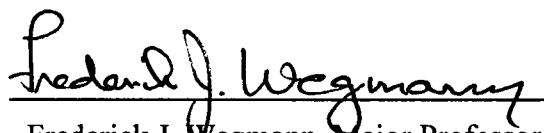
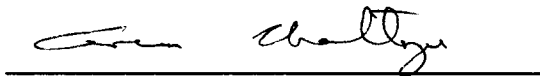


To the Graduate Council :

I am submitting herewith a dissertation written by Tae Youn Jang entitled "Analysis of Travel Behavior Characteristics of Individuals through Work-Related Trip-Chaining." I have examined the final copy of this dissertation for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Doctor of Philosophy with a major in Civil Engineering.


Frederick J. Wegmann, Major Professor

We have read this dissertation
and recommend its acceptance:







Accepted for the Council:


Associate Vice Chancellor and
Dean of The Graduate School

ANALYSIS OF TRAVEL BEHAVIOR
CHARACTERISTICS OF INDIVIDUALS
THROUGH WORK-RELATED TRIP-CHAINING

A Dissertation
Presented for the
Doctor of Philosophy Degree
The University of Tennessee, Knoxville

Tae Youn Jang
May, 1996

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ABSTRACT

As travel costs increase, individuals may try to consolidate trips into a chain, resulting in an increase of nonhome-based trips and a decrease of home-based trips. This study analyzes the trip-chaining behavior related to work and the 1990 Nationwide Personal Transportation Survey data is used. Nine work-related trip-chaining patterns are developed based on the sequential link of activities occurring in a day. The study explores trip linkages with their first trip starting at home and their last trip ending at home. If all activities made by an individual in a day are related, resulting in interdependence with time and spatial constraints, it is desirable that they should be sequentially analyzed from the first trip to the last trip.

More than sixty percent of trips for work in urban area represents complex trip-chaining patterns. From the results of chi-square test, the study finds that choosing each trip-chaining pattern is dependent upon socio-demographic characteristics of individuals. The relationship between trip-chaining patterns and socio-demographic characteristics implies that changes in individuals' characteristics means changes in choosing each trip-chaining pattern. From the results of analysis of variance (ANOVA), each gender has significant variation between trip-chaining patterns in trip rates for non-work activities, travel distance, and travel time. There are also significant gender differences in trip rates and travel resources in each trip-chaining pattern, resulting from t-test. Simultaneous equation models are built to find causal relationships among variables in each trip-

chaining pattern. Two-stage least square method is used. Endogenous variables, which are considered to have two-way causation among them, are the number of trips, travel distance, and travel time.

The study confirms that socio-demographic characteristics of individuals considerably influence the opportunities in making travel activity choices, which leads to different trip-chaining behavior for work. Females are likely to make more non-work trips to satisfy trip purposes and they use less travel resources in trip-chaining behavior. These tendencies are particularly of concern to transportation policy and planning since individuals' trip-chaining behavior may ultimately change trip generation. Changes in characteristics of individuals may mean changes in urban travel patterns, resulting in uncertainty in forecasting future amount of travel. As a result, effort toward more convincing travel demand models should be made using trip-chaining behavior concept.

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CHAPTER 1

INTRODUCTION

BACKGROUND

The conventional travel demand estimation model has a four step process: trip generation, trip distribution, modal split, and traffic assignment. Trip generation, the foundation of the process, is used to estimate the number of trips generated by each area unit, and these are established as a function of the socioeconomic and land use characteristics of a zone. There are two types of trips in conventional transportation travel demand model in terms of trip purpose: they are home-based and nonhome-based trips. A home-based trip is any trip where one end of the trip is at home - that is, it may have either started at home or ended at home. A trip is classified as nonhome-based if both ends of the trip are not at home.

Trip generation models estimate the number of home-based trips and nonhome-based trips using separately formulated models. That is, home-based and nonhome-based trips are treated separately in trip generation. The implicit assumption that home-based and nonhome-based trips are mutually independent is dubious, because the travel activities pursued by individuals at each trip destination may be related to each other, resulting in interdependence (Goulias et al. 1990).

The conventional travel demand models are based on measurements and estimated relationship from a single point in time, with an assumption that the estimated relationships will not change over time. In many cases, the models are based on simple assumptions, or are just simply unresponsive to certain aspects of the urban transportation system and policy issues. Transportation service variables are typically not incorporated into trip generation models, so by assumption the model asserts that trip generation is totally independent of changes in the transportation system and policy.

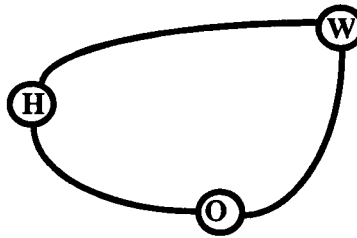
As a result, the models are non-behavioral and non-causal since they do not represent the decisions faced by individual trying to decide how frequently to make trips. In order to correctly forecast the effects of changes of policy and transportation level of services on trips, a travel demand model requires a causal and behavioral relationship, establishing the link between the attributes of the transportation system and the decisions of individuals for travel. Disaggregate studies that try to uncover the ways in which individuals make travel decisions are called behavioral because they focus explicitly on the attributes and preferences that lie behind decision making (Hanson and Schwab 1986). Studies at the individual are needed in order to understand the causal and behavioral relationships among the characteristics of individual, travel patterns, and travel decision making. Recently one area receiving attention is trip chaining.

TRIP-CHAINING

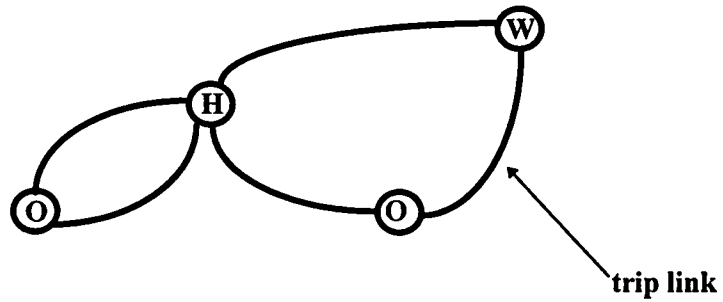
1. Trip-chaining Defined

A trip chain (multistop tour or multipurpose trip patterns) is generally defined as a connected sequence of trips to visit more than one destination (Figure 1-1). This study defines trip chain as those trips occurring during a 24 hour travel day including work which are sequentially linked. That is, the focus of this study is on linking work trips and non-work activities into a chain performed by an individual worker in a day. A travel linkage is created when the individuals moves from one location to another; hence a travel linkage involves both a spatial connection and a functional connection between two urban activities (Hanson 1980). Trip link is the travel movement which carries an individual between stops. A set of consecutive trip links which begin and end at an individual's home is called a trip tour. A trip tour can be expressed as a sequence of one-way trips that begin and end at home. Trips are to be one-way; therefore, the simplest possible tour involves two trips and a single destination. Trips usually do not have purposes in themselves, and the two major consequences of trips are the reaching of desired destinations and the consumption of valuable resources. Purposes are served at destinations through appropriate activities (Horowitz 1982). As a result, a trip tour is composed of trip links, and a trip chain can also be composed of more than one trip tour. A trip-chaining pattern refers to the set of trip tours made by an individual within a fixed time period (usually 24 hour).

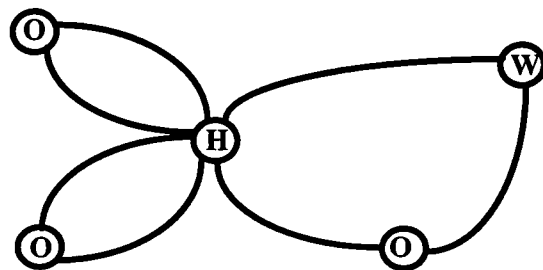
One trip tour



Two trip tour



Three trip tour



H : Home
W : Work
O : Non-work activities

Figure 1-1
Definition of Trip Chain

2. Advantages of Study for Trip-Chaining

People's trips result from activities practiced in various places within a urban area: this fact explains the importance of analyzing activity practices in order to understand the trip-making phenomenon, its social meaning, and its future development. As mentioned above, models which do not account for the varying behavioral effects of travel for activities are likely to result in a biased forecast. To reduce those biases, various types of improvement to existing models should be explored along with entirely new models such as travel behavior models including the trip-chaining concept. The analysis of out-of-home activity is conducted within a framework which views all of the daily activities of an individual as a linked sequence of activity choices.

The advantage of the trip-chaining approach is that it offers a framework for rigorous investigation of possible interrelationships among different types of activities pursued, socio-demographic status and structure of household, and the characteristics of trips made (Goulias et al. 1990). This evidence challenges the planners to understand, describe, and be able to reproduce the travel-chaining patterns generated by a given land use mix. Domencich and McFadden (1975) say that although aggregates of people is useful, their behavior can probably best be understood by considering the behavior of individual travelers. It is important to know (and be able to model) the real decisions an individual faces in his travel behavior, and the factors which influence these decision.

NEEDS OF STUDY FOR TRAVEL BEHAVIOR

1. Transportation Policy Issues

The conventional travel demand models have limited sensitivity to changes in transportation policy. The conventional models do not reflect the decision made by individuals trying to decide how frequently to travel and to link trips. Household travel patterns may be altered by policy changes. For example, previously the gasoline shortage in U.S. was a serious shock to many transportation planners who had assumed in their planning methodology and plans that gasoline would continue to be cheap and easily obtained. Despite new car fuel efficiency gains, automobile travel consumes forty percent more oil now than 15 years ago. Transportation accounts for more than 63 percent of total domestic oil consumption, most of it to fuel private automobiles (Burwell et al 1991). Linkages of trips from travel behavior may prove critically important to transportation planners in assessing such impacts as those stemming from energy shortages (Hanson 1980). A gasoline shortage and subsequent increases in the retail price of gasoline may have an impact on household travel patterns (e.g., impact of rising energy prices on the consolidation of simple trips into trip chains). If travelers try to accomplish their required trips by linking them as a multiple-stop chain, then unnecessary return trips from destinations to an origin may be eliminated. As a result, total travel time and travel miles for all trips are reduced, leading to a savings in out-of-pocket travel costs. A rise in the price of gasoline increases the out-of-pocket cost

savings from making multiple-purpose trips and might be expected to induce households to increase their use of tours. Stearns (1976) finds that combining non-work destinations with work trips increased sharply during the fuel shortage.

The problem of controlling air pollution generated by mobile sources is also part of the larger public policy concerned with improving air quality. Public policy with regard to air quality and transportation has focused on two elements: control of engine pollutant emissions through nationally mandated emission standards and the implementation of controls on the use of vehicles in urban areas. Motor vehicles account for 25 percent of all U.S. emissions of CO₂, a primary greenhouse gas, and 16 percent of the U.S. emissions of chlorofluorocarbon. Congestion exacerbates air pollution problems, yet vehicle-miles of travel (VMT) is projected to increase 45 percent by the year 2010, whereas highway capacity will only increase six percent (Burwell et al 1991). Vehicle emissions are generally estimated based on emission rates (grams per unit distance) and vehicle-miles of travel (VMT). There are many ways in which air pollution might be reduced, some conflicting and some complementary, not only with each other but with other policy goals. One of such ways is reducing vehicle travel or redistributing it to minimize the amount of emission produced per unit of travel by vehicle. Trip-chaining can reduce the number of trips and then vehicle-miles of travel. Strathman and Dueker (1994) say that analyzing trip chaining activity may lead to better understanding of travel behavior and provide a more appropriate framework for examining some transportation policy issues.

2. Simplification of Travel Demand Models

Most existing studies deal with the journey to work in terms of a single home to work movement and neglect the fact that a traveler may make stops at service establishments on the way from home to work. The conventional travel demand models are based on home interview origin-destination data that have been aggregated into units (e.g., zones) and average values developed as the parameters for model development. The models do not account for trip formations. The models are also confined to consideration of simple one-stop trips, even if a large percentage of urban travel is composed of more complicated multiple-stop trips (Lerman and Adler 1976, Oster 1978, and Horowitz 1982). Models simply assume that a traveler leaves home for a single destination such as work and then directly returns home. Hanson (1980) indicates that one reason for this view is that a major focus of many journey to work studies has been on understanding the role of the daily commute in the residential location decision. Journey to work studies with this perspective have quite naturally directed their attention primarily at the distance separating home from workplaces, and this emphasis may in part lie behind the conceptualization of the work trip as a single home work link. Another factor has been the prevailing notion that a trip consists of a single movement between two locations.

3. Increases of Non-work Activities

Non-work trips have been increasing during commuting hours. Non-work trips are frequently linked with work trips. Gordon et al. (1988) recognizes, from the

Nationwide Personal Transportation Survey (NPTS) of 1977 and 1983-1984, that increases in the number of nonwork trips are becoming more significant over time. They state that the nonwork trip is estimated to account for three-fourths of the total number of household trips taken, and this proportion is likely to increase as lifestyle changes further affect daily travel behavior. The survey indicates that the nonwork trip growth is concentrated in the family's personal and social and recreational travel. This increase has occurred across all city size classes and across all income groups.

4. Demographic Changes in Households

There have been substantial changes in the structure and activities of the typical family. Between 1970 and 1980, 44 percent of the growth in U.S. households consisted of new single-person households. Single-parent households with children represent another 25.5 percent of the increase. The number of households formed by single elderly individuals and women as heads of households represents a significant portion of the total number of new households (Meyer and Miller 1984). One of the most profound changes is the largely unanticipated growth (Smith 1976) in the salaried employment of mothers in both two or single parent households. As the number of women working outside the home continues to grow, questions arise as to the impact of women's employment on household travel patterns. The implication of these changes for transportation planning is that the variables once used to explain travel behavior might no longer be relevant. The use of trip-chaining patterns has much to do with household characteristics and a change

in the demography of urban residents may result in a change in the aggregate patterns of travel, resulting in questions about forecasts of future travel amounts.

RESEARCH HYPOTHESIS

1. Factors Influencing Trip-Chaining Behavior

When travel is viewed as a linkage between activities, it is logical to examine the factors that have important effects on individuals' and households' trip-chaining patterns. The work trip pattern of an individual may be the outcome of the worker's employment and residential location decisions, which are both presumably influenced by the worker's socio-demographic factors. The first hypothesis of this research is that the social circumstances in which an individual lives should have a considerable influence on the opportunities and the constraints that he (or she) faces in making travel activity choices and that these activity choices lead to differing travel behavior. This hypothesis deals with the determinants of trip-chaining patterns for work. Specifically, it examines whether there are interpretable and significant differences in trip-chaining patterns for different socio-demographic characteristics.

2. Differences in Travel Resources and Trip Rates by Gender

The second hypothesis is that there are differences between males and females in trip-chaining behavior. Since participation of females in the work force increases and

thus they perform household responsibilities requiring travel in addition to work, it is obvious to draw attention to gender differences in travel-chaining behavior in order to design appropriate transportation planning. The hypothesis is also to find if there are any differences in average number of nonwork trips and travel resources per trip-chaining pattern performed by gender. An important indicator of the extent of trip chain formation in a given household is its average chain length. Trip length can be measured in a number of different ways: the number of non-work activities in a chain and the total time (or distance) length of a chain.

3. Causal Relationship

The third hypothesis is that there are positive or negative interrelationships among variables such as trip rates, travel miles and travel time resulting from individual trip-chaining behavior, in addition to socio-demographic characteristics of a household. The hypothesis tries to find the causal relationships on which independent variables positively or negatively influence on dependent variables, under the assumption that there are two-way causation among trip rates, travel distance, and travel time.

OBJECTIVES OF STUDY

The purpose of this study is to investigate the validity of conventional transportation demand models which use a simple work trip concept. Resulting from

simple work trip concept, generally, conventional travel demand models are likely to underestimate the number of nonhome-based trips. This study tries to enhance an understanding of the trip-chaining behavior of individuals. A greater understanding of trip-chaining behavior eventually may improve trip forecasting, as non-work trips are generally components of trip chains as well as eventually facilitate the evaluation of various policy changes, such as increased travel costs and land use changes, on travel behavior. This study encompasses an analysis of individuals' trip-chaining patterns and non-work activities. The major effort in attempting to analyze trip-chaining is made to find gender differences in trip-chaining behavior. In order to achieve its purpose, this study uses the 1990 NPTS (Nationwide Personal Transportation Survey) data providing information on the sequential performance of activities and the characteristics of individuals and has the following specific objectives established:

- Study the trend of different trip-chaining patterns by socioeconomic and demographic characteristics of individual.
- Determine if there are differences in trip activities, trip-chaining patterns, and travel resources by gender.
- Examine the relationship between lifecycle stages and socioeconomic characteristics and investigate the differences in trip rates among lifecycle groups.
- Examine the impact that activity allocations have on travel behavior.
- Develop structural models by using the simultaneous equation method to analyze the interactions and find interrelationships among socio-demographic characteristics of individuals, trip frequency, travel time, and trip distance.

CHAPTER 2

LITERATURE REVIEW

The study is based on work-related trip-chaining patterns which represent the linking of non-work activities with work trips, resulting from spatial-temporal constraints, and tries to find causal factors influencing the formation of trip-chaining patterns in relation to socio-demographic characteristics of individuals. Most efforts are also made to find gender differences in travel behavior. In this chapter, some of literature concerning the various activities, spatial-temporal approaches to travel behavior, gender differences in transportation, and the effects of lifecycle are discussed.

ACTIVITY-BASED ANALYSIS

Activity-based approaches to travel analysis make extensive contributions to the development of a more comprehensive understanding of travel behavior and the likely effects of travel on social and policy changes. Activities are defined as the basic building blocks of behavior: the means by which household members satisfy physiological needs, role commitments and personal wants (Jones et al. 1983). Jones et al. (1990) stated:

“The motivation for the development of activity-based approaches has derived largely from dissatisfaction with the established procedures. In some instances the forecasts of trip-based models have proved to be inaccurate, and this seems to be the result of mis-specification: an inappropriate representation of travel behavior relationships - often through a failure to recognize the existence of linkages among trips, and between trips

and activity participation. An activity-based analysis approaches these problems through a deeper understanding of travel behavior”.

1. Elements of Activity-based Analysis

Damm (1983) suggested consideration of the following elements for activity behavior:

- Timing (clock time and relative time)
- Duration
- Location (absolute location as given by coordinates and relative location, such as distance from the last stop)
- Mode(s) to reach activity (including non-motorized)
- Frequency participation
- Sequencing
- Flexibility or elasticity (how easily moved in time and space)
- Importance or priority
- Variety (over period longer than one day)

Damm (1982) also investigated the effect of interdependence within household on daily activities across five different time periods of the day by using conventional home interview survey data from Minneapolis/St. Paul. The five different time periods were:

- Before the work trips
- On the way from home to work
- During work-related activities
- On the way from work to home
- After the work trips

His research delineated the boundaries of activity-based behavior by developing a model of activity-related choice. The findings supported the judgment made about factors operating to influence that whether an individual participated in an activity and if so, how long. The unique characteristics of study was that he tried to capture the

interrelatedness of a person's decisions made in the different time period. The study indicated that conventional travel dataset are deficient for activity-based analysis.

2. Travel Behavior Pattern Based on Activity and Household Characteristics

Glob and Glob (1982) stated that activity approaches had been emerging in recent years as a challenge to the orthodoxy of the established travel-demand modeling techniques. The most ambitious goal of these approaches was the understanding of what had been termed complex travel behavior. This required an understanding of individual behavior as well as of household interactions as a means of explaining and predicting responses to a host of activity influences. They said that the potential advantages of activity-based approaches appeared to be considerable. For policy evaluation purposes, the approaches were attractive because of their suitability in considering policies in which effects might be indirect (for example, changes in working hours).

Clark et al. (1981) showed the usefulness of the activity-based travel at data-collection, analysis, and modeling stages of transportation planning. They found that the importance of linkages between household members led to another immediately practicable theme: use of the stage in the family life cycle as a classificatory variable. They looked at the impact on travel of the differences in activity pattern across life-cycle groups in the analysis of behavior patterns and concluded that there were real differences in travel between households.

The relationships between travel behavior and the socioeconomic and demographic characteristics of households have received considerable attention from researchers. Golob (1986) researched the relationship between the activity patterns in the home-based trip chain and the characteristics of the persons (workers, students, and others), such as age, sex, working status, income, life cycle, car ownership, and residential location, by using tools of multivariate analysis and non-linear canonical correlation analysis. Research findings from the Dutch National Mobility Panel indicated that life cycle was uniformly the most effective explanatory variables for all person groups, followed by age and income.

A sequential model of daily travel patterns that consisted of activity and destination choice submodels was developed by Kitamura and Kermanshah (1984). The model was estimated by using the standard logit estimation procedures with small-scale survey results. The analysis using 1977 Baltimore travel demand data showed that non-home-based destination choice was critically dependent on the residence location of the individual. The authors concluded that the activity choices were influenced by time-of-day, activity history, and socioeconomic attributes of the persons. On the other hand, destination choice behavior was proved to be influenced by socioeconomic and historical variables to a limited extent.

