
L(0)	-3449.29		-3676.77		-3526.75	
L(β)	-2299.08		-2514.13		-2556.62	
Degrees of Freedom	19		19		19	
Chi square	2300.4		2325.3		1940.3	

From Table C.1 and C.2, it is shown that for both auto and transit commuters, male commuters are less likely to engage in non-work activities. Work duration as well as commute distance negatively influence non-work activity engagement. Commuters from larger households tend not to engage in non-work activities, presumably because obligatory household tasks are shared by more members.

C.2 The Nested Logit Model of Trip Making and Commute Mode Choice for Commuters

The model system is estimated for auto commuters and transit commuters separately. The two sets of models are tied together by a nested logit model of trip making and commute mode choice which indicates the probability that a commuter will use the automobile.

Although it is outside the scope of this study, application of the model system to forecasting calls for the capability of predicting who will be auto commuters. Nested logit models of trip generation and commute mode choice are therefore developed as a precursor to the simultaneous equations model system, to determine the probabilities that a worker will:

make no trip ($v_W = 0$, $v_{NW} = 0$),
make at least one trip, but will not make a commute trip ($v_W = 0$, $v_{NW} \geq 0$),
make a commute trip using an automobile ($v_W \geq 0$), or
make a commute trip without using an automobile ($v_W \geq 0$)

on a given day. The nest structure is shown in Figure C.1 and the distribution of observed choices is given in Table C.3 for the respective years. The models are estimated by the full-information maximum likelihood (FIML) method using NLOGIT Version 3.0 in LIMDEP Version 8.0, with the coefficient estimates obtained from sequential estimation used as initial values. The results are presented in Table C.4.

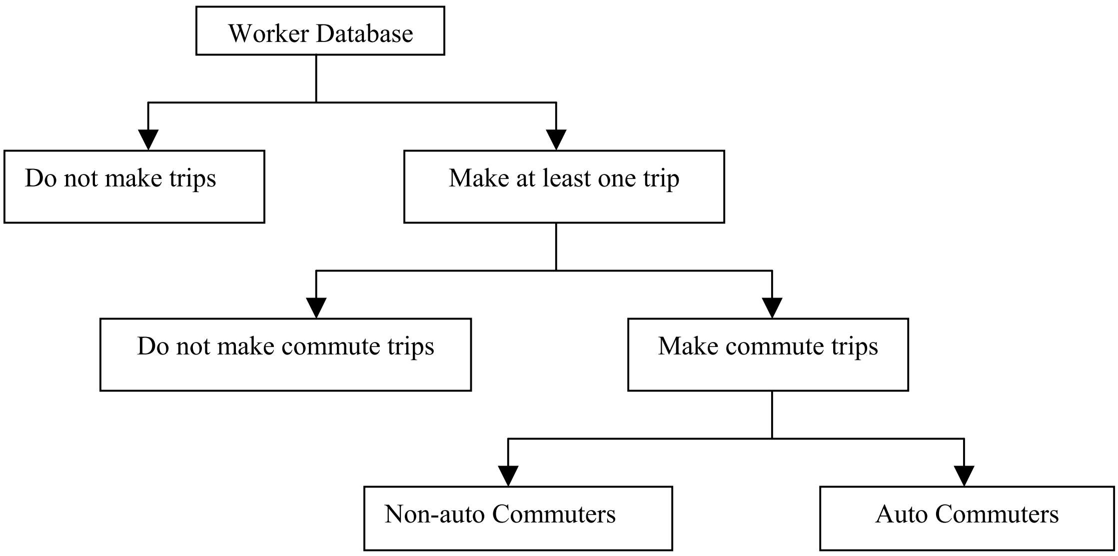


FIGURE C.1 Nest Structure of the Nested Logit Model of Commute Trip Making

The coefficient estimates for the choice in the highest level (whether a trip is made at all) indicate that a male worker is less likely to make a trip than his female counterpart, presumably because the latter tends to perform various domestic chores even on days when she is not working. Holding a driver's license has positive effects in the 1990 and 2000 models, but not in the 1980 model. The number of automobiles per adult household member shows negative coefficient in all of the models; automobility thus does not have clear-cut effects on whether a worker makes a trip at all on a given day.

TABLE C.3 Distribution of Workers by Trip Making and Commute Mode Choice†

Year		No Trips: $v_W = 0$, $v_{NW} = 0$	No Work Trips: $v_W = 0$, $v_{NW} \geq 0$	Auto Commuters : $v_W \geq 0$	Non-auto Commuters : $v_W \geq 0$	Total	*N*
1980	Full Data	15.4	5.3	45.4	33.9	100.0	86,083
	Estimation Sample	16.9	4.8	45.5	32.8	100.0	4,274
1990	Full Data	13.5	5.5	47.1	33.9	100.0	109,777
	Estimation Sample	13.7	5.3	47.5	33.5	100.0	5,448
2000	Full Data	11.8	8.8	46.2	33.2	100.0	113,444
	Estimation Sample	11.6	9.1	47.0	32.3	100.0	5,691

†In percent
"Estimation Sample" is the sub-sample of the full data set that was used to estimate the nested logit models

The explanatory variables for the choice in the next level, whether a worker will make a work trip, are all dummy variables representing the worker's age. This specification is motivated by the prospect that, among the variables available in the data sets, age is the primary variable that is associated with illness or absenteeism. Marital status was examined but turned out insignificant. Whether a worker works at home is a critical determinant of work trip generation, but unfortunately this information is not available from the data set. The results offer consistent indication across the three years that an older worker is less likely to make a work trip.

The coefficient estimates for commute mode choice indicate that auto availability is its primary determinant. Both the number of automobiles per adult household member and driver's license holding have consistent and significant positive effects on the use of an automobile for commuting. Also there is a clear indication that work zone accessibility to retail activities negatively affects auto use for commuting; evidently a worker commuting to a more commercialized area tends not to use the automobile.

In the table μ_T and μ_W represent the coefficients of the inclusive price variables. Falling between 0 and 1, they take on legitimate values. Notably μ_T are not significantly different from 1.0 in the 1980 and 2000 model, indicating that there is no correlation between the error terms of the two alternatives under *make at least one trip*, i.e., *do not make commute trips* and *make commute trips*. On the other hand, μ_W is not significantly different from 0 for any of the years; the error term associated with commuting by auto and that associated with commuting by non-auto modes are highly correlated, and the choice in the higher level, *do not make commute trips* vs. *make commute trips*, is not significantly influenced by the attributes of the alternatives in the lower level.

The goodness-of-fit statistics presented in the table indicate that the models are all highly significant. This is the case when the contributions of the constant terms, which replicate the sample distribution of chosen alternatives, are excluded (see $-2[L(\beta) - L(C)]$ and $1 - L(\beta)/L(C)$).

The model, however, is not stable over time. The results of likelihood ratio tests (Table C.5) indicate that the model coefficients are not stable between any pair of years, prompting the conclusion that trip making and commute mode choice are not stable between 1980 and 2000 in the Osaka metropolitan area. The changes seen in Table 5.2 are thus due to structural changes as well as changes in the contributing factors.

TABLE C.4 Nested Logit Models of Trip Making and Commute Mode Choice

	1980		1990		2000	
Make Trips vs. No Trip	Coef.	t	Coef.	t	Coef.	t
Male [D]	-0.334	-3.06	-0.290	-2.99	-0.361	-3.74
Household with Children [D]	-0.067	-0.74	0.119	1.35	-0.051	-0.55
Number of Autos per Adult Household Member	-0.865	-5.31	-0.810	-5.21	-0.209	-1.27
Driver's License Holding [D]	0.034	0.23	0.207	1.61	0.300	2.29
Residence Zone Accessibility to Population (×100)	-8.066	-2.74	-0.871	-0.28	0.373	0.27
μ_T†	0.929	1.08	0.831	2.59	0.937	0.85
Make Commute Trips vs. No Commute Trip						
Constant	3.375	16.98	3.133	19.24	2.395	16.40
25 - 34 Years Old [D]	-0.210	-1.22	-0.191	-1.17	-0.003	-0.02
35 - 44 Years Old [D]	-0.722	-4.19	-0.349	-2.25	-0.069	-0.46
45 - 54 Years Old [D]	-0.716	-4.13	-0.541	-3.52	-0.109	-0.75
55 - 64 Years Old [D]	-1.208	-6.39	-0.965	-5.83	-0.532	-3.56
65 Years Old or Over [D]	-1.998	-8.84	-1.884	-8.80	-1.254	-7.31
μ_W	0.105	0.60	0.171	1.46	0.042	0.38
Commute by Auto vs. Commute by Other Mode						
Constant	-1.384	-8.43	-2.460	-11.83	-2.337	-12.42
Residence Zone Accessibility to Employment	0.374	3.76	0.497	7.37	-0.011	-0.43
Work Zone Accessibility to Retail Area (×10)	-0.256	-7.81	-0.441	-14.77	-0.147	-15.31
Household with Children [D]	0.207	2.64	0.106	1.46	0.139	1.96
Number of Autos per Adult Household Member	0.719	4.88	0.886	6.35	1.156	8.46
Driver's License Holding [D]	1.762	18.68	2.993	18.66	2.358	14.34
One-way Commute Distance (×10)	0.130	2.00	0.331	6.65	0.017	0.38
N	4273		5448		5652	
L(0)	-7742		-10094		-10560	
L(C)	-5001		-6254		-6760	
$L(\beta)$	-4599		-5557		6135	
-2[$L(0)$ - $L(\beta)$] (χ^2, df = 20)	6287		9075		8850	
-2[$L(C)$ - $L(\beta)$] (χ^2, df = 18)	804		1394		1250	
1 - $L(\beta)$/L(0)	0.406		0.449		0.419	
1 - $L(\beta)$/L(C)	0.080		0.111		0.092	

†*T*-statistics for H_0: $\beta = 1$ are shown.
L(0): Log-likelihood with no model coefficients
L(*C*): Log-likelihood with constant terms only
L(β): Log-likelihood with all model parameters at convergence

TABLE C.5 Stability of the Nested Logit Models of Trip Making and Commute Mode Choice

Years Compared	χ^2	df
1980 vs. 1990	191.6	20
1980 vs. 2000	162.6	20
1990 vs. 2000	172.6	20
1980 vs. 1990 vs. 2000	349.9	40

The critical value of χ^2 at $\alpha = 0.05$ is 31.4 with df = 20, and 55.8 with df = 40.

APPENDIX D:
The Structural Relationships Model for Non-Workers

TABLE D.1 Model of Time Expenditure for Non-Work Activity (t_{NW})

	1980		1990		2000	
	Coeff.	t	Coeff.	t	Coeff.	t
Constant	83.96	5.94	134.9	4.16	183.4	9.27
Male [D]	22.55	3.90	23.12	4.06	23.58	5.69
25 - 34 Years Old [D]	-10.11	-1.32	-38.99	-3.52	-54.37	-4.84
35 - 44 Years Old [D]	-1.61	-0.20	-32.34	-2.90	-47.81	-4.22
45 - 54 Years Old [D]	-9.08	-1.16	-38.27	-3.51	-50.83	-4.78
55 - 64 Years Old [D]	-4.57	-0.58	-30.46	-2.83	-46.80	-4.55
65 Years Old or Over [D]	-5.21	-0.66	-27.79	-2.55	-55.09	-5.38
Number of Household Members	0.80	0.64	-2.35	-1.46	-2.97	-2.01
Household with Dependent Child [D]	-4.87	-1.28	7.38	1.45	2.76	0.53
Number of Cars per Adult Household Member	-15.28	-3.46	-6.23	-1.03	5.46	0.96
Driver's License Holding [D]	8.77	2.15	8.32	1.92	3.05	0.79
Resides in Commercial Area [D]	-7.73	-0.52	-18.94	-0.60	-34.66	-1.88
Resides in Mixed Commercial/Residential Area [D]	-7.70	-0.66	-20.48	-0.68	-37.16	-2.25
Resides in Autonomous Area [D]	-3.02	-0.25	-21.43	-0.72	-47.50	-2.82
Resides in Satellites Area [D]	-9.76	-0.85	-15.62	-0.53	-38.41	-2.37
Residence Zone Accessibility to Population	0.12	1.28	1.32	0.73	0.38	0.74
Fraction of Auto Trip in Given Day Trip Pattern	59.01	10.69	49.37	9.55	52.57	12.73
Fraction of Transit Trip in Given Day Trip Pattern	112.6	28.24	103.0	20.13	116.0	25.02
N	5322		5386		6673	
Mean of Y (minutes)	90		111		127	
Standard Deviation of Y	103		124		126	
Regression Sum of Squares	8880144		7954968		11863434	
Residual Sum of Squares	47646613		74734000		93550866	
Total Sum of Squares	56526757		82688968		105414300	
F	58.15		33.61		49.64	
Degrees of Freedom	(17, 5304)		(17, 5368)		(17, 6655)	
R^2	0.1571		0.0962		0.1125	
Adjusted R^2	0.1544		0.0933		0.1103	

