MODELS OF NON-WORK ACTIVITY DURATION

by

JESSE JACOBSON

Ingénieur Diplomé de l'Ecole Polytechnique Fédérale Lausanne
(1975)
S.M., Massachusetts Institute of Technology
(1977)

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Certified by..
Thesis Supervisor

Accepted by..
Chairman, Departmental Committee on Graduate Students of the
Department of Civil Engineering

ABSTRACT

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This study describes both theoretical and empirical models of non-work activity patterns (duration and participation). Most current research has neglected to regard travel demand as demand derived from more basic needs such as non-work activity patterns. By better understanding the decision process that leads to non-work activity participation, however, it is possible to obtain more realistic predictions of travel behavior. In particular, this study considers that activity patterns, and not travel, are the "commodities" that are subject to two types of constraints, monetary and temporal. Thus, it is assumed that decision makers act as utility maximizers, subject to the two types of constraints.

Empirical models of individual activity participation are estimated for three types of non-work activities: shopping, social/recreation, and remaining activities. The sample used for estimation is obtained from a home interview survey collected in the Minneapolis-St. Paul area in 1970. Socioeconomic, land-use, and transportation level-of-service data are used. Two model types are developed. The first model assumes that individuals act independently of other members of their household. The second model relaxes the independence assumption. and assumes that household members decide jointly on activity patterns.

The analysis of the policy predictions suggests that transportation level-of-service changes impact significantly on activity patterns, primarily for travel time policies (in- and out-of-vehicle times). In particular, a decrease in the speed of travel decreases activity duration for all the activities modelled, and decreases the total time individuals spend travelling. The importance of socioeconomic characteristics is also significant. Specifically, the possession of a driver's license, which represents the desire for vehicular mobility, has a large impact on activity patterns. The estimation of models for the joint activity patterns within the household has not been entirely satisfactory, and further research on this topic is suggested.

The feasibility of modelling activity pattern and the importance of such models in predicting travel impacts indicate the direction for future development. In particular it is suggested to investigate further the complex nature of the travel-related choice structure, both theoretically and empirically.

Thesis Supervisor: Moshe E. Ben-Akiva
Title: Associate Professor of Civil Engineering

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER I

INTRODUCTION

1.1 Background

Extensive effort has been devoted in the past to the understanding of non-work travel patterns. It has, in fact, been shown in several instances (Adler and Ben-Akiva, 1976; Adler, 1976; Ben-Akiva, et.al. 1977; Oster, 1978) that in many transportation planning contexts one cannot ignore the impact of policy changes on non-work travel patterns. Specifically, the low transaction costs involved in even the most radical changes in non-work activity patterns suggest a sensitivity to changes in transportation service which is different in magnitude than the response of travel to work. Moreover, the daily volume of non-work travel is significant, and ignoring it would bias considerably the forecasts of impacts of specific policies. An analysis of survey data collected in the Washington, D.C. metropolitan area in 1968 revealed that home based work trips account for less than forty percent of the daily automobile vehicle-miles travelled and less than forty percent of the daily emissions due to auto travel (Horowitz, 1974). Also, analysis of these data show that, in Washington, D.C., only fifty-three percent of the morning peak hour traffic are home based work trips (Jacobson, 1977).

It is commonly recognized that non-work travel is more flexible than work travel since, as mentioned above, it involves lower transaction costs. As an example, an individual's response to a gasoline price increase might be to participate less often in social/recreation or shopping activities.

This is in constrast with the expected response of the same individual to the same pricing policy when considering alternative modes or routes for the trip to work. The individual is, in the latter case, willing to "absorb" a much higher gasoline price increase (for example by shifting to the more inconvenient public transportation) before deciding to change job or residential location.

1.2 Behavioral Issues

Models currently available for predicting consumers' responses to transportation policy have been limited in a number of ways. First, although it has been recognized for some time that travel demand is derived from demand for more basic activities, current models have not incorporated this notion explicitly.

Second, most available models do not explicitly incorporate time constraints as determinants of the daily activity patterns. In order to test the impact of temporal policies such as flexible work schedules (flexi-time), four-day work week, stores' opening hours, etc., it is just as important to determine which destinations are within reach of the consumers as it is to determine by which mode they will go.

The purpose of this study is to start the development of a methodology that explicitly addresses the above issues. The major aim of the past research on non-work activity patterns has been to understand and develop a theory of short-run behavioral response to changes in the socioeconomic and demographic characteristics of the population. However, few of the studies have developed econometric models; most of the empirical research has been limited to data analysis with categorization of the population into subgroups having similar behavior. Moreover, little inquiring has been made into the linkage of travel-related activity patterns and transportation level-of-service. It is the purpose of this research to develop both a behavioral theory and parametric models that allow better understanding of the most important factors that influence activity duration, with specific emphasis on transportation level-of-service.

1.3 Definitions of Terms Used in This Research

Activity patterns is the all-inclusive term defining the components of the travel-related activity decisions. The two major dimensions of activity patterns are activity duration and travel patterns. Activity duration is the time allocated to the activity under consideration. Total activity duration includes both the time actually spent performing the activity, and the travel time to and from the activity; net activity duration excludes travel time. The travel pattern includes all the components of travel such as travel time, origin, destination, mode of travel, routing, time of day, etc. A non-work activity program is the set of durations for all non-work activities summed over the day, by purpose. Other general terms such as sojourns, tours, home based tours and home-work based tours, are used and, because they have a specific meaning in this research, their definition is included. A sojourn is a stop at a destination other than home, work or school. Work and school travel are choices made within a longer time frame than travel for purposes such as shopping, social/recreation, etc. When non-work/non-school travel is analyzed, choices related to the work or school travel are considered exogenous. A tour is a trip that starts and ends at the same place. A tour can include soujourns. For illustrative purposes, assume the following travel diary: home-shopping-work-social/recreation-personal business-work-home. This diary is composed of a home based tour and a work based tour; one sojourn for the home based tour, the shopping destination, and two sojourns for the work based tour, the social/recreation and personal business destination. For convenience another type of tour is defined: the home-work based tour. Home-work based tours are a subset of the home based tours, and include trip sequences that start at home and end at work, with or without sojourns.

1.4 Research Objective

The scope of this research is somewhat limited by the complexity that the development of a comprehensive activity pattern theory would involve. A more limited set of objectives was selected as follows:

1) To better understand decision maker behavior in allocating time to non-work activities,

2) To investigate the feasibility of modelling directly the participation in those activities for which motorized travel is only the means of access,

3) To analyze the sensitivity of activity duration and travel time to different transportation scenarios (pricing policies, auto restraint policies, etc), and

4) To analyze the impact of demographic and socioeconomic trends on activity patterns.

1.5 The Approach

The approach taken was to develop a general theory of behavior with respect to activity patterns and to estimate models using a currently available data base. Transportation level-of-service, one of the determinants of activity patterns, is specifically included in the models that predict the duration of different non-work activities (such as shopping, social/recreation and remaining activities) on an average weekday.