Adiv (1983) divided the work-trips of 515 workers in the San Francisco Bay Area into three segments:

- Primary (or first) trip, home to work on a day
- Primary (or last) trip, work to home on a day

- Trips during work - generally trips falling between these two primary trips

His paper analyzed whether in fact people were engaged in extra activities during their work trip and to what extent. This study showed that the commute trip from work to home was not simply a mirror image of the trip from home to work, as most conventional models imply. The return trip to home not only included twice as many activities, but it also consumed more time, both for travel as well as for the activities.

TIME AND SPATIAL CONSTRAINTS

1. Concepts of Time and Spatial Constraints

Trips, trip chains or travel patterns might be the outcome of environmental constraints on behavior, or of avoidance of other strategies, and not the usual choices or decisions, for many, at all (Burennett and Hanson 1982). Considered in the activity-based approach is the presence of time and space constraints under which a household makes travel decisions. The concept of time-space prism, which can represent constraints on human activity under temporal and spatial elements, has been used in the analysis of travel behavior. When the constraints on the trip opportunities of individuals imposed by the limitation of space and time are identified, a travel behavior pattern may be predicted. The constraints that were conceptualized by Hagerstrand (1970) and were summarized by Burns (1979) include:

- Capacity constraints that circumscribe behavior by demanding large blocks of time for physiological necessities (sleeping, eating, and personal care) and by

- limiting the distances an individual can travel within a particular time span in accord with the available transportation system
- Coupling constraints that pinpoint where, when, and for how long an individual must join other individuals (or objects) in order to participate in production, consumption, social, and other miscellaneous activities
- Authority constraints that determine who does and does not have access to specific domains at specific times to do specific things as a result of general rules, laws, economic barriers, and power relationships

2. Analysis of Travel Pattern Based on Time and Spatial Constraints

Kitamura et al. (1981) examined the effects of life-cycle status, income, and car ownership on trip chaining, given the number of stops in the path restricted by time and space characteristics. Nishii et al. (1988) determined the conditions in the travel movement that encouraged or discouraged linking of trips into a multistop chain using a simple model of trip chaining behavior under time-space constraints. Their models assumed that trip makers were homogeneous and that the properties identified through the model apply uniformly to all individuals. The focus of their study was on linking working trips and other trips in a constrained environment. The probability of combining work and other activities into one home-based trip chain was related to parameters characterizing the travel environment, such as the travel speed and commuting distance. The theoretical results indicated that the likelihood of pursuing an additional activity in a separate home-based chain increased with the speed of travel, and that of multistop chains increased with commuting distance, travel cost, and the density of opportunity. The empirical results using the data set from the Kyoto-Osaka-Kobe metropolitan area in Japan supported the relationship between commuting distance and trip chaining.

The analysis by Kondo and Kitamura (1987) was motivated by the likelihood of combining non-work, out-of-home activities governed by constraints referred to as prism constraints imposed by work activity into a multi-stop trip chain. The study showed an empirical analysis of activity patterns under the consideration of constraints by the travel mode choice, activity duration, and the effect of home-to-work distance. The constrained discrete-choice model was also used to obtain the probability of choosing the activity pattern, which quantifies the effects of time constraints. The authors indicated that the likelihood depended on whether or not the marginal benefit of time spent in-home activities diminishes.

LIFECYCLE

The lifecycle framework is most powerful in demographically-based analyses. By understanding the travel behavior of segments of the populations which can be defined on the basis of demographic parameters, such as age and sex the impact of demographic changes can be addressed. Clark (1981) recognized the household structure (in terms of the number and age of children) as a major determinant of daily behavior and hence of travel. The lifecycle framework could also be used in policy analysis to complement the more typical income class or regional analysis (Zimmerman 1982). If travel behavior was influenced by lifecycle stage, policies impinging on travel would benefit from a lifecycle analysis of the policy's impact.

The study of Kostyniuk et al. (1983) explored households' evening out-of-home activities and travel paths in time and space. The emphasis was placed on how various factors affect the characteristics of these paths. Of particular concern were the interpersonal linkage constraint within the household and the role and responsibilities of individual members. Statistical investigation of the 1965 Detroit Area Transportation and Land Use Study (TALUS) dataset indicated that the lifecycle stage of the household affected many aspects of the evening path: type of paths, involvement of a spouse, number of stops, and time of returning home.

Jones et al. (1983) developed the eight stages of lifecycle from the survey of trend in Banbury in Britain. The prototypical activity patterns for households from different lifecycle groups were developed from the in-depth interview work, and then compared with a graphical representation of aggregate behavior derived from the quantitative diary data. They also investigated differences between the time budgets of households in different lifecycle groups, and determined whether there was any other classification which provided a better framework for grouping together households who behaved similarly. The findings were that the presence of children of different ages was very significant factor influencing the activity time budgets of the adult members of households. There was considerable variance between the lifestyles of households within each lifecycle group, corresponding to differing preferences and, in all likelihood, to membership of different socioeconomic classes and income levels. They suggested that further work on classifying household lifestyles should examine the effect of

socioeconomic variables within lifecycle. Knippenberg et al. (1990) studied the demographic development, such as the increasing participation of households (resulting from the increasing divorce rate). These types of changes in household structure might affect people's activity patterns, and, as a result, their travel behavior. They carried out a study with the aim of comparing the travel behavior of traditional and non-traditional households, by using Netherlands' household data. The main distinction between traditional and non-traditional households was whether or not the women were working, or whether they did or did not have a partner with whom to share responsibilities. Very few differences were found between working women from single parent households and those from two-parent households, nor in commuting behavior, or shopping behavior. The main differences appeared to be in car ownership and car use.

GENDER

Hanson and Hanson (1981) examined the effects of a wife's employment status on her own travel activity pattern and on that of her husband by using data from Uppsala Household Travel Survey in Sweden. They compared the travel patterns of married women employed full time with those of married women employed part time and married woman not working outside the home. Then, they compared the travel patterns of the three corresponding groups of husbands. The results showed that women employed full-time reduced their participation in some non-work activities although the distances

traveled to activity sites were not shorter than those traveled by the other women. This suggested that the reduced time constraints imposed by part-time employment enabled part-time workers to undertake travel for non-work purposes in conjunction with the journey to or from work more easily than full time workers. The wife's employment status had little discernible impact on the husband's allocation of time to different activities. In sum, the men's travel activity patterns yielded fewer significant intergroup differences than was the case for the women and suggested that a wife's participation in the paid labor force did not produce as many substantial shifts in the husband's daily travel pattern as it did in her own.

Rosenbloom (1989) explored differences in the travel patterns of men and women by focusing on one indicator of the complexity of individual travel behavior: trip-chaining, or linking trips to or from work with trips to carry out personal or household responsibilities, by analyzing descriptive data from France, the Netherlands and the U.S. She performed the analysis by obtaining percentages of mothers who linked trips to work and from work according to age of youngest child. Those percentages were compared with men's. In all three countries, women had more complicated activity patterns than comparably situated men. The data analyzed were not sufficient to indicate the cause of such behavioral differences and did not show the sequential patterns of activities. She concluded that the differences in the travel patterns suggested that both transportation policy makers and planners must consider alternative ways of delivering transport

services now and in the future. Current transportation planning methodologies were not likely to accurately capture or project these complicated travel patterns.

Hamilton and Jenkins (1989) indicated that the major problem in attempting to analyze transport and travel in gender terms was that transport statistics were often not broken down by gender at all. The aim of their paper was to offer a synopsis of the main differences between travel patterns of men and women. In terms of total number of journeys made, available information on the study of West Yorkshire indicated an even split between men and women. However, they found that when the travel indicator was mileage rather than trips, a very different patterns emerges. In every age group, men made substantially longer journeys on average than women, and this differentiation was most marked for people in the 30-59 age group. Journey length varied markedly by journey purpose, and here gender was an important covariant. Journeys to work tended to account for a higher proportion of men's journeys, while shopping and personal business trips and escort and other trips accounted for a higher proportion of women's, in the 20-60 age range.

METHODOLOGICAL APPROACHES TO TRAVEL BEHAVIOR

1. Stochastic Analysis

One of the earliest and still popular methods of describing travel behavior patterns is the Markov process representing one of the best-known and most useful classes of

stochastic processes. The Markov process has three typical properties (Budnick et al. 1988): first, it has discrete state space; second, given that the (or most recent) state is known, the conditional probability of the next state is independent of states prior to the present (or most recent) state. Stated a little differently, it is a time-based process where the probability of a state on the next trial (time period) depends only on the state in the current trial (time period) and not on how we got to the present state; third, it has one-step transition probabilities that remain constant over time (termed stationary transition probabilities).

The simple Markov process has often been used to represent trip chaining. Marble (1964) used simple Markov chain model to represent interactions between activities. Horton and Schuldiner (1967) developed a probabilistic model, assuming that each group of land used within the spatial structure of urban land is a member of a finite collection of states which a tripmaker might choose as a trip end, and further assuming that the movement of a tripmaker was part of a process such that if he is in a given state, there was some probability that he would move to another given state in any given time period. Hemmens (1970) conducted the analysis of out-of-home activity patterns within a framework which viewed all of the daily activities of an individual as a linked sequence of activity choices. In this study the Markov chain model permitted easy and economical reconstruction of journey patterns from the data.

For the convenience of describing the movement of persons through a Markov chain, Sasaki (1972) defined a base as the starting place of the first person trip in a day,

principally, home, hotel, office, or terminal. After people started from their base, people completed a chain of trips to achieve their objectives. If the end point of the final trip coincided with the starting place of the first trip, a chain of trips forms a cycle. If the distribution of various bases according to the land use plan, the number and purpose of the first trips, and the transition matrix for trip purpose were known, the person trip pattern could be determined. The linkage between successive stages of multi-stage journey was examined by Bentley (1977) with data containing the number of journeys made in the course of week, the journey activities undertaken on each day, and the activity linkages that occurred within journeys.

However, the simple Markov application has drawbacks due to a set of faulty assumptions. Since the duration of activity in each state does not vary over time as indicated in the third property of the Markov process, a semi-Markov process derives the duration of a state from a probability distribution. Lerman (1979) developed a model which used the theory of semi-Markov processes, to produce a modeling approach which effectively captures much of non-work trip behavior in a way which was far more realistic. Lerman applied a semi-Markov process by considering every state of the process as a particular travel destination (stop location) reached by a particular mode at a given time. Gilbert et al. (1972) discussed the possible analysis of multi-purpose journeys in terms of semi-Markov processes, allowing for the duration of activities to affect the probability of transitions from one state to another. Borgers and Timmermans

(1986) and O'Kelly (1981) modeled the case of multipurpose and multideestination, based on time-varying Markov processes.

Kitamura(1983) developed a sequential model of trip chaining, which consisted of history-dependent probabilities of activity choice. He identified a consistent hierarchical order in sequencing activities in a chain where less-flexible activities tended to be pursued first and the set of activities in the chain tended to be homogeneous. The results showed that homogeneity of activity types, patterns in sequencing activities, and transitions in activities were all closely interrelated.

2. Cluster Analysis

Much research has been guided by the principle that people who are similar in certain key respects may also be similar in other respects such as travel. Cluster analysis (Romesbury 1984) is a procedure in which a deterministic fashion classifies objects or elements of a data matrix into groups. Salomon and Ben-Akiva (1982) applied market segmentation concepts in travel demand analysis when market segmentation was used as a method for accounting for cross-sectional taste differences. They suggested the employment of the life-style concept as an improved basis for segmentation. The study defined life-style as the behavioral pattern that resulted from the decision to form a household, the decision to participate in the labor force, and the orientation toward leisure. By using available socioeconomic variables, an attempt was made to identify

life-style groups by using the cluster method and to use them as market segments in a joint mode and destination choice model.

The methodology suggested by Pas (1982), which facilitated systematic identification of groups of similar travel-activity patterns, was used to derive the typologies of travel patterns. The methodology was applied to a sample of 236 daily travel-activity patterns drawn from the Baltimore travel demand data set surveyed in 1977. He tested the hypothesis that a set of daily travel-activity patterns could usefully be described by its membership in a limited number of interpretable general classes. The results showed that the 236 daily patterns could be grouped into between 12 and 5 relatively homogeneous groups. The results also showed that the clusters might be interpreted by defining a small number of representative daily travel-activity patterns for each group.

Neale and Hutchinson (1981) used a cluster analysis to group households together on the basis of similarities in their travel time profiles. The study analyzed the travel times of various types of activities of a sample of Vancouver households using a mutual information statistic. The basic objective of this analysis was to isolate household factors influencing the consumption of travel. Cluster analysis was used to develop clusters of households with similar travel time consumption profiles and the information statistic was used to identify the most important household descriptor variables. As a conclusion, obligations to travel and household income, which were both strongly related to work

travel, emerge as the dominant variables, with stage in lifecycle emerging as the third most important variable.

3. Utility Maximization

The travel demand analysis has progressed with the development of mathematical models of the relationship between travel choices and variables through the use of probabilistic discrete choice. A class of mathematical models called the discrete-choice model provides techniques that apply the utility-theoretical concepts of microeconomics to make choices among discrete sets of alternatives. This theory of utility-maximization originates from microeconomics tools that examine consumer behavior. Utility refers to a size of attractiveness which is a measure that the decision maker attempts to maximize through his or her choice. This utility theory assumes that an individual has a utility function representing preference. Preference includes the observed attributes of an alternative, observed socioeconomic characteristics such as gender, education, and age, and unobserved characteristics of alternatives, such as intelligence, experience and training. In the model the individual tries to choose the alternative with the highest utility which maximizes his or her preference.

For the application of discrete choice processes, multinomial logit model (MLM) is typically applied for travel demand analysis (Agresti 1990; Ben-Arkiva and Lerman 1985; Domencich and McFadden 1975; McFadden 1974). A utility-maximizing framework was used to analyze travel frequency, destination choice and mode choice for

single and multi-destination travel by Horowitz (1980). In his paper, a structural model of the demand for multi-destination non-work travel was developed, and an empirical illustration of the structural model was presented. The structural model was based on the principle of utility maximization. Empirical tests of the model produced encouraging results concerning the model's structural validity. The empirical tests also indicated that there was a need to develop improved sets of explanatory variables for non-work travel. Horowitz (1982) developed a stochastic model which reflected how tour formation was affected by the numbers and types of destinations that a household reaches in a day, by using utility-maximizing techniques. The model was compared with travel data from Baltimore collected in 1977. His study suggested that the model could help in the analysis of problems requiring knowledge of the full probability distributions of tours and trips. The model could also be used to estimate numbers of "nonhome-based" trips for different groups of travelers, thereby bypassing at least one empirical procedure in the trip generation step in the urban transportation modeling framework. The model had a logit form, but the utility function included only a single calibrated parameter, which took into consideration the return trip to home. That is, a large number of travel variables were ignored in the development of the trip tour model. The concept of the prospective utility of a destination zone as a measure of its attractiveness was employed, considering the future dependency of destination choice and thus representing the interdependencies across travel choices in a trip chain by Kitamura (1984).

4. Categorical Data Analysis

Kostyniuk and Kitamura (1983) explored the characteristics of a household's time-space paths in the evening period and identified how the attributes of the household and its members influenced the path. Many factors interactively affected an individual's behavior. A particular combination of factor values might result in an effect which could not be expressed as the sum of the independent effects of the respective factors. The study explored how various factors affected the characteristics of evening paths. A log-linear model analysis incorporating three factors, path type, lifecycle stage, and household work trip status was performed on data from 1728 households in Detroit according to lifecycle stages by treating path type as the dependent variable. The best model included main effects and interaction effects of all paired combinations of three factors.

Kostyniuk and Kitamura (1984) also studied the temporal stability of urban travel patterns from origin-destination survey data of 1965 and 1980 of Southeast Michigan. In addition to the traditional indicators of travel patterns, such as trip rates, trip duration, and travel time budgets, the distribution of trips within trip chains, the sequencing and linkages of activities, and the time-of-day dependency of out-of-home activity participation are considered in the analysis. A series of hypotheses about the temporal stability of these indicators was tested by using log-linear models of contingency table analysis. The results indicated that, generally, these aspects of travel patterns were not stable over time. However, temporal stability was identified in the linkages and

sequencing of activities and in the time-of-day dependencies of the decision to return home.

SUMMARY

This chapter reviews some literature for significant factors to be considered to study trip-chaining travel behavior, such as activity analysis, time and spatial constraints, lifecycle, and gender. Trip-chaining patterns may be a product from the complex adjustment responses of changes in the activity participation, the socio-demographic characteristics of individual/household, household structure, the travel constraints of other household members, and time and spatial relationship between activities. That is, interactions among individual characteristics, time and spatial constraints, and household structure may all be significant motivations which determine an individual's activity pattern. Then, activity-based analysis of travel will extensively contribute to the understanding of trip-chaining behavior.

CHAPTER 3

STUDY APPROACHES

It is important to know the characteristics of individuals and structure of households in order to analyze what elements affect the form of individual travel behavior patterns. From the literature review, activity-based analysis, spatial-temporal analysis, lifecycle stage, and gender are identified as the major concepts which should be investigated to understand travel behavior of individuals. These concepts may be influenced by the characteristics of individual households. Socio-demographic information on households and individuals is a good source of data for this purpose. This study utilizes the 1990 Nationwide Personal Transportation Survey (NPTS) data collected by the Research Triangle Institute. The general information about NPTS data briefly mentioned in the following section is explained in the User's Guide For The Public Use Tapes: 1990 Nationwide Personal Transportation Survey (Research Triangle Institute 1991).

GENERAL INFORMATION ON NPTS DATA

1. Overview of NPTS Data

The Nationwide Personal Transportation Survey compiles national data on the nature and characteristics of personal travel. It addresses a broad range of travel in the

United States. The purpose of collecting NPTS Data is to provide data on all personal trips and transportation pattern for all purposes. When the 1990 data is used in conjunction with previous NPTS data, it is possible to track, over time, both personal travel and the characteristics related to that travel for the entire nation. NPTS data may be used to describe current travel patterns and, given projections of demographic change, can provide a valuable tool to forecast future travel demand.

The sample of 1990 NPTS data was collected from 48,385 persons, representing 22,317 households between March 1990 and March 1991. Information from the national household sample was collected about all trips taken during a designated 24-hour period (travel day). The travel day was defined as beginning at 4:00 a.m. on the designated day and ending at 3:59 a.m. on the following day. Additional details were collected for trips of 75 miles or further (one-way) that were taken during the preceding 14-day period (travel period). In this study, the 24-hour travel day data will be used because 24-hour travel day data contains the information on trip chain patterns that can be compared with socio-demographic factors of individuals.

A household-level interview was conducted with an adult resident of the household to obtain information on the number of household vehicles, availability of public transportation, household location, and household income. A person-level interview was attempted for each resident 5 years old or older. A knowledgeable household resident, age 14 or older, was asked to report all trips taken by household members between the ages of 5 and 13 years. In addition, the person-level interview

gathered data on occupation and work-related travel, vehicle driver information, and accidents.

The 1990 NPTS updates information gathered during similar studies conducted in 1969, 1977, 1983. Publicly available tapes with data from 1990 study have the following general features: first, the data are arranged in six hierarchical files to facilitate analysis, and, second, the data are available in the Statistical Analysis System (SAS) or standard EBCDIC format.

2. Contents of NPTS Data

The NPTS dataset contains:

- Household data on relationship of household members, educational levels through graduate or professional school, income categories, and other demographic information
- Data on availability of public transportation.
- Data on motor vehicles, including year, make, model and other vehicle-related information
- Information about drivers, including information on travel as an essential part of their jobs
- Data on trips taken during a 14-day period where the farthest point of the trip was at least 75 miles from home including the dates the trip started and ended, the day of the week, mode of travel, distance, number in travel party, and the purpose of the trip
- Information about trips taken during a designated 24-hour period including the time when the trip begin, length of the trip, composition of the travel party, mode of transportation, purpose of the trip, and vehicle used (if travel was in a household vehicle)
- Data on traffic accidents and accident reporting for motor vehicle accidents that occurred, when the respondent was driving, within the last five years

3. Six Files for NPTS data

The 1990 NPTS data base is composed of six files: Household File, Person File, Vehicle File, Travel Day File, Travel Day File (Segmented Trips only), and Travel Period File. The Household File contains household-level demographics such as geography and household composition. Travel Day Trip is defined as any one-way travel from one address (place) to another by any means of transportation (e.g., private motor vehicle, public transportation, bicycle, or walking). When travel is to more than one destination, a separate trip exists each time one or both of the following criteria is satisfied: the travel time between two destinations exceed five minutes, and/or the purpose for travel to one destination is different from the purpose for travel to another.

The Person File includes person-level characteristics for members of households participating in the NPTS. The Vehicle File contains data on each vehicle used by the responding households. The Travel Day File includes specific data on each trip taken by respondents during the travel day (typically the day before the interview occurred). Travel day trips are classified as "segmented" trips if the respondent indicates that some mode of public transportation is used on the trip and a transfer from one vehicle to another took place while using the public transportation. For segmented trips, additional data collected for each segment appear in the segmented travel day trip file. The Travel Day Period File includes data on longer trips (75 or more miles one-way) that took place during the two weeks prior to a respondent's interview. However, these longer trips will be eliminated in this study.