TABLE D.2 Model of Number of Non-Work Visits (v_{NW})

	1980		1990		2000	
	Coeff.	t	Coeff.	t	Coeff.	t
Constant	1.010	18.78	0.114	1.05	0.632	7.17
Male [D] [x10^2]	-0.001	-0.02	-0.139	-5.03	-0.132	-6.22
25 - 34 Years Old [D] [x10^2]	0.289	5.85	0.558	9.38	0.416	7.58
35 - 44 Years Old [D] [x10^2]	0.174	3.54	0.395	7.09	0.373	7.06
45 - 54 Years Old [D] [x10^2]	0.076	1.54	0.448	7.70	0.371	7.39
55 - 64 Years Old [D] [x10^2]	0.080	1.65	0.334	6.39	0.386	8.37
65 Years Old or Over [D] [x10^2]	0.123	2.67	0.268	5.17	0.382	7.85
Number of Household Members [x10^2]	0.007	0.84	0.010	1.15	0.018	2.15
Household with Dependent Child [D] [x10^2]	0.020	0.74	-0.064	-2.26	0.056	2.02
Number of Cars per Adult Household Member [x10^2]	-0.090	-2.81	-0.091	-2.77	-0.104	-3.64
Driver's License Holding [D] [x10^2]	0.053	1.87	0.012	0.53	0.103	5.24
Resides in Commercial Area [D] [x10^2]	0.259	2.73	1.243	10.59	0.541	7.16
Resides in Mixed Commercial/Residential Area [D] [x10^2]	0.226	3.34	1.243	11.60	0.573	8.88
Resides in Autonomous Area [D] [x10^2]	0.230	3.40	1.226	11.59	0.555	7.80
Resides in Satellites Area [D] [x10^2]	0.245	3.76	1.169	11.68	0.545	8.71
Residence Zone Accessibility to Population [x10^3]	0.251	2.65	-0.091	-0.99	-0.002	-0.06
Fraction of Auto Trip in Given Day Trip Pattern [x10^3]	-1.334	-2.79	-4.584	-9.32	-2.763	-7.67
Fraction of Transit Trip in Given Day Trip Pattern [x10^3]	-3.258	-6.28	-8.404	-12.57	-5.593	-10.95
N	5322		5386		6673	
Mean of Y (minutes)	1.362		1.445		1.584	
Standard Deviation of Y	0.680		0.735		0.831	
Regression Sum of Squares	68		147		172	
Residual Sum of Squares	2394		2761		4433	
Total Sum of Squares	2463		2908		4605	
F	8.93		16.80		15.19	
Degrees of Freedom	(17, 5304)		(17, 5368)		(17, 6655)	
R^2	0.0278		0.0505		0.0374	
Adjusted R^2	0.0247		0.0475		0.0349	

TABLE D.3 Model of Number of Trip Chains (n_C)

	1980		1990		2000	
	Coeff.	t	Coeff.	t	Coeff.	t
Constant	1.00	32.91	0.59	8.23	0.95	18.55
Male [D] [x10^2]	1.77	0.90	1.09	0.75	-0.02	-0.02
25 - 34 Years Old [D] [x10^2]	4.52	1.78	2.93	0.97	5.50	1.92
35 - 44 Years Old [D] [x10^2]	-1.45	-0.54	1.37	0.45	9.00	3.12
45 - 54 Years Old [D] [x10^2]	-6.22	-2.27	-1.40	-0.47	4.24	1.53
55 - 64 Years Old [D] [x10^2]	-1.45	-0.53	-0.73	-0.25	7.75	2.90
65 Years Old or Over [D] [x10^2]	-2.61	-1.02	-3.07	-1.05	6.77	2.52
Number of Household Members [x10^2]	0.04	0.10	0.34	0.82	-0.05	-0.15
Household with Dependent Child [D] [x10^2]	5.58	4.25	1.27	0.98	3.63	2.91
Number of Cars per Adult Household Member [x10^2]	-6.91	-4.83	-4.32	-2.52	-3.62	-2.64
Driver's License Holding [D] [x10^2]	1.95	1.45	0.40	0.35	2.52	2.66
Resides in Commercial Area [D] [x10^2]	19.67	4.39	55.48	8.14	14.38	3.26
Resides in Mixed Commercial/Residential Area [D] [x10^2]	16.63	5.45	53.19	8.25	12.05	3.03
Resides in Autonomous Area [D] [x10^2]	14.49	4.38	49.94	7.92	13.02	3.07
Resides in Satellites Area [D] [x10^2]	15.04	5.05	50.81	8.10	11.95	3.00
Residence Zone Accessibility to Population [x10^3]	-1.20	-0.27	-19.50	-4.24	-2.01	-1.66
Fraction of Auto Trip in Given Day Trip Pattern [x10^3]	-4.34	-0.24	-38.60	-2.93	-27.65	-2.86
Fraction of Transit Trip in Given Day Trip Pattern [x10^3]	-70.26	-5.12	-67.18	-4.92	-83.95	-7.16
N	5322		5386		6673	
Mean of Y (minutes)	1.203		1.204		1.216	
Standard Deviation of Y	0.457		0.446		0.455	
Regression Sum of Squares	44		48		41	
Residual Sum of Squares	1069		1025		1339	
Total Sum of Squares	1114		1073		1380	
F	12.96		14.83		12.05	
Degrees of Freedom	(17, 5304)		(17, 5386)		(17, 6655)	
R^2	0.0399		0.0449		0.0299	
Adjusted R^2	0.0368		0.0418		0.0274	

TABLE D.4 Model of Total Travel Time (t_T)

	1980		1990		2000	
	Coeff.	t	Coeff.	t	Coeff.	t
Constant	57.83	30.37	31.09	5.28	48.55	10.37
Male [D]	3.61	5.57	3.09	5.38	1.98	4.27
25 - 34 Years Old [D]	-1.74	-2.13	-2.19	-1.88	-0.69	-0.53
35 - 44 Years Old [D]	-2.85	-3.31	-2.33	-1.99	-0.55	-0.43
45 - 54 Years Old [D]	-3.17	-3.58	-1.14	-0.99	-0.52	-0.42
55 - 64 Years Old [D]	-2.68	-3.07	-0.73	-0.65	1.22	1.01
65 Years Old or Over [D]	-2.77	-3.35	-0.77	-0.67	0.48	0.39
Number of Household Members	-0.29	-2.06	-0.43	-2.63	-0.67	-4.09
Household with Dependent Child [D]	0.59	1.36	0.49	0.97	0.38	0.66
Number of Cars per Adult Household Member	-5.14	-11.03	-3.04	-4.41	-2.52	-3.93
Driver's License Holding [D]	1.29	2.92	0.56	1.25	1.27	2.91
Resides in Commercial Area [D]	-12.56	-8.70	1.23	0.46	-3.96	-1.96
Resides in Mixed Commercial/Residential Area [D]	-12.88	-13.08	0.65	0.26	-4.59	-2.50
Resides in Autonomous Area [D]	-9.22	-8.70	1.81	0.71	-4.02	-2.08
Resides in Satellites Area [D]	-10.70	-11.22	1.87	0.74	-4.26	-2.33
Residence Zone Accessibility to Population	0.76	5.12	0.12	0.68	0.060	1.07
Fraction of Auto Trip in Given Day Trip Pattern	6.41	10.67	6.14	12.07	5.742	12.91
Fraction of Transit Trip in Given Day Trip Pattern	20.34	45.38	29.11	52.07	23.34	41.72
N	5322		5386		6673	
Mean of Y (minutes)	34.93		41.36		46.11	
Standard Deviation of Y	32.90		39.61		41.97	
Regression Sum of Squares	1742163		3142298		2828159	
Residual Sum of Squares	4018045		5305352		8922055	
Total Sum of Squares	5760208		8447650		11750215	
F	135.28		187.02		124.09	
Degrees of Freedom	(17, 5304)		(17, 5368)		(17, 2732)	
R^2	0.3024		0.3720		0.2407	
Adjusted R^2	0.3002		0.3700		0.2388	

APPENDIX E:
The Structural Relationships Model for Auto Commuters

TABLE E.1 Model of Time Expenditure for Non-Work Activity (t_{NW})

	1980		1990		2000	
	Coeff.	t	Coeff.	t	Coeff.	t
Constant	368.68	6.98	396.07	5.71	261.42	5.42
Male [D]	122.23	9.23	133.38	9.66	90.71	5.45
25 - 34 Years Old [D]	-44.58	-2.72	-58.75	-3.42	-43.7	-2.12
35 - 44 Years Old [D]	-43.78	-2.34	-43.18	-2.46	-51.94	-2.32
45 - 54 Years Old [D]	-28.07	-1.40	-29.66	-1.70	-30.96	-1.51
55 - 64 Years Old [D]	-45.20	-1.96	-31.70	-1.46	-60.24	-2.89
65 Years Old or Over [D]	21.02	0.47	-220.41	-4.83	-20.38	-0.69
Number of Household Members	3.55	0.79	8.60	2.01	6.46	1.72
Household with Dependent Child [D]	-16.66	-1.27	-47.17	-3.83	-27.33	-2.35
Number of Cars per Adult Household Member	-2.68	-0.16	-0.68	-0.04	27.84	1.84
Driver's License Holding [D]	-7.88	-0.67	0.33	0.01	9.68	0.47
Resides in Commercial Area [D]	-50.48	-0.68	-19.14	-0.30	-1.56	-0.03
Resides in Mixed Commercial/Residential Area [D]	26.11	0.79	-43.62	-0.81	3.30	0.11
Resides in Autonomous Area [D]	24.79	0.90	-22.19	-0.43	-8.77	-0.30
Resides in Satellites Area [D]	10.00	0.37	-15.77	-0.31	-21.35	-0.74
Residence Zone Accessibility to Population	-14.91	-1.76	8.81	0.92	-1.25	-0.79
Work Zone Accessibility to Population	4.72	0.62	-6.94	-0.84	0.58	0.39
Work Activity Time (min)	-0.05	-0.31	-0.13	-1.30	-0.22	-2.37
Number of Work Trip / Day	-34.64	-4.74	-21.57	-1.77	21.82	1.61
Work One-way Commute Distance	1.51	1.79	0.04	0.06	0.23	0.36
IMR (Inversely Mill's Ratio)	-164.38	-3.90	-160.36	-4.88	-91.87	-2.20
N	455		497		700	
Mean of Y (minutes)	170		173		115	
Standard Deviation of Y	154		164		136	
Regression Sum of Squares	7183445		8688135		6620479	
Residual Sum of Squares	3620932		4649135		6217803	
Total Sum of Squares	10804377		13337270		12838282	
F	43.05		44.48		36.15	
Degrees of Freedom	(20, 434)		(20, 476)		(20, 679)	
R^2	0.6649		0.6514		0.5157	
Adjusted R^2	0.6494		0.6368		0.5014	

TABLE E.2 Model of Number of Non-Work Visits (v_{NW})