The activity duration models are statistically estimated using a limited dependent variable model. This model is written as a regression equation with the addition of a restriction on the range of values that the dependent variable can take. This type of estimator, first proposed by Tobin (1958), is well adapted to activity duration modelling since activity duration cannot take values lower than zero or higher than the total amount of time allocated to non-work activities. The empirical models are estimated using a data base collected in 1970 in the Minneapolis-St. Paul metropolitan area. The usefulness of the data base for modelling activity patterns is somewhat limited since it was primarily collected for conventional travel demand modelling. However, this data base was selected for this research because of its immediate availability and because the recording of travel information is complete. The data base includes a home interview survey of a 1% random sample of households, transportation level-of-service attributes for each zonal pair in the metropolitan area, and zonal-level land-use information. The home interview survey includes a diary-type survey with travel information for each individual reported only for one day.

1.6 Summary of Major Findings

This research includes theoretical and empirical results which are of particular interest in the analysis of current issues in transportation planning. The theoretical section presents the utility maximization framework developed for activity duration modelling and discusses the importance of accessibility as a determinant of activity patterns.

The models developed in the empirical section are sensitive to transportation level-of-service and to socioeconomic and demographic characteristics of the individuals. In general the results suggest that shifts in level-of-service (cost and time) cause significant changes in activity programs and in travel times. The elasticity of activity duration with respect to in-vehicle and out-of-vehicle time is very significant. The elasticity with respect to out-of-pocket cost is, however, much smaller.

The changes in activity programs due to shifts in population characteristics are also quite significant. Specifically, the most important characteristic is whether the individual has a driver's license, which can be interpreted as an indicator of the desire and capability for mobility. The activity duration elasticity with respect to the work status is small. This suggests that, if in the future the duration of the work day were to decrease, individuals would allocate a large proportion of their new "leisure" time to in-home activities.

The predicted effect of the increased participation of women in the labor force on non-work activity duration is small. Much more significant is the effect of an increased number of individuals with driver's licenses. In fact, for all activity types, the possession of a driver's license yields longer and more frequent participation in all activities.

Overall, the results of this research suggest that the analysis of activities has great potential for understanding travel related choices. This is all the more relevant in travel demand analysis if the importance of travel characteristics is appropriately considered.

1.7 Outline of the Remaining Chapters

Chapter II reviews current literature in the field of activity duration. Both theoretical and statistical contributions are analyzed in this chapter. Chapter III presents the data base used in this research, and some of the aggregate characteristics of the population such as average activity duration by activity type, activity participation rates, etc. Chapter IV develops a theoretical framework for activity duration based on the economic theory of utility maximization. Chapter V discusses the statistical issues involved in estimation of activity duration models. Chapter VI presents the empirical results of model estimation. Prototypical predictions using the estimated models are presented in Chapter VII. Finally, in Chapter VIII, the results of this research are summarized and recommendations are given for further research.

CHAPTER II

LITERATURE REVIEW

2.1 Introduction

This chapter reviews the literature on activity patterns which is the most relevant to this research, placing particular emphasis on activity duration.

The chapter is divided into five sections. The first section presents studies in micro-economic theory of time allocation, based on the general framework of the theory of choice and utility maximization. The second section presents studies which have tried to identify the exogenous determinants of activity patterns through descriptive data analysis. The third section presents another significant body of literature which develops the theoretical concepts of physical reach and constrained time budgets. The fourth section presents the results of parametric models of activity patterns. The fifth section, the summary, reviews the state of the art and discusses the relevance of existing studies to the objectives of this research.

2.2 Economic Theory of Time Allocation

The most general and most innovative theoretical formulation of time allocation can be found in Becker (1965). He suggests that households act both as producers and as utility maximizers. As producers, households combine basic commodities such as time and market goods to produce activities. As utility maximizers, they purchase the commodities in the optimal mix. The fundamental result of Becker's theory is that the marginal utility of activity is directly porportional to the shadow price of money and to the full price of a unit of activity. The full price of an activity is the sum of the prices of the goods and time used per unit of activity. If the full price of activity i increases, i.e. if either the price of goods or time used to produce one unit of activity i goes up, then, at the optimum, the marginal utility of activity i increases. As an example, if the price of movies were to increase, the optimal marginal utility of movies at optimality would increase. Since it is reasonable to assume that the movie-going activity has positive and diminishing marginal utility, an increase in marginal utility implies a decrease in the optimal "quantity" of movie-going.

A review of more recent economic work on the value of time is found in Watson (1974). Watson presents all the work done since Becker's innovative paper as an extension of the original theory of time allocation. Specifically, variables such as work duration, and wage rate were included as decision variables of the time allocation process.

More recently, Gronau (1977) has presented theoretical findings showing that "the average wage rate can be used as, at best, a very crude approximation of the value of time". He demonstrates that there is no unique value of time, and that it is important to recognize its variation across individuals (because of socioeconomic and demographic characteristics) and most significantly across activities.

The theoretical approach proposed in this research will combine Becker's theory of time allocation, with Gronau's findings on cross-sectional variability of consumer behavior.

2.3 Descriptive Studies of Activity Duration

While a number of studies have reported results of descriptive analysis on activity duration, Chapin (1974) is the most complete study. Chapin develops a classification method based on both theoretical and empirical results. His method combines a-priori knowledge of the factors influencing the activity program with analysis of empirical observations. The results of Chapin's study suggest that the "preconditioning and predisposing factors" of activity patterns behavior are the decision-making role in the household and the mix of sex, breadwinning and child care roles. Chapin also suggest that some personal characteristics are people's age, stage in life-cycle, and general level of health. Needs are also included as determinants of activity patterns and two main categories can be identified: subsistence needs and culturally, socially and individually-defined needs. Similar conclusions were derived by Kutter (1973), who proposes a classification of individuals along the dimensions of age, sex, stage in family life cycle, and females' work status. Based on this classification, Kutter assumes that, in the aggregate, the activity patterns for specified groups are, within the period of one day, similar to the activity patterns of a single person during a longer period (e.g. one month). Empirical tests which Kutter performed on a sample of observations confirm, at least in the aggregate, this theory.

A study by Bullock et.al. (1974) analyzes data collected at two different colleges and finds that the significantly different time allocation in the two groups was due primarily to different class schedules in the two schools. One of the schools left plenty of time for lunch, and the other little or no time. Yeung and Yeh (1975) find that inhabitants of two distinct settlements (one a squatter and one a public housing project) allocate similarly their "obligatory" activity pattern, but show significant differences in their leisure time activity pattern. They concluded that both social and locational dimensions, such as employment and housing type (apartment, squatter settlement, etc.) influence time allocation.

A theoretical study by Doob (1971) emphasizes the importance of activity duration as a determinant of activity patterns by suggesting that the value of an activity is positively correlated with the frequency of participation and its duration. Chapin gives an additional justification of the study of activity duration. He proposed to use it as a description (or common measuring unit) of the "intensity" of participation in different activities in the urban system. Nevertheless, he warns that time allocation alone cannot fully describe the activities and that, in particular cases, additional measures need to be specified.