For this study, Household File and Travel Day File are used. From Travel Day File, work trips and non-work activities of individuals are examined according to the starting time of day trips, which becomes the base for development of work-related trip-chaining patterns.

NPTS DATA FOR THE STUDY OF TRIP-CHAINING

1. Socio-demographic Characteristics and trips

For the travel pattern analysis, this study uses the information on the characteristics of households, person level characteristics and the main reason for the trips, provided by the 1990 NPTS dataset (Research Triangle Institute 1991). They include:

- Household socioeconomic data, such as income categories, car ownership, the number of children, number of workers in household, number of household members, number of drivers, number of adults, and educational levels through graduate or professional school
- Lifecycle stages
- Information on the demographic characteristics of household
- Trip purposes such as home-based and non-home-based trips
- Total vehicle-miles in 24 hours
- Total vehicle-minutes in 24 hours
- Vehicle-minutes and vehicle-miles traveled for each trip link
- Starting times of trips

- Main reasons for the trips performed from 4:00 a.m. on the designated day to 3:59 a.m. on the following day to find trip-chaining patterns, that is, data on travel activities taken sequentially in a travel day. The study is developed based on an individual's trip-chaining pattern, the first trip starting at home and the last trip ending at home

2. Scope of Study

Strathman and Dueker (1994) presented five work related trip-chaining patterns and two non-work related trip-chaining patterns which represented travel behavior that occurred with only one tour between home and work, by using 1990 NPTS data. That is, for work, their trip-chaining patterns were formed from the time that individuals left home to go to work to the time that they come back home from work. Their study provides a descriptive analysis of trip-chaining without any statistical proof for establishing a relationship between trip-chaining patterns and the socio-demographic characteristics of individuals.

However, some activities may be performed within an independent trip tour before an individual starts work trips or after they come back home from work. As mentioned before, if all activities made by an individual in a whole day are related, resulting in dependence under the time and spatial constraints, it is desirable that the travel activities accomplished by an individual should be sequentially analyzed from first trip to the last trip in a travel day.

Simple work trip concept used in conventional travel demand models may be likely to fail to capture the possible nonhome-based trips, as mentioned before. In this

study, only work-related trip-chaining patterns are examined on a basis of a 24-hour time period to find the existence of nonhome-based trip in worker's travel behavior and then to prove the necessity of modification in conventional transportation demand models. These chains are classified in detail into nine trip-chaining patterns, grouped into three kinds of trip tours. These trip-chaining patterns for work are formed by sequentially linking all travel activities performed by an individual in a day. The origin of first trip in a chain is home and the destination of last trip is also home. The relationship of trip-chaining patterns to socio-demographic characteristics of an individual will be analyzed. The variations between trip-chaining patterns for trip rates, travel time, and travel distance are studied, and simultaneous equation models are developed to find causal relationships between the characteristics of an individuals and his (her) trip rates and travel resources. The analysis also reflects the hypothesis that there are significant gender differences in trip-chaining travel behavior.

CHAPTER 4

WORK-RELATED TRIP-CHAINING PATTERN

This chapter is divided into two sections. The first section examines individual travel activities, which occur sequentially in a designated 24-hour period and are associated with one of nine work-related trip-chaining patterns. The analysis of travel activity patterns is conducted within a framework which views all the daily activities of an individual as a linked sequence of activity choices. Jens Kofoed (1970) states that activities should be investigated as an sequence which describes the successive activity since it is important to understand how activities relate to each other.

The second section studies the relationships between trip-chaining patterns and socio-demographic characteristics. The trip-chaining patterns resulting from travel activities generated by the members of a household may be influenced by the structure and socioeconomic and demographic characteristics of that individual.

TRIP-CHAINING PATTERNS

1. Travel Activity Behavior

This study explores all trips, including work and non-work activities, performed by an individual and tries to find possible work-related trip-chaining patterns. It is difficult to consider all travel activity behavior performed by individuals during a day as

separate alternatives because there is a wide range of variations in travel activity patterns. Individual behavior is composed of activities which are obligatory or discretionary (Goulias et al 1990). In this study, it is assumed that obligatory activities are work trips and discretionary activities are school trips, personal business, shopping, and social and recreational trips. Unlike obligatory trips, discretionary trips have a large degree of flexibility in the number of trips generated, timing and the location. Given the obligatory trips for work, it is possible to determine the number of non-work activities and finally link those trips.

The linkage between activities which travel provides is conditioned and constrained by the time available for movement and the time restrictions resulting from the desire to undertake an activity at a given place at a given time. Trip-chaining pattern may also reflect the interdependent nature of decisions for activity participation of individuals. Therefore, it is important to study trip-chaining behavior performed by an individual during a whole day, since all trips which occur may influence each other under the time and spatial constraints.

2. Formation of Trip-chaining Patterns

Work-related trip-chaining patterns are developed according to the sequential order of occurrence of work and non-work activities. In other words, trip-chaining patterns are not classified based on workplaces for obligatory activities, because they are spatially fixed and regularly visited. Treating the workplaces differently from other

places for non-work activities is a departure from traditional practice and warrants further justification. Daily travel to work is not a trip over which individuals can usually have much choice. The number of trips for work, time of day, and location are essentially fixed.

The distribution of nine types of trip-chaining patterns is presented in Table 4-1. The name of the chain, such as to work, from work, before work, and after work, reflects the sequencing of non-work activities with respect to the work. These trip-chaining patterns are divided into three types according to the number of trip tours. Trip-chaining patterns which include one trip tour are trip-chaining pattern 1 (SIMPLE WORK), trip-chaining pattern 2 (TO WORK), trip-chaining pattern 3 (FROM WORK), trip-chaining pattern 4 (TO/FROM WORK), and trip-chaining pattern 5 (DURING WORK).

Two trips tour groups include trip-chaining pattern 6 (BEFORE WORK) and trip-chaining pattern 7 (AFTER WORK). Two or more trip tour groups include trip-chaining pattern 8 (MULTIWORK) and 9 (MIXED CHAIN), which are the most complex trip-chaining patterns.

The simple work trip chain represents a trip activity pattern which includes work or work related business in a chain during a day. This type of chain is a typical pattern used in current transportation planning models to predict the number of trips for work. This represents the travel behavior of an individual who leaves home for work and directly returns home without doing any non-work activities.

There are eight complex trip-chaining patterns. Trip-chaining pattern 2 (TO

Table 4-1
Structure of Typical Work-related Trip-chaining Patterns

Code	Description	Trip-chaining Pattern ¹	Frequency
Simple Pattern of Trip-chaining			
1	SIMPLE WORK (no non-work activities except work-related business, occurring during a designated day)	H-W-H	4556
Complex Pattern of Trip-chaining			
<u>One tour chain</u>			
2	TO WORK (Non-work activities occurring on the way from home to work)	H-O-W-H	320
3	FROM WORK (Non-work activities occurring on the way home from work)	H-W-O-H	1820
4	TO/FROM WORK (Non-work activities occurring between home and work and between work and home)	H-O-W-O-H	409
5	DURING WORK (Non-work activities occurring during work hour)	H-W-O-W-H	253
<u>Two tour chain</u>			
6	BEFORE WORK (A tour with non-work activities before a tour with work trips and non-work activities)	H-O-H-W-H ²	484
7	AFTER WORK (A tour with non-work activities after a tour with work trips and non-work activities)	H-W-H-O-H ²	3122
<u>Two or more tour chain</u>			
8	MULTIWORK (Two tours for work trips and a tour with possible non-work activities after work)	H-W-H-W-H-[-O-H] ²	357
9	MIXED CHAIN		503
Total			11824
H : Home			
W : Work or work related trips			
O : Other activities excluding work or work related trips			
1: There can be multiple activities for W and O			
2: There can be multiple activities for O within H-W-H			

WORK) represents a chain with non-work activities occurring on the way from home to work. There can also be several work activities or work-related business after non-work activities are completed. Trip-chaining pattern 6 (BEFORE WORK) is a similar pattern to trip-chaining pattern 2 in that the individual performs non-work activities before work. This pattern is formed when an individual performs non-work activities within an independent trip tour before he (or she) leaves home for work. In trip-chaining pattern 6 which has the two trip tour, the first trip tour is for one or more non-work activities and the second trip tour includes work trips and possible non-work activities. Trip-chaining patterns 3 (FROM WORK) and 7 (AFTER WORK) represent chains with non-work activities occurring after work finishes. A travel behavior pattern which includes one or more non-work activities on the way from work to home is included in trip-chaining pattern 3. Trip-chaining pattern 7 is a pattern in which one or more non-work activities are performed after an individual comes back home from work. That is, the first tour is for a work trip which may include non-work activities and the second tour is used only for a non-work activity (or non-work activities).

Performing one or more non-work activities both on the way from home to work and on the way from work to home is the travel behavior included in trip-chaining pattern 4 (TO/FROM WORK). Trip-chaining pattern 5 (DURING WORK) is a pattern in which there are no non-work activities between home and work. However, an individual takes trips for non-work activities during working hours, which forms a tour based on work.

Trip-chaining pattern 8 (MULTIWORK) has two independent tours for work trips each of which is the same as the simple trip-chaining pattern and possibly a third trip tour

for non-work activities. Trip-chaining pattern 9 (MIXED CHAIN) is the most complex travel behavior as it may have two or more trip tours in a chain.

TRIP-CHAINING PATTERNS AND SOCIO-DEMOGRAPHIC CHARACTERISTICS OF INDIVIDUALS

This part examines specifically the relationship between trip-chaining patterns and the socio-demographic characteristics of individuals. The socio-demographic characteristics of individuals are significant elements in order to decide their travel behavior patterns. The analysis is performed by comparing the column percentages in each trip-chaining pattern, which gives a dynamic view of changes in each socio-demographic characteristic.

Chi-square tests summarize the amount of disagreement between observed and expected frequencies and computes the probability of this agreement of discrepancy by pure chance. The hypothesis is that there are statistically significant differences in the formation of trip-chaining patterns according to the socio-demographic characteristics of households. That is, the research hypothesis to be tested is that the socio-demographic factors of individuals are not related to the type of trip-chaining pattern. The definition of socio-demographic characteristics is provided by the 1990 NPTS data book.

1. Income Level

Household income is the money income of all family members in the household, including those temporarily absent. The income for the 12 months preceding the interview, includes income from all sources, such as wages and salary, commissions, tips, cash bonuses, income from a business or farm, pensions, dividends, interest, unemployment or workmen's compensation, social security, veterans' payment, rent received from owned property, public assistance payments, regular gifts of money from friends or relatives not living in the household, alimony, child support, and other kinds of periodic money income other than earnings. Household income is classified into six different income levels in this chapter.

Dependence of trip-chaining patterns on household income

Table 4-2 shows the relationship between trip-chaining patterns and income level of the household in which an individual is included. Individuals are highly dependent upon their household income level for trip-chaining travel behavior. That is, Chi-square value is 90.8, which reflects a significant dependence upon income for the formation of trip-chaining patterns at $p < 0.01$ level.

Simple trip-chaining pattern

Table 4-2 gives information on how each trip-chaining pattern is chosen according to the changes in income levels. This table shows that as income level

Table 4-2
Stratification of Individuals by Trip-chaining Pattern and Income Level

Percent	Trip-chaining pattern									
	1	2	3	4	5	6	7	8	9	Total
Income level										
1	37.41	3.40	14.15	2.59	1.50	7.48	24.49	2.99	5.99	100.00 (735)
2	36.69	2.04	15.86	3.75	1.75	4.96	27.10	3.65	4.18	100.00 (2055)
3	36.43	2.64	15.66	3.42	2.03	4.28	26.87	3.94	4.72	100.00 (2311)
4	34.50	2.92	15.39	4.48	2.38	3.62	29.32	2.86	4.54	100.00 (1852)
5	34.25	2.08	16.08	4.81	2.74	2.63	30.09	2.52	4.81	100.00 (914)
6	36.41	3.14	18.12	3.05	3.23	2.69	26.55	3.05	3.77	100.00 (1115)
Average	35.95	2.63	15.88	3.74	2.22	4.20	27.52	3.32	4.55	
Chi-square value=90.8 (significant at $p < 0.01$)										
Income level of household:										
1 = \$0 - \$14,999										
2 = \$15,000 - \$29,999										
3 = \$30,000 - \$44,999										
4 = \$45,000 - \$59,999										
5 = \$60,000 - \$74,999										
6 = \$75,000 +										
Trip-chaining pattern:										
1=SIMPLE WORK										
2=TO WORK										
3=FROM WORK										
4=TO/FROM WORK										
5=DURING WORK										
6=BEFORE WORK										
7=AFTER WORK										
8=MULTIWORK										
9=MIXED CHAIN										

() sample size

increases up to \$75,000, the percentages of simple trip-chaining pattern decrease and for the highest income level there is an increase in frequency. Generally, individuals in lower income levels are more likely to choose trip-chaining pattern 1 (SIMPLE WORK) than those in other income levels.

Complex trip-chaining patterns

The lowest income group has the higher rate of preference for trip-chaining pattern 2 (TO WORK) than any other group and income groups 2 and 5 have the lowest percentages. In general, there is a variation among income groups in choosing this pattern; that is, there is no consistency in the distribution of percentages as income level changes. Trip-chaining pattern 3 (FROM WORK) is used more by the individuals as their income increases; that is, increasing income encourages the individuals to engage in non-work activities on the way home from work. Trip-chaining pattern 4 (TO/FROM WORK), generally, is increasingly used as income level increases. Income level 5 has the higher percentage than any other income level. However, the highest income group shows decrease in percentage of choosing this pattern. Higher income groups have more opportunities to perform non-work activities during working hours (trip-chaining pattern 5), while lower income groups are likely to have less chance.

The lowest income group (\$0 - \$14,999) uses trip-chaining pattern 6 (BEFORE WORK) with the highest percentage among all income groups; that is, there is highest rate of lowest income individuals among income groups who perform trip-chaining

pattern 6. In general, as income increases, this pattern is less preferred by individuals. Individuals are less likely to engage in non-work activities by this pattern, as income increases. The lowest income group tends to pursue non-work activities less within trip-chaining pattern 7 (AFTER WORK) than any other income group.

Trip-chaining pattern 8 (MULTIWORK), which includes at least two tours in a chain, is preferred by the third income group but shows that there is not much difference in percentages among other income groups. While trip-chaining pattern 9 (MIXED CHAIN) is likely to be preferred by the lowest income group, it is least used by the highest income group.

2. Urban Size

Urbanized area as defined by NPTS dataset is an approximate classification of sample households as belonging to an urbanized area or not. Those households classified as belonging to an urbanized area live either in a central city of an MSA or in a MSA but outside the central city, or within a zip code area with a population density of at least 500 people per square mile in 1990. Five urban areas are defined according to the population.

Dependence of trip-chaining patterns on urban size

Table 4-3 shows the relationship between trip-chaining patterns and urban sizes for individuals. Dependency of trip-chaining patterns on urban size is significant at $p < 0.05$ level.

Table 4-3
Stratification of Individuals by Trip-chaining Pattern and Urban Size

Percent	Trip-chaining pattern									Total
	1	2	3	4	5	6	7	8	9	
Urban size										
1	36.33	2.62	15.64	2.72	2.06	5.34	27.90	3.09	4.31	100.00 (1068)
2	38.38	1.56	15.44	3.28	2.81	4.68	26.37	3.28	4.21	100.00 (641)
3	36.18	2.99	14.73	4.16	1.60	4.01	28.74	2.48	5.11	100.00 (1371)
4	38.55	2.75	15.58	3.38	2.60	3.95	26.91	2.60	3.69	100.00 (1925)
5	41.21	3.17	15.65	2.76	1.97	3.35	26.15	2.16	3.58	100.00 (2684)
Average	38.73	2.82	15.45	3.20	2.15	4.01	27.06	2.55	4.03	
Chi-square value=47.07 (significant at $p < 0.05$)										
Urban size:										
1 = 50,000-199,999										
2 = 200,000-499,999										
3 = 500,000-999,999										
4 = 1,000,000 or more without subway/rail										
5 = 1,000,000 or more with subway/rail										
Trip-chaining pattern:										
1=SIMPLE WORK										
2=TO WORK										
3=FROM WORK										
4=TO/FROM WORK										
5=DURING WORK										
6=BEFORE WORK										
7=AFTER WORK										
8=MULTIWORK										
9=MIXED CHAIN										

() sample size

Simple trip-chaining pattern

Individuals living in urban size 5, which has a population of 1,000,000 with a subway/rail system, perform simple work trip pattern (trip-chaining pattern 1) in the highest percentage (41.21 %). It is expected that individuals living in the smallest urban area tend to take work trips with a complex pattern. As a result, if an individual considers the possible traffic congestion and consequently longer travel time of larger urban areas, he (or she) may try to simplify his (or her) work trips.

Complex trip-chaining patterns

As a whole, the percentage of trip-making with trip-chaining pattern 2 (TO WORK) is generally low but trip-chaining pattern 2 is chosen more often by individuals in urban size 5. That is, individuals in urban size 5 are more likely to make non-work trips on the way from home to work than any other individual in other urban sizes. Generally, trip-chaining pattern 3 (FROM WORK) is almost equally used by individuals in all urban sizes except those in urban size 3. Trip-chaining pattern 4 (TO/FROM WORK) is the least favorite for individuals living in the smallest urban area or in the largest urban area. During working hours, individuals in urban size 3 has the smallest percentage of performing non-work activities.

As urban size increases, the percentage of trip-chaining pattern 6 (BEFORE WORK) decreases. This may reflect that individuals living in a smaller urban size has fewer work schedule constraints for non-work activities before work; for example, those

living in smaller urban areas may have more flexibility in time for activities as a result of less traffic congestion. Trip-chaining pattern 7 (AFTER WORK), which contains the largest percentage of individuals compared to the other complex trip chains, is popularly used by individuals in urban size 3.

Individuals show the similar inclination to choose trip-chaining patterns 8 (MULTIWORK) and 9 (MIXED CHAIN). That is, smaller urban sizes have higher percentages for those patterns, reflecting that individuals living in smaller urban areas prefer the most complex trip-chaining patterns rather than those in larger urban areas.

3. Household size

Household size refers to the total number of members in a household. Household members are people, whether present or temporarily absent, whose usual place of residence is in the sample unit. They include people staying in the sample unit who have no other usual place of residence elsewhere.

Dependence of trip-chaining patterns on household size

Individuals are classified into three groups according to the number of persons in the households, as shown in Table 4-4. The formation of trip-chaining patterns are significantly dependent upon the number of members in the household at $p < 0.01$ level.

Table 4-4
Stratification of Individuals by Trip-chaining Pattern and Household Size

Percent	Trip-chaining pattern									Total
	1	2	3	4	5	6	7	8	9	
HH size										
A	37.99	2.00	18.56	2.07	2.57	3.12	27.53	2.68	3.48	100.00 (4394)
B	38.51	3.13	14.03	4.41	1.99	4.23	26.00	3.15	4.56	100.00 (5531)
C	39.81	3.11	12.01	3.90	1.58	5.95	25.01	3.48	5.16	100.00 (1899)
Average	38.53	2.71	15.39	3.46	2.14	4.09	26.41	3.03	4.25	
Chi-square value=155.36 (significant at $p < 0.01$)										

Household size:

A = 1-2

B = 3-4

C = 5 or more

Trip-chaining pattern:

1=SIMPLE WORK

2=TO WORK

3=FROM WORK

4=TO/FROM WORK

5=DURING WORK

6=BEFORE WORK

7=AFTER WORK

8=MULTIWORK

9=MIXED CHAIN

() sample size

Simple trip-chaining pattern

The use of the simple work trip pattern increases as the number of members in the household increases; that is, individuals are less likely to link non-work activities with work trips as the household size increases. This may result from the reason that as the number of household members increases, responsibilities of the household may be shared with other family members.

Complex trip-chaining patterns

Trip-chaining pattern 2 (TO WORK) is chosen less by individuals with one or two members (size A) in the household than by those in other household sizes. As the number of members in a household increases, individuals tend to take fewer non-work trips on the way home from work (trip-chaining pattern 3) or during working hours (trip-chaining pattern 5). Trip-chaining pattern 4 (TO/FROM WORK) is more often chosen by individuals in the household with three or more family members (sizes B or C) than those in household size A.

As the number of members in a household increases, individuals are more likely to engage in trip-chaining pattern 6 (BEFORE WORK). Like the case of trip-chaining pattern 2 (TO WORK), since the larger size of a household may mean that there is one or more than one child in that household, individuals make school or other trips before work trip starts. Trip-chaining pattern 7 (AFTER WORK) is also more likely to be used by an individual with smaller number of family members. That is, as the number of members

in a household increases, the use of trip-chaining pattern 7 decreases. Trip-chaining patterns 8 (MULTIWORK) and 9 (MIXED CHAIN), with two or more trip tours, are used more often as the number of household members increases.

4. Number of Vehicles

Dependence of trip-chaining patterns on vehicle ownership

Table 4-5 shows cross-classification between trip-chaining patterns and the number of vehicles in a household. Dependency of trip-chaining patterns on the vehicle ownership of household is statistically significant at $p < 0.01$. Individuals are sensitive to the number of vehicles in the households in forming work-related trip-chaining patterns.