	1980		1990		2000	
	Coeff.	t	Coeff.	t	Coeff.	t
Constant	1.382	11.00	1.429	10.51	1.606	12.29
Male [D] [x10^2]	-0.016	-0.48	-0.006	-0.18	-0.017	-0.41
25 - 34 Years Old [D] [x10^2]	0.000	0.00	0.037	1.09	-0.013	-0.17
35 - 44 Years Old [D] [x10^2]	-0.009	-0.22	-0.009	-0.24	-0.026	-0.33
45 - 54 Years Old [D] [x10^2]	-0.043	-1.11	-0.011	-0.31	-0.067	-0.95
55 - 64 Years Old [D] [x10^2]	-0.054	-1.20	0.018	0.47	-0.031	-0.44
65 Years Old or Over [D] [x10^2]	-0.028	-0.36	-0.066	-0.40	0.071	0.85
Number of Household Members [x10^2]	-0.005	-0.64	-0.008	-1.15	-0.008	-0.69
Household with Dependent Child [D] [x10^2]	0.011	0.39	0.015	0.62	0.019	0.50
Number of Cars per Adult Household Member [x10^2]	-0.028	-0.86	-0.010	-0.33	0.137	2.73
Driver's License Holding [D] [x10^2]	-0.011	-0.37	-0.040	-0.71	0.025	0.31
Resides in Commercial Area [D] [x10^2]	-0.111	-0.29	0.005	0.06	-0.069	-0.45
Resides in Mixed Commercial/Residential Area [D] [x10^2]	-0.020	-0.32	0.022	0.30	-0.166	-1.75
Resides in Autonomous Area [D] [x10^2]	-0.010	-0.20	-0.011	-0.18	-0.139	-1.50
Resides in Satellites Area [D] [x10^2]	-0.026	-0.52	0.013	0.22	-0.119	-1.32
Residence Zone Accessibility to Population [x10^3]	0.162	0.99	-0.202	-1.08	0.033	0.56
Work Zone Accessibility to Population [x10^3]	-0.142	-0.99	0.104	0.65	-0.056	-0.95
Work One-way Commute Distance [x10^3]	0.016	1.19	0.011	0.79	0.008	0.36
IMR (Inversely Mill's Ratio)	-0.102	-1.50	-0.101	-1.44	-0.212	-2.71
N	455		497		700	
Mean of Y (minutes)	1.156		1.185		1.290	
Standard Deviation of Y	0.420		0.433		0.551	
Regression Sum of Squares	3		3		8	
Residual Sum of Squares	77		89		204	
Total Sum of Squares	80		93		212	
F	1.01		1.10		1.64	
Degrees of Freedom	(18, 437)		(18, 479)		(18, 682)	
R^2	0.0376		0.0376		0.0394	
Adjusted R^2	0.0002		0.0034		0.0154	

TABLE E.3 Model of Number of Trip Chains (n_C)

	1980		1990		2000	
	Coeff.	t	Coeff.	t	Coeff.	t
Constant	0.68	61.15	0.92	133.84	0.89	101.64
Male [D] [x10^2]	5.67	6.12	-3.04	-5.64	-3.49	-5.93
25 - 34 Years Old [D] [x10^2]	1.56	1.30	-1.71	-2.18	-1.04	-0.84
35 - 44 Years Old [D] [x10^2]	-0.56	-0.42	0.01	0.01	-1.05	-0.82
45 - 54 Years Old [D] [x10^2]	-0.74	-0.53	-0.92	-1.12	0.32	0.27
55 - 64 Years Old [D] [x10^2]	-0.41	-0.23	-0.88	-0.91	-0.25	-0.20
65 Years Old or Over [D] [x10^2]	-1.56	-0.53	6.16	2.77	6.52	3.68
Number of Household Members [x10^2]	2.51	8.65	0.63	3.38	1.12	5.18
Household with Dependent Child [D] [x10^2]	-1.97	-2.06	2.15	3.67	2.39	3.32
Number of Cars per Adult Household Member [x10^2]	11.62	10.68	1.78	2.29	2.23	2.23
Driver's License Holding [D] [x10^2]	-1.03	-1.07	1.19	0.93	2.82	1.87
Resides in Commercial Area [D] [x10^2]	-0.70	-0.16	7.64	3.10	4.03	1.63
Resides in Mixed Commercial/Residential Area [D] [x10^2]	11.33	5.26	7.96	4.29	7.31	4.19
Resides in Autonomous Area [D] [x10^2]	15.42	9.78	8.83	5.45	9.97	6.10
Resides in Satellites Area [D] [x10^2]	15.43	9.01	7.87	4.87	7.76	5.01
Residence Zone Accessibility to Population [x10^3]	23.26	4.07	-1.25	-0.30	-1.16	-1.02
Work Zone Accessibility to Population [x10^3]	-13.68	-2.69	0.65	0.18	2.27	2.04
Work One-way Commute Distance [x10^3]	-1.88	-3.81	-1.01	-3.08	-2.69	-6.95
N	2893		3512		3559	
Mean of Y (minutes)	1.109		1.041		1.070	
Standard Deviation of Y	0.322		0.199		0.277	
Regression Sum of Squares	122		19		56	
Residual Sum of Squares	178		120		217	
Total Sum of Squares	299		139		272	
F	115.99		33.48		53.66	
Degrees of Freedom	(17, 2875)		(17, 3494)		(17, 3541)	
R^2	0.4068		0.1401		0.2048	
Adjusted R^2	0.4033		0.1359		0.2010	

TABLE E.4 Model of Total Travel Time (t_T) for Simple Commuters

	1980		1990		2000	
	Coeff.	t	Coeff.	t	Coeff.	t
Constant	24.84	7.61	39.34	5.53	46.07	9.52
Male [D]	0.26	0.19	2.82	2.29	1.82	1.71
25 - 34 Years Old [D]	0.61	0.38	-3.06	-1.86	-0.63	-0.34
35 - 44 Years Old [D]	0.33	0.19	-5.40	-3.28	0.15	0.07
45 - 54 Years Old [D]	0.87	0.48	-4.53	-2.68	-0.04	-0.02
55 - 64 Years Old [D]	1.67	0.70	-2.18	-1.12	-1.11	-0.57
65 Years Old or Over [D]	2.79	0.71	-6.37	-1.80	-4.82	-1.88
Number of Household Members	-1.09	-2.81	-1.81	-4.43	-1.74	-4.75
Household with Dependent Child [D]	1.29	1.07	1.86	1.50	0.85	0.70
Number of Cars per Adult Household Member	-9.30	-5.92	-5.91	-3.28	-8.13	-4.51
Driver's License Holding [D]	4.26	3.04	-8.36	-3.01	-1.23	-0.42
Resides in Commercial Area [D]	0.63	0.09	-9.12	-1.20	-6.61	-1.16
Resides in Mixed Commercial/Residential Area [D]	3.09	0.91	-1.04	-0.17	-6.35	-1.75
Resides in Autonomous Area [D]	6.49	2.40	3.83	0.63	-4.75	-1.40
Resides in Satellites Area [D]	0.95	0.34	0.20	0.03	-5.94	-1.77
Residence Zone Accessibility to Population	-4.26	-5.31	-0.94	-1.09	0.594	2.94
Work Zone Accessibility to Population	6.70	9.06	5.22	6.82	0.588	3.20
Work One-way Commute Distance	3.05	42.16	3.05	45.58	3.09	49.23
N	2344		2924		2750	
Mean of Y (minutes)	49.57		56.64		56.23	
Standard Deviation of Y	32.11		34.09		32.82	
Regression Sum of Squares	1225637		1656611		1491427	
Residual Sum of Squares	1190359		1740080		1469235	
Total Sum of Squares	2415996		3396691		2960662	
F	140.88		162.74		163.13	
Degrees of Freedom	(17, 2326)		(17, 2906)		(17, 2732)	
R^2	0.5073		0.4877		0.5037	
Adjusted R^2	0.5037		0.4847		0.5007	

TABLE E.5 Model of Total Travel Time (t_T) for Complex Commuters

	1980		1990		2000	
	Coeff.	t	Coeff.	t	Coeff.	t
Constant	27.69	4.39	33.84	3.77	34.31	6.63
Male [D]	1.25	1.29	2.49	2.39	2.35	3.75
25 - 34 Years Old [D]	0.23	0.16	0.23	0.14	2.30	1.52
35 - 44 Years Old [D]	1.17	0.74	0.36	0.20	1.04	0.68
45 - 54 Years Old [D]	1.24	0.73	2.45	1.38	0.42	0.29
55 - 64 Years Old [D]	0.69	0.35	-1.22	-0.57	1.52	1.02
65 Years Old or Over [D]	7.22	2.15	4.90	0.91	2.06	1.01
Number of Household Members	-0.64	-1.88	-0.91	-2.34	-0.36	-1.51
Household with Dependent Child [D]	-0.51	-0.46	0.09	0.07	-0.65	-0.82
Number of Cars per Adult Household Member	-6.86	-5.19	-6.23	-3.77	-5.58	-5.06
Driver's License Holding [D]	3.34	3.24	4.40	1.68	4.28	2.65
Resides in Commercial Area [D]	2.84	0.54	11.16	2.19	6.11	2.21
Resides in Mixed Commercial/Residential Area [D]	6.66	2.74	0.42	0.10	3.07	1.51
Resides in Autonomous Area [D]	7.10	3.81	4.13	1.16	3.00	1.60
Resides in Satellites Area [D]	5.08	2.51	3.05	0.86	2.74	1.51
Residence Zone Accessibility to Population	-3.19	-4.94	-1.55	-1.69	0.13	1.05
Work Zone Accessibility to Population	4.08	7.14	2.54	3.24	0.20	1.62
Work One-way Commute Distance	0.68	12.36	0.77	11.08	0.75	16.65
N	549		588		809	
Mean of Y (minutes)	67.30		76.06		72.39	
Standard Deviation of Y	49.15		53.22		41.44	
Regression Sum of Squares	744384		637597		553315	
Residual Sum of Squares	579171		1024770		834113	
Total Sum of Squares	1323555		1662367		1387428	
F	40.15		20.86		30.87	
Degrees of Freedom	(17, 531)		(17, 570)		(17, 791)	
R^2	0.5624		0.3835		0.3988	
Adjusted R^2	0.5484		0.3652		0.3859	

APPENDIX F:
The Structural Relationships Model for Transit Commuters

TABLE F.1 Model of Time Expenditure for Non-Work Activity (t_{NW})

	1980		1990		2000	
	Coeff.	t	Coeff.	t	Coeff.	t
Constant	520.13	15.35	347.17	7.29	242.04	4.04
Male [D]	96.72	13.04	109.88	17.61	75.37	9.27
25 - 34 Years Old [D]	-43.34	-4.66	-52.02	-5.72	-19.05	-1.71
35 - 44 Years Old [D]	-27.63	-2.69	-51.81	-5.60	-36.11	-3.04
45 - 54 Years Old [D]	-39.57	-3.77	-53.58	-5.97	-46.20	-4.18
55 - 64 Years Old [D]	-79.09	-5.78	-71.17	-6.76	-59.55	-5.22
65 Years Old or Over [D]	-119.25	-5.25	-124.68	-6.42	-131.38	-7.95
Number of Household Members	-4.65	-1.62	1.81	0.73	-3.65	-1.29
Household with Dependent Child [D]	-21.08	-2.55	-27.94	-3.99	-27.32	-3.50
Number of Cars per Adult Household Member	-63.16	-5.81	-7.12	-0.81	-37.97	-4.34
Driver's License Holding [D]	2.21	0.31	4.17	0.71	21.87	3.41
Resides in Commercial Area [D]	-5.05	-0.15	-11.13	-0.24	81.72	1.38
Resides in Mixed Commercial/Residential Area [D]	-36.53	-1.26	-29.88	-0.68	66.86	1.15
Resides in Autonomous Area [D]	2.81	0.10	-44.45	-1.00	71.55	1.21
Resides in Satellites Area [D]	-35.16	-1.26	-33.46	-0.77	60.78	1.05
Residence Zone Accessibility to Population	-10.15	-2.27	-11.37	-2.38	2.08	1.94
Work Zone Accessibility to Population	12.60	3.11	11.64	3.06	-3.05	-2.82
Work Activity Time (min)	-0.84	-8.24	-0.28	-5.81	-0.53	-10.10
Number of Work Trip / Day	-18.78	-2.60	25.98	4.58	43.33	6.54
Work One-way Commute Distance	-0.28	-0.71	0.44	1.10	1.51	4.61
IMR (Inversely Mill’s Ratio)	42.54	1.54	-82.17	-5.00	7.72	0.38
N	1491		1578		1606	
Mean of Y (minutes)	194		178		145	
Standard Deviation of Y	168		166		153	
Regression Sum of Squares	25128150		29131909		21937661	
Residual Sum of Squares	17059736		14547791		15616706	
Total Sum of Squares	42187887		43679700		37554368	
F	108.26		155.89		111.33	
Degrees of Freedom	(20, 1470)		(20, 1557)		(20, 1585)	
R^2	0.5956		0.6669		0.5842	
Adjusted R^2	0.5901		0.6627		0.5789	

TABLE F.2 Model of Number of Non-Work Visits (v_{NW})