Chapin's study also looks at the dynamic process by which the individual's actions are motivated, produce a choice and finally yield an outcome. The most important element in this process is the initial motivational drive whose characteristics can vary across individuals (or groups of individuals). Recognizing this variability, Brail and Chapin (1973) state that individuals don't all have equal access to opportunities, and that their status is an essential determinant of their motivation. This is why it is very important, in human activity pattern studies, to segment (or group) the population into categories according to income, work status, sex role and family responsibility. Doob (1971) discusses what he believes is the ability to formulaté good predictions of behavior of a group member. In order to do this he classifies the population along characteristics which include age, sex, occupation, social status, beauty and strength.

Chapin points out that the essential purpose of activity pattern studies is to detect "a tendency for a population to behave similarly". This leads to the necessary simplification of grouping acts into activity classes. It is thus possible to "define behavior patterns that are common to whole groups of people". But grouping of acts is not done solely for the purpose of finding commonalities, but also to facilitate analysis. As an example, if our concern is with the shopping activity, a very detailed definition of the in-home activities might not be necessary.

A discussion of limitations of previous activity program studies is presented by Szalai (1972). First of all, noting that "individuals often perform several activities at the same time", he warns of the importance, when trying to describe individuals' motivations and behavioral drives, of identifying whether individuals perform joint activites (such as listening to music while reading, taking a walk while window shopping, etc.) or independent activities. Michelson and Reed (1975) note that, in questionnaires, usually only one activity is reported for a specific time period, thus rendering impossible the analysis of simultaneously-executed activities.

Another issue that Szalai discusses is that very few studies have "added an analysis of the timing of daily activities to the analysis of their duration", although "some highly characteristic features of social life in the industrial age are connected with timing: office hours, rush hours, shifts, timetables...". Moreover few time-budget studies have looked into a theoretical model of the sequential structure of people's daily agenda. This issue has, however, been investigated in some detail by Stone (1972). After briefly presenting Markov models of time-budget, Stone suggest that they don't address the complexities of the observed data. Stone's personal contribution is the theoretical development of "path analysis models of causality" and of a "process model". The main purpose of the models of causality is to trace and quantify the dependency of one variable (or event) of the model on another. Although the "causal analysis" process is self-explanatory, Stone does not suggest what type of procedure should be used to quantify the dependencies. The "process model", on the other hand, "attempts to represent the decision making that goes into determining time allocation." Stone suggest that this model should be used to find decisions which are common to a certain class of individuals, in order to simulate behavior of population groups.

2.4 Constraints on Activity Duration

Another area of research has been the study of individual's activity patterns under spatial and temporal constraints. This area has been pioneered by Hägerstrand (1970) whose theoretical framework presents the concept of physical reach. The space of reach is the dimensional volume (two geographical coordinates and one temporal coordinate) that an individual can visit given his schedule and travel speed constraints. Hägerstrand shows that the space defined by the individuals' constraint is a prism. It is useful here to discuss in more detail some of Hägerstrand's ideas which will be the base of the theoretical development presented in Chapter IV.

Assume a city with no barriers and constant airline speed of travel. An individual travelling in the city is limited in the locations he can reach, given his origin, and given he has to reach a destination at a particular time. In the simplified case where the origin and the final destination of a tour are the same (a simple example of this could be a home-shop-home tour), and the individual has m minutes available for the activity, different scenarios can occur:

- The individual remains at the origin (no-travel option)
- The individual travels for t minutes ($0 \leqslant m < T$) and spends T-m time at the destination(s) of his choice

The physical reach for the first scenario is straightforward; the individual has only his origin as space to perform his activities. For the second scenario, the individual can reach all destinations that are within m/2 min. travel time from his origin. The maximum surface that encloses this activity pattern is a circle of radius ($s \cdot m/2$) where s is the speed of travel. At the upper bound of m=T the individual can reach destinations at a distance of ($s \cdot T/2$), but cannot perform any activity at the destination(s).

Assume now that the individual's origin is not the same as his final destination. Given that the individual decides to travel for m minutes (not including direct travel from the origin to the destination of the tour), the maximum surface of intermediate destinations available to him is enclosed within an ellipse with distance from any point of the ellipse to the foci of (s•m).

Lenntorp (1976) has formalized this concept of reachable domains. Lenntorp's contribution is a more rigorous framework of analysis and an empirical application to a model of simulation of urban travel.

An additional contribution to the study of time budgets can be found in recent work by Zahavi (1977). Zahavi's primary assumption is that a travel pattern can be predicted through constraints on travel time and money expenditures that restrict the consumer's set of possible choices.

Somewhat different from previous studies is the approach to the understanding of activity patterns adopted by Jones (1976). Jones is more interested in the "physical representation of the human activity approach to studying travel behavior". The emphasis of his study is on the scheduling of activities and the process by which individuals satisfy their needs without violating the constraints. Jones assumes that the household acts as a single decision-making entity, and his research methodology tries to describe the complex process of intra-household duty-sharing. Unfortunately this approach, although very attractive from a theoretical perspective, does not, at this stage of its development, lend itself to simplification for use in mathematical modelling.

2.5 Parametric Models of Activity Duration

Bain (1976), in an empirical application of a model for activity time allocation, used a limited dependent variable model of the type proposed by Tobin (1958) and Amemiya (1973). Bain proposed four categories of explanatory variables: activity characteristics, travel mode and trip characteristics, socioeconomic characteristics of the individual and of his or her family, and the distribution of locations where the activity can be performed. However, due primarily to limitations in the data base, only total activity time (total travel time and destination time) and socioeconomic information were specified for the actual model estimation.

Four activity duration models were estimated for combinations of two groups of activities, shopping-personal business and social/recreation, and for two time periods, weekdays and weekend. The results show the significant differences in the prediction of activity duration between the weekday and the weekend model. The estimated models were used in forecasting the impact of a four-day week on non-work activity duration, and showed that on the free weekday both shopping-personal business and social/recreation activity increase by approximately 20%, in part offsetting the reduction in travel due to the elimination of the trip to work. Oster (1978) investigated non-work trips in close relation to work trips. Using alternative assumptions on consumer's behavior, Oster estimated a model for the prediction of the use of work trips to visit non-work destinations. The exogenous variables in this model are household income, the number of household members over 15 years of age, the number of household members ages 5 to 15, the number of household members age less than 5, accessibility indices for the residence, workplace of the head and workplace of the second worker, and dummy variables for the availability of a second (and third) automobile, and for the second worker in the household. Oster's results suggest that, among these variables, the primary determinants of the use of the work-related trip to visit non-work destinations are household income, the household size and number of children under 16 years of age, and the presence of a second worker in the household.

2.6 Conclusions

It appears, from the review of the literature, that most of the work in activity patterns has been devoted to descriptive analysis of observed behavior. Very little work has been done in integrating the theoretical framework of activity patterns with empirical observations. In particular, the work by Becker, Doob, Hagerstrand, Gronau and Szalai presents a discussion of theoretical models but derive only qualitative conclusions on activity patterns. Work by Bain, Chapin, and Kutter, on the other hand, is more empirical in nature, and presents a theory of activity patterns which relies heavily on observations rather than on a more structured model of behavior. Only the models of constrained behavior (Lenntorp and Zahavi) have been somewhat able to integrate theoretical and empirical findings into an analytical framework. Nevertheless, present theory of constrained behavior is incomplete. In fact, the assumptions that individuals behave solely according to constraints does not explain the evident trade-offs that individuals face when making decisions. If an individual goes from his home in the suburbs to a downtown shopping center, this implies not only, as constrained behavior modelling suggests, that he has time and money available; it also implies that downtown shopping is more desirable than, say, shopping at the nearby mall.