Simple trip-chaining pattern

Individuals in zero vehicle ownership group have a higher percentage of use of trip-chaining pattern 1 than those in other vehicle ownership groups. This may mean that if there is no vehicle in a household, it is more difficult to make non-work trips, resulting in that an individual performs simple work trip pattern. Individuals in a household with one vehicle have the lowest percentage for trip-chaining pattern 1 among all vehicle ownership groups. However, if there is at least one vehicle in the household, the percentages of simple trip-chaining pattern increase as the number of vehicles increases; that is, increase of vehicle ownership contributes to lowering the percentage of complex trip chaining patterns.

Table 4-5
Stratification of Individuals by Trip-chaining Pattern and the Number of Vehicles
in the Household

Percent	Trip-chaining pattern									
	1	2	3	4	5	6	7	8	9	Total
Vehicles										
0	44.29	4.64	19.64	1.43	2.50	3.57	19.64	2.14	2.14	100.00 (280)
1	36.85	2.55	17.55	3.94	2.41	4.35	24.63	2.92	4.81	100.00 (2160)
2	38.13	2.68	15.19	3.80	2.11	3.92	27.15	2.77	4.25	100.00 (5555)
3 or more	39.62	2.69	14.16	2.85	2.01	4.23	26.82	3.53	4.10	100.00 (3829)
Average	38.53	2.71	15.39	3.46	2.14	4.09	26.41	3.03	4.25	
Chi-square value=55.08 (significant at p=<0.01)										
Trip-chaining pattern:										
1=SIMPLE WORK										
2=TO WORK										
3=FROM WORK										
4=TO/FROM WORK										
5=DURING WORK										
6=BEFORE WORK										
7=AFTER WORK										
8=MULTIWORK										
9=MIXED CHAIN										

() sample size

Complex trip-chaining patterns

Individuals classified into the zero vehicle ownership group have the highest percentage of choosing trip-chaining pattern 2 (TO WORK) compared to those in other vehicle ownership groups. Trip-chaining pattern 2 is almost equally used by those groups with at least one vehicle ownership. This is unusual because if no one has a vehicle in the household, she (or he) must use other transportation modes which may provide limited time flexibility and may provide no chance to engage in non-work activities. Trip-chaining pattern 3 (FROM WORK) shows a decreasing pattern of percentage as vehicle ownership becomes higher. In general, individuals with fewer vehicles in the household are more likely to perform non-work activities on the way home from work. Trip-chaining pattern 4 (TO/FROM WORK) is more often used by at least one vehicle ownership groups than by zero vehicle ownership group. Trip-chaining pattern 5 (DURING WORK) is chosen by individuals in all vehicle ownership groups almost equally.

Individuals in zero vehicle ownership group are less likely to choose trip-chaining pattern 6 (BEFORE WORK) than any other individual in other vehicle ownership groups but the difference in percentages among vehicle ownership groups is not much pronounced. As vehicle ownership levels increase, the percentages of trip-chaining pattern 7 (AFTER WORK) also increases. However, the table shows a difference in percentages between the zero vehicle ownership group and the one or more vehicle ownership groups. That is, if households have at least one vehicle, individuals have a

higher proportion of choosing trip-chaining pattern 7 than those in the zero vehicle group. This may reflect the fact that as there are more vehicles in a household, individuals are more likely to perform non-work activities in trip-chaining pattern 7. Trip-chaining pattern 8 (MULTIWORK) shows slightly higher percentage in three or more vehicle ownership group than in other vehicle ownership groups, while the zero vehicle ownership group tends to choose this pattern less. As expected, trip-chaining pattern 9 (MIXED CHAIN) is chosen less often at the zero vehicle ownership level than at other vehicle ownership levels. Without mobility, it may be difficult to form the most complex trip-chaining patterns.

5. Number of drivers

Dependence of trip-chaining patterns on number of drivers

Table 4-6 show formation of trip-chaining patterns by individuals is significantly related to the number of drivers in the household at $p < 0.01$.

Simple trip-chaining pattern

From Table 4-6, the simple work trip pattern is most popularly used by an individual whose household does not have any drivers. The simple trip-chaining pattern is least used if there is one driver in the household and the percentage of this pattern increases as the number of drivers in the household increases. No drivers in the

Table 4-6
Stratification of Individuals by Trip-chaining Pattern and the Number of Drivers in the Household

Percent	Trip-chaining pattern									Total
	1	2	3	4	5	6	7	8	9	
Drivers										
0	50.60	3.57	16.07	3.57	2.38	3.57	16.67	1.79	1.79	100.00 (168)
1	34.50	2.56	18.65	3.30	2.72	3.65	26.65	2.99	4.97	100.00 (2574)
2	38.20	2.70	15.10	3.98	2.11	3.61	26.97	3.04	4.30	100.00 (6483)
3	41.27	2.63	13.19	2.74	1.86	5.58	25.89	3.12	3.72	100.00 (1827)
4 or more	45.60	3.24	12.05	1.30	1.04	6.22	24.22	3.11	3.24	100.00 (772)
Average	38.53	2.71	15.39	3.46	2.14	4.09	26.41	3.03	4.25	
Chi-square value=131.33 (significant at $p < 0.01$)										
Trip-chaining pattern:										
1=SIMPLE WORK										
2=TO WORK										
3=FROM WORK										
4=TO/FROM WORK										
5=DURING WORK										
6=BEFORE WORK										
7=AFTER WORK										
8=MULTIWORK										
9=MIXED CHAIN										

() sample size

household means that there may be no vehicles in the household, which may limit travel for non-work activities. As a result, it may be natural that an individual with no driver in the household tends to form a simple work trip pattern. If there is one driver in the household, an individual may be likely to form complex trip-chaining patterns because he (or she), being the only driver in the household, must do both work and non-work activities for the household. Similar to the case of vehicle ownership, non-work activities such as grocery and other shopping for a household are shared among drivers as the number of drivers increases.

Complex trip-chaining patterns

Trip-chaining pattern 2 (TO WORK) is almost equally used by individuals but individuals with zero drivers and four or more drivers in the household are likely to have slightly higher percentages. Individuals included in the household with zero or one driver group have higher percentages for trip-chaining pattern 3 (FROM WORK) than those in other driver groups. Performing non-work activities in trip-chaining patterns 4 (TO WORK) and 5 (DURING WORK) is chosen least by individuals with four or more drivers in the household.

As the number of drivers in the household increases, trip-chaining pattern 6 (BEFORE WORK) is likely to be chosen more often by individuals. Trip-chaining pattern 7 (AFTER WORK) shows a difference in percentage between group with zero driver and groups with one or more drivers in the household; no driver group shows

lower percentage than any other group in choosing trip-chaining pattern 7. Trip-chaining patterns 8 (MULTIWORK) and 9 (MIXED CHAIN) show the lowest percentage at the zero driver group. As mentioned before, this may reflect the fact that an individual without drivers in the household has limited opportunities to pursue non-work activities when he (or she) travels for work. Trip-chaining pattern 8 has an increase of percentage as the number of drivers increases.

6. Number of children

Dependence of trip-chaining patterns on number of children

From Table 4-7, the formation of trip-chaining patterns is significantly related to the number of children aged 0 to 4 in the household. The chi-square value is 258.75, which represents a very high dependence of trip-chaining patterns on the number of children.

Simple trip-chaining pattern

Individuals in the household with one child aged 0-4 are less likely to choose simple trip-chaining pattern than those in the households with zero and two or more children.

Table 4-7
Stratification of Individuals by Trip-chaining Pattern and the Number of Children
aged 0-4 in the Household

Percent	Trip-chaining pattern									Total
	1	2	3	4	5	6	7	8	9	
Children										
0	38.70	2.52	15.71	2.35	2.23	3.94	27.58	2.94	4.02	100.00 (9768)
1	37.24	3.97	13.90	8.50	1.74	4.97	20.92	3.41	5.34	100.00 (1611)
2 or more	39.33	2.25	13.71	9.44	1.57	4.27	20.45	3.60	5.39	100.00 (445)
Average	38.53	2.71	15.39	3.46	2.14	4.09	26.41	3.03	4.25	
Chi-square value=258.75 (significant at p=<0.01)										
Trip-chaining pattern:										
1=SIMPLE WORK										
2=TO WORK										
3=FROM WORK										
4=TO/FROM WORK										
5=DURING WORK										
6=BEFORE WORK										
7=AFTER WORK										
8=MULTIWORK										
9=MIXED CHAIN										

() sample size

Complex trip-chaining patterns

While individuals with at least two children in the household are not likely to choose trip-chaining pattern 2 (TO WORK), individuals without children or with one child show a higher proportion of use. Individuals show differences in pursuing the non-work activities on the way home from work. As the number of children increases, they choose it less often. There is an especially big difference in the percentages between zero child group and at least one child group in pursuing non-work activities in trip-chaining pattern 4 (TO/FROM WORK); individuals with at least one child in the household choose trip-chaining pattern 4 higher than those with zero child group.

As the number of children in the household increases, individuals are more likely to choose trip-chaining patterns 5 (DURING WORK) and 7 (AFTER WORK). Trip-chaining patterns 6 (BEFORE WORK), 8 (MULTIWORK), and 9 (MIXED WORK) are more used by individuals with at least one child than by those with zero child group.

7. Start Time of Trips

Dependence of trip-chaining patterns on starting time of trips

Table 4-8 represents the relationships between trip-chaining patterns and the starting time of the first trip of chain for males and females respectively. Chi-square value reveals that the formation of trip-chaining patterns is very highly dependent upon the starting time of trip chains.

Table 4-8

Stratification of Individuals by Trip-chaining Pattern and Starting Time of Trips

Percent	Trip-chaining pattern									
	1	2	3	4	5	6	7	8	9	Total
Start time										
Early	41.81	1.59	14.40	2.48	0.99	0.79	29.49	4.47	3.97	100.00 (1007)
Peak	36.65	2.37	16.25	3.77	2.41	2.59	28.65	2.95	4.36	100.00 (8346)
Late	31.71	4.54	13.78	3.59	2.63	14.18	20.40	3.67	5.50	100.00 (1255)
Afternoon	56.07	4.11	11.94	2.05	0.88	6.85	13.99	1.66	2.45	100.00 (1022)
Average	38.27	2.69	15.44	3.49	2.18	4.06	26.54	3.04	4.28	
Chi-square value=713.03 (significant at $p < 0.01$)										

Start time:

Early=4:00-6:00

Peak=6:00-9:00

Late=9:00-12:00

Afternoon=12:00-

Trip-chaining pattern:

1=SIMPLE WORK

2=TO WORK

3=FROM WORK

4=TO/FROM WORK

5=DURING WORK

6=BEFORE WORK

7=AFTER WORK

8=MULTIWORK

9=MIXED CHAIN

() sample size

Simple trip-chaining pattern

Simple trip-chaining pattern is most frequently taken if trips start after 12:00. This may reflect that most individuals making trips after 12:00 are likely to use the simple work trip pattern because there may be limits to the amount of time for non-work activities. The percentage of use of this pattern is high if trips start between 4:00 a.m. and 6:00 a.m. but gradually decreases as time passes until 12:00 noon.

Complex trip-chaining patterns

As time passes, the percentages of trip-chaining pattern 2 (TO WORK) increase. Individuals making their first trip between 4:00 a.m. and 9:00 a.m. prefer doing non-work activities on the way home from work. Trip-chaining patterns 4 (TO/FROM WORK), 5 (DURING WORK), and 6 (BEFORE WORK) are used more often by individuals making first trip for work during Peak and Late. Individuals making their first trip during Late show a higher percentage for trip-chaining pattern 6 than individuals in other time period.

Individuals, starting their trips before 9:00 a.m., have higher percentages of trip-chaining pattern 7 (AFTER WORK), which may result from more extra time to engage in non-work activities after they come back home from work if they are considered as a regular employed person. While trip-chaining pattern 8 (MULTIWORK) is used more often by individuals making trips between 4:00 a.m. and 6:00 a.m., it is least used by those making trips after 12:00 noon. The percentages for trip-chaining pattern 9 gradually increase before 12:00 noon but after 12:00 it has a lower percentage.

8. Educational Level

An individual's highest level of education refers to the number of years of regular schooling completed in graded public, private, or parochial schools, or in colleges, universities, or professional schools, whether day school or night school. Regular schooling advances a person toward an elementary or high school diploma, or a college, university or professional school degree.

Dependence of trip-chaining patterns on educational level

From Table 4-9, dependence of trip-chaining patterns on educational level is very high: chi-square value 194.66. Therefore, the formation of trip-chaining patterns is highly related to the educational level.

Simple trip-chaining pattern

The percentages of the simple trip-chaining pattern for individuals decreases, as the educational level becomes higher. That is, as a whole, educated persons may prefer to take complex trip-chaining patterns. The table shows that there are differences in percentages between educational level 1 and educational levels 2 and 3 . An individual with a low educational background chooses simple work trips more often than those in the higher educational level groups.

Table 4-9
Stratification of Individuals by Trip-chaining Pattern and Educational Level

Percent	Trip-chaining pattern									Total
	1	2	3	4	5	6	7	8	9	
Education										
1	42.76	2.66	13.45	3.12	1.50	4.82	25.14	3.13	3.42	100.00 (5680)
2	34.87	2.75	17.10	3.55	2.43	3.91	27.20	2.99	5.20	100.00 (4654)
3	30.70	2.93	18.61	4.47	3.96	1.68	29.96	2.86	4.84	100.00 (1365)
Average	38.22	2.73	15.51	3.44	2.15	4.09	26.52	3.04	4.29	
Chi-square value=194.66 (significant at $p < 0.01$)										

Educational level:

1=1st-12th grade and technical school after high school

2=College level or equivalent

3=Graduate school or more

Trip-chaining pattern:

1=SIMPLE WORK

2=TO WORK

3=FROM WORK

4=TO/FROM WORK

5=DURING WORK

6=BEFORE WORK

7=AFTER WORK

8=MULTIWORK

9=MIXED CHAIN

() sample size

Complex trip-chaining patterns

Pursuing non-work activities on the way home to work and in trip-chaining pattern 8 (MULTIWORK) shows generally equal percentages among educational levels. As individuals' educational levels become higher, while trip-chaining patterns 3 (FROM WORK), 4 (TO/FROM WORK), 5 (DURING WORK), and 7 (AFTER WORK) are more likely to be used, trip-chaining pattern 6 (BEFORE WORK) is less used. Trip-chaining pattern 9 is chosen more frequently by individuals with a college level education but those, with the education at the graduate school level, still have a high preference for this pattern.

SUMMARY

Formation of trip-chaining patterns

The study develops nine work-related trip-chaining patterns performed by the members of households. The development for trip-chaining pattern is based on the concept that all activities made by an individual are related under time and spatial constraints. Trip-chaining patterns are also based on the sequential order of occurrence of non-work activities performed by an individual during a day since non-work activities have a large degree of flexibility in frequency, timing and the location.

Dependence of trip-chaining patterns on socio-demographic characteristics

Generally, the formation of trip-chaining patterns is highly dependent upon socio-demographic characteristics for individuals. Income level, household size, number of vehicles, the number of drivers, the number of children, start time of trips, and educational level are statistically significant at $p < 0.01$ level and urban size at $p < 0.05$ level. The following statements summarize how socio-demographic characteristics of individuals influence the formation of trip-chaining patterns.

A. Income level

- Lower income groups are likely to prefer simple work trip pattern.
- Generally, the higher income groups prefer pursuing non-work activities on the way home from work.
- As income level increases, individuals are likely to engage in non-work activities during working hours.
- As income level increases, individuals are less likely to choose trip-chaining pattern 6 (BEFORE WORK).
- The lowest income group uses more often trip-chaining pattern 9 (MIXED CHAIN) than any other income group.

B. Urban size

- Simple trip-chaining pattern is more likely to be taken by individuals living in the larger urban areas.
- In urban size 3, trip-chaining patterns 3 (FROM WORK) and 5 (DURING WORK) are less favorably used for making non-work trips, while patterns 4 (TO/FROM WORK), 7 (AFTER WORK), and 9 (MIXED CHAIN) are popularly chosen.

- Trip-chaining pattern 2 is almost equally popular in all urban areas except urban size 2.
- Individuals prefer choosing trip-chaining pattern 6 (BEFORE WORK), with two trip tours, if they live in smaller urban areas.
- Complex trip-chaining patterns 8 (MULTIWORK) and 9 (MIXED CHAIN) are used less often by individuals living in larger urban area.

C. Household size

- As the number of family members increases, individuals are likely to choose the simplified work trip pattern.
- In the analysis of the complex patterns for individuals, trip-chaining patterns 3 (FROM WORK), 5 (DURING WORK), and 7 (AFTER WORK) are less popularly used and trip-chaining pattern 2 (TO WORK), 4 (TO/FROM WORK), 6 (BEFORE WORK), 8 (MULTIWORK) and 9 (MIXED CHAIN) are more often chosen as household size increases.

D. Number of vehicles in the household

- The simple trip-chaining pattern is chosen by the zero vehicle ownership group at the highest percentage among vehicle ownership groups due to the lack of mobility.
- The simple trip-chaining pattern is also preferred by an individual with three or more vehicles in his (or her) household due to the independent use of a vehicle for the purpose of work.
- Generally, individuals show lower percentage of choosing complex trip-chaining patterns except trip-chaining patterns 2 (TO WORK), 3 (FROM WORK), and 5 (DURING WORK) when they have no vehicles in the household. This may reflect the fact that they have higher restrictions to make trips complex without vehicles.

E. Number of drivers

- An individual in zero driver group in the household prefers the simple work trip pattern rather than those in other driver groups because he (or she) may be limited in pursuing non-work activities.
- An individual with one driver in the household prefers complex trip-chaining patterns which may result from the fact that he (or she), being the only driver in the household, must take non-work trips for household chores.
- As the number of drivers in the household increases, the percentages for trip-chaining patterns 3 (FROM WORK), 4(TO/FROM WORK), and 5 (DURING WORK) decrease and those for trip-chaining patterns 6 (BEFORE WORK) and 8 (MULTIWORK) decrease.
- Trip-chaining patterns 7 (AFTER WORK) and 8 (MULTIWORK) is least used by zero driver group.

F. Number of children aged 0-4

- While two or more children's group prefers the simple work trip pattern, one child group chooses it less.
- In complex trip-chaining patterns, as the number of children in the households increases, while the percentages of trip-chaining patterns 3 (FROM WORK), 5 (DURING WORK), and 7 (AFTER WORK) decrease, those of trip-chaining patterns 4 (TO/FROM WORK), 6 (BEFORE WORK), 8 (MULTIWORK), and 9 (MIXED CHAIN) increase.

G. Start time of trips

- The percentage of simple work trip decreases as time passes but then it dramatically increases because there is no time to engage in non-work activities if the first trip starts after 12:00 noon.
- Trip-chaining patterns 4 (TO/FROM WORK), 5 (DURING WORK), and 6 (BEFORE WORK) are highly used by individuals making trips between 6:00 a.m. and 12:00 noon.

- As time passes, the percentage for trip-chaining patterns 3 (FROM WORK) and 7 (AFTER WORK) generally decreases and it for trip-chaining pattern 2 (TO WORK) increases.

H. Educational level

- The simple trip-chaining pattern is preferred by individuals with lower educational levels.
- As the educational level becomes higher, complex trip-chaining pattern 3 (FROM WORK), 4 (TO/FROM WORK), 5 (DURING WORK), and 7 (AFTER WORK) are increasingly used and trip-chaining patterns 6 (BEFORE WORK) and 8 (MULTIWORK) are decreasingly used.

This chapter confirms that there are significant factors influencing the formation of trip-chaining patterns. Chi-square test proves that choosing each trip-chaining pattern is dependent on socio-demographic characteristics of individuals. The relationship between trip-chaining patterns and socio-demographic characteristics implies that changes in individuals' characteristics mean changes in choosing each trip-chaining pattern.

CHAPTER 5

ANALYSIS OF ELEMENTS FOR TRIP-CHAINING BEHAVIOR

In the chapter 4, nine work-related trip-chaining patterns were developed and it was indicated that the relationships between trip-chaining patterns and socio-demographic characteristics of households are significant. This chapter is composed of four sections. The analysis is based on the concept that there are gender differences in travel behavior. The first section proves that most work trips of individuals are not simply performed as the traditional transportation planning process for work trip assumes. The second section of this chapter analyzes the frequency of non-work activities in each trip-chaining pattern by gender. This section establishes that most employed individuals perform non-work activities during their work trips, which results in complex trip-chaining patterns. Therefore, if the travel behavior patterns of individuals are shown to be complex, it is important to know what kinds of trip purposes are pursued.

The third section of this chapter studies which travel activities are most frequently linked with the trip chain for individuals. The fourth section analyzes the travel resources resulting from trip-chaining behavior. If the linking of activities into a chain can reduce the use of transportation resources more than the simple trip pattern, encouraging or forming such trip chains also has the potential to reduce the problems generated by transportation.