	1980		1990		2000	
	Coeff.	t	Coeff.	t	Coeff.	t
Constant	1.268	0.08	1.254	12.58	1.411	15.42
Male [D] [x10^2]	-0.093	-5.44	-0.024	-1.25	-0.077	-3.40
25 - 34 Years Old [D] [x10^2]	-0.027	-1.48	0.034	1.62	0.022	0.58
35 - 44 Years Old [D] [x10^2]	-0.036	-1.79	-0.018	-0.81	0.001	0.01
45 - 54 Years Old [D] [x10^2]	-0.051	-2.39	-0.036	-1.69	-0.018	-0.46
55 - 64 Years Old [D] [x10^2]	-0.053	-2.13	-0.016	-0.70	0.033	0.80
65 Years Old or Over [D] [x10^2]	-0.031	-0.73	0.000	0.01	0.036	0.60
Number of Household Members [x10^2]	-0.011	-2.09	-0.009	-1.80	-0.028	-3.32
Household with Dependent Child [D] [x10^2]	0.017	1.02	0.050	2.96	0.081	2.93
Number of Cars per Adult Household Member [x10^2]	-0.106	-4.79	-0.111	-5.69	-0.126	-4.08
Driver's License Holding [D] [x10^2]	0.024	1.79	-0.025	-1.78	0.052	2.40
Resides in Commercial Area [D] [x10^2]	0.127	2.38	0.024	0.44	0.071	1.15
Resides in Mixed Commercial/Residential Area [D] [x10^2]	0.127	3.05	0.055	1.12	0.104	1.77
Resides in Autonomous Area [D] [x10^2]	0.108	3.06	0.033	0.67	0.181	2.57
Resides in Satellites Area [D] [x10^2]	0.131	3.49	0.079	1.77	0.115	2.02
Residence Zone Accessibility to Population [x10^3]	0.042	0.51	0.105	0.97	-0.041	-1.18
Work Zone Accessibility to Population [x10^3]	-0.0001	0.00	-0.047	-0.57	0.015	0.42
Work One-way Commute Distance [x10^3]	0.005	0.69	-0.003	-0.32	-0.003	-0.33
IMR (Inversely Mill's Ratio)	-0.105	0.05	-0.064	-1.12	-0.101	-1.73
N	1491		1578		1606	
Mean of Y (minutes)	1.223		1.210		1.327	
Standard Deviation of Y	0.526		0.521		0.648	
Regression Sum of Squares	34		25		29	
Residual Sum of Squares	378		403		644	
Total Sum of Squares	412		428		673	
F	7.86		5.81		4.28	
Degrees of Freedom	(18, 1473)		(18, 1560)		(18, 1588)	
R^2	0.0831		0.0595		0.0438	
Adjusted R^2	0.0726		0.0493		0.0336	

TABLE F.3 Model of Number of Trip Chains (n_C)

	1980		1990		2000	
	Coeff.	t	Coeff.	t	Coeff.	t
Constant	0.58	61.26	0.92	151.24	0.92	127.28
Male [D] [x10^2]	2.11	3.18	-4.01	-9.50	-5.77	-12.69
25 - 34 Years Old [D] [x10^2]	3.55	3.94	1.61	2.46	-0.63	-0.71
35 - 44 Years Old [D] [x10^2]	5.45	5.49	1.27	1.86	1.86	1.94
45 - 54 Years Old [D] [x10^2]	3.56	3.57	-0.20	-0.31	1.67	1.88
55 - 64 Years Old [D] [x10^2]	7.03	6.05	1.94	2.69	3.09	3.36
65 Years Old or Over [D] [x10^2]	3.67	1.98	-1.03	-0.94	6.08	4.72
Number of Household Members [x10^2]	0.19	0.75	0.18	1.06	0.07	0.38
Household with Dependent Child [D] [x10^2]	3.21	4.01	2.19	4.15	2.43	3.97
Number of Cars per Adult Household Member [x10^2]	2.25	2.25	1.59	2.46	1.03	1.41
Driver's License Holding [D] [x10^2]	-1.25	-1.85	-1.46	-3.40	0.09	0.17
Resides in Commercial Area [D] [x10^2]	28.40	10.75	14.60	8.96	10.68	7.88
Resides in Mixed Commercial/Residential Area [D] [x10^2]	30.72	16.62	14.72	10.96	13.11	10.62
Resides in Autonomous Area [D] [x10^2]	36.64	22.84	16.36	13.45	16.95	10.92
Resides in Satellites Area [D] [x10^2]	31.27	19.82	15.45	13.45	15.04	12.72
Residence Zone Accessibility to Population [x10^3]	21.99	5.51	2.41	0.74	-0.51	-0.58
Work Zone Accessibility to Population [x10^3]	-3.50	-0.98	-7.10	-2.77	-0.12	-0.14
Work One-way Commute Distance [x10^3]	-1.15	-3.39	-2.85	-10.92	-3.20	-13.37
N	6307		6773		6134	
Mean of Y (minutes)	1.179		1.068		1.088	
Standard Deviation of Y	0.450		0.273		0.315	
Regression Sum of Squares	595		92		121	
Residual Sum of Squares	684		413		488	
Total Sum of Squares	1279		506		608	
F	321.75		88.66		88.93	
Degrees of Freedom	(17, 6289)		(17, 6755)		(17, 6116)	
R^2	0.4652		0.1824		0.1982	
Adjusted R^2	0.4637		0.1804		0.1960	

TABLE F.4 Model of Total Travel Time (t_T) for Simple Commuters

	1980		1990		2000	
	Coeff.	t	Coeff.	t	Coeff.	t
Constant	38.33	11.28	37.57	5.26	45.16	7.02
Male [D]	1.98	2.28	5.77	6.25	5.04	5.85
25 - 34 Years Old [D]	-5.98	-4.69	-1.64	-1.21	1.22	0.93
35 - 44 Years Old [D]	-7.71	-5.65	-3.33	-2.39	0.17	0.11
45 - 54 Years Old [D]	-5.76	-4.30	-2.88	-2.15	-1.54	-1.14
55 - 64 Years Old [D]	-5.84	-3.96	-1.15	-0.78	0.33	0.24
65 Years Old or Over [D]	-1.69	-0.75	-1.70	-0.70	-3.88	-1.90
Number of Household Members	0.89	2.66	0.21	0.59	0.36	1.14
Household with Dependent Child [D]	-3.63	-3.42	-3.59	-3.21	-3.46	-3.34
Number of Cars per Adult Household Member	-8.81	-7.00	-9.05	-6.59	-4.42	-3.42
Driver's License Holding [D]	-1.96	-2.19	-2.00	-2.12	-0.43	-0.48
Resides in Commercial Area [D]	-3.63	-0.79	-10.97	-1.58	-18.17	-2.83
Resides in Mixed Commercial/Residential Area [D]	3.12	0.80	-1.67	-0.25	-11.65	-1.94
Resides in Autonomous Area [D]	2.72	0.76	-3.82	-0.59	-16.47	-2.78
Resides in Satellites Area [D]	2.52	0.69	-3.99	-0.62	-15.28	-2.62
Residence Zone Accessibility to Population	-1.26	-2.33	0.19	0.28	0.39	2.83
Work Zone Accessibility to Population	2.06	4.35	1.74	3.13	0.34	2.30
Work One-way Commute Distance	3.17	69.46	3.95	68.63	3.39	77.23
N	4706		5086		4390	
Mean of Y (minutes)	68.10		71.26		65.52	
Standard Deviation of Y	42.05		47.71		41.69	
Regression Sum of Squares	5238266		7498256		5118729	
Residual Sum of Squares	3081283		4078135		2511416	
Total Sum of Squares	8319549		11576391		7630145	
F	468.81		548.13		524.17	
Degrees of Freedom	(17, 4688)		(17, 5068)		(17, 4372)	
R^2	0.6296		0.6477		0.6709	
Adjusted R^2	0.6283		0.6465		0.6696	

TABLE F.5 Model of Total Travel Time (t_T) for Complex Commuters

	1980		1990		2000	
	Coeff.	t	Coeff.	t	Coeff.	t
Constant	21.78	4.94	36.11	7.52	31.07	7.98
Male [D]	0.90	1.62	2.20	3.60	3.18	6.84
25 - 34 Years Old [D]	-1.30	-1.72	-1.23	-1.30	-3.12	-3.33
35 - 44 Years Old [D]	-1.56	-1.87	-2.22	-2.26	-3.40	-3.43
45 - 54 Years Old [D]	-0.32	-0.38	-0.05	-0.05	-3.54	-3.82
55 - 64 Years Old [D]	0.69	0.69	2.84	2.69	-4.20	-4.41
65 Years Old or Over [D]	0.45	0.27	4.57	2.81	-2.36	-1.82
Number of Household Members	0.32	1.48	0.23	0.96	-0.54	-2.76
Household with Dependent Child [D]	-2.16	-3.23	-0.61	-0.82	-0.85	-1.39
Number of Cars per Adult Household Member	-4.34	-5.03	-4.76	-5.14	-3.08	-4.26
Driver's License Holding [D]	1.39	2.46	0.78	1.29	1.10	2.25
Resides in Commercial Area [D]	5.26	2.14	3.06	1.20	11.86	7.53
Resides in Mixed Commercial/Residential Area [D]	6.59	3.62	3.33	1.54	11.07	7.39
Resides in Autonomous Area [D]	6.99	4.23	4.06	2.02	10.37	5.94
Resides in Satellites Area [D]	8.53	5.17	2.98	1.54	10.26	7.06
Residence Zone Accessibility to Population	-0.12	-0.36	1.12	2.30	-0.06	-0.65
Work Zone Accessibility to Population	0.49	1.62	-0.42	-1.09	0.04	0.40
Work One-way Commute Distance	0.73	25.25	0.93	23.14	0.75	29.03
N	1601		1687		1744	
Mean of Y (minutes)	81.57		86.13		74.64	
Standard Deviation of Y	56.16		58.33		47.38	
Regression Sum of Squares	2857008		2772904		1827079	
Residual Sum of Squares	2189794		2963477		2086360	
Total Sum of Squares	5046803		5736382		3913439	
F	121.49		91.86		88.91	
Degrees of Freedom	(17, 1583)		(17, 1669)		(17, 1726)	
R^2	0.5661		0.4834		0.4669	
Adjusted R^2	0.5614		0.4781		0.4616	

APPENDIX G:
Pair Wise Comparison Test for the Models' Parameters between Years

TABLE G.1 Pair Wise Comparison for Non-workers Model

a. Model of Time Expenditure for Non-Work Activity (t_{NW})

	t (2000,1990)	t (1990,1980)	t (2000,1980)
Constant			****
Male [D]			
25 - 34 Years Old [D]		**	****
35 - 44 Years Old [D]		**	****
45 - 54 Years Old [D]		**	****
55 - 64 Years Old [D]		*	****
65 Years Old or Over [D]	*	*	****
Number of Household Members			*
Household with Dependent Child [D]		*	
Number of Cars per Adult Household Member			****
Driver's License Holding [D]			
Resides in Commercial Area [D]			
Resides in Mixed Commercial/Residential Area [D]			
Resides in Autonomous Area [D]			**
Resides in Satellites Area [D]			
Residence Zone Accessibility to Population			
Fraction of Auto Trip in Given Day Trip Pattern			
Fraction of Transit Trip in Given Day Trip Pattern	*		

* = significant at $\alpha = 0.1$, ** = significant at $\alpha = 0.05$, *** = significant at $\alpha = 0.01$, **** = significant at $\alpha = 0.005$

b. Model of Number of Non-Work Visits (v_{NW})

	t (2000,1990)	t (1990,1980)	t (2000,1980)
Constant	****	****	****
Male [D]		****	****
25 - 34 Years Old [D]	*	****	*
35 - 44 Years Old [D]		****	****
45 - 54 Years Old [D]		****	****
55 - 64 Years Old [D]		****	****
65 Years Old or Over [D]		**	****
Number of Household Members			
Household with Dependent Child [D]	****	**	
Number of Cars per Adult Household Member			
Driver's License Holding [D]	****		
Resides in Commercial Area [D]	****	****	**
Resides in Mixed Commercial/Residential Area [D]	****	****	****
Resides in Autonomous Area [D]	****	****	****
Resides in Satellites Area [D]	****	****	****
Residence Zone Accessibility to Population		****	***
Fraction of Auto Trip in Given Day Trip Pattern	****	****	***
Fraction of Transit Trip in Given Day Trip Pattern	****	****	****

* = significant at $\alpha = 0.1$, ** = significant at $\alpha = 0.05$, *** = significant at $\alpha = 0.01$, **** = significant at $\alpha = 0.005$

c. Model of Number of Trip Chains (n_C)

	t (2000,1990)	t (1990,1980)	t (2000,1980)
Constant	****	****	
Male [D]			
25 - 34 Years Old [D]			
35 - 44 Years Old [D]	*		****
45 - 54 Years Old [D]			****
55 - 64 Years Old [D]	**		***
65 Years Old or Over [D]	***		***
Number of Household Members			
Household with Dependent Child [D]		***	
Number of Cars per Adult Household Member			*
Driver's License Holding [D]			
Resides in Commercial Area [D]	****	****	
Resides in Mixed Commercial/Residential Area [D]	****	****	
Resides in Autonomous Area [D]	****	****	
Resides in Satellites Area [D]	****	****	
Residence Zone Accessibility to Population	****	****	
Fraction of Auto Trip in Given Day Trip Pattern			
Fraction of Transit Trip in Given Day Trip Pattern			