It is the purpose of this research to bridge the gap still existing between theoretical and empirical studies. Based on the previous studies, this research develops a theory that considers activity patterns to be derived from a utility maximization process subject to physical constraints (such as time and cost). The major factors that cause people to choose among alternative activity patterns include socioeconomic, demographic characteristics, and transportation level-of-service. The remaining chapters present the theory and the model estimation results.

CHAPTER III

DATA ANALYSIS

3.1 Introduction

The purpose of this chapter is to discuss the data base used in this research and the data processing required for estimation of the models of activity duration. The data base was originally collected in Minneapolis-St. Paul, Minnesota, for use in a conventional urban transportation study. It contains a one day diary-type home interview survey, transportation level-of-service derived from networks and land-use information. The main reason for choosing this data base were the easy access to it and the fact that the survey was conducted in 1970, a census year.

3.2 The Data Base

The data was collected as part of the Travel Behavior Inventory (TBI) conducted by the Metropolitan Council of the Twin Cities Area, between April and July 1970 in the Minneapolis-St. Paul metropolitan area. The home interview survey, the transportation level-of-service, and land-use information which were used in this research are part of the TBI study.

The Home Interview Survey(*)

The home interview survey is a 1% random sample of households in the Minneapolis-St. Paul metropolitan area drawn from electric utility records and consisting of 5,700 interviews. The usable portion of the survey(**)

(*) The home interview survey is described in detail in Metropolitan Council of the Twin Cities Area (1974) and Mid-continent Surveys, Inc. (1970a,1970b).

(**) The original survey data contained severe coding errors. Observations which contained such coding errors were excluded from the estimation sample.

includes 5,009 households and a total sample of 15,416 individuals. Information is collected at the household level (mainly for socioeconomic data), at the person level (mainly socioeconomic data), and at the trip level (mainly data on reported level-of-service, timing and purpose of the trip). The list of the principal items included in the survey is presented in Figure 3.1. The trip-level diary covers a 24-hour time period going from 4:00 AM of the day preceding the interview to 3:59 AM of the interview day.(***) The travel information recorded in the survey is fairly complete; specifically, information is available on the number of public transportation transfers (if transit was used), on the automobile parking cost (if auto used) and the purpose of the activity at the destination. Nine different types of activities are recorded on the survey: in-home activities, work, school, shopping, outdoor recreation, other social or recreational activities, medical (doctor, dentist, etc.), personal business (bank, barber, lawyer, etc.), and picking up or dropping off a passenger. No additional information is available and heterogeneous activities such as shopping (i.e. shopping for food, for clothing, for furniture) are coded in one category. Morever only one activity can be recorded for a given sojourn, typically the primary activity for that sojourn. A change of activity during the same sojourn is not recorded; if an individual goes to a mall and has lunch before the shopping visit, the purpose of the sojourn will be recorded as a shopping, with an evident over-reporting of shopping duration and under-reporting of social/recreation duration.

(***) While the day for which travel is to be reported is fixed for each house hold, call-backs were made up to three days after that day.

Figure 3.1

Items of Information Gathered in the Home Interview Survey (*)

For Each Household

- Type of dwelling(owner/renter, single family/two family/(multi-family)
- Household type (families with/without children marital status, age groups)
- Income classification
- Car ownership and car availability (includes company-owned cars and friends' cars available for use)
- Tenure at address
- Previous residence (location)
- Reason for changing residence
- Usual shopping place (except for food and drugs)
- Reason for shopping there
- How long shopped there
- Previous shopping place
- Reason for changing shopping place
- Weekend recreational trips
- Travel date

For Each Person

- Household relationship
- Sex
- Age
- Work Status
- Employment
- Work Place
- Driver's license
- Number air trips in past 12 months

For Each Trip

- Place of origin/destination
- Purpose
- Land activity types at trip end
- Mode of travel
- Time/duration of trip
- Blocks walked to or from auto or bus
- Time waited for bus
- Number transfers
- Fare
- Auto availability (if trip made by bus)
- Auto parking type/cost(for driver only)
- Persons in car
- Carpool
- Bridge crossings
- Freeway usage
- Bus availability (if person made trip by auto)
- Comparative bus data

(*)Source: Metropolitan Council of the Twin Cities Area(1974)

Another problem encountered in the survey data is that activity duration is not reported explicitly in the travel diary. Activity duration has to be determined by computing the reported time elapsed between arrival at the sojourn and the departure from sojourn. This measure of activity duration, although the best available from the survey, is not, however, completely accurate,primarily because of reporting errors. The errors are all the more important considering that individuals are not required, in the survey, to retrospectively time their activities, but only to time their travel.

Note that, as in most major U.S. transportation surveys, no information is available on trips made using the walk or the bicycle modes. In addition to the complete loss of information on tours made exclusively by these two modes (for example to go to the nearby grocery store), there are vehicular tours which appear, from the recorded data, to be incomplete. However, in most cases, it is possible to determine, by inspection, whether this is due to miscoding or to missing walk links.

Land Use Data

The land use data is compiled for the 1,058 zones within the metropolitan area. All data items are zone-specific and include employment data by type of business (manufacturing, wholesale, transportation, retail, service, financial, etc.), acreage by land use (recreational, vacant, commercial, etc.) and zonal distribution of household income, automobile ownership and household size.

Transportation Level-of-Service

The transportation level-of-service is recorded as a matrix of skim trees -- origin-destination minimum path times, travel costs and number of transfers measured from coded networks. The level-of-service information is mode-specific (highway and transit) and includes in-vehicle and out-of-vehicle times, and number of transfers and fare for the transit mode. A vector of parking costs is also available. It is very important to point out that the level-of-service data is averaged over the whole day. That is, no distinction is made to account for the difference in peak and off-peak speeds, transit schedules, and parking costs. This averaging of level-of-service information across the day causes under-estimation of peak period travel times and over-estimation of off-peak travel times. This has an impact on activity duration models. In fact, tabulations of average network times (Metropolitan Council of the Twin Cities Area, 1974) show significant differences in travel times for different times of the day. In particular, travel time during the morning peak is 21.5% higher than travel time during the off-peak period. Moreover, since most home-to-work or work-to-home tours are made during the peak traffic period, using average level-of-service under-estimates the travel time and cost required for a non-work deviation during such tours.

3.3 Assumptions in Data Processing

The original data base, which includes the home interview survey, land-use and transportation level-of-service, had to be reformatted and processed for estimation of models of activity duration and travel time. This was required because the original storage and coding did not permit efficient accessing of the information needed for this research. It should be pointed out that the transportation level-of-service variables which have been appended to the socioeconomic and demographic characteristics of the individuals and the households, are skim-tree values, i.e. estimated and not reported values. This is done for two primary reasons. First, it permits the evaluation of level-of-service of non-chosen alternatives for which no recorded data is available in the home interview survey. Second, the use of skim-tree values avoids the bias that exists in travel characteristics which are reported by individuals in the household survey. In particular, cognitive dissonance causes consistent under-reporting of the time and cost of the chosen travel alternatives (and consistent over-reporting of the time and cost of the non-chosen alternative.)