PREVALENCE OF COMPLEX TRIP-CHAINING PATTERNS

1. Complexity of Urban Travel Patterns

The first question to be considered is that of the complexity of the urban work trip. Table 5-1 shows that not only is the multiple-destination trips for work and non-work activities more common than the single destination work trip, but also there are gender differences in the trip-chaining. Of a total of 11,824 work-related trip-chaining patterns made by individuals in NPTS data, 4554, or 38.51 % represent simple work trips which do not include any non-work activities excluding work-related business trips, while 61.49 % include complex work trip patterns. This means that more than 60 % of urban travel for work includes non-work activities. Therefore, the traditional transportation models, which may use the simple work trip concept, represent only part of the story of urban travel. Under the traditional concept, single destination trips (or simple trip chain pattern), which include only trips to and from work with no intermediate stops, are only about 40 percent of the total trip chaining patterns performed by individuals. As a result, the assumptions derived from using only single purpose trips may not properly reflect the manner in which individuals form travel behavior patterns for work.

Among complex trip-chaining patterns, 26.41 percent of individuals, which is the highest percentage among the complex trip-chaining patterns, prefer engaging in non-work activities after they come back home from work (AFTER WORK). The second most common complex trip-chaining is pattern 3 (FROM WORK), in which non-work

Table 5-1
Distribution of Trip-chaining Pattern by Gender

Pattern Code	All (11824)	Male (6365)	Female (5459)
Simple chain			
1 (SIMPLE WORK)	38.51	42.80	33.52
Complex chain			
<u>1 tour chain</u>			
2 (TO WORK)	2.71	2.61	2.82
3 (FROM WORK)	15.39	13.29	17.84
4 (TO/FROM WORK)	3.46	2.39	4.71
5 (DURING WORK)	2.14	1.90	2.42
<u>2 tour chain</u>			
6 (BEFORE WORK)	4.09	3.83	4.40
7 (AFTER WORK)	26.41	26.72	26.05
<u>2+ tour chain</u>			
8 (MULTIWORK)	3.03	3.16	2.88
9 (MIXED CHAIN)	4.25	3.30	5.37
Complex total	61.49	57.20	66.48
Total	100 %	100 %	100 %

() sample size

activities occurred on the way home from work. As a result, the majority of non-work activities are undertaken after finishing work, which means that most non-work activities may occur in the afternoon. It may be more convenient to perform non-work activities after work because an individual generally has fewer schedule constraints when returning from work or after work than on the way to work or before work.

The percentage of individuals engaging in non-work activities on the way from home to work (TO WORK) is 2.71 %; the percentage of a pattern of a tour with non-work activities before a tour with work and non-work activities (BEFORE WORK) is 4.09 %. If an individual wants to perform non-work activities before work starts, he (or she) is likely to perform non-work activities by trip-chaining pattern 6 (BEFORE WORK) with two tours rather than by trip-chaining pattern 2 (TO WORK) with one trip tour. Trip-chaining pattern 5 (DURING WORK) has the lowest percentage, which reflects a less flexible time schedule to have non-work activities during working hours.

2. Gender Differences

42.80 % of males and 33.52 % of females choose the simple work-related trip-chaining pattern; this means that males are likely to use a simpler work trip pattern than females. We can expect that females take more non-work trips for personal or family-related activities, which results in the use of more complex trip-chaining patterns.

Although females make more complex trip-chaining patterns than males, males have a slightly higher percentage in trip-chaining pattern 7 and 8 (AFTER WORK and

MULTIWORK). The percentage of trip-chaining pattern 7 for males is especially high if we consider only complex trip-chaining patterns. This may reflect the fact that most males choosing the complex trip-chaining patterns usually prefer a trip-chaining pattern of a tour with non-work activities after a tour with work and non-work activities (AFTER WORK).

Males and females show a significant difference in the frequency between trip-chaining pattern 3 and 7. While males prefer a trip-chaining pattern of AFTER WORK, females prefer FROM WORK.

ANALYSIS OF FREQUENCY FOR NON-WORK ACTIVITIES

1. Statistical Approaches for Elements of Trip-chaining Behavior

Variation of trip frequency and travel resources

To analyze the variations in trip frequency of non-work activities and travel resources between trip-chaining patterns, an analysis of variance (ANOVA) is used. It is assumed that an individual travels under some constraints, such as travel time, travel distance, and his (or her) characteristics of household and thus, to finish all activities including work, he (or she) generates specific trip-chaining patterns. This study has reviewed one simple trip-chaining pattern and eight complex trip-chaining patterns. If everyone pursues the same number of non-work activities and the same travel resources

are consumed among the various trip-chaining patterns, the above assumption may not be valid.

The analysis of variance, or more briefly ANOVA, is a technique of statistical analysis that permits one to overcome the ambiguity involved in assessing significant differences when more than one comparison is made. It allows us to answer this question: is there an overall indication that the experimental treatments are producing differences among the means of the various groups ? This study uses a single-factor, single-classification or one-way ANOVA which involves the analysis of data sampled either from more than two numerical populations (distribution) or data from experiments in which more than two treatments have been used.

To test the hypothesis, F-ratio, the value of variance between samples over variance within samples is used. The hypothesis is that, for the second section in this chapter, there is no significant difference in the frequency of non-work activities between the complex trip-chaining patterns and, for the fourth section in this chapter, there is no significant difference in the average travel resources among all trip chaining patterns.

Differences in mean values for trip frequency and travel resources by gender

The mere fact that the mean of a sample from group A is higher than the mean of a sample from group B is not conclusive evidence that the averages in the two groups are not the same. Remembering that two samples drawn from the same sample population rarely show the same arithmetic mean, we must be very careful in interpreting the

difference between the means of samples from two groups. When two sample means are different, it is important to decide whether the difference between the two means is significant. The standard procedure is to test the validity of the null hypothesis, which states that there is no difference between two sample means. On the basis of the evidence produced by the two samples, a null hypothesis is either rejected or judgment is reserved. If the null hypothesis is rejected, the observed difference between the two sample means is deemed significant. However, the observed difference is deemed not significant whenever judgment is reserved.

The hypothesis to be tested by t-ratio is that, for the second section, there are no difference in average total non-work activities between males and females as a whole and in the average total non-work activities in each trip-chaining pattern by gender. For the fourth section, it is tested that there is no difference in the average number of travel miles and travel minutes between males and females as a whole and in the average travel miles and travel minutes in each trip-chaining pattern by gender.

2. Definition of Non-work Activities

The 1990 NPTS dataset defines ten types of activities excluding work (Research Triangle Institute 1991). These are work-related business, shopping, vacation, doctor/dentist, school/church, other family/personal business, visit friends/relatives, pleasure driving, other social/recreational, and other. The ten non-work activities are defined as follows:

- **Work-related business:** Trips related to business activities except travel to the place of work; for example, a plumber drives to a wholesale dealer to purchase supplies for his business or a company executive travels from his office to another firm to attend a business meeting;
- **Shopping:** Trips which include “window-shopping” and purchase of commodities such as groceries, furniture, clothing, etc. for use or consumption elsewhere;
- **Doctor/Dentist:** Trips made for medical, dental, or psychiatric treatment or other related professional services;
- **Other family or personal business:** Trips including the purchase of services such as cleaning garments, servicing an automobile, haircuts, banking, legal services, etc.;
- **School/Church:** Trips to school, college or university for class(es), to PTA meetings, seminars, etc., to church services or to participate in other religious activities. Social activities that take place at a church or school but cannot be classified as religious or educational are not included in this category;
- **Vacation:** Trips reported by the respondent as “vacation”;
- **Visit friends or relatives:** Trips made to visit friends or relatives
- **Pleasure driving:** Driving trips made with no other purpose listed but to “go for a drive” with no destination in mind;
- **Other social or recreational:** Trips taken to enjoy some form of social activity involving friends or acquaintances. These include trips for general entertainment or recreation (both as observer or as participant);
- **Other:** For trips that do not fit in any of the other categories.

3. Trip Rates for Non-work Activities

Table 5-2 shows the distribution of total mean number of non-work activities, broken down by trip-chaining patterns for males and females.

Table 5-2
Mean Total Number of Non-work Activities

Trip-chaining patterns	Male		Female		t-values
	N	Activities (std. dev.)	N	Activities (std. dev.)	
1 (SIMPLE WORK)	2724	0.06 (0.35)	1830	0.04 (0.29)	1.71
2 (TO WORK)	166	1.30 (1.11)	154	1.31 (1.14)	-0.03
3 (FROM WORK)	846	1.54 (1.11)	974	1.55 (1.15)	-0.13
4 (TO/FROM WORK)	152	2.76 (1.47)	257	2.79 (1.41)	-0.21
5 (DURING WORK)	121	1.89 (1.58)	132	2.36 (1.77)	*-2.23
6 (BEFORE WORK)	244	1.95 (1.42)	240	2.07 (1.62)	-0.83
7 (AFTER WORK)	1701	1.80 (1.33)	1422	2.03 (1.48)	** -4.46
8 (MULTIWORK)	201	1.28 (1.40)	157	1.43 (1.48)	-1.01
9 (MIXED CHAIN)	210	3.53 (2.17)	293	3.73 (1.98)	-1.07
F-ratio ¹		**71.10		**93.27	
All	6365	1.08 (1.42)	5459	1.38 (1.61)	** -10.58

* Significant at $p \leq 0.05$.
** Significant at $p \leq 0.01$.
1: Not include trip-chaining pattern 1.

Analysis of variations between trip-chaining patterns for trip rates

As a result of the ANOVA analysis from Table 5-2, F-values are obtained: 71.10 for males and 93.27 for females. These values are calculated to estimate the variations for the mean total number of non-work activities included in trip-chaining pattern 2 through 9 for each gender, except for trip-chaining pattern 1 (SIMPLE WORK). Trip-chaining pattern 1 shows a big difference in the number of non-work activities and has a different characteristic including only work or work-related trips, from other complex trip-chaining patterns. The variations between complex trip-chaining patterns for the mean total number of activities for each gender are significant at $p < 0.01$ level. That is, there is a significant difference between complex trip-chaining patterns in the mean total number of non-work activities by each gender.

Analysis of mean trip rates by gender in each trip-chaining pattern

Non-work trip rates stratified by type of trip-chaining pattern and by gender are shown in Table 5-2. As a whole, males perform 1.08 average total non-work trips and females 1.38 per day. This difference between males and females for the mean total number of non-work activities is statistically significant at $p < 0.01$ level. That is, the information in the table does not lend further support to the null hypothesis that males have the same mean total number of non-work activities as females. Therefore, females perform more non-work activities in a designated day than males. As mentioned before,

this may result from the fact that females take more household responsibilities than males in addition to work or work-related business.

More males prefer taking the simple work trip pattern than females, as mentioned in the previous chapter, and engage in more work-related business in trip-chaining pattern 1 (SIMPLE WORK). The mean total non-work activities in trip-chaining pattern 5 (DURING WORK) shows a significant difference between males and females at $p < 0.05$ level. Generally, males are likely to perform 1.89 non-work activities during working hours, while females tend to perform 2.36 non-work activities. Trip-chaining pattern 7 (AFTER WORK), which is the most popularly chosen by individuals making a complex trip-chaining pattern, shows a very high gender difference for the average number of non-work activities. Although females have higher values for non-work activities in trip-chaining pattern 2 (TO WORK), 3 (FROM WORK), 4 (TO/FROM WORK), 6 (BEFORE WORK), 8 (MULTIWORK), and 9 (MIXED CHAIN), no significant differences in the mean total number of non-work activities can be found.

TRAVEL ACTIVITIES PURSUED IN TRIP-CHAINING PATTERNS

Table 5-3 shows the percentage distribution of non-work activities, broken down by types of activities for males and females respectively. Each non-work activity is classified as having been made for one of ten purposes. Travel activities are the motivation for the trip. For a survey day trips, if there is more than one purpose, and the

Table 5-3
Non-work Activities Pursued by Gender (%)

Activities	Male	Female
Work-related business	9.45	6.54
Shopping	18.89	21.28
Other fam/per business	41.48	45.56
School/church	6.89	7.15
Doctor/dentist	1.20	2.05
Vacation	0.00	0.00
Visit friend/relatives	6.62	6.81
Pleasure drive	0.23	0.11
Other social/recreational	14.51	10.11
Other	0.72	0.40
Total	100.00	100.00

purposes do not involve different destinations, then only the main purpose is chosen. If there are two or more purposes, and they each involve different destinations, then each purpose is classified as a separate trip.

1. Proportion of Gender for Non-work Activities

Table 5-3 reveals that there are differences between males and females in the purpose which each trip serves. Activities performed for work-related business account for about nine percent and about seven percent of the trips made by males and females respectively. Males make work-related business more often. This result is consistent with the expectation that males have more active jobs such as salesmen and service repairmen. One reason for this difference may be the fact that males and females make up different proportions of major occupation groups.

More shopping activities are taken by females than by males; about 19 percent of non-work activities are performed by males for shopping and about 21 percent by females. Females are most likely to make shopping activities on the way home from work.

About 41 percent of other family/personal business is done by males compared to about 46 percent by females. This may result from the fact that females more frequently perform activities such as delivering or picking cleaning garments, getting haircuts and banking.

Activities for school/church are taken at almost the same proportion (7 %) by males as by females. Females make about two percent of the trips to doctor/dentist and males about one percent in a travel day for activities of doctor/dentist. The activities for visit of friend/relatives are about seven percent for both males and females respectively.

Other social/recreational activities are one of the main non-work activities performed by males. Males perform about 15 percent of non-work activities for other social/recreational purposes, while females perform about 10 percent. This reflects the fact that males are more likely to take their trips for social/recreational pleasures.

Travel activities for pleasure driving and other trips are not popularly pursued and vacation trips have almost zero percent.

2. Comparison among Trip-chaining Patterns for Non-work activities

Figure 5-1 through Figure 5-7 show the comparisons for percentage of each travel activity in each complex trip-chaining pattern by gender. Trip-chaining pattern 1 (SIMPLE WORK) is excluded for the comparison because it includes only work-related business as non-work activity.

Work-related business

From Figure 5-1, it is obvious that the percentage for work-related business trips performed by males is higher than females through all trip-chaining patterns. Males have the highest percentage of using trip-chaining pattern 8 (MULTIWORK), which has two or more trip tours; two tours are contributed for work. Also, males are likely to perform

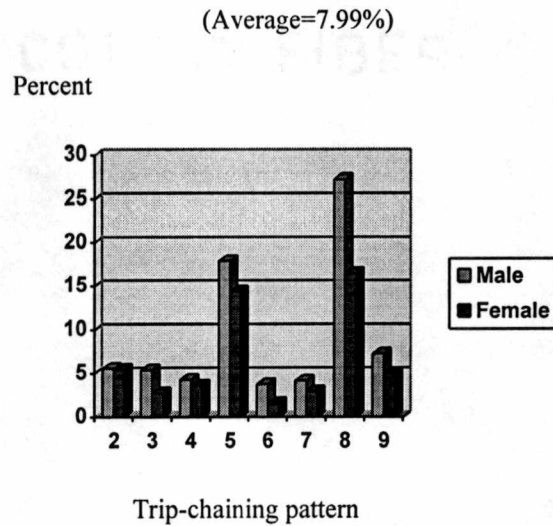


Figure 5-1
Percentage of Work-related Business Trips among Non-work Activities

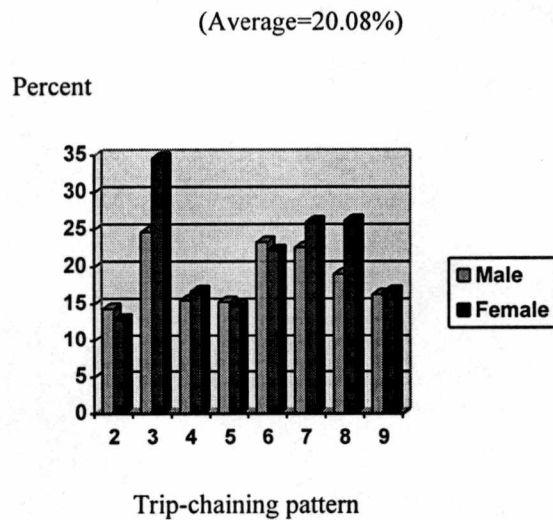


Figure 5-2
Percentage of Shopping Trips among Non-work Activities

(Average=43.52%)

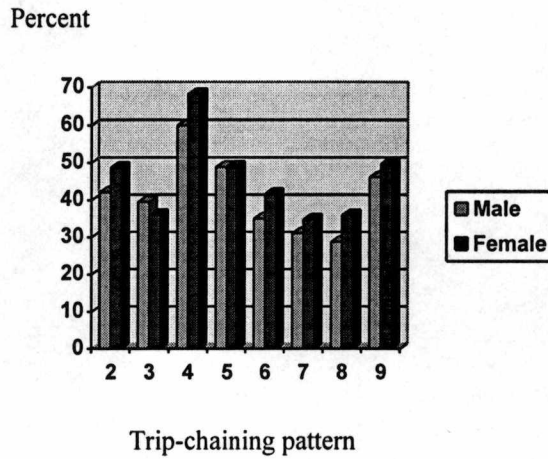


Figure 5-3
Percentage of Other Family/personal Business Trips among Non-work Activities

(Average=6.52%)

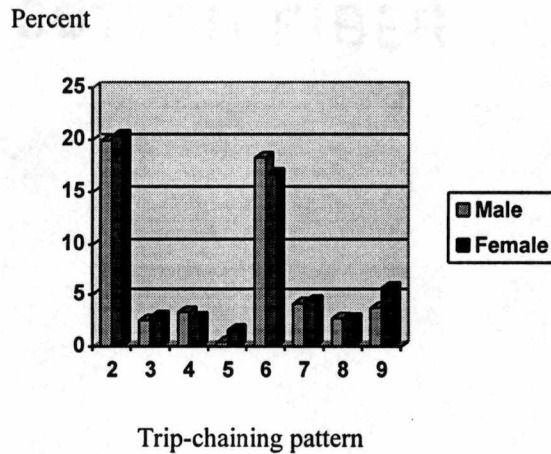


Figure 5-4
Percentage of School/church Trips among Non-work Activities

(Average=1.62%)

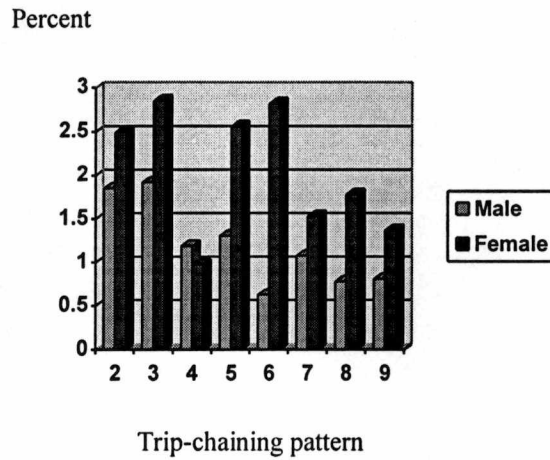


Figure 5-5
Percentage of Doctor/dentist Trips among Non-work Activities

(Average=6.72%)

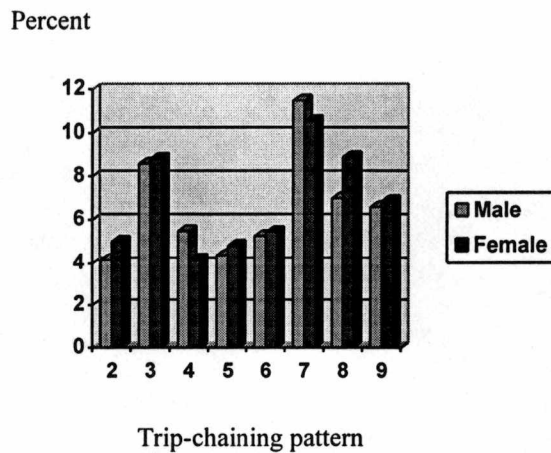


Figure 5-6
Percentage of Visit Friends/relatives Trips among Non-work Activities

(Average=12.31%)

Percent

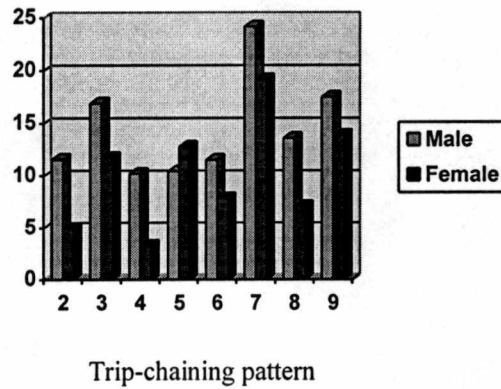


Figure 5-7
Percentage of Other Social/recreation Trips among Non-work Activities

work-related business during working hours (trip-chaining pattern 5). Females show the same pattern as males; trip-chaining pattern 5 (DURING WORK) or 8 (MULTIWORK) for females also represents the highest percentages, but there is big difference between both genders in trip-chaining pattern 8.

Shopping activities

Figure 5-2 shows that trip-chaining pattern 3 (FROM WORK), 6 (BEFORE WORK), 7 (AFTER WORK), AND 8 (MULTIWORK) are highly used to take shopping trips by females. Shopping activities within trip-chaining pattern 2 (TO WORK), 6, 7, and 8 are popularly performed by males.