* = significant at $\alpha = 0.1$, ** = significant at $\alpha = 0.05$, *** = significant at $\alpha = 0.01$, **** = significant at $\alpha = 0.005$

d. Model of Total Travel Time (t_T)

	t (2000,1990)	t (1990,1980)	t (2000,1980)
Constant	**	****	*
Male [D]			**
25 - 34 Years Old [D]			
35 - 44 Years Old [D]			
45 - 54 Years Old [D]			*
55 - 64 Years Old [D]			****
65 Years Old or Over [D]			**
Number of Household Members			*
Household with Dependent Child [D]			
Number of Cars per Adult Household Member		***	****
Driver's License Holding [D]			
Resides in Commercial Area [D]		****	****
Resides in Mixed Commercial/Residential Area [D]	*	****	****
Resides in Autonomous Area [D]	*	****	***
Resides in Satellites Area [D]	**	****	****
Residence Zone Accessibility to Population		****	****
Fraction of Auto Trip in Given Day Trip Pattern			
Fraction of Transit Trip in Given Day Trip Pattern	****	****	****

* = significant at $\alpha = 0.1$, ** = significant at $\alpha = 0.05$, *** = significant at $\alpha = 0.01$, **** = significant at $\alpha = 0.005$

TABLE G.2 Pair Wise Comparison for Auto Commuters Model

a. Model of Time Expenditure for Non-Work Activity (t_{NW})

	t (2000,1990)	t (1990,1980)	t (2000,1980)
Constant			
Male [D]	**		
25 - 34 Years Old [D]			
35 - 44 Years Old [D]			
45 - 54 Years Old [D]			
55 - 64 Years Old [D]			
65 Years Old or Over [D]	****	****	
Number of Household Members			
Household with Dependent Child [D]		*	
Number of Cars per Adult Household Member			
Driver's License Holding [D]			
Resides in Commercial Area [D]			
Resides in Mixed Commercial/Residential Area [D]			
Resides in Autonomous Area [D]			
Resides in Satellites Area [D]			
Residence Zone Accessibility to Population		*	
Work Zone Accessibility to Population			
Work Activity Time (min)			
Number of Work Trip / Day	***		****
Work One-way Commute Distance			
IMR (Inversely Mill Ratio)			

* = significant at α = 0.1, ** = significant at α = 0.05, *** = significant at α = 0.01, **** = significant at α = 0.005

b. Model of Number of Non-Work Visits (v_{NW})

	t (2000,1990)	t (1990,1980)	t (2000,1980)
Constant			
Male [D]			
25 - 34 Years Old [D]			
35 - 44 Years Old [D]			
45 - 54 Years Old [D]			
55 - 64 Years Old [D]			
65 Years Old or Over [D]			
Number of Household Members			
Household with Dependent Child [D]			
Number of Cars per Adult Household Member	***		****
Driver's License Holding [D]			
Resides in Commercial Area [D]			
Resides in Mixed Commercial/Residential Area [D]			
Resides in Autonomous Area [D]			
Resides in Satellites Area [D]			
Residence Zone Accessibility to Population		*	
Work Zone Accessibility to Population			
Work One-way Commute Distance			

* = significant at α = 0.1, ** = significant at α = 0.05, *** = significant at α = 0.01, **** = significant at α = 0.005

c. Model of Number of Trip Chains (n_C)

	t (2000,1990)	t (1990,1980)	t (2000,1980)
Constant	****	****	****
Male [D]		****	****
25 - 34 Years Old [D]		**	
35 - 44 Years Old [D]			
45 - 54 Years Old [D]			
55 - 64 Years Old [D]			
65 Years Old or Over [D]		**	***
Number of Household Members	*	****	****
Household with Dependent Child [D]		****	****
Number of Cars per Adult Household Member		****	****
Driver's License Holding [D]			**
Resides in Commercial Area [D]		*	
Resides in Mixed Commercial/Residential Area [D]			
Resides in Autonomous Area [D]		****	***
Resides in Satellites Area [D]		****	****
Residence Zone Accessibility to Population		****	****
Work Zone Accessibility to Population		**	****
Work One-way Commute Distance	****		

* = significant at α = 0.1, ** = significant at α = 0.05, *** = significant at α = 0.01, **** = significant at α = 0.005

d. Model of Total Travel Time (t_T) for Simple Commuters

	t (2000,1990)	t (1990,1980)	t (2000,1980)
Constant		*	****
Male [D]			
25 - 34 Years Old [D]			
35 - 44 Years Old [D]	**	***	
45 - 54 Years Old [D]	*	**	
55 - 64 Years Old [D]			
65 Years Old or Over [D]		*	
Number of Household Members			
Household with Dependent Child [D]			
Number of Cars per Adult Household Member			
Driver's License Holding [D]	*	****	*
Resides in Commercial Area [D]			
Resides in Mixed Commercial/Residential Area [D]			*
Resides in Autonomous Area [D]			****
Resides in Satellites Area [D]			
Residence Zone Accessibility to Population	*	****	****
Work Zone Accessibility to Population	****		****
Work One-way Commute Distance			

* = significant at α = 0.1, ** = significant at α = 0.05, *** = significant at α = 0.01, **** = significant at α = 0.005

e. Model of Total Travel Time (t_T) for Complex Commuters

	t (2000,1990)	t (1990,1980)	t (2000,1980)
Constant			
Male [D]			
25 - 34 Years Old [D]			
35 - 44 Years Old [D]			
45 - 54 Years Old [D]			
55 - 64 Years Old [D]			
65 Years Old or Over [D]			
Number of Household Members			
Household with Dependent Child [D]			
Number of Cars per Adult Household Member			
Driver's License Holding [D]			
Resides in Commercial Area [D]			
Resides in Mixed Commercial/Residential Area [D]			
Resides in Autonomous Area [D]			
Resides in Satellites Area [D]			
Residence Zone Accessibility to Population	*		****
Work Zone Accessibility to Population	****		****
Work One-way Commute Distance			

* = significant at $\alpha = 0.1$, ** = significant at $\alpha = 0.05$, *** = significant at $\alpha = 0.01$, **** = significant at $\alpha = 0.005$

TABLE G.3 Pair Wise Comparison for Transit Commuters Model

a. Model of Time Expenditure for Non-Work Activity (t_{NW})

	t (2000,1990)	t (1990,1980)	t (2000,1980)
Constant		****	****
Male [D]	****		*
25 - 34 Years Old [D]	**		*
35 - 44 Years Old [D]		*	
45 - 54 Years Old [D]			
55 - 64 Years Old [D]			
65 Years Old or Over [D]			
Number of Household Members		*	
Household with Dependent Child [D]			
Number of Cars per Adult Household Member	***	****	*
Driver's License Holding [D]	**		**
Resides in Commercial Area [D]			
Resides in Mixed Commercial/Residential Area [D]			
Resides in Autonomous Area [D]			
Resides in Satellites Area [D]			
Residence Zone Accessibility to Population	****		****
Work Zone Accessibility to Population	****		****
Work Activity Time (min)	****	****	****
Number of Work Trip / Day	**	****	****
Work One-way Commute Distance	**		****
IMR (Inversely Mill Ratio)	****	****	

* = significant at α = 0.1, ** = significant at α = 0.05, *** = significant at α = 0.01, **** = significant at α = 0.005

b. Model of Number of Non-Work Visits (v_{NW})

	t (2000,1990)	t (1990,1980)	t (2000,1980)
Constant	****		****
Male [D]	***	****	
25 - 34 Years Old [D]		**	
35 - 44 Years Old [D]			
45 - 54 Years Old [D]			
55 - 64 Years Old [D]			**
65 Years Old or Over [D]			
Number of Household Members	**		*
Household with Dependent Child [D]			**
Number of Cars per Adult Household Member			
Driver's License Holding [D]	****	****	
Resides in Commercial Area [D]			
Resides in Mixed Commercial/Residential Area [D]			
Resides in Autonomous Area [D]	**	*	
Resides in Satelites Area [D]			
Residence Zone Accessibility to Population			
Work Zone Accessibility to Population			
Work One-way Commute Distance			

* = significant at α = 0.1, ** = significant at α = 0.05, *** = significant at α = 0.01, **** = significant at α = 0.005

c. Model of Number of Trip Chains (n_C)

	t (2000,1990)	t (1990,1980)	t (2000,1980)
Constant		****	****
Male [D]	****	****	****
25 - 34 Years Old [D]	**	*	****
35 - 44 Years Old [D]		****	****
45 - 54 Years Old [D]	*	****	
55 - 64 Years Old [D]		****	****
65 Years Old or Over [D]	****	**	
Number of Household Members			
Household with Dependent Child [D]			
Number of Cars per Adult Household Member			
Driver's License Holding [D]	***		
Resides in Commercial Area [D]	*	****	****
Resides in Mixed Commercial/Residential Area [D]		****	****
Resides in Autonomous Area [D]		****	****
Resides in Satellites Area [D]		****	****
Residence Zone Accessibility to Population		****	****
Work Zone Accessibility to Population	***		
Work One-way Commute Distance		****	****

* = significant at α = 0.1, ** = significant at α = 0.05, *** = significant at α = 0.01, **** = significant at α = 0.005

d. Model of Total Travel Time (t_T) for Simple Commuters

	t (2000,1990)	t (1990,1980)	t (2000,1980)
Constant			
Male [D]		****	***
25 - 34 Years Old [D]		***	****
35 - 44 Years Old [D]	*	**	****
45 - 54 Years Old [D]			**
55 - 64 Years Old [D]		**	****
65 Years Old or Over [D]			
Number of Household Members			
Household with Dependent Child [D]			
Number of Cars per Adult Household Member	***		***
Driver's License Holding [D]			
Resides in Commercial Area [D]			*
Resides in Mixed Commercial/Residential Area [D]			**
Resides in Autonomous Area [D]			****
Resides in Satellites Area [D]			****
Residence Zone Accessibility to Population		*	****
Work Zone Accessibility to Population	***		****
Work One-way Commute Distance	****	****	****

* = significant at α = 0.1, ** = significant at α = 0.05, *** = significant at α = 0.01, **** = significant at α = 0.005

e. Model of Total Travel Time (t_T) for Complex Commuters

	t (2000,1990)	t (1990,1980)	t (2000,1980)
Constant		**	
Male [D]			****
25 - 34 Years Old [D]			
35 - 44 Years Old [D]			
45 - 54 Years Old [D]	****		***
55 - 64 Years Old [D]	****		****
65 Years Old or Over [D]	****	*	
Number of Household Members	***		****
Household with Dependent Child [D]			
Number of Cars per Adult Household Member			
Driver's License Holding [D]			
Resides in Commercial Area [D]	****		**
Resides in Mixed Commercial/Residential Area [D]	****		*
Resides in Autonomous Area [D]	***		
Resides in Satellites Area [D]	****	**	
Residence Zone Accessibility to Population	***	**	
Work Zone Accessibility to Population		*	
Work One-way Commute Distance	****	****	

* = significant at $\alpha = 0.1$, ** = significant at $\alpha = 0.05$, *** = significant at $\alpha = 0.01$, **** = significant at $\alpha = 0.005$

APPENDIX H:
Profiles of Estimation Samples for Action Space Analysis for Long Term Period

Parameters and Indices	1980	1990	2000
Individual and Household Parameters			
Male [D]	44.6%	45.1%	44.3%
20 - 24 Years Old [D]	10.5%	11.9%	8.6%
25 - 34 Years Old [D]	29.2%	20.7%	25.7%
35 - 44 Years Old [D]	27.7%	26.6%	20.6%
45 - 54 Years Old [D]	21.1%	24.3%	23.9%
55 - 64 Years Old [D]	11.5%	16.5%	21.3%
Worker [D]	69.5%	73.6%	72.7%
Non Worker [D]	30.5%	26.4%	27.3%
Number of Household Members	3.32	3.24	3.27
Parent with Dependent Children [D]	47.4%	40.5%	37.5%
Number of Cars per Adult Household Member	0.36	0.40	0.44
Driver's License Holding [D]	41.7%	59.3%	72.4%
Accessibilities and Residential Location Indices			
Resides in Commercial Area [D]	2.9%	3.1%	3.0%
Resides in Mixed Commercial/Residential Area [D]	26.0%	26.7%	30.7%
Resides in Autonomous Area [D]	7.4%	9.5%	5.6%
Resides in Suburbs Area [D]	62.6%	60.4%	60.1%
Resides in Un-urbanized Area [D]	1.2%	0.2%	0.6%
Residence Zone Accessibility Index to Population	3.98	3.94	5.67
Work Zone Accessibility Index to Population	2.93	3.12	3.82