The following paragraphs present the major steps of the data processing, which include the reduction of the size of the estimation sample and the evaluation of the variables used for estimation of the models of activity duration.

Sample Size Reduction

The first major step in the data processing was the reduction of the number of observations in the home interview survey file by random sampling (one in nine) of households from the original file. This permitted a reduction in the cost of subsequent data processing steps. While computation costs were reduced, the reliability of parameter estimates was, however, also reduced. The loss of reliability is best quantified by the variance of the parameter estimates. The variance of the parameter estimates is proportional to the inverse of the size of the estimation sample. Thus a doubling of the sample size is expected to reduce the variance by half.

Evaluation of Accessibility

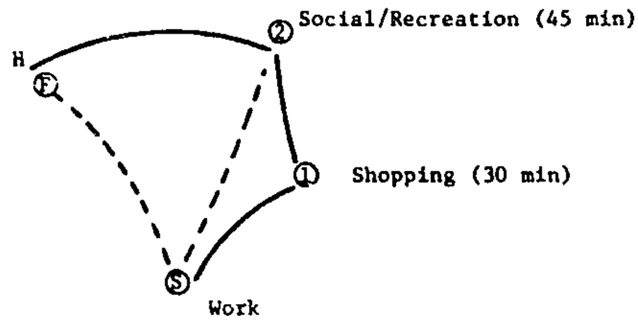
While socioeconomic variables such as work status, sex, age, are easily obtained from the recorded data, it is somewhat more complicated to evaluate a measure of accessibility to destinations where a given activity could be performed. As discussed in more detail later, accessibility is one of the key explanatory variables of activity pattern.

The evaluation of accessibility, which is specific to each decision maker, requires extensive data processing.

Evaluation of Total Activity Duration

The dependent variable of the models, total activity duration, includes both actual time spent performing the activity (net activity duration) and travel time to the activity. As discussed earlier, net activity duration for each activity is computed as the time elapsed between the arrival at the sojourn where the activity is performed, and the departure from the sojourn. If an individual performs the same activity at two sojourns, the two net activity durations are added. However, in a multiple sojourn tour, when several activities are performed, it is not straightforward to allocate travel time to each activity and a more complex algorithm is necessary to evaluate travel time to each activity type. In fact, if the origin and destination of the tour are different, then the travel time allocated to the activity is equal only to the travel time incurred in excess of the direct travel time from the origin to the destination of the tour.

For multiple sojourn tours, it is necessary to develop a procedure to allocate travel time to the different activities performed at the different sojourns. Instead of allocating the tour travel time equally among sojourns, it was considered more appropriate to allocate it differently depending on the importance of the sojourn. It was hypothesized that the sojourns are ranked on the basis of activity duration, i.e. the longer the time spent at the sojourn performing the activity, the higher the rank of the sojourn. Clearly, many other assumptions could have been made for ranking of sojourns, but the one proposed here seemed to be, among the ones considered, the most appropriate in many instances. The procedure for allocating travel times assumes that travel time to the primary sojourn is equal to the time incurred in excess of the direct travel from the origin to the destination of the tour. If the origin and the destination of the tour coincide, then travel time to the primary sojourn is equal to the round-trip time from the origin to that sojourn. Travel time allocated to the secondary sojourn is equal to the travel time incurred in excess of the travel time of the tour that includes only the origin of the tour, the primary sojourn, and the destination of the tour. Travel time to lower ranking sojourns is only the marginal (or excess) travel time to those sojourns, and it is shared among them as a proportion of the time spent at the sojourn performing the activity. A simplified example of the allocation algorithm is presented in Figure 3.2. Summarizing, travel time to the primary sojourn is equal to the total travel time to that sojourn, while travel time to the remaining sojourns in the same tour is equal only to the marginal travel time.



Travel time allocated to social/recreation is travel time Ⓢ-②-Ⓕ minus travel time Ⓢ-Ⓕ . Travel time allocated to shopping is travel time Ⓢ-①-② minus travel time Ⓢ-②

Figure 3.2

Example of Allocation of Travel Time to Activities

3.4 Conclusions

This chapter has described the data used in this research and the data processing required for estimation of the econometric models. A major portion of the data processing costs was related to the evaluation of accessibilities. An alternative, less expensive measure, which does not involve enumeration of alternatives, has been considered. This measure, however, is derived from highly simplifying assumptions on the distribution of alternatives available to individuals, and has not been sufficiently tested to be used in this research. The measure of accessibility which involves enumeration of alternatives was used. Nevertheless, the difference in computational costs between the two measures is large enough to justify additional tests of the validity of the simplified measure of accessibility.

CHAPTER IV

THE THEORETICAL MODEL OF NON-WORK ACTIVITY DURATION

4.1 Introduction

This chapter presents a theory of non-work activity duration. Only travel related activities, that is, activities that have to be performed away from home or work, and reached by a motorized vehicle are analyzed. Primarily because of data limitations, it was not possible to model neither in-home activities, nor activities which can be reached by a short walk. Nevertheless, it should be noted that the largest proportion of participation in out-of-home non-work activities requires motorized travel.

For the purpose of modelling non-work activity duration, it is assumed that work or school duration, the mode to work or school, residential location, and automobile ownership are exogeneous variables. This implies that the choice of activity duration is made conditional on these variables. While the scope of this research is limited to the modelling of activity duration, related research currently in progress (Damm, 1978) is investigating the issues involved in the scheduling of activities and travel.

4.2 Theory of Time Allocation Revisited

This section presents a theory of time allocation which includes explicitly transportation level-of-service. The theory of time allocation presented in this section is a reformulation of Becker's (1965) theory, with explicit inclusion of transportation level-of-service. It is hypothesized that consumers behave rationally and have perfect information and that the consumers' preferences are represented by a utility function. The utility of an activity program is written as follows:

$$U = U(Z_1, \ldots, Z_i, \ldots, Z_I) \qquad (4.1)$$

where Z_i is the "quantity" of activity i, with I non-work/non-school activities. The "quantity" of activity i is assumed to be a function of the inputs required. The inputs can be divided into three components: goods (X_i), durational component (a_i), and locational component (A_i). The "quantity" of activity is dependent on the type and quantity of goods purchased (or enjoyed) during the activity. The durational component of the activity is the time input, i.e. the actual time spent performing the activity, net of travel time. The locational component is the travel input. The travel input is represented by the travel pattern of individuals. Note, however, that consumers decide on activity duration prior to their decision on the travel pattern. Thus, the input to models of activity duration is only a measure of an indeterminate travel pattern. Appendix I discusses such a measure, which is called accessibility.