Other family/personal business

Activities for other family/personal business are popularly performed by females but males make them in trip-chaining pattern 3 (FROM WORK) more than females (Figure 5-3). This trip represents above thirty percent through all trip-chaining patterns except for trip-chaining pattern 8 (MULTIWORK) for males.

School/church

Figure 5-4 shows that most males and females go to school or church on the way home to work (TO WORK) or with trip-chaining pattern 6 (BEFORE WORK). There are not much differences in percentages between males and females, but males have a

slightly higher preference for choosing trip-chaining pattern 4 (TO/FROM WORK) and 6 (BEFORE WORK). If someone is a student, he (or she) usually goes to school first and then to work. Trip-chaining pattern 5 (DURING WORK) is the least frequently used. Males tend to participate less in school/church activities during work hours than do females.

Doctor/dentist

Figure 5-5 shows that females have a higher percentage for doctor/dentist activities in all trip-chaining patterns except trip-chaining pattern 4 (TO/FROM WORK). Females especially visit doctor/dentist on the way home from work, during working hours, or with trip-chaining pattern 6 (BEFORE WORK). There are big differences in percentages between males and females for doctor/dentist activities in trip-chaining pattern 3 (FROM WORK), 5 (DURING WORK), or 6 (BEFORE WORK). Males popularly pursue doctor/dentist visits in trip-chaining pattern 2 (TO WORK) and 3 (FROM WORK).

Visit of friends/relatives

From Figure 5-6, males visit their friends or relatives frequently in trip-chaining pattern 3 (FROM WORK) and 7 (AFTER WORK). Trip-chaining pattern 8 (MULTIWORK) or 9 (MIXED CHAIN) are also popularly used to visit friends/relatives. Females tend to make trips for visiting friends/relatives in trip-chaining pattern 2 (TO

WORK), 3 (FROM WORK), 5 (DURING WORK), 6 (BEFORE WORK), 8 (MULTIWORK), and 9 (MIXED WORK) at a higher percentage than do males, while males in trip-chaining pattern 4 (TO/FROM WORK) or 7 (AFTER WORK) show higher percentages than females.

Other social/recreational trips

Figure 5-7 shows that social/recreational activities are made most frequently by males on the way from work to home, and in trip-chaining pattern 7 (AFTER WORK) and 9 (MIXED CHAIN). Females popularly make these activities by trip-chaining pattern 3 (FROM WORK), 7 and 9. Except for trip-chaining pattern 5 (DURING WORK), males have higher percentages for social and recreational trips over all trip-chaining patterns than females. Females are likely to make more other social/recreational trips during working hours than males. Females have a lower percentage of social/recreational activities than males but these activities are still one of the major purposes pursued by females.

ANALYSIS OF TRAVEL RESOURCES

This study determines whether or not the travel resources resulting from trip-chaining behavior are different for males and females. The reason that an individual visits places by using multiple-stop trips can be determined by considering how an

individual allocates his (or her) resources devoted to travel. Travel resources include travel miles and travel minutes between origin and destination. "Travel miles" is the distance in miles of trip and "travel minutes" is the reported length of a trip in minutes. Trip link is defined as the travel movement which carries an individual between temporally consecutive stops.

1. Analysis of Travel Distance

Variations in travel distances between trip-chaining patterns

A. Total travel distances per trip-chaining pattern

Total travel distance includes all vehicle miles of travel from first trip to last trip resulting from trip-chaining behavior. The question of interest here is whether there are differences in the average distance traveled, associated with the different stops in trip-chaining behavior. The null hypothesis states that there are no differences in average travel distances between trip-chaining patterns, and the alternative hypothesis says that the two means differ from one another. From Table 5-4, a F-ratio between trip-chaining patterns for males is 37.82 and for females 57.43. Mean total travel distances between trip-chaining patterns are significantly different at $p < 0.01$ level. Females have more variations in trip-chaining patterns for mean total travel miles than males.

B. Travel distances per trip link for nonwork activities

Travel distance per trip link for non-work activities includes average vehicle miles

Table 5-4
Mean Total Travel Distances by Trip-chaining Patterns

	Male		Female		
Trip-chaining patterns	N	Miles (std. dev.)	N	Miles (std. dev.)	t-values
Simple chain					
1 (SIMPLE WORK)	2724	29.03 (26.50)	1830	21.70 (20.70)	**10.44
Complex chain					
2 (TO WORK)	166	33.08 (29.83)	154	25.11 (22.22)	**2.72
3 (FROM WORK)	846	35.54 (28.74)	974	29.62 (24.80)	**4.67
4 (TO/FROM WORK)	152	41.70 (32.60)	257	31.83 (22.75)	**3.29
5 (DURING WORK)	121	43.35 (41.26)	132	34.43 (30.01)	*1.95
6 (BEFORE WORK)	244	39.01 (31.45)	240	34.93 (31.32)	1.43
7 (AFTER WORK)	1701	42.59 (32.71)	1422	37.64 (29.49)	**4.44
8 (MULTIWORK)	201	38.00 (35.01)	157	31.03 (25.17)	*2.19
9 (MIXED CHAIN)	210	51.84 (39.73)	293	46.77 (33.60)	1.50
F-ratio		**37.82		**57.43	
Average	6365	35.62 (30.78)	5459	30.34 (26.77)	**9.97
* Significant at p =< 0.05.					
**Significant at p = <0.01.					

of travel of links used in travel for non-work activities; it does not count the distance of trips from work to home. Table 5-5 gives F-ratio 18.94 for males and 19.79 for females. These values prove that there are significant differences at $p < 0.01$ level between trip-chaining patterns for travel distance per trip link for nonwork activities. Females have slightly greater variations between trip-chaining patterns in link travel miles for non-work activities than do males.

Comparison of travel distances by gender in each trip-chaining pattern

A. Travel distances per trip-chaining pattern

Table 5-4 shows that to perform all linked trips occurring during a designated day, an average of 35.62 miles are used by males and 30.34 miles by females per trip chain. This indicates that males make longer trips, an average five miles in distance, than do females in a given travel day. It is statistically clear that there are gender differences in travel distances resulting from trip-chaining behavior for work. That is, the hypothesis that there is no difference between males and females in mean travel distance for linked activities during a day is not accepted at a 99 % confidence level.

There is more than an eight mile difference in travel distance between males and females for the simple trip-chaining pattern. This result shows that males' workplaces are located farther from home than females' because the simple trip-chaining pattern only refers to a work trip from home to work. Table 5-5 shows that the average commuting

Table 5-5
Travel Distances per Trip Link for Non-work Activities

	Male	Female	
Trip-chaining patterns	Miles (std. dev.)	Miles (std. dev.)	t-values
Simple chain			
1 (SIMPLE WORK)	14.18 (12.89) ¹	10.66 (10.27) ¹	
Complex chain			
2 (TO WORK)	10.11 (11.74)	7.78(8.42)	**3.70
3 (FROM WORK)	10.24 (11.29)	8.47 (8.96)	**6.83
4 (TO/FROM WORK)	9.05 (10.79)	6.83 (7.23)	**4.84
5 (DURING WORK)	9.15 (11.92)	6.84 (8.22)	**3.90
6 (BEFORE WORK)	8.03 (9.23)	6.95 (8.11)	**3.04
7 (AFTER WORK)	8.83 (9.92)	7.51 (8.44)	**8.86
8 (MULTIWORK)	7.24 (9.24)	5.65 (6.01)	**4.51
9 (MIXED CHAIN)	7.27 (9.26)	6.43 (7.85)	**2.86
F-ratio ²	**18.94	**19.79	
Average ²	10.17 (11.23)	7.95(8.78)	**22.93
**Significant at p = <0.01.			
1: Travel distance from home to work			
2: Not include trip-chaining pattern 1			

distance from home to work for males is about 15 miles and for females about 11 miles in trip-chaining pattern 1 (SIMPLE WORK).

There are several plausible explanations for females making shorter trips to work. Madden's (1981) studies show that females' shorter trips may result from their lower pay, their shorter job tenure, their shorter working hours, and their greater household responsibilities. Also, because distances for journey to work have been found to vary by occupation (Cubukgil and Miller, 1982), females' shorter work trips could reflect the fact that they tend to work in different occupations from males. Hanson and Johnston (1985) show that females' sensitivity to distance appears to have more to do with their labor force characteristics than directly with their "dual roles" as wage earners and homemakers. The authors also indicate that females' shorter work trips are related to their lower incomes, their holding of female-dominated jobs, and their use of certain modes of transportation. However, they do not agree with the popular hypothesis that females' greater household responsibility is the primary reason for their working closer to home.

From Table 5-4, trip-chaining pattern 2 (TO WORK), representing the trip-chaining pattern for non-work activities occurring on the way from home to work, results in less mileage than pattern 3 (FROM WORK), which represents the trip-chaining pattern for non-work activities occurring on the way home from work. Similar phenomenon can be found by comparing trip-chaining pattern 6 (BEFORE WORK) and pattern 7 (AFTER WORK). Under time and spatial constraints, an individual is likely to pursue activities

requiring more time in the process of going home after work. Since an individual should arrive at the workplace on time, time and spatial constraints may lead him (her) to try to find non-work activities which are closer to home. Pattern 6 (BEFORE WORK) shows that the difference between mean total travel distances for males and females is not significant. There is a five mile difference in performing non-work activities before work trips but the significance of this difference is not important. Among the most complex trip-chaining patterns, we see that while trip-chaining pattern 8 (MULTIWORK) is significant at $p < 0.05$ level, trip-chaining pattern 9 (MIXED CHAIN) is not significant.

B. Travel distances per trip link for non-work activities

A trip chain is composed of several trip links. Table 5-5 shows an average 10.17 miles for males and 7.95 miles for females per trip link to perform non-work activities. This also indicates that males make trips about an average of more than two miles per trip link for non-work activities longer than females. This difference is statistically significant. The hypothesis that there is no difference between males and females in mean travel distance per trip link is rejected at $p < 0.01$ level. That is, it is statistically clear that there is a gender difference in travel distances per trip link resulting from trip-chaining behavior.

From Table 5-4 and 5-5, trip-chaining pattern 2 (TO WORK), linking non-work activities on the way from home to work, shows fewer miles than trip-chaining pattern 3 (FROM WORK), linking non-work activities on the way home from work. A similar

phenomenon can be found between pattern 6 (BEFORE WORK) and pattern 7 (AFTER WORK). If a person engages in non-work activities after work, he (or she) tends to travel a longer distance from origin to destination.

Differences between males and females in travel distances per trip link for non-work activities through all trip-chaining patterns are statistically significant at $p < 0.01$ level.

2. Analysis of Travel Time

Variations in travel times between trip-chaining patterns

A. Travel time per trip-chaining pattern

Travel time includes all times of travel resulting from trip-chaining behavior. From Table 5-6, we see that variations between trip-chaining patterns can be tested by the F-ratio. The null hypothesis states that there are no differences in average travel time between trip-chaining patterns for males and females, and the alternative hypothesis says that at least two trip-chaining patterns for travel time differ from one another. In Table 5-6, the F-ratio between trip-chaining patterns for males is 76.21 and for females 95.08. These two F-ratios are significantly higher than those of travel distance, which means that differences between trip-chaining patterns are stronger in travel time than in travel distance. The mean total travel time between trip-chaining patterns is significantly different at $p < 0.01$ level. Females have more variations between trip-chaining patterns in mean total travel minutes than males.

Table 5-6
Mean Total Travel Times by Trip-chaining Patterns

	Male		Female		
Trip-chaining patterns	N	Minutes (std. dev.)	N	Minutes (std. dev.)	t-values
Simple chain					
1 (SIMPLE WORK)	2724	50.61 (38.41)	1830	42.74 (33.62)	**7.30
Complex chain					
2 (TO WORK)	166	61.99 (42.12)	154	48.12 (32.12)	**3.33
3 (FROM WORK)	846	63.59 (40.82)	974	57.31 (36.65)	**3.43
4 (TO/FROM WORK)	152	72.31 (43.43)	257	62.74 (35.03)	*2.31
5 (DURING WORK)	121	77.54 (51.75)	132	66.02 (40.65)	1.95
6 (BEFORE WORK)	244	73.21 (42.19)	240	67.97 (43.40)	1.35
7 (AFTER WORK)	1701	78.24 (48.58)	1422	73.58 (42.57)	**2.86
8 (MULTIWORK)	201	72.68 (49.35)	157	61.42 (38.61)	*2.42
9 (MIXED CHAIN)	210	97.57 (54.63)	293	90.31 (50.11)	1.54
F-ratio		**76.21		**95.08	
Average	6365	64.16 (45.23)	5459	59.23 (41.01)	**6.21
* Significant at p <= 0.05.					
**Significant at p <= 0.01.					

B. Travel time per trip link for non-work activities

Travel time per trip link for non-work activities includes average time of travel of links used in travel for non-work activities; it does not count the travel time from work to home or from location for non-work activity to work. Table 5-7 shows F-ratio as 20.79 for males and as 33.51 for females. These values indicate that there is a significant difference between trip-chaining patterns for travel minutes per trip link for non-work activities for each gender. Females have more variations between trip-chaining patterns in link travel time than males to engage in non-work activities.

Comparison of travel times by gender in each trip-chaining pattern

A. Travel time per trip-chaining pattern

From Table 5-6, we see that to perform all linked trips occurring during a travel day, it averages 64.16 minutes for males and 59.23 minutes by females per a whole trip pattern. This indicates that males make longer trips, an average of five minutes more in travel time, than females. There is statistically significant difference between males and females in average travel time for linked activities. That is, it is statistically proven that there are gender differences in average total travel time resulting from trip-chaining behavior for work. Table 5-7 shows that the average commuting time from home to work for males is about 24.99 minutes and for females about 21.31 minutes in the simple trip-chaining pattern.

Table 5-7
Travel Times per Trip Link for Non-work Activities

	Male	Female	
Trip-chaining patterns	Minutes (std. dev.)	Minutes (std. dev.)	t-values
Simple chain			
1 (SIMPLE WORK)	24.99 (18.55) ¹	21.31 (17.22) ¹	
Complex chain			
2 (TO WORK)	19.19 (16.69)	15.24 (12.13)	**4.35
3 (FROM WORK)	18.46 (16.30)	16.49 (13.61)	**5.15
4 (TO/FROM WORK)	15.97 (14.07)	13.60 (10.75)	**3.81
5 (DURING WORK)	16.57 (15.10)	13.25 (11.55)	**4.25
6 (BEFORE WORK)	15.16 (12.92)	13.64 (11.49)	**3.01
7 (AFTER WORK)	16.36 (16.29)	14.82 (12.41)	**6.59
8 (MULTIWORK)	13.90 (12.94)	11.26 (8.83)	**5.28
9 (MIXED CHAIN)	13.80 (13.42)	12.50 (11.39)	**3.04
F-ratio ²	**20.79	**33.51	
Average ²	18.48 (16.95)	15.65 (13.55)	**19.09
**Significant at p = <0.01.			
1: Travel time from home to work			
2: Not include trip-chaining pattern 1			

Table 5-6 shows that as the trip-chaining patterns become more complex, mean total travel time is also likely to increase. Gender difference for the simple trip-chaining pattern for work is shown to be very significant statistically at $p < 0.01$ level. There are significant differences in travel time between males and females for trip chaining patterns 2, 3, and 7 (TO WORK, FROM WORK, AND AFTER WORK). Trip-chaining patterns 5 and 6 (DURING WORK AND BEFORE WORK) show that difference in the mean total travel minutes between males and females is not significant. Among the most complex trip-chaining patterns, while trip-chaining pattern 8 (MULTIWORK) shows a significant difference at $p < 0.05$ level between males and females, trip-chaining pattern 9 (MIXED CHAIN) does not express any significance.

B. Travel time per trip link for non-work activities

Table 5-7 shows males take an average of 18.48 minutes per link for non-work activities and females 15.65 minutes. This also indicates that males make longer trips, an average of 3 minutes more per trip link, than females to engage in non-work activities. This difference is statistically significance. The hypothesis that there is no difference between males and females in average travel time per trip link is rejected at $p < 0.01$ level. That is, it is statistically proved that there is gender difference in travel minutes per trip link for non-work activities resulting from trip-chaining behavior for work.

In Table 5-7, differences for each trip-chaining pattern in the travel time by gender are statistically significant at least $p < 0.01$ level.

3. Analysis of Travel Modes

Table 5-8 shows the usage of transportation modes in trip-chaining patterns. Private vehicles include automobile, passenger van, and pickup truck. Public vehicles include bus, Amtrak, commuter train, streetcar/trolley, elevated rail/subway, and taxi. There are 43,103 trip links within 11,824 trip-chaining patterns explored in this study. Over 93 percent of all trip links in trip-chaining behavior are performed by private vehicles exclusively; that is, private vehicles are a significant transportation mode in trip-chaining behavior of workers. The percentage of public transportation is 2.80 percent, while 1.25 percents of trips are performed by walking. The simple work trip pattern shows slightly lower percentages for private vehicles than any other pattern, and a higher percentage for public transportation. This may support the fact that if individuals are likely to use public transit, it is more difficult for them to link non-work activities into work trips, resulting in choosing a simple trip-chaining pattern. Trip-chaining pattern 5 (DURING WORK), 6 (BEFORE WORK), and 8 (MULTIWORK) also have slightly lower percentages than the average for private vehicles. Except trip-chaining pattern 5, trip-chaining patterns with one trip tour including the simple work trip pattern show slightly higher percentages of walking than trip-chaining patterns with two or more trip tours. Beyond a simple trip-chaining pattern, trip-chaining pattern 5 among complex trip-chaining patterns has the highest percentage for public vehicle and walking, while it has the least of private vehicle. This may reflect the land use density which is served by

Table 5-8
Travel Modes in Trip-chaining Patterns

Percent	Travel Modes				
	Private Vehicle ¹ (40385)	Public Vehicle ² (1205)	Walking (537)	Other (976)	Total (43103)
Simple chain					
1 (SIMPLE WORK)	90.59	6.13	0.93	2.34	100.00 (9343)
Complex chain					
2 (TO WORK)	93.65	3.18	0.77	2.41	100.00 (1039)
3 (FROM WORK)	94.43	2.65	0.91	2.00	100.00 (6341)
4 (TO/FROM WORK)	96.47	1.27	0.47	1.79	100.00 (1897)
5 (DURING WORK)	91.73	3.65	2.67	1.94	100.00 (1234)
6 (BEFORE WORK)	92.93	1.67	2.26	3.14	100.00 (2389)
7 (AFTER WORK)	94.78	1.74	1.44	2.04	100.00 (15323)
8 (MULTIWORK)	93.52	1.57	1.04	3.87	100.00 (1914)
9 (MIXED CHAIN)	95.64	0.69	1.30	2.37	100.00 (3623)
Average	93.69	2.80	1.25	2.26	100.00
1: Private vehicles include auto, passenger van, and pickup truck.					
2: Public vehicles include bus, Amtrak, commuter train, streetcar/trolley, elevated rail/subway, and taxi.					
() number of trip links					

public transportation and walking to perform activities during working hours or lunch hours.

SUMMARY

In this chapter, it is examined than how individuals use non-work activities in trip-chaining behavior. The prevalence of complex trip-chaining patterns and gender difference in trip-chaining behavior implies that policy makers and planners should consider alternative ways for forecasting future amount of travel and transportation services since current transportation demand models do not include complex trip-chaining behavior in urban travel to work.

Performance of trip-chaining patterns

The study finds that more than 60 percent of urban travel for work are complex trip-chaining patterns. That is, complex trip-chaining patterns are common phenomenon of urban work trip. Trip-chaining patterns 3 (FROM WORK) and 7 (AFTER WORK) among complex trip-chaining patterns are highly chosen by individuals. Males are likely to use a simpler work trip pattern than females.

Trip rates

There is a significant variation between complex trip-chaining patterns for the mean total number of activities for each gender. Males perform 1.08 average total non-work activities and females 1.38 and this difference is statistically significant; that is, females engage in more non-work activities in a designated day than males. Trip-chaining pattern 7 (AFTER WORK), which is the most popularly used by individuals making a complex trip-chaining pattern, shows a very high gender difference for non-work activities.

Trip activities

- While females make more non-work activities for shopping and other family business trips, males are more likely to perform work-related business and social/recreational activities.
- Trips for work-related business are popularly taken by individuals with trip-chaining pattern 5 (DURING WORK) or 8 (MULTIWORK).
- Both males and females tend to choose trip-chaining pattern 3 (on the way from work to home) for shopping activities and generally use trip-chaining patterns with two or more trip tours (BEFORE WORK, AFTER WORK, and MULTIWORK).
- Other family/business activities are popularly taken in trip-chaining pattern 4 (TO/FROM WORK).
- School/church trips have a very high percentage to be taken on the way home to work (TO WORK) or with a pattern of an independent tour before individuals go to work (BEFORE WORK).
- Trip-chaining pattern 2 (TO WORK), 3 (FROM WORK), 5 (DURING WORK), or 6 (BEFORE WORK) are frequently used for doctor/dentist visits by females, while males choose trip-chaining pattern 2 or 3.