APPENDIX I:
The Descriptive Statistics of Individual's Action Space Indices

TABLE I.1 Individual's Action Space Indices based on Employment

a. Action Space Indices

Employment Status		Simple Trip Makers[19]			Complex Trip Makers[20]		
		1980	1990	2000	1980	1990	2000
Worker[21]	I_H	117.2	123.5	162.8	76.5	89.5	101.6
	I_C	0.0	0.0	0.0	4.7	6.7	9.0
	N	69,814	80,439	69,640	26,151	24,178	24,322
Non-worker	I_H	16.9	22.2	30.5	24.3	30.6	38.8
	I_C	0.0	0.0	0.0	1.6	2.6	3.7
	N	32,071	27,203	23,154	12,868	13,643	18,065
All Respondent	I_H	84.1	96.1	125.9	58.5	67.3	73.4
	I_C	0.0	0.0	0.0	3.7	5.3	6.9
	N	106,114	112,160	98,337	40,651	40,142	47,052

b. Expanding Rate of Activity Locations

Employment Status	% of Sample whose activities center is outside home municipality ($I_H > 0$)			% of Sample who make activities across municipalities ($I_C > 0$)		
	1980	1990	2000	1980	1990	2000
Simple Trip Maker Respondent						
Worker	57.1%	60.1%	64.8%	NA		
Non Worker	14.0%	16.4%	20.9%			
All	42.8%	48.3%	52.5%			
Complex Trip Maker Respondent						
Worker	49.2%	56.6%	59.1%	10.7%	11.6%	13.6%
Non Worker	23.0%	27.7%	33.4%	3.5%	4.5%	6.0%
All	40.4%	45.9%	48.1%	8.2%	9.1%	10.5%

[19] Simple trip maker is individual who only make two trips/day with one out-of-home activity location. His or her $I_C = 0$ and total second moment value = I_H.

[20] Complex trip maker is individual who make more than two trips/day with more than one out-of-home activity location. His or her total second moment value = $I_H + I_C$.

[21] Worker defined as an individual who made at least one work trip on a given day. Worker sample that did not made work trip on a given day are excluded.

TABLE I.2 Individual's Action Space Indices based on Residential Area Type

a. Action Space Indices

Residential Area		Simple Trip Makers			Complex Trip Makers		
		1980	1990	2000	1980	1990	2000
Commercial Area	I_H	49.74	56.74	73.85	30.51	39.98	44.16
	I_C	0.00	0.00	0.00	3.51	6.16	7.62
	N	1,950	2,770	2,358	842	1,155	1,287
Mixed Commercial / Residential Area	I_H	44.78	49.29	71.98	32.75	32.51	42.53
	I_C	0.00	0.00	0.00	4.18	4.65	6.86
	N	20,796	24,648	25,400	8,383	9,457	12,441
Autonomous City	I_H	51.99	71.31	86.17	30.79	38.99	49.78
	I_C	0.00	0.00	0.00	1.76	3.55	5.35
	N	13,467	15,843	8,368	5,549	5,484	3,698
Suburbs Area	I_H	102.58	120.09	155.35	74.42	88.80	90.65
	I_C	0.00	0.00	0.00	3.93	5.84	7.01
	N	67,879	68,469	61,310	24,943	23,932	29,246
Un-urbanized Area	I_H	112.92	129.47	151.00	54.01	90.48	87.62
	I_C	0.00	0.00	0.00	4.78	13.85	11.23
	N	2,022	430	901	934	114	380
All Respondent	I_H	84.06	96.11	125.93	58.49	67.34	73.42
	I_C	0.00	0.00	0.00	3.70	5.28	6.89
	N	106,114	112,160	98,337	40,651	40,142	47,052

b. Expanding Rate of Activity Locations

Residential Area	% of Sample whose activities center is outside home municipality ($I_H > 0$)			% of Sample who make activities across municipalities ($I_C > 0$)		
	1980	1990	2000	1980	1990	2000
Simple Trip Maker Respondent						
Commercial Area	45.4%	47.1%	49.7%	NA		
Mixed Commercial/Residential Area	47.8%	54.2%	55.2%			
Autonomous City	22.7%	31.9%	34.8%			
Suburbs Area	45.2%	49.9%	53.8%			
Un-urbanized Area	45.1%	64.9%	64.2%			
All	42.8%	48.3%	52.5%			
Complex Trip Maker Respondent						
Commercial Area	49.9%	53.2%	51.8%	12.7%	11.7%	11.5%
Mixed Commercial/Residential Area	49.6%	54.3%	52.9%	11.9%	12.5%	12.6%
Autonomous City	17.2%	27.5%	31.2%	2.1%	4.1%	6.2%
Suburbs Area	42.5%	46.4%	47.7%	8.3%	8.7%	10.0%
Un-urbanized Area	31.4%	53.5%	63.9%	5.4%	14.0%	19.2%
All	40.4%	45.9%	48.1%	8.2%	9.1%	10.5%

TABLE I.3 Individual's Action Space Indices based on Car Availability

a. Action Space Indices

Number of Car per Adult Household Member (Ceiling at 1)		Simple Trip Makers			Complex Trip Makers		
		1980	1990	2000	1980	1990	2000
0	I_H	92.78	91.00	102.07	66.80	68.32	64.38
	I_C	0.00	0.00	0.00	3.51	4.57	6.95
	N	35,229	24,829	16,119	14,106	10,274	8,769
0 - 0.5	I_H	88.47	104.07	142.77	61.74	68.87	76.18
	I_C	0.00	0.00	0.00	3.90	4.42	6.06
	N	24,048	32,913	28,718	8,278	10,779	13,477
0.5	I_H	79.76	92.52	126.34	57.23	67.44	76.78
	I_C	0.00	0.00	0.00	3.69	5.58	6.54
	N	19,068	24,815	23,420	7,274	8,983	11,281
0.5 – 1	I_H	75.13	99.59	132.56	44.46	66.60	72.05
	I_C	0.00	0.00	0.00	3.53	5.74	7.13
	N	11,815	13,601	15,116	4,470	4,352	6,597
1	I_H	69.87	90.31	111.99	47.44	63.12	75.31
	I_C	0.00	0.00	0.00	3.95	7.35	8.76
	N	15,954	16,002	14,964	6,523	5,754	6,928
All Respondent	I_H	84.06	96.11	125.93	58.49	67.34	73.42
	I_C	0.00	0.00	0.00	3.70	5.28	6.89
	N	106,114	112,160	98,337	40,651	40,142	47,052

b. Expanding Rate of Activity Locations

Number of Car per Adult Household Member (Ceiling at 1)	% of Sample whose activities center is outside home municipality ($I_H > 0$)			% of Sample who make activities across municipalities ($I_C > 0$)		
	1980	1990	2000	1980	1990	2000
Simple Trip Maker Respondent						
0	44.5%	49.3%	50.8%	NA		
0 - 0.5	45.0%	49.3%	54.2%			
0.5	42.2%	47.3%	51.8%			
0.5 - 1	39.8%	46.6%	53.3%			
1	39.1%	47.5%	51.6%			
All	42.8%	48.3%	52.5%			
Complex Trip Maker Respondent						
0	43.2%	48.8%	49.3%	9.3%	9.7%	12.1%
0 - 0.5	41.4%	44.4%	45.9%	8.4%	8.3%	9.6%
0.5	40.7%	45.0%	47.9%	8.0%	9.0%	10.2%
0.5 - 1	34.2%	42.7%	47.2%	6.5%	8.4%	9.9%
1	37.2%	47.5%	51.6%	7.3%	10.1%	11.4%
All	40.4%	45.9%	48.1%	8.2%	9.1%	10.5%

TABLE I.4 Individual's Action Space Indices based on Driver License Ownership

a. Action Space Indices

Driver License Ownership		Simple Trip Makers			Complex Trip Makers		
		1980	1990	2000	1980	1990	2000
No	I_H	64.69	63.76	68.11	45.97	47.60	49.21
	I_C	0.00	0.00	0.00	2.36	2.97	4.10
	N	60,787	43,480	25,164	23,779	17,392	14,363
Yes	I_H	110.03	116.60	145.82	76.13	82.42	84.05
	I_C	0.00	0.00	0.00	5.58	7.05	8.11
	N	45,327	68,680	73,173	16,872	22,750	32,689
All Respondent	I_H	84.06	96.11	125.93	58.49	67.34	73.42
	I_C	0.00	0.00	0.00	3.70	5.28	6.89
	N	106,114	112,160	98,337	40,651	40,142	47,052

b. Expanding Rate of Activity Locations

Driver License Ownership	% of Sample whose activities center is outside home municipality ($I_H > 0$)			% of Sample who make activities across municipalities ($I_C > 0$)		
	1980	1990	2000	1980	1990	2000
Simple Trip Maker Respondent						
No	34.2%	35.9%	36.6%	NA		
Yes	54.4%	56.1%	58.0%			
All	42.8%	48.3%	52.5%			
Complex Trip Maker Respondent						
No	33.9%	37.0%	39.3%	6.1%	6.6%	7.3%
Yes	49.6%	52.8%	51.9%	11.2%	11.0%	11.9%
All	40.4%	45.9%	48.1%	8.2%	9.1%	10.5%

TABLE I.5 Individual's Action Space Indices based on Fraction of Car Trips in Given Day Trip Pattern

a. Action Space Indices

Fraction of Car Trips in Given Day Trip Pattern		Simple Trip Makers			Complex Trip Makers		
		1980	1990	2000	1980	1990	2000
0 %	I_H	88.50	106.18	147.80	58.74	70.66	80.37
	I_C	0.00	0.00	0.00	2.36	3.03	4.90
	N	75,082	68,954	58,233	27,075	23,756	25,263
0 - 50 %	I_H	NA			77.99	97.53	97.54
	I_C				7.46	12.41	12.53
	N				1,294	1,275	1,791
50 %	I_H	79.98	98.04	106.43	72.68	70.34	70.93
	I_C	0.00	0.00	0.00	2.30	3.53	5.59
	N	1,245	916	685	3,049	3,595	3,351
50 – 100 %	I_H	NA			62.98	64.55	64.58
	I_C				7.26	10.16	10.53
	N				1,082	1,338	2,323
100 %	I_H	73.02	79.66	93.97	48.66	55.10	60.15
	I_C	0.00	0.00	0.00	7.59	9.62	9.39
	N	29,787	42,290	39,419	8,151	10,178	10,178
All Respondent	I_H	84.06	96.11	125.93	58.49	67.34	73.42
	I_C	0.00	0.00	0.00	3.70	5.28	6.89
	N	106,114	112,160	98,337	40,651	40,142	47,052

b. Expanding Rate of Activity Locations

Fraction of Car Trips in Given Day Trip Pattern	% of Sample whose activities center is outside home municipality ($I_H > 0$)			% of Sample who make activities across municipalities ($I_C > 0$)		
	1980	1990	2000	1980	1990	2000
Simple Trip Maker Respondent						
0%	39.2%	45.4%	50.0%	NA		
50%	54.0%	59.7%	57.2%			
100%	51.5%	52.7%	56.2%			
All	42.8%	48.3%	52.5%			
Complex Trip Maker Respondent						
0%	36.0%	42.6%	43.7%	6.5%	7.4%	9.0%
0 - 50 %	58.4%	61.4%	59.5%	15.2%	17.3%	16.3%
50%	52.9%	50.8%	50.1%	5.4%	4.3%	6.0%
50 - 100 %	57.0%	55.7%	54.0%	16.8%	15.0%	13.0%
100%	45.6%	48.6%	52.9%	12.8%	13.0%	13.1%
All	40.4%	45.9%	48.1%	8.2%	9.1%	10.5%