In order to simplify the discussion, assume that the Z_i's are the final activities, and that there is no joint production (i.e. producing one activity does not produce any other activity). The "quantity" of activity i can thus be written as:

$$Z_i = f_i(a_i, A_i, \vec{X}_i) \qquad (4.2)$$

where f_i is the "production function" via which a_i, A_i, and $\vec{X}_i$ are transformed into the activity. Assume that the production function is continuous in the N-dimensional vector of goods $\vec{X}_i$ and in the total activity duration T_i, and that the utility function U is continuous in the Z_i's. Consumers are faced with time and budget constraints:

$$\sum_{i=1}^{I} T_i = T \tag{4.3}$$

$$\sum_{i=1}^{I} (tc_i + \vec{P}'\vec{X}_i) = R \tag{4.4}$$

where T is the time available for non-work/non-school activities, tc_i is the travel cost to activity i, $\vec{P}$ is the vector of unit costs of market goods used as input in activities, R is the sum of earned and non earned income. Note that T and R are considered exogeneous attributes of the behavioral process modelled here.

Activity time a_i is by definition:

$$a_i \equiv T_i - tt_i \tag{4.5}$$

where tt_i is travel time to activity i.

For a given activity program, i.e. the set of activity durations $(T_1,\ldots,T_i,\ldots,T_I)$, the travel pattern is described by A_i's, tt_i's, and tc_i's. A_i is the utility of the destinations for the optimal travel pattern; tt_i and tc_i are, respectively, the travel time and the travel costs of the trips in the optimal travel pattern. The three measures above are a function of activity durations (T_i), and of land use ($\vec{LU}_i$) and level-of-service characteristics ($\vec{LOS}_i$). This implies the following relationship:

$$A_i = A_i(T_i, \vec{LU}_i, \vec{LOS}_i) \qquad (4.6)$$

$$tc_i = tc_i(T_i, \vec{LU}_i, \vec{LOS}_i) \qquad (4.7)$$

$$tt_i = tt_i(T_i, \vec{LU}_i, \vec{LOS}_i) \qquad (4.8)$$

Defining the shadow price of time as μ and the shadow price of money as λ, the Lagrangian of the constrained maximization is written as:

$$L = U - \mu(\Sigma T_i - T) - \lambda[\Sigma(tc_i + \vec{P}'\vec{X}_i) - R] \qquad (4.9)$$

The first order conditions with respect to the decision variables T_i and $\vec{X}_i$ are:

$$\frac{\partial U}{\partial X_{in}} - \frac{\lambda P_n}{\partial U/\partial Z_i} = 0 \qquad (4.10)$$

$$\frac{\partial U}{\partial T} - \lambda \frac{\partial tc_i}{\partial T_i} - \mu = 0 \qquad (4.11)$$

Equations (4.10) and (4.11) can be transformed as:

$$\frac{\partial Z_i}{\partial X_{in}} = \frac{\lambda P_n}{\partial U/\partial Z_i} \qquad (4.12)$$

$$\frac{\partial Z_i}{\partial T_i} = \frac{\mu + \lambda \frac{\partial tc_i}{\partial T_i}}{\frac{\partial U}{\partial Z_i}} \qquad (4.13)$$

Deriving from (4.12) and (4.13) the marginal rate of substitution:

$$\frac{\partial Z_i}{\partial T_i} / \frac{\partial Z_i}{\partial X_i} = \frac{\frac{\mu}{\lambda} + \frac{\partial tc_i}{\partial T_i}}{P_n} \qquad (4.14)$$

Note that $\partial T_i/\partial Z_i$ and $\partial X_i/\partial Z_i$ are, respectively, the marginal input of time and goods in the production of the "quantity" of activity Z_i. The left hand side of equation (4.14) is thus the marginal rate of substitution of time for market goods in the production of activity i. The second term in the right hand side numerator of (4.14) is the marginal travel cost to activity i. Thus the "price" of activity duration for activity i is the "value of time" as a resource (μ/λ) plus the marginal travel cost.

Similarly, at the optimum, the ratio of the marginal utilities with respect to total activity time is written as:

$$\frac{\partial U}{\partial T_i} / \frac{\partial U}{\partial T_j} = \frac{\frac{\mu}{\lambda} + \frac{\partial tc_i}{\partial T_i}}{\frac{\mu}{\lambda} + \frac{\partial tc_j}{\partial T_j}} \qquad (4.15)$$

Equation (4.15) also implies that, if the marginal travel costs to all activities were identical, then the ratio of marginal utilities of time would be constant. Note however that the hypothesis of identical marginal travel costs is not very realistic since trips to destinations where different activities are performed involve different congestion levels, roadway design, average speed and, in general, varying ease of access, all elements which may increase the cost of travel.

The implicit solution to the maximization problem in equation (4.1), (4.3), and (4.4) will be

$$T_i = T_i(T,\ R,\ P,\ \vec{LOS},\ \vec{LU}) \qquad \forall i \qquad (4.16)$$

It is necessary now to provide a stochastic structure to the model to account for taste variations in the population. It is assumed that total activity times T_i^t for different individuals t differ only through an observable vector S^t of socioeconomic and demographic characteristics, plus an additive term ε_i^t representing idiosyncratic preferences for various activities. Equation (4.16) is thus generalized to:

$$T_i^{\ t} = T_i^{\ t}\ (T^t,\ R^t,\ \vec{LOS}^t,\ \vec{LU}^t,\ S^t,\ \vec{P}) + \varepsilon_i^t \qquad \forall i \qquad (4.17)$$

Typically T^t and R^t will vary across individuals depending on the work duration, the duration of in-home activities, and the individual's income and wealth. $\vec{LOS}^t$, $\vec{LU}^t$ will vary across the individual's residential location, auto ownership, and work place. Note that the observed value of T_i^t can never be negative or larger than T^t, since no activity can have negative duration (physical constraint) or have a duration exceeding the duration allocated to all activities (time budget constraint).

CHAPTER V

ECONOMETRIC MODELS

5.1 Introduction

This chapter presents the econometric models of travel-related activity duration. Daily duration of an activity, i.e. the time spent performing the activity (including travel time to that activity), has a lower limit at zero and an upper limit at 24 hours. For at least some of the non-work, out-of-home activities many individuals will report null activity duration during a given day because they did not participate in the given activity. However, nobody will report a 24-hour activity duration. The form of the model porposed for estimation of activity duration takes into account the concentration of observations at the boundaries of activity duration. Observations for the individuals that did not participate in the activity modelled are concentrated at the lower limit. However, no individual will be observed at the higher limit. The proposed model form also assumes, because of model estimation requirements, that the explanatory variables influence both the probability of participation and the duration of the activity given participation. If only the probability of participation, without regard to the value of duration given participation, were to be predicted, a probit or other model of discrete choice would be suitable. The required estimator, however, would predict, in addition to the probability of participation, also the duration of the activity given participation. If no individual had zero activity duration, estimation of the model by ordinary least squares would be acceptable. However, for the problem at hand, ordinary least squares is not an acceptable estimator, because of the heavy concentration of observations at the lower limit; a hybrid of probit analysis and multiple regression is thus required.