- Most individuals choose trip-chaining pattern 3 (FROM WORK), 7 (AFTER WORK), 8 (MULTIWORK), or 9 (MIXED CHAIN) to visit their friends or relatives.
- Social/recreational trips are frequently performed using trip-chaining pattern 3 (FROM WORK), 7 (AFTER WORK), or 9 (MIXED CHAIN) by males, while trip-chaining pattern 7 is given the highest proportion for trips performed by females.

Travel resources and travel modes

The null hypothesis that there is no significant difference between trip-chaining patterns in average total travel distances per trip-chaining pattern and per trip link for non-work activities is rejected. To perform all linked activities occurring during a designated day, an average of 35.62 miles are used by males and 30.34 miles by females. Travel times per trip-chaining pattern and per trip link for non-work activities also show significant variations between trip-chaining patterns. Travel times average 64.16 minutes for males and 59.23 by females per a trip chain. As a result, analysis shows significant gender differences in travel resources.

Most trip links in trip-chaining behavior are performed by private vehicles. The simple trip-chaining pattern has slightly higher proportion of public transit and less proportion of private travel modes than any other trip-chaining patterns.

CHAPTER 6

EFFECTS OF LIFECYCLE ON TRAVEL BEHAVIOR

Lifecycle stage is a useful classificatory factor of individual behavior, partly because it is a composite concept. Lifecycle provides certain natural linkage with several other variables including patterns of household employment, income and expenditure. Collin (1983) says that using the lifecycle concept, it is possible to identify relatively stable groups of persons with homogeneous activities whose activity patterns are also stable when viewed over a period of time.

This chapter studies travel behavior of individuals based on lifecycle stages. The relationship between lifecycle groups and several characteristics of individuals is examined in the first section. The second section analyzes average trip frequencies by trip purpose across lifecycle groups in each trip-chaining pattern.

CHARACTERISTICS ACROSS LIFECYCLE STAGES

1. Trip-chaining Patterns and Lifecycle

Combination of trip-chaining patterns

This study has explored nine work-related trip-chaining patterns. In this chapter, for efficient analysis, they are combined into four trip-chaining patterns, based on the number of trip tours. The possible combination of lifecycle stage and trip-chaining

pattern is shown in Table 6-1. Trip-chaining pattern 2 (TO WORK), 3 (FROM WORK), and 4 (TO/FROM WORK) are included into COMPLEX 1. Trip-chaining pattern 5 (DURING WORK) is COMPLEX 2. Trip-chaining pattern 5, which makes the trip tour for non-work activities during working hours, is separated from other one tour trip-chaining patterns because it is expected that non-work activities in trip-chaining pattern 5 may be performed under more time and spatial constraints. Trip-chaining pattern 6 (BEFORE WORK), 7 (AFTER WORK), 8 (MULTIWORK), and 9 (MIXED CHAIN), which have two or more tours, are included into COMPLEX 3, which is the most complicated trip-chaining pattern

Lifecycle stages

Table 6-2 provides four different lifecycle stages defined in terms of the age of the youngest child in the household in which individuals live. If there are several children in the household, only the youngest child is considered for the classification of lifecycle groups. All persons over 21 are considered to be adults.

The idea of lifecycle is simply that as a family matures it passes through a series of stages within each of which it behaves in a different manner. The basic reason behind the variations is that the different stages are defined in terms of the presence or absence of children of various ages, and so within each stage there will be different demands and constraints on adults' travel behavior. However, it should be noted that several other relevant variables such as age of adult members of the household and other socio-

Table 6-1
Combined Trip-chaining Patterns

Combined trip-chaining pattern	Trip-chaining pattern
SIMPLE CHAIN	Pattern 1 (SIMPLE WORK)
COMPLEX 1	Pattern 2 (TO WORK) Pattern 3 (FROM WORK) Pattern 4 (TO/FROM WORK)
COMPLEX 2	Pattern 5 (DURING WORK)
COMPLEX 3	Pattern 6 (BEFORE WORK) Pattern 7 (AFTER WORK) Pattern 8 (MULTIWORK) Pattern 9 (MIXED CHAIN)

Table 6-2
Lifecycle Groups

Group	Definition
Nchild	No children
A0-5	The youngest child age 0-5 in the household
A6-15	The youngest child age 6-15 in the household
A16-21	The youngest child age 16-21 in the household

demographic factors are also likely to be correlated with lifecycle stages and these, rather than just the household structure, may be the causes of some observed variations in behavior.

Lifecycle groups in trip-chaining patterns

Table 6-3 shows the distribution of individuals included in each lifecycle group by trip-chaining patterns. An analysis is performed by comparing the column values in each trip-chaining pattern, which gives information on how frequently lifecycle groups choose each trip-chaining pattern as they change.

The trip pattern for SIMPLE CHAIN is most frequently chosen by individuals in Group NChild. Individuals in the group with the youngest child aged 6-15 have the lowest percentage for simple trip-chaining pattern among groups, reflecting that they most frequently choose complex trip-chaining patterns. In general, individuals with the youngest child aged 0-15 (Group A0-5 and A6-15) less prefer a simple pattern for work because they may have more household responsibilities for their children.

Individuals with youngest child aged 0-5, who choose COMPLEX 1, show the highest proportion. Individuals with the youngest child aged above six are less likely to choose it. COMPLEX2 is slightly more frequently used by no children group and is least frequently used by individuals with the youngest child aged 15-21. While the most complex pattern, COMPLEX 3, has the highest percentage in group with the youngest

Table 6-3
Distribution of Lifecycle Stages by Trip-chaining Patterns

Percent	Trip-chaining pattern				
Lifecycle	SIMPLE CHAIN	COMPLEX1	COMPLEX2	COMPLEX3	Total
NChild	40.49	21.21	2.37	35.93	100.0 (5488)
A0-5	37.21	26.22	1.95	34.62	100.0 (2357)
A6-15	35.03	19.26	2.04	43.67	100.0 (2659)
A16-21	39.30	19.20	1.79	39.71	100.0 (1229)
Avg.	38.01	21.47	2.04	38.49	

() Sample size

child aged 6-15, it is less frequently chosen by individuals with the youngest child aged under five or no children in the household.

2. Relationships Between Characteristics of Individuals and Lifecycle

The use of lifecycle stage based on child's youngest age as an independent variable encourages a dynamic view to be taken of changes in an individual's characteristics and behavior. This is because the lifecycle dimension refers us to continual transitions, or cohorts in the population moving between successive lifecycle stages. The relationship between lifecycle groups and several socio-demographic characteristics are analyzed at the household level to which an individual belongs. Figure 6-1 through 6-5 show the ways in which several variables relate to four lifecycle groups.

Household size

Four lifecycle groups are defined in terms of the youngest child in the household. Figure 6-1 shows the relationship between the number of members in the household and lifecycle groups. As we expect, the no children group has the lowest household size. Individuals with the youngest child aged 0-5 have the highest household size and as the youngest child's age increases, the number of household members decreases.

Household size

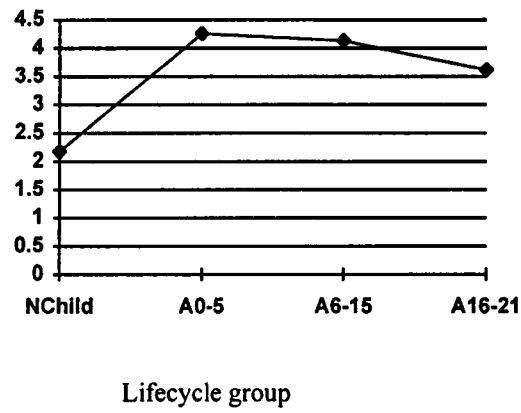


Figure 6-1
Household Size and Lifecycle Groups

Number of trips

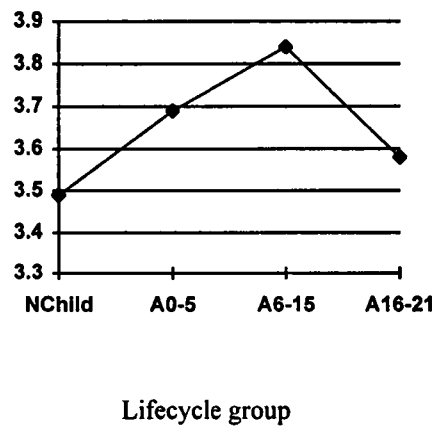


Figure 6-2
Trip Frequency and Lifecycle Groups

Minutes

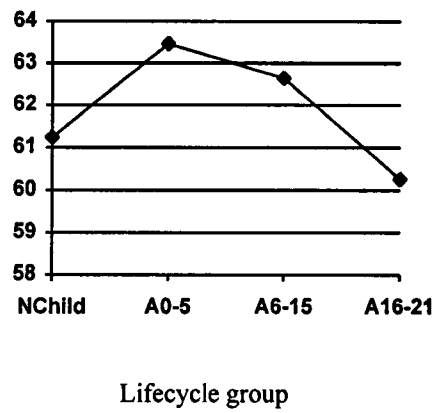


Figure 6-3
Travel Time and Lifecycle Groups

Miles

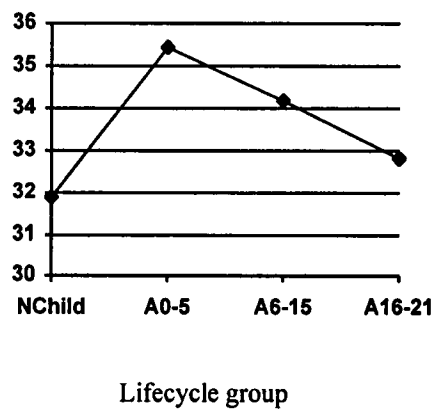


Figure 6-4
Travel Miles and Lifecycle Groups

Ratio of driver over vehicles

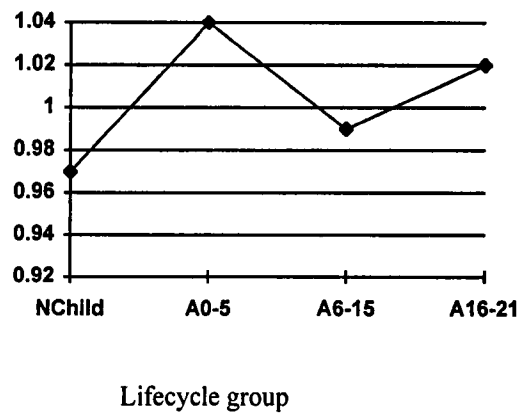


Figure 6-5
Ratio of Drivers over the Number of Vehicles and Lifecycle Groups

Trip frequency

Trip frequency is the average total number of trips resulting from trip-chaining behavior by a worker in a day. Figure 6-2 shows that individuals with the youngest child aged 6-15 most actively engage in making trips. If there are no children in the household, trip frequency generated by individuals in that household is lower; that is, this reflects the fact that the existence of children may significantly influence on adult's trip-making.

Travel time and travel distance

From Figure 6-3 and 6-4, individuals with the youngest child aged 0-5 have the highest travel time and miles. While individuals with no children in the household show the lowest travel miles, those with the youngest child aged 16-21 show the lowest travel time.

Ratio of drivers over the number of vehicles in the household

Figure 6-5 shows the ratio of the number of drivers to the number of vehicles in the household. Individuals in the household with the youngest child aged 0-5 have the highest ratio of drivers over the number of vehicles. Individuals with no children and with the youngest child aged 6-15 show the ratio less than one.

ANALYSIS OF TRIP PURPOSES BY LIFECYCLE GROUPS IN EACH TRIP-CHAINING PATTERN

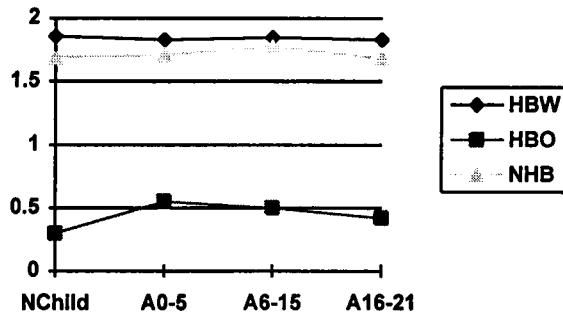
Figure 6-6 through 6-8 show that basic differences exist between the home-based and non-home based trip frequencies among different lifecycle groups within each trip chain. The trips are classified into home-based work (HBW), home-based other (HBO), and non-home-based trips (NHB). The 1990 NPTS dataset classifies travel day trips by purposes that are most often used in the urban planning process. Since almost all trips in pattern of SIMPLE CHAIN are home-based, analysis is excluded for this pattern.

From Figure 6-6 for COMPLEX 1 which combines trip-chaining patterns 2 (TO WORK), 3 (FROM WORK), and 4 (TO/FROM WORK), we see that home-based work trips and non-home-based trips are almost equally made by all lifecycle groups. Home-based other trips are least frequently made by individuals with no children in the household.

Figure 6-7 shows that individuals with the youngest child aged 16-21 have the highest average trip rates for home-based work in COMPLEX 2 which is trip-chaining pattern 5 (DURING WORK). As the child's age increases, the trip rates for non-home-based slightly decrease. Individuals with the youngest child aged 0-5 show a little higher trip rates for home-based other trips. COMPLEX 2 shows higher home-based work trips than any other trip-chaining pattern.

Trip rates in COMPLEX 3 which combines trip-chaining pattern 6 (BEFORE WORK), 7 (AFTER WORK), 8 (MULTIWORK), and 9 (MIXED CHAIN) are around

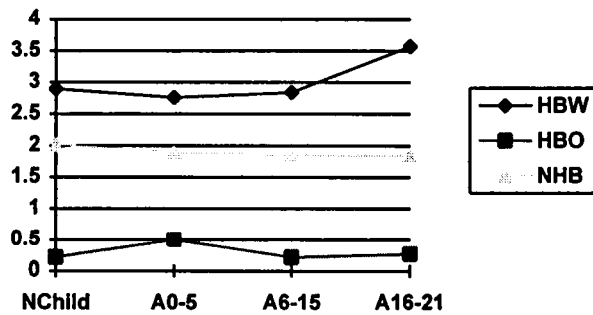
Avg. trip frequency



Lifecycle stages

Figure 6-6
Trip Rates per Person in Trip-chaining Pattern COMPLEX 1

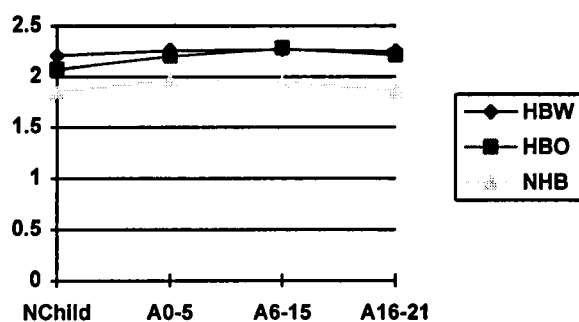
Avg. trip frequency



Lifecycle stages

Figure 6-7
Trip Rates per Person in Trip-chaining Pattern COMPLEX 2

Avg. trip frequency



Lifecycle stages

Figure 6-8
Trip Rates per Person in Trip-chaining Pattern COMPLEX 3

two for all trip purposes (Figure 6-8). Home-based other trips in this pattern especially show higher trip rates than those in any other pattern. That is, difference between COMPLEX 3 and COMPLEXES 1 and 2 is in the number of home-based other trips.

SUMMARY

This chapter studies the relationship between trip-chaining pattern and lifecycle stages. Lifecycle stages are classified into four groups based on the age of the youngest child in the household. Trip-chaining patterns are combined for efficient analysis. COMPLEX 1 includes trip-chaining pattern 2 (TO WORK), 3 (FROM WORK), and 4 (TO/FROM WORK). COMPLEX 2 is trip-chaining pattern 5 (DURING WORK). COMPLEX 3 includes trip-chaining pattern 6 (BEFORE WORK), 7 (AFTER WORK), 8 (MULTIWORK), and 9 (MIXED CHAIN). The study proves that there are observed differences in trip rates and trip-chaining patterns; that is, existence of children influences adults' trip-chaining behavior. The following statements summarize the several findings in this chapter.

- SIMPLE CHAIN pattern is frequently used by individuals with no children or with the youngest child aged 16-21. COMPLEX 1 is most frequently chosen by individuals with the youngest child aged 0-5 and is also highly chosen by those with the youngest child aged 0-5. No children group more frequently chooses COMPLEX 2 than any other age group. If there are the youngest child aged over 6 in the household, COMPLEX 3 is highly used.
- If there is the youngest child aged 0-5 in the household, household size is the largest. Individuals in the household with the youngest child aged 6-15 most frequently generates trips for all purposes. Individuals in the household with the youngest child aged 0-5 have the highest travel time and travel miles in linking

trips. While No children group has the lowest ratio of driver over vehicles, group with the youngest child aged 0-5 has the highest ratio.

- Home-based and non-home-based trips are most equally generated over lifecycle groups in COMPLEX 1. Individuals in lifecycle group with the youngest child aged 16-21 show higher frequency for home-based work trips than any other individual in other lifecycle groups in COMPLEX 2. COMPLEX 2 shows higher home-based work trips than any other complex pattern. COMPLEX 3 has the highest home-based other trips over lifecycle groups among trip-chaining patterns.

CHAPTER 7

STRUCTURAL MODELING FOR TRIP-CHAINING BEHAVIOR

In this chapter, potential interactions among variables, which may decide trip-chaining behavior, such as trip frequencies, travel time, and distances, in addition to the socio-demographic characteristics of households are studied. This approach may be useful for the development of a basic technique for dealing with dependent variables that are generally treated separately. Econometric models frequently involve a set of relationships designed to explain the behavior of certain variables. The structural equation (or structural relationship) model is a specific type of simultaneous equation system in which the variables are divided into two sets - endogenous variables and exogenous variables - and each equation in the system represents the direct effect of one variable upon another variable. Structural analysis can be used for the purpose of constructing and statistically testing a hypothetical model or theory.

SIMULTANEOUS EQUATION METHOD

1. Concept of Method

In a system of simultaneous equations all the endogenous variables are random variables - a change in any disturbance term changes all the endogenous variables since they are determined simultaneously. That is, simultaneous equation models are applied

to all the equations of the model at the same time and give estimates of all the parameters simultaneously. The application of least squares to a single equation assumes that the explanatory variables are truly exogenous and that there is one-way causation between the dependent variables and the predetermined variables. If this is not true, that is, if the predetermined variables are at the same time determined by dependent variables, the application of this method yields biased and inconsistent estimates. If there is two-way causation in a function, the implication is that the function cannot be treated in isolation as a single equation model, but belongs to a wider system of equations which describes the relationships among all the relevant variables. The function of simultaneous equation is:

$$\begin{aligned}
 Y_1 &= b_{10} + b_{11}x_{11} + b_{12}x_{12} + \dots + b_{1k}x_{1k} + r_2Y_2 + r_3Y_3 + \dots + r_nY_n \\
 Y_2 &= b_{20} + b_{21}x_{21} + b_{22}x_{22} + \dots + b_{2k}x_{2k} + r_1Y_1 + r_3Y_3 + \dots + r_nY_n \\
 Y_3 &= b_{30} + b_{31}x_{31} + b_{32}x_{32} + \dots + b_{3k}x_{3k} + r_1Y_1 + r_2Y_2 + \dots + r_nY_n \\
 &\vdots \\
 &\vdots \\
 Y_n &= b_{n0} + b_{n1}x_{n1} + b_{n2}x_{n2} + \dots + b_{nk}x_{nk} + r_1Y_1 + r_2Y_2 + \dots + r_{n-1}Y_{n-1}
 \end{aligned}$$

where

- Y_i : endogenous variables
- x_{ij} : exogenous variables
- b_{ij} : the coefficients of exogenous variables
- r_i : the coefficients of endogenous variables
- ($i = 1, 2, \dots, n$ and $j = 1, 2, \dots, k$)

2. Two-stage Least Square Method

A two-stage least square model, which is one of the simultaneous equation methods, involves the application of the method of least square in two successive stages. A block recursive structure is developed to examine various levels of interaction among variables. A two-stage least square model is utilized in an attempt to remove the potential of mutual dependency of one variable on another where each is used as a predictor of the other. By utilizing this technique it is possible to test whether feedback relationships exist among variables or whether the presumed direction of causality runs in only one direction. It gives more information than the single-equation techniques, that is, it considers the entire structure of the model with all the restrictions that these structures impose on the values of the parameters.

This study uses PROC SYSLIN, one of procedures of SAS (SAS Institute Inc, 1988). PROC SYSLIN estimates parameters in an interdependent system of linear equations using two-stage least square method. This technique is a special case of the instrumental variable technique in which the best instrumental variables are used. The exogenous variables are all good candidates for instrumental variables (Peter, 1979).

- Stage 1: regress each endogenous variable acting as a regressor in the equation being estimated on all the exogenous variables in the system of simultaneous equations (i.e., estimate the reduced form), and calculate the estimated values of these endogenous variables.
- Stage 2: use these estimated values as instrumental variables for these endogenous variables or simply use these estimated values and the included exogenous variables as regressors in an OLS (Ordinary Least Squares) regression.