TABLE I.6 Individual's Action Space Indices based on Fraction of Transit Trips in Given Day Trip Pattern

a. Action Space Indices

Fraction of Transit Trips in Given Day Trip Pattern		Simple Trip Makers 1980	Simple Trip Makers 1990	Simple Trip Makers 2000	Complex Trip Makers 1980	Complex Trip Makers 1990	Complex Trip Makers 2000
0 %	I_H	31.88	44.32	55.57	23.02	30.17	34.33
	I_C	0.00	0.00	0.00	2.44	3.77	4.46
	N	72,759	78,696	69,533	28,630	28,319	34,994
0 – 50 %	I_H	NA			98.03	106.64	132.04
	I_C				4.34	9.40	9.21
	N				2,278	1,947	2,506
50 %	I_H	75.99	98.90	108.52	172.92	187.54	222.79
	I_C	0.00	0.00	0.00	2.43	3.56	7.61
	N	1,312	905	681	4,923	4,754	3,818
50 – 100 %	I_H	NA			127.90	141.16	181.24
	I_C				6.68	7.89	13.02
	N				3,075	3,469	3,917
100 %	I_H	202.86	221.24	300.33	143.65	157.13	199.07
	I_C	0.00	0.00	0.00	21.82	25.76	35.74
	N	32,043	32,559	28,123	1,745	1,653	1,817
All Respondent	I_H	84.06	96.11	125.93	58.49	67.34	73.42
	I_C	0.00	0.00	0.00	3.70	5.28	6.89
	N	106,114	112,160	98,337	40,651	40,142	47,052

b. Expanding Rate of Activity Locations

Fraction of Transit Trips in Given Day Trip Pattern	% of Sample whose activities center is outside home municipality ($I_H > 0$) 1980	1990	2000	% of Sample who make activities across municipalities ($I_C > 0$) 1980	1990	2000
Simple Trip Maker Respondent						
0%	25.9%	32.7%	37.7%	NA		
50%	52.8%	59.9%	58.0%			
100%	80.9%	85.7%	89.1%			
All	42.8%	48.3%	52.5%			
Complex Trip Maker Respondent						
0%	24.9%	30.7%	35.8%	4.5%	5.5%	6.7%
0 - 50 %	66.0%	71.4%	73.3%	12.4%	14.5%	16.7%
50%	80.8%	85.7%	86.5%	7.0%	6.7%	9.4%
50 - 100 %	76.3%	80.4%	84.1%	18.2%	17.6%	20.1%
100%	84.4%	89.7%	91.4%	50.5%	52.7%	58.3%
All	40.4%	45.9%	48.1%	8.2%	9.1%	10.5%

TABLE I.7 Individual's Action Space Indices based on Fraction of Non-motorized Trips in Given Day Trip Pattern

a. Action Space Indices

Fraction of Non-motorized Trips in Given Day Trip Pattern		Simple Trip Makers			Complex Trip Makers		
		1980	1990	2000	1980	1990	2000
0 %	I_H	139.47	140.99	179.58	71.82	76.83	83.09
	I_C	0.00	0.00	0.00	10.35	12.99	13.65
	N	62,905	75,625	68,071	10,967	12,897	17,373
0 - 50 %	I_H	NA			108.91	115.44	134.75
	I_C				5.78	6.79	10.17
	N				3,871	4,481	5,956
50 %	I_H	10.76	11.09	14.73	130.50	131.50	144.06
	I_C	0.00	0.00	0.00	1.16	1.13	2.71
	N	513	353	358	7,210	7,554	6,171
50 – 100 %	I_H	NA			85.35	86.51	95.54
	I_C				2.42	2.63	2.65
	N				1,987	1,759	2,492
100 %	I_H	3.29	3.15	5.15	3.49	3.67	5.40
	I_C	0.00	0.00	0.00	0.08	0.07	0.20
	N	42,696	36,182	29,908	16,616	13,451	15,060
All Respondent	I_H	84.06	96.11	125.93	58.49	67.34	73.42
	I_C	0.00	0.00	0.00	3.70	5.28	6.89
	N	106,114	112,160	98,337	40,651	40,142	47,052

b. Expanding Rate of Activity Locations

Fraction of Non-motorized Trips in Given Day Trip Pattern	% of Sample whose activities center is outside home municipality ($I_H > 0$)			% of Sample who make activities across municipalities ($I_C > 0$)		
	1980	1990	2000	1980	1990	2000
Simple Trip Maker Respondent						
0%	66.6%	67.0%	69.9%	NA		
50%	17.0%	20.1%	26.8%			
100%	8.1%	9.3%	13.3%			
All	42.8%	48.3%	52.5%			
Complex Trip Maker Respondent						
0%	54.7%	56.6%	59.0%	20.2%	19.3%	18.9%
0 - 50 %	70.6%	72.6%	72.2%	16.5%	15.3%	16.4%
50%	68.5%	69.1%	67.0%	3.8%	3.5%	4.7%
50 - 100 %	58.3%	60.3%	59.4%	8.1%	7.8%	9.2%
100%	9.7%	11.9%	16.2%	0.4%	0.5%	1.1%
All	40.4%	45.9%	48.1%	8.2%	9.1%	10.5%

APPENDIX J:
Tobit Model for I_H Value of Simple Trip Makers[22]

TABLE J.1 Tobit Model for I_H Value of Simple Trip Workers

Explanatory Variables	1980		1990		2000	
	Coeff.	t	Coeff.	t	Coeff.	t
Constant	-255.48	-7.17	-229.13	-5.67	-290.86	-9.39
Male [D]	8.43	0.83	22.38	3.80	17.19	2.61
20 - 24 Years Old [D]	12.30	0.74	-13.33	-1.43	-11.97	-1.04
25 - 34 Years Old [D]	12.77	0.85	-11.28	-1.32	-7.00	-0.78
35 - 44 Years Old [D]	30.25	1.90	-5.41	-0.62	-5.45	-0.54
45 - 54 Years Old [D]	18.44	1.19	-4.36	-0.52	-9.36	-1.00
Number of Household Members	-3.18	-0.93	0.65	0.30	-2.35	-0.93
Parent with Dependent Child [D]	-6.15	-0.58	-12.48	-1.92	1.39	0.18
Number of Cars per Adult Household Member	-18.15	-1.34	-5.73	-0.65	-8.56	-0.81
Driver's License Holding [D]	-14.82	-1.43	2.32	0.34	1.76	0.20
Resides in Commercial Area [D]	115.61	2.83	28.41	0.83	118.53	3.80
Resides in Mixed Commercial/Residential Area [D]	132.13	4.16	-10.23	-0.33	72.86	2.70
Resides in Autonomous Area [D]	-64.95	-2.17	-65.20	-2.12	-28.40	-1.02
Resides in Suburbs Area [D]	43.64	1.52	-71.91	-2.38	-0.80	-0.03
Residence Zone Accessibility to Population	19.74	4.69	2.28	0.47	-4.32	-3.93
Work Zone Accessibility to Population	-42.47	-68.23	-0.81	-0.26	0.02	0.56
One-way Commute Distance	42.51	74.55	36.75	101.65	40.16	110.50
Distance to Metropolitan Center	0.01	0.20	0.84	3.43	0.56	2.50
Fraction of Transit Trips in Given Day Trips Pattern	-0.24	-0.02	8.36	1.30	-4.76	-0.67
Fraction of Non Motorized Trips in Given Day Trips Pattern	-140.76	-9.02	-45.84	-4.61	-30.49	-2.80
σ	269.40	92.64	175.81	102.34	198.37	99.49
N	6987		7987		7082	
L (β)	-28998		-32256		-30910	

[22] I_H is 0 if the activity location is within the same municipality as residence. I_H is greater than 0 if the activity location is outside the home municipality.

TABLE J.2 Tobit Model for I_H Value of Simple Trip Non-workers

Explanatory Variables	1980		1990		2000	
	Coeff.	t	Coeff.	t	Coeff.	t
Constant	-359.97	-3.78	-98.41	-0.54	-191.01	-1.47
Male [D]	72.68	2.13	23.32	0.57	131.79	3.58
20 - 24 Years Old [D]	69.44	1.70	-14.65	-0.27	-132.33	-1.53
25 - 34 Years Old [D]	30.33	1.16	-74.47	-2.21	-25.88	-0.65
35 - 44 Years Old [D]	15.63	0.54	45.93	1.40	-53.93	-1.22
45 - 54 Years Old [D]	30.13	1.13	49.38	1.76	-75.35	-2.16
Number of Household Members	10.13	1.33	2.39	0.25	7.02	0.57
Parent with Dependent Child [D]	-8.90	-0.41	-45.84	-1.60	-84.52	-2.19
Number of Cars per Adult Household Member	-21.77	-0.83	21.82	0.62	116.57	2.48
Driver's License Holding [D]	22.31	1.05	35.89	1.53	-12.22	-0.39
Resides in Commercial Area [D]	229.35	2.32	-193.36	-1.19	75.12	0.53
Resides in Mixed Commercial/Residential Area [D]	153.01	1.71	-206.60	-1.36	38.99	0.33
Resides in Autonomous Area [D]	29.85	0.34	-326.58	-2.15	-82.77	-0.67
Resides in Suburbs Area [D]	107.24	1.26	-222.27	-1.49	23.16	0.21
Residence Zone Accessibility to Population	6.60	0.79	12.33	0.67	-11.67	-2.43
Distance to Metropolitan Center	0.18	1.57	0.89	0.89	-1.19	-1.16
Fraction of Transit Trip in Given Day Trip Pattern	152.64	5.61	284.74	9.92	321.65	8.67
Fraction of Non Motorized Trip in Given Day Trip Pattern	-257.63	-9.50	-272.13	-9.68	-357.43	-10.48
σ	248.23	26.85	302.06	28.14	389.91	29.53
N	3196		2707		2284	
L (β)	-3472		-3717		-4036	

APPENDIX K:
Tobit Model for I_H Value of Complex Trip Makers[23]

TABLE K.1 Tobit Model for I_H Value of Complex Trip Workers

Explanatory Variables	1980		1990		2000	
	Coeff.	t	Coeff.	t	Coeff.	t
Constant	-185.83	-5.76	-60.74	-0.80	-300.56	-6.01
Male [D]	45.60	5.11	28.90	3.38	14.29	1.26
Resides in Commercial Area [D]	126.56	2.97	-35.56	-0.51	153.02	2.81
Resides in Mixed Commercial/Residential Area [D]	82.23	2.34	-71.90	-1.10	135.97	2.80
Resides in Autonomous Area [D]	-19.77	-0.59	-109.55	-1.69	-27.32	-0.53
Resides in Suburbs Area [D]	53.67	1.64	-75.17	-1.17	51.40	1.11
Residence Zone Accessibility to Population	19.04	4.45	-18.33	-2.03	-3.01	-1.39
Work Zone Accessibility to Population	-26.56	-40.51	18.18	2.71	0.14	1.99
Work One-way Commute Distance	26.63	42.05	25.91	35.96	35.94	49.67
Distance to Metropolitan Center	0.03	0.89	-0.09	-0.20	1.33	3.04
Fraction of Transit Trips in Given Day Trips Pattern	75.56	5.12	23.58	1.62	-12.73	-0.67
Fraction of Non Motorized Trips in Given Day Trips Pattern	-76.85	-6.06	-77.77	-5.97	-67.20	-3.97
σ	171.01	51.98	170.12	52.87	219.99	53.49
N	2681		2456		2347	
L (β)	-9176		-9297		-9548	

[23] I_H is 0 if the activity location is within the same municipality as residence. I_H is greater than 0 if the activity location is outside the home municipality. I_C is 0 if the activity locations and the centroid lie in same municipality or all activities locations lie in home municipality. I_C is greater than 0 if the activity locations lie across municipalities.