5.2 Single Equation Limited Dependent Variable Model

The hybrid probit and multiple regression model mentioned in the previous paragraph was first developed by Tobin (1958). The model, called the limited dependent variable model, includes the following relationships for an individual t:

$$Y_t^* = \beta' X_t + \varepsilon_t$$

$$Y_t = \begin{cases} Y_t^* & \text{if } Y_t^* > 0 \\ 0 & \text{otherwise} \end{cases} \qquad (5.1)$$

Y_t^* is a latent (not directly observable) random variable, Y_t is the observed dependent variable, X_t is a column vector of constants for the observed exogeneous variables, ε_t is the error term which is assumed homoskedastic, serially uncorrelated and independent of X_t with distribution N $(0,\sigma^2)$, and β is a column vector of constants to be estimated. The log likelihood of the model for M observations is written as:

$$L^* = \sum_{t \varepsilon \Psi_1} \ln \left[1 - \Phi\left(\frac{\beta' X_t}{\sigma}\right)\right] - \frac{M_2}{2} \log \sigma^2 - \frac{1}{2\sigma^2} \sum_{t \varepsilon \Psi_2} (Y_t - \beta' X_t)^2 \qquad (5.2)$$

where ϕ (•) and Φ (•) are the unit normal density and cumulative functions respectively, Ψ_1 is the set of observations for which $Y_t = 0$, Ψ_2 is the set for which $Y_t > 0$, and M_2 is the number of individuals that did participate. The estimation of β and σ requires the maximization of the likelihood function. This maximization is performed by an iterative algorithm, and requires the repeated evaluation of the cumulative normal density function. Different types of iterative algorithms for estimation of the β's and σ can be used: optimal gradient search algorithms (such as the well known Newton-Raphson), and non-optimal search algorithms. Olsen (1976) has demonstrated that the likelihood function in equation (5.2) has a single maximum, and that any values of β and σ which do not cause the matrix of the second derivatives of the likelihood function (i.e. the hessian) to be singular, would be acceptable as initial values for an algorithm. Olsen's findings permitted the development of a search algorithm which differs from the Newton-Raphson procedure. This procedure (Fair, 1977) is shown to be considerable faster, for many problems, than the Newton-Raphson procedure.(*) For this research, however, the Newton-Raphson procedure was available (National Bureau of Economic Research, Inc., 1975; Nelson, 1974).

The expected mean and variance of the dependent variable are computed somewhat differently than for the multiple regression model. Specifically, the unconditional expected value of Y_t given the estimated constants β_o and σ_o and given the lower limit of Y_t at zero, is written as:

(*)A program to run Fair's procedure on IBM 370 systems has been developed and is available from the author.

$$E(Y_t | \beta_o'X_t, 0) = \beta_o'X_t \Phi(\frac{\beta_o'X_t}{\sigma_o}) + \sigma_o \phi(\frac{\beta_o'X_t}{\sigma_o}) \tag{5.3}$$

The expected value of Y_t given participation, and given β_o, σ_o and the lower limit at zero, is written:

$$E(Y_t | \beta_o'X_t + \varepsilon_t > 0, 0) = \beta_o'X_t + \sigma_o \frac{\phi(\frac{\beta_o'X_t}{\sigma_o})}{\Phi(\frac{\beta_o'X_t}{\sigma_o})} \tag{5.4}$$

The conditional variance of Y_t given $\beta_o'X_t+\varepsilon_t>0$ and the limit is written as:

$$E(Y_t^2 | \beta_o'X_t + \varepsilon_t > 0, 0) = \beta_o'X_t E(Y_t) + \sigma_o^2 \tag{5.5}$$

Note, in particular, that the conditional expected value of equation (5.4) is equal to the linear combination term $\beta_o'X_t$ plus a correction term which becomes small when $\beta_o'X_t/\sigma_o$ becomes large. $E(Y_t | \beta_o'X_t+\varepsilon_t>0,0)$ tends to $\beta_o'X_t$, the "regression's" expected value. The probability of participation in the activity (a binary probit) is written as:

$$P(\beta_o'X_t + \varepsilon_t > 0) = \Phi(\frac{\beta_o'X_t}{\sigma_o}) \tag{5.6}$$

5.3 Extension of the Single Equation Limited Dependent Variable Model

The limited dependent variable model presented in the previous paragraph assumes that the probability of participation and the time duration are influenced by the same explanatory variables. A more general model, proposed by Westin (1975), relaxes this assumption and allows the probability of participation and the time duration to have different explanatory variables. The two states are: participation (i.e. positive duration) and non-participation (i.e. null duration). The probability density function of vector Y_t (with elements Y_{t_1} and Y_{t_2}, the durations for the two states) is written:

$$\begin{pmatrix} Y_{t_1} \\ Y_{t_2} \end{pmatrix} \sim N\left[\begin{pmatrix} 0 \\ \beta' X_t \end{pmatrix}, \begin{pmatrix} o & o \\ o & \sigma^2 \end{pmatrix}\right] \quad (5.7)$$

where the two states subscripts on β and σ are supressed. The probability of choosing either state is defined by a probit model of choice:

$$P_{t_2}(Y_t, W_t) = \Phi(\alpha Y_{t_2} + \gamma' W_t) \quad (5.8)$$

and

$$P_{t_1}(Y_t, W_t) = 1 - P_{t_2}(Y_t, W_t) \quad (5.9)$$

where W is a vector of explanatory variables, γ a vector of constants, and α a scalar constant. The log likelihood function for the model is written as:

$$L^* = -\frac{M_2}{2} \ln \sigma^2 - \frac{1}{2\sigma^2} \sum_{t \varepsilon \Psi_2} (Y_{t_2} - \beta' X_t)^2 + \sum_{t \varepsilon \Psi_2} \ln \Phi(\alpha Y_{t_2} + \gamma' W_t) +$$

$$+ \sum_{t \varepsilon \Psi_1} \ln[1 - \Phi[(\alpha\beta' X_t + \gamma' W_t)/\sqrt{1+\alpha^2\sigma^2}]] \quad (5.10)$$

where M_2 is the number of individuals who participated in the activity. Note that even in the case where α is constrained to one and γ is constrained to zero, the log likelihood of Westin's model is not equal to the log likelihood of the limited dependent variable. In fact, the log likelihood in (5.10) has an extra term, $\sum_{t \varepsilon \Psi_2} \ln \Phi(\alpha Y_{t_2} + \gamma' W_t)$, which is equal to the component of the likelihood function for the probit analysis for the individuals who participated in the activity, if duration is included as an explanatory variable. Moreover the denominator of the fourth term in equation (5.10) has a correction $(1 + \alpha^2\sigma^2)^{1/2}$, instead of σ. Westin's estimator is clearly more desirable than Tobin's estimator since it imposes fewer restrictions on the model's specification. Nevertheless, the five stage estimation procedure of the model as proposed by Westin and Gillen (1977) produces estimates with very high variance when few individuals participated in the given activity, because $(\alpha\beta' X_t + \gamma' W_t / \sqrt{1 + \alpha^2\sigma^2})$ cannot be reliably evaluated. Thus, although Westin's theoretical model is attractive, the empirical application is, in this case, unfeasible. The models of activity duration presented in Chapter VI will thus be estimated using Tobin's estimator.