STRUCTURAL MODELS

1. Variables Defined

Table 7-1 shows the exogenous variables to be used for the simultaneous equation model to find causal relationships with endogenous variables. In the model, numerical data and categorical data are used. From the numerical variables, it can be learned how the marginal increase of exogenous variables influences the magnitude of endogenous variables. The categorical variables such as gender, education level, income level, lifecycle groups, and urban sizes have the value of one if an individual has the specific characteristics for them; zero otherwise. Endogenous variables are the number of trips generated, the total travel time in minutes and the total travel distance in miles for a chain.

2. Analysis of Causal Relationship Between Variables

During the modeling, model reductions are performed by getting rid of several variables due to two reasons to get good model fitness. First, if it is found that there are correlation between variables, one of them is eliminated from the model. Second, the hypothesis for the test of estimated variable coefficients is that estimated coefficients are zero. If the probability of estimated variable coefficients to be zero is over 50 percent, variables are eliminated. Table 7-2 shows the summary of significant exogenous variables to predict endogenous variables, while the detailed models are given in the

Table 7-1
Exogenous Variables for Structural Models

Variable Name	Description	Assigned value
Vehcnt	Number of vehicles in the household	0 - 9
	Household family income category	
Lincome	Low = \$0-\$24,999	1, otherwise 0
Mincome	Middle = \$25,000-\$49,000	1, otherwise 0
Hincome	High = \$50,000	1, otherwise 0
Hsize	Total number of persons in household	1 - 10
	Lifecycle stages	
Nchild	No children in the household	1, otherwise 0
A0-5	Youngest child aged 0-5 in the household	1, otherwise 0
A6-15	Youngest child aged 6-15 in the household	1, otherwise 0
A16-21	Youngest child aged 16-21 in the household	1, otherwise 0
Nwork	Number of workers in the household	0-7
	Education level	
Educ1	1st-12th grade	1, otherwise 0
Educ2	Technical school after high school	1, otherwise 0
Educ3	college	1, otherwise 0
Educ4	graduate school	1, otherwise 0
Nadult	Number of adults in the household	
Ndriver	Number of drivers in the household	
	Gender	
Male	Male	1, otherwise 0
Female	Female	1, otherwise 0
Child	Number of children with age 0-4 in the household	
	Size of urbanized area	
Urbsize1	1=50,000-199,999	1, otherwise 0
Urbsize2	2=200,000-499,999	1, otherwise 0
Urbsize3	3=500,000-999,999	1, otherwise 0
Urbsize4	4=1,000,000+ without subway/rail	1, otherwise 0
Urbsize5	5=1,000,000+ with subway/rail	1, otherwise 0

Table 7-2
Summary of Significant Variables of Simultaneous Equation Models

	SIMPLE CHAIN				COMPLEX1				COMPLEX2				COMPLEX3		
	Ttrip	Ttime	Tmile		Ttrip	Ttime	Tmile		Ttrip	Ttime	Tmile		Ttrip	Ttime	Tmile
Ttrip															■
Ttime			■										■		■
Tmile		■			■	■			■				■	■	
Hsize							□		□		■		■	□	□
Vehcnt		□	■			□									
Nwork			□												
Nadult					□										
Ndriver		□	■												
Child	■														
Educ1	■						□								
Educ2	■														
Educ3	■														
Educ4	■						□								
Lincome		■	□												□
Mincome		■	□												
Hincome							■				■				
Nchild															
A0-5			■												
A6-15	■		■												
A16-21							□			■	□				
Male							■			■					■
Female			□		■				■				■		
Urbsize1		■	□		■		□						■		□
Urbsize2	■	■	□				□				□		■		□
Urbsize3		■	□			■	□							■	
Urbsize4	■	■	□			■				■				■	
Urbsize5		■	□		□	■			□	■				■	

■: Positive relationship

□: Negative relationship

SIMPLE CHAIN: Trip-chaining pattern 1 (SIMPLE WORK)

COMPLEX 1: Trip-chaining patterns 2 (TO WORK), 3 (FROM WORK), and 4 (TO/FROM WORK)

COMPLEX 2: Trip-chaining pattern 5 (DURING WORK)

COMPLEX 3: Trip-chaining pattern 6 (BEFORE WORK), 7 (AFTER WORK), 8 (MULTIWORK), and 9 (MIXED CHAIN)

Ttrip: Number of trips

Tmile: Travel distance

Ttime: Travel time

Appendix. The independent variables in the table have more than 90 percents of the probabilities that their coefficients are not zero. The following discussion is based on Table 7-2 and the tables in the Appendix.

SIMPLE CHAIN

Table 7-2 and A-1 in appendix show the causal relationship for trip-chaining pattern 1 (SIMPLE CHAIN). Generally, most individuals make two kinds of trips such as work and work-related business in a simple work trip pattern. That is, even if there are various levels of socio-demographic characteristics, variation for the number of trips may be small. The number of children aged 0-4 in the household has a significant positive relationship. Education level show the positive relationship with the total number of trips and as individuals' education level become higher, they generate slightly more trips. Urban size 2 and 4 are strongly related to the number of trips in trip chaining pattern 1.

Travel miles have a highly positive relationship with travel time; that is, as the travel distance increases, the travel time also increases. The number of vehicles and the number of drivers show negative relationship with travel time; that is, as those increase, travel time decreases. Individuals with income under \$ 49,000 are positively related to travel time. Female is also positively related to travel time. All urban sizes positively influence on the total travel time with their coefficients being generally high, which means that total travel time is highly dependent upon urban sizes. Individuals living in urban size 5 are likely to take longer travel times.

Travel time is positively related to travel miles. The number of vehicles and the number of drivers in the household have the positive relationship with travel distance. Lifecycle group with the youngest child aged 0-15 (A0-5 and A6-15) also has the positive relationship. While urban sizes have the positive relationship with travel time, they are negatively related to travel miles in the simple trip-chaining pattern. Travel miles are negatively influenced by female.

COMPLEX 1

From Table 7-2 and A-2 in appendix, while travel miles, female, and urban size 1 have the positive relationship with the number of trips in trip-chaining pattern COMPLEX 1, the number of adults and urban size 5 are negatively related to it.

Travel miles and urban sizes 3, 4, and 5 have the positive relationship with travel time. The number of vehicles in the household negatively influences on travel time.

As the number of household increases, travel miles decrease. Education level 1 and 4 have the negative relationship with travel distance. Urban size 1, 2, and 3 are negatively related to travel distance. Individuals in highest income group travel more in distance and male also positively influences on travel distance.

COMPLEX 2

From Table 7-2 and A-3 in appendix, travel miles are positively related to the number of trips; that is, an increase in travel distance means an increase in the number of

trips. If interviewer choose trip-chaining pattern 5 and is female, she is likely to positively generates trips. As the number of household members increases, the number of trips decreases.

Lifecycle group of A16-21 and male have the positive relationship with travel time. Individuals living in the largest urban area positively influence travel time.

The number of household members and the highest income level are positively related to travel miles. Lifecycle group with the youngest child aged 16-21 and urban size 2 have the negative relationship with travel distance.

COMPLEX 3

From Table 7-2 and A-4 in appendix, travel time and miles are positively related to the number of trips. Household size has the positive relationship with the number of trips; increasing the number of household members in the household encourages more trips. If individuals are females, they are likely to make more trips than males. Urban sizes 1 and 2 are positively related to trip rates.

Travel miles are positively related to travel time. Travel time is positively dependent upon urban sizes 3, 4, and 5.

The number of trips generated is positively related to travel miles; the more the number of trips individuals make, the more travel miles they undertake. Travel time is positively related to travel miles. If individuals are females, they have the positive

relationship with travel miles. Individuals with low income and in urban sizes 1, and 2 have the negative relationship with travel distance.

SUMMARY

This chapter develops the simultaneous equation models to find positive or negative relationships between variables under assumption that an endogenous variable is dependent upon exogenous variables and other endogenous variables. The main point is that there is two way causation between endogenous variables. Trip rate, travel time, and travel distance are endogenous variables and socio-demographic characteristics of individuals are exogenous variables. The followings summarize the findings in this chapter.

- The number of trips is a significant variable for travel miles only in COMPLEX 3; that is, trip frequency is not a useful factor to predict travel time and distance in trip-chaining behavior.
- The variable of female is positively related to the number of trips in complex trip-chaining patterns, reflecting the fact that females are more likely to pursue complex trip-chaining patterns, while males prefer the simple work trip pattern.
- Urban sizes are generally chosen to find relationship over all trip-chaining patterns.
- Household size is popularly used to find relationship with all endogenous variables in COMPLEXES 2 and 3.
- Educational level is significant variable in SIMPLE CHAIN to find relationship with the number of trips.
- Travel miles and travel time are significant for each other in SIMPLE CHAIN and COMPLEX 3. Travel miles are significant for trip rates and travel time in

COMPLEX 1. Males show positive relationship with travel miles and time, reflecting the fact that they travel more time and distance than females

CHAPTER 8 CONCLUSIONS

In this study, nine trip-chaining patterns related to work, which considered a stop (stops) for a non-work activity in addition to a stop (stops) for work in a chain, are developed. Different travel movements performed over a 24-hour period may be in some sense all part of the same journey. The handling of non-work trips and work trips, and the structure of trip linkages are better understood by noting and linking the activities which occur between each individual movement over the day.

SUMMARY

This study finds several results. First, the study finds that the formation of trip-chaining patterns is significantly dependent on the socio-demographic characteristics of the individual. Income levels, household sizes, the number of vehicles for females, the number of drivers, the number of children aged 0-4, start time of trips, and education level all have statistical significance in relationship with trip-chaining patterns at $p < 0.01$ level. Urban size show a statistical significance in relationship with trip-chaining patterns at $p < 0.05$ level.

Second, the study establishes that more than 60 percent of urban travel for work is composed of complex trip-chaining patterns, which suggests that current transportation

demand models should be modified to predict more valid trip generation. Males have a greater possibility of choosing the simple work trip pattern than females and males also show a slightly higher percentage of complex trip-chaining pattern 7 (AFTER WORK) and 8 (MULTIWORK). Among males choosing complex trip-chaining patterns, about half of them choose trip-chaining pattern 7.

Third, as a whole, males perform 1.08 average total non-work activities and females 1.38 in a 24-hour period. This difference between males and females is statistically significant at $p < 0.01$ level. It is also shown that there is a statistical significance in differences for the average total number of non-work activities in trip-chaining pattern 5 and 7 between males and females. The following summarizes trip purposes popularly pursued by gender in a trip chain.

- While females frequently engage in non-work activities such as shopping and other family business trips more often, males are likely to prefer work-related business, visit friend/relatives, and social/recreational activities.
- While females are most likely to make shopping trips in trip-chaining pattern 3 (FROM WORK), males do so in trip-chaining pattern 2 (TO WORK) or trip-chaining pattern 6 (BEFORE WORK).
- School/church trips are performed by females at a slightly higher percentage than by males, and they are popularly made by both males and females in trip-chaining pattern 2 (TO WORK) or trip-chaining pattern 6 (BEFORE WORK).
- Other family business trips most frequently occur in trip-chaining pattern 4 (TO/FROM WORK) by both genders.
- Social/recreational trips are popularly performed in trip-chaining pattern 7 (AFTER WORK) by both genders.
- Trips for work-related business are frequently taken by individuals in trip-chaining pattern 5 (DURING WORK) and 8 (MULTIWORK).

Fourth, in general, many variations between trip-chaining patterns are significant in travel resources on the average. Males travel 35.62 miles per trip chain and 10.17 miles per link for non-work activities, and females 30.34 miles per trip chain and 7.95 miles per link for non-work activities. Males travel 64.16 minutes per trip chain and 18.48 minutes per trip link for non-work activities, and females 59.23 minutes per trip chain and 15.65 minutes per trip link for non-work activities. These differences in travel resources between males and females are statistically significant. Some trip-chaining patterns show significant differences in travel resources between males and females.

Fifth, the four different lifecycle stages, defined in terms of the presence or absence of children of various ages, show different demands and constraints on adult behavior. The 1990 NPTS data set classifies travel day trips by those purposes most often used in the urban planning process. This study confirms the hypothesis that there are basic differences between the home-based and non-home-based trips among different lifecycle groups within each trip chain. Trip-chaining patterns also have a significant influence on the number of trips by purpose. The study finds several interesting points of relationship between trip-chaining patterns and lifecycle stages, as follows:

- SIMPLE CHAIN is most frequently chosen by individuals with no children in the household and individuals with the youngest child aged 16-21 also popularly choose it.
- A pattern of COMPLEX 1 is frequently used by individuals if they have no children or the youngest child aged 0-5.

- COMPLEX 2, trip-chaining pattern 5, is most frequently chosen by individuals with no children in the household.
- COMPLEX 3, which includes patterns with two or more tour, is preferably used by individuals with the youngest child aged above 6.
- Generally, while individuals with the youngest child aged 0-5 in the household have the highest household size, travel time and miles, ratio of drivers over the number of vehicles, those with the youngest child aged 6-15 have the highest trip rates.
- Individuals with the youngest child aged 16-21 most frequently choose home-based work trips in COMPLEX 1. The pattern of COMPLEX 3 show much higher home-based other trips than any other complex trip-chaining pattern; generally, while less than 0.5 home-based other trips are made in COMPLEX 1 and 2, there are more than two home-based trips.

Sixth, simultaneous equation models resulting from two stage least square method provide information on the relationship between an endogenous variable and exogenous and other endogenous variables. From models it is known there are the positive or negative effects among variables and possible significant elements of individuals for travel time, travel distance, and trip rates in each trip chain.

CONCLUSION

This study finds that complex trip-chaining patterns are significant components in urban travel for work. If these trips are simplified or misclassified, travel demand models would obviously lead to unreliable forecast of future travel. Non-work activities may be easily controlled more than work trips. They are also more sensitive to changes in travel

costs and policies. As travel costs increase due to policy changes, individuals may try to consolidate their trips into a chain, resulting in decrease in home-based trips and increase in nonhome-based trips. Therefore, acceptance of trip-chaining behavior into current transportation demand models will improve forecast of future amount of travel and facilitate transportation engineers and planners to design better transportation services.

It is confirmed that socio-demographic characteristics of individuals considerably influence the opportunities and the constraints that they face in making travel activity choices and that these activity choices lead to different trip-chaining behaviors. It indicates that there are significant gender differences in trip-chaining patterns, which means that some constraints might be imposed on individuals by traditionally conceived gender roles.

There are also significant variations between trip-chaining patterns in trip rates, travel resources used, and travel activities pursued. As a result, a change in these characteristics of individuals may mean a change in urban travel patterns and thus provide uncertainty in forecasting future amounts of travel. Since females make more trips in a trip chain than males and females' participation in work force is increasing dramatically, then these tendencies are of particular concern to transportation policy and planning since changes in individuals' travel behavior may ultimately alter trip generation and distribution.

The simultaneous equation models provide a promising method for a comprehensive exploration of decision factors of trip-chaining and travel behavior. By

identifying the causal relationships among variables, we can grasp the nature of the adjustments made in individual's activities and trips resulting from a reaction to his (or her) changed circumstances.

FUTURE RESEARCH

For future research, there is a possibility in looking into the high chi-square value in more detail. Some trip-chaining patterns or some levels of each socio-demographic characteristics may contribute for the high variance between expected frequencies and observed frequencies. As a result, it will be known that which trip-chaining patterns or levels of each socio-demographic characteristics are major contributors deciding the dependency of trip-chaining patterns on socio-demographic characteristics.

The analysis of travel behavior in this study is performed using data of a single day for an individual, although travel behavior patterns may vary from day to day; that is, the analysis using one day data gives rise to doubts about the validity of stability of individual's travel behavior. If multi-day data sets become available, first, the spatial and temporal stability of trip-chaining behavior may be studied using socio-demographic characteristics of the individual or household.

Second, there are potential areas of statistical analysis such as principal components, cluster analysis, and etc. to find significant factors to model trip-chaining behavior. For example, some of the highly correlated variables in the models can be

included in the models in the form of their principal components which are jointly uncorrelated. Cluster analysis may be another useful technique to group similar trip-chaining patterns and socio-demographic characteristics of individuals, which is available to analyze day-to-day variability. If there is day-to-day variability in the individual's trip-chaining pattern, an understanding of this variability will be also important to design or assess transportation services.

Third, based on the findings in this study, efforts toward more convincing transportation modeling should be made using a concept that includes both temporal and spatial approaches to travel choice behavior and that considers trip-chaining behavior making multistop.

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APPENDIX

Simultaneous Equation Models

Table A-1
Causal Relationship between Variables in Simple Trip-chaining Pattern

Exogenous variables	Endogenous variables		
	Ttrip	Ttime	Tmile
Ttrip			
Ttime			**0.515
Tmile		**1.353	
Hsize		0.908	-0.398
Vehcnt		**2.045	**1.647
Nwork	0.013		*-0.931
Nadult	-0.012	0.759	-0.536
Ndriver		*-1.321	*1.009
Child	*0.039	-1.848	1.753
Educ1	**0.200	-1.405	2.367
Educ2	**0.198	-2.686	4.130
Educ3	**0.241	-1.693	3.547
Educ4	**0.290		3.599
Lincome		**7.046	**4.782
Mincome		**2.360	**1.825
Hincome			
Nchild	0.017	-6.563	5.964
A0-5	0.041	-8.976	*7.521
A6-15	*0.047	-8.887	**7.540
A16-21		-4.638	4.483
Male			
Female		*2.853	**3.179
Urbsize1		**14.477	**10.702
Urbsize2	**0.080	**16.691	**11.501
Urbsize3	-0.013	**16.551	**11.070
Urbsize4	*0.038	**14.888	**9.096
Urbsize5		**20.348	**10.944
R-Square	0.02	0.08	0.11
*: Significant at $p \leq 0.1$			
**: Significant at $p \leq 0.05$			

Table A-2
Causal Relationship between Variables in Trip-chaining Pattern COMPLEX 1

Exogenous variables	Endogenous variables		
	Ttrip	Ttime	Tmile
Ttrip			7.937
Ttime			
Tmile	**0.041	**0.597	
Hsize	0.051		** -2.084
Vehcnt		* -0.964	1.179
Nwork	-0.085		
Nadult	* -0.989		1.971
Ndriver	0.057		
Child	0.076		
Educ1			** -5.753
Educ2		-5.472	
Educ3			
Educ4			** -3.977
Lincome	-0.084		
Mincome	-0.100		2.704
Hincome			**3.908
Nchild		-9.427	-2.085
A0-5		-7.780	
A6-15	0.107	-7.661	
A16-21	0.106	-9.296	* -4.430
Male			**6.605
Female	**0.350		
Urbsize1	**0.345	2.520	** -8.852
Urbsize2	0.198		** -5.536
Urbsize3	0.133	**6.502	** -4.379
Urbsize4		**3.849	
Urbsize5	** -0.294	**8.664	2.678
R-Square	0.04	0.04	0.06
*: Significant at $p \leq 0.1$			
**: Significant at $p \leq 0.05$			

Table A-3
Causal Relationship between Variables in Trip-chaining Pattern COMPLEX 2

Exogenous variables	Endogenous variables		
	Ttrip	Ttime	Tmile
Ttrip			7.573
Ttime	0.023		
Tmile	**0.022		
Hsize	*-0.261	4.342	**8.047
Vehcnt		-4.323	-3.680
Nwork		-3.452	
Nadult			
Ndriver			4.251
Child			-8.631
Educ1			
Educ2			-9.489
Educ3			-4.371
Educ4			
Lincome	0.353	-7.101	-5.846
Mincome			
Hincome			**15.685
Nchild	-0.444	8.084	
A0-5			
A6-15			** -15.759
A16-21		**22.675	
Male		**14.728	
Female	**0.712		
Urbsize1			
Urbsize2	0.396		*-14.513
Urbsize3	-0.682	8.134	
Urbsize4	-0.562	*11.800	
Urbsize5	** -0.892	*10.584	
R-Square	0.06	0.10	0.15
*: Significant at p=<0.1			
**: Significant at p=<0.05			

Table A-4
Causal Relationship between Variables in Trip-chaining Pattern COMPLEX 3

Exogenous variables	Endogenous variables		
	Ttrip	Ttime	Tmile
Ttrip		3.264	**12.653
Ttime	*0.032		**0.458
Tmile	**0.047	**0.432	
Hsize	**0.094	*-1.087	** -1.312
Vehcnt		-0.926	1.183
Nwork			
Nadult			
Ndriver	-0.072		
Child	-0.148		
Educ1	0.496	1.620	
Educ2	0.609		
Educ3	0.503		2.233
Educ4	0.702		
Lincome	0.178		*-3.778
Mincome			
Hincome	-0.160	2.385	2.910
Nchild		-1.526	
A0-5			3.211
A6-15			
A16-21			
Male			**5.734
Female	**0.352		
Urbsize1	**1.047		** -17.722
Urbsize2	**0.678		** -11.758
Urbsize3		**6.426	
Urbsize4		**5.358	
Urbsize5	-0.194	**12.348	
R-Square	0.03	0.02	0.03
*: Significant at p=<0.1			
**: Significant at p=<0.05			

VITA

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