TABLE K.2 Tobit Model for I_C Value of Complex Trip Workers

Explanatory Variables	1980		1990		2000	
	Coeff.	t	Coeff.	t	Coeff.	t
Constant	-242.37	-17.01	-255.64	-16.54	-221.66	-17.00
Male [D]	-0.154	-2.64	-0.100	-1.65	-0.0002	-0.01
20 - 24 Years Old [D]	-0.327	-3.03	0.036	0.35	0.062	0.73
25 - 34 Years Old [D]	-0.258	-3.01	-0.019	-0.21	-0.003	-0.06
35 - 44 Years Old [D]	-0.225	-2.30	0.080	0.86	0.046	0.76
45 - 54 Years Old [D]	-0.231	-2.35	-0.136	-1.34	0.013	0.22
Number of Household Members	0.021	1.00	0.011	0.41	0.024	1.58
Parent with Dependent Child [D]	-0.011	-0.15	-0.028	-0.37	-0.042	-0.80
Number of Cars per Adult Household Member	-0.064	-0.84	0.216	2.32	0.012	0.18
Resides in Commercial Area [D]	0.217	1.33	0.498	1.31	0.008	0.07
Resides in Mixed Commercial/Residential Area [D]	0.556	4.09	0.622	2.03	0.084	0.93
Resides in Autonomous Area [D]	0.124	0.69	0.361	1.20	0.025	0.21
Resides in Suburbs Area [D]	0.377	3.04	0.293	1.00	-0.081	-0.96
Residence Zone Accessibility to Population	0.070	2.68	0.096	2.01	0.010	1.62
Work Zone Accessibility to Population	0.041	1.94	0.015	0.52	0.006	0.83
Work One-way Commute Distance	-0.020	-6.57	-0.031	-5.82	-0.017	-6.19
Distance to Metropolitan Center	0.006	3.78	0.003	0.96	0.003	2.49
Fraction of Transit Trips in Given Day Trips Pattern	0.256	2.41	0.079	0.70	0.210	2.26
Fraction of Non Motorized Trips in Given Day Trips Pattern	-0.908	-6.72	-1.177	-8.00	-0.640	-5.68
Commute with Car [D]	0.267	2.78	0.054	0.55	-0.019	-0.23
Work Duration [minutes]	-0.0001	-0.59	0.0001	0.89	0.0005	4.18
Number of Work Trips	0.139	3.53	0.208	5.46	0.156	5.47
σ	132.13	20.82	141.73	21.35	140.58	21.82
N	2681		2456		2347	
L (β)	-2072		-2242		-2353	

TABLE K.3 Tobit Model for I_H Value of Complex Trip Non-workers

Explanatory Variables	1980		1990		2000	
	Coeff.	t	Coeff.	t	Coeff.	t
Constant	-35.54	-0.46	-332.81	-2.03	25.24	0.39
Male [D]	57.42	1.70	47.85	1.05	15.86	0.71
20 - 24 Years Old [D]	-20.23	-0.51	-100.65	-1.45	6.45	0.16
25 - 34 Years Old [D]	-7.36	-0.33	-26.87	-0.84	-1.04	-0.04
35 - 44 Years Old [D]	-0.48	-0.02	7.98	0.23	41.09	1.65
45 - 54 Years Old [D]	-2.35	-0.10	17.33	0.55	22.65	1.16
Number of Household Members	20.19	3.21	-9.60	-0.98	-0.44	-0.07
Parent with Dependent Child [D]	-20.77	-1.18	-33.92	-1.23	-47.03	-2.21
Number of Cars per Adult Household Member	-32.05	-1.50	10.73	0.30	-13.25	-0.53
Driver's License Holding [D]	29.46	1.83	-23.86	-1.00	-12.42	-0.74
Resides in Commercial Area [D]	-37.50	-0.45	-135.73	-0.98	-63.08	-0.90
Resides in Mixed Commercial/Residential Area [D]	-32.98	-0.45	-42.74	-0.34	-15.54	-0.27
Resides in Autonomous Area [D]	-119.84	-1.65	-111.24	-0.90	-127.40	-2.08
Resides in Suburbs Area [D]	-61.64	-0.88	-25.67	-0.21	-25.60	-0.46
Residence Zone Accessibility to Population	-2.80	-0.44	70.31	3.71	-7.58	-2.72
Distance to Metropolitan Center	-0.01	-0.17	3.56	3.69	0.38	0.76
Fraction of Transit Trips in Given Day Trips Pattern	212.16	7.87	244.78	6.44	286.98	10.56
Fraction of Non Motorized Trips in Given Day Trips Pattern	-140.25	-6.11	-281.83	-9.15	-177.84	-9.13
Spreadness of Activity Locations (I_C)	0.70	2.26	0.70	2.18	0.27	3.26
σ	153.60	23.26	251.07	25.39	208.61	31.80
N	1267		1351		1711	
L (β)	-2389		-2848		-4382	

TABLE K.4 Tobit Model for I_C Value of Complex Trip Non-workers

Explanatory Variables	1980		1990		2000	
	Coeff.	t	Coeff.	t	Coeff.	t
Constant	-386.39	-0.06	-131.19	-1.37	-548.28	-7.54
Male [D]	-56.63	-1.63	-59.29	-2.08	12.01	0.49
20 - 24 Years Old [D]	66.10	2.10	64.37	1.67	-52.40	-0.95
25 - 34 Years Old [D]	42.81	1.64	15.89	0.79	-18.88	-0.68
35 - 44 Years Old [D]	46.48	1.66	-9.28	-0.41	-84.86	-2.81
45 - 54 Years Old [D]	50.01	1.92	-24.87	-1.22	-52.39	-2.32
Number of Household Members	-10.12	-1.69	4.98	0.76	12.94	1.69
Parent with Dependent Child [D]	-0.82	-0.05	20.10	1.12	41.80	1.62
Number of Cars per Adult Household Member	41.36	2.21	-24.20	-1.02	31.51	1.04
Driver's License Holding [D]	-14.95	-1.06	12.20	0.82	11.00	0.53
Resides in Commercial Area [D]	-86.73	-0.01	66.86	0.88	150.45	2.15
Resides in Mixed Commercial/Residential Area [D]	302.63	0.05	18.55	0.29	13.78	0.23
Resides in Autonomous Area [D]	305.42	0.05	51.16	0.81	121.02	1.84
Resides in Suburbs Area [D]	309.84	0.05	-9.29	-0.15	8.88	0.16
Residence Zone Accessibility to Population	-16.50	-2.83	-23.93	-1.86	12.00	3.70
Distance to Metropolitan Center	-1.56	-7.61	-1.90	-2.77	-0.82	-1.35
Fraction of Transit Trips in Given Day Trips Pattern	-84.55	-2.87	-252.59	-6.41	-570.57	-11.15
Fraction of Non Motorized Trips in Given Day Trips Pattern	-11.34	-0.53	13.56	0.56	52.42	1.83
Activity Centroid Distance from Home Location ($\hat{I}_H$)	1.50	7.52	2.12	9.45	4.19	16.86
σ	61.44	8.70	84.81	9.77	143.78	13.41
N	1267		1351		1711	
L (β)	-331		-468		-888	

APPENDIX L:
Pair Wise Comparison Test for Action Space Models' Parameters

TABLE L.1 Pair Wise Comparison Test for I_H Value of Simple Trip Workers

	t (2000,1990)	t (1990,1980)	t (2000,1980)
Constant			
Male [D]			
20 - 24 Years Old [D]			
25 - 34 Years Old [D]			
35 - 44 Years Old [D]		**	*
45 - 54 Years Old [D]			
Number of Household Members			
Parent with Dependent Child [D]			
Number of Cars per Adult Household Member			
Driver's License Holding [D]			
Resides in Commercial Area [D]	*		
Resides in Mixed Commercial/Residential Area [D]	**	****	
Resides in Autonomous Area [D]			
Resides in Suburbs Area [D]	*	****	
Residence Zone Accessibility to Population		****	****
Work Zone Accessibility to Population		****	****
Work One-way Commute Distance	****	****	****
Distance to Metropolitan Center		****	***
Fraction of Transit Trips in Given Day Trips Pattern			
Fraction of Non Motorized Trips in Given Day Trips Pattern		****	****
Sigma	****	****	****

* = significant at α = 0.1, ** = significant at α = 0.05, *** = significant at α = 0.01, **** = significant at α = 0.005

TABLE L.2 Pair Wise Comparison Test for I_H Value of Simple Trip Non-workers

	t (2000,1990)	t (1990,1980)	t (2000,1980)
Constant			
Male [D]	**		
20 - 24 Years Old [D]			**
25 - 34 Years Old [D]		***	
35 - 44 Years Old [D]	*		
45 - 54 Years Old [D]	****		***
Number of Household Members			
Parent with Dependent Child [D]			*
Number of Cars per Adult Household Member			***
Driver's License Holding [D]			
Resides in Commercial Area [D]		**	
Resides in Mixed Commercial/Residential Area [D]		**	
Resides in Autonomous Area [D]		**	
Resides in Suburbs Area [D]		*	
Residence Zone Accessibility to Population			*
Distance to Metropolitan Center			
Fraction of Transit Trips in Given Day Trips Pattern		****	****
Fraction of Non Motorized Trips in Given Day Trips Pattern	*		**
Sigma	****	****	****

* = significant at α = 0.1, ** = significant at α = 0.05, *** = significant at α = 0.01, **** = significant at α = 0.005

TABLE L.3 Pair Wise Comparison Test for I_H Value of Complex Trip Workers

	t (2000,1990)	t (1990,1980)	t (2000,1980)
Constant	****		*
Male [D]			**
Resides in Commercial Area [D]	**	**	
Resides in Mixed Commercial/Residential Area [D]	***	**	
Resides in Autonomous Area [D]			
Resides in Suburbs Area [D]		*	
Residence Zone Accessibility to Population	*	****	****
Work Zone Accessibility to Population	****	****	****
Work One-way Commute Distance	****		****
Distance to Metropolitan Center	**		****
Fraction of Transit Trips in Given Day Trips Pattern		***	****
Fraction of Non Motorized Trips in Given Day Trips Pattern			
Sigma	****		****

* = significant at α = 0.1, ** = significant at α = 0.05, *** = significant at α = 0.01, **** = significant at α = 0.005

TABLE L.4 Pair Wise Comparison Test for I_C Value of Complex Trip Workers

	t (2000,1990)	t (1990,1980)	t (2000,1980)
Constant	*		
Male [D]			**
20 - 24 Years Old [D]		***	****
25 - 34 Years Old [D]		*	***
35 - 44 Years Old [D]		**	***
45 - 54 Years Old [D]			**
Number of Household Members			
Parent with Dependent Child [D]			
Number of Cars per Adult Household Member	*	**	
Resides in Commercial Area [D]			
Resides in Mixed Commercial/Residential Area [D]	*		****
Resides in Autonomous Area [D]			
Resides in Suburbs Area [D]			****
Residence Zone Accessibility to Population	*		**
Work Zone Accessibility to Population			
Work One-way Commute Distance	**	*	
Distance to Metropolitan Center			
Fraction of Transit Trips in Given Day Trips Pattern			
Fraction of Non Motorized Trips in Given Day Trips Pattern	****		
Commute with Car [D]			**
Work Duration [minutes]	*		****
Number of Work Trips			
Sigma			

* = significant at α = 0.1, ** = significant at α = 0.05, *** = significant at α = 0.01, **** = significant at α = 0.005

TABLE L.5 Pair Wise Comparison Test for I_H Value of Complex Trip Non-workers

	t (2000,1990)	t (1990,1980)	t (2000,1980)
Constant	**		
Male [D]			
20 - 24 Years Old [D]			
25 - 34 Years Old [D]			
35 - 44 Years Old [D]			
45 - 54 Years Old [D]			
Number of Household Members		***	**
Parent with Dependent Child [D]			
Number of Cars per Adult Household Member			
Driver's License Holding [D]		*	*
Resides in Commercial Area [D]			
Resides in Mixed Commercial/Residential Area [D]			
Resides in Autonomous Area [D]			
Resides in Suburbs Area [D]			
Residence Zone Accessibility to Population	****	****	
Distance to Metropolitan Center	****	****	
Fraction of Transit Trips in Given Day Trips Pattern			*
Fraction of Non Motorized Trips in Given Day Trips Pattern	****	****	
Spreadness of Activity Locations (IC)			
Sigma	****	****	****

* = significant at $\alpha = 0.1$, ** = significant at $\alpha = 0.05$, *** = significant at $\alpha = 0.01$, **** = significant at $\alpha = 0.005$

TABLE L.6 Pair Wise Comparison Test for I_C Value of Complex Trip Non-Workers

	t (2000,1990)	t (1990,1980)	t (2000,1980)
Constant	****		
Male [D]	*		
20 - 24 Years Old [D]	*		*
25 - 34 Years Old [D]			
35 - 44 Years Old [D]	**		****
45 - 54 Years Old [D]		**	****
Number of Household Members		*	***
Parent with Dependent Child [D]			
Number of Cars per Adult Household Member		**	
Driver's License Holding [D]			
Resides in Commercial Area [D]			
Resides in Mixed Commercial/Residential Area [D]			
Resides in Autonomous Area [D]			
Resides in Suburbs Area [D]			
Residence Zone Accessibility to Population	****		****
Distance to Metropolitan Center			
Fraction of Transit Trips in Given Day Trips Pattern	****	****	****
Fraction of Non Motorized Trips in Given Day Trips Pattern			*
Activity Centroid Distance from Home Location (IH)	****	**	****
Sigma	****	**	****

* = significant at $\alpha = 0.1$, ** = significant at $\alpha = 0.05$, *** = significant at $\alpha = 0.01$, **** = significant at $\alpha = 0.005$