5.4 Simultaneous Equations Limited Dependent Variable Model

Although single-equation limited dependent variable models have been studied in detail, few econometricians have developed an estimator for simultaneous equation systems. The basic problem is that the full information maximum likelihood (FIML) estimator requires the evaluation of a multivariate normal cumulative distribution function, which is very tediuos to compute.(*) The two basic references for simultaneous models of the type discussed here are Amemiya (1974) and Nelson and Olson (1977). The model specification presented here is Nelson and Olson's, since it is the better adapted for the estimation of activity duration models. Amemiya's specification, in fact, breaks down when the proportion of observations at the limit is large, as is the case for the data used in this research.

For ease of exposition, a two equation model is presented. Both dependent variables are limited:

$$\text{(a)}\quad Y_{it}^{*} = \alpha_i Y_{jt}^{*} + \beta_i{}' X_t + \varepsilon_{it}$$

$$\text{(b)}\quad Y_{it} = \begin{cases} Y_{it}^{*} \text{ if } Y_{it}^{*} > 0 \\ 0, \text{ otherwise} \end{cases} \qquad \begin{matrix} i=1,2 \\ j=1,2, j \neq i \end{matrix} \qquad (5.11)$$

The reduced form is written as:

$$\text{(a)}\quad Y_{it}^{*} = \pi_i{}' X_t + \varepsilon_{it}{}'$$

$$\text{(b)}\quad Y_{it} = \begin{cases} Y_{it}^{*} \text{ if } Y_{it}^{*} > 0 \\ 0, \text{ otherwise} \end{cases} \qquad i=1,2 \qquad (5.12)$$

(*) Several references proposed simplified procedures for the approximate evaluation of the multivariate normal cumulative function. Among them Clark (1961), Dutt (1976), Hausman and Wise (1976), Manski _et al._ (1977). It was however not feasible, within this research to develop the FIML estimator using any of the proposed procedures.

The estimation of the model of equation (5.11) by FIML estimation requires the maximization of the following likelihood function:

$$L = \prod_{\Psi_1} \int_{-\infty}^{0} (1 - \alpha_1\alpha_2)\ f\ (Y_{1t}-\alpha_1 y-\beta_1{'}X_t,\ y-\alpha_2 Y_{1t}-\beta_2{'}X_t)\ dy$$

$$\prod_{\Psi_2} \int_{-\infty}^{0} (1 - \alpha_1\alpha_2)\ f\ (y-\alpha_1 Y_{2t}-\beta_1{'}X_t, Y_{2t}-\alpha_2 y-\beta_2{'}X_t)\ dy$$

$$\prod_{\Psi_3} \int_{-\infty}^{a} \int_{-\infty}^{0} (1 - \alpha_1\alpha_2)\ f\ (y-\alpha^1 z-\beta_1{'}X_t,\ Z-\alpha_2 y-\beta_2{'}X_t)\ dydz$$

$$\prod_{\Psi_4} (1 - \alpha_1\alpha_2)\ f\ (Y_{1t}-\alpha_1 Y_{2t}-\beta_1{'}X_t, Y_{2t}-\alpha_2 Y_{1t}-\beta_2{'}X_t) \qquad (5.13)$$

where Ψ_1 is the set of observations for which Y_{2t} is at the limit, Ψ_2 is the set for which Y_{1t} is at the limit, Ψ_3 is the set for which Y_{1t} Y_{2t} are at the limit, and Ψ_4 is the set that has neither Y_{1t} nor Y_{2t} at the limit; $f(\cdot,\cdot)$ is the bi-variate joint normal density function of ε_{1t} and ε_{2t}. Although the maximization of (5.13) is mathematically feasible,(*) in order to implement this estimator, a new computer program would have to be written. This, however, was deemed outside of the scope of this research. It was decided, instead, to follow the procedure proposed by Nelson and Olson.

Nelson and Olson developed an estimator equivalent to the two stage least square for estimation of simultaneous limited dependent variable

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(*) John (1959) has derived a simple reduction expression for the evaluation of the cumulative of a multivariate normal distribution.

models (2SLDV). For a proof of consistency, and for the derivation of the covariance matrix, the reader is referred to the original paper by Nelson and Olson (1977) and to Amemiya (1977). The computational procedure for the 2SLDV model is repeated here, for the special case of equation (5.11).

(a) Estimate π_i, i=1,2 in (5.12(a)) by maximum likelihood applied to the 2 equations separately.

(b) Form the instruments $Y_{it}* = \pi_i' X_t$

(c) Replace the Y_{it}^*'s on the right hand side of equation (5.11(a)) by the corresponding Y_{it}^*'s and, treating these instruments as fixed regressors and the resulting equations as single equation models, estimate the structural parameters in (5.11) by maximum likelihood applied to the two equations separately.

The covariance matrix of the estimated coefficients can be computed using the equations proposed by Amemiya (1977). However, for simplicity, the simultaneous models presented in the next chapter report only the approximated standard error computed by the second stage maximum likelihood. Further investigation should be devoted to the measurement of the error introduced by this approximation.

One major problem arises in the case of estimation of activity duration models using the 2SLDV procedure. As Nelson and Olson suggest, the 2SLDV procedure is well adapted when the limit on the dependent variable arises because of incomplete data reporting. When this is the case, $Y_{it}*$, the underlying value of the dependent variable, is a good substitute for Y_{it}. However, in the case of activity duration the equations in model (5.11) should be written as:

$$\text{(a)} \quad Y_{it}^* = \alpha_i Y_{jt} + \beta_i' X_t + \varepsilon_{it}$$

$$\text{(b)} \quad Y_{it} = \begin{cases} Y_{it}^* \text{ if } Y_{it}^* > 0 \\ 0, \text{ otherwise} \end{cases} \qquad \begin{matrix} i=1,2 \\ j=1,2 \;\; j \neq i \end{matrix} \qquad (5.14)$$

The simplicity of the procedure proposed by Nelson and Olson however cannot be duplicated with model (5.14). Since the development of a new estimation specification was outside of the scope of this research, it was decided to use as an approximation the 2SLDV procedure.

CHAPTER VI

EMPIRICAL MODELS

6.1 Introduction

This chapter describes the empirical results of the estimation of models for out-of-home non-work activity duration and travel time. Two types of models are estimated. The first type, the individual model, assumes that the basic decision unit is the individual, and that each individual makes activity duration decisions independent of the actual duration decisions made by other members of the household. The second type, the joint model, assumes, like the individual model, that the basic decision unit is the individual, but, contrary to the individual model, it assumes that activity duration for the male head of household is a function of the activity duration for the female head of household.

The theoretical background for the individual activity duration model is presented in Chapter IV. Because of the high non-linearity of the process modelled, an algebraic expression for the optimal activity duration cannot be found even when simplifying assumptions are made on some of the underlying relationships of the process. Thus, it was chosen to simplify the problem by assuming that the function relating the exogeneous variables (total time allocated to non-work activities, remaining income, land-use, level-of-service and the price of goods purchased) to activity duration is accessibility to the given activity. The other variables that enter the model include the socioeconomic and demographic characteristics of the individual which were found in the literature review (Chapter II) to be most relevant to activity duration.

The purpose of the first model type is to test empirically the validity of the activity duration theory presented in Chapter IV and the relative importance of the independent variables of the model. The second model type explicitly tests whether the husband's activity duration is dependent on the wife's activity duration and vice-versa.

The models of activity duration are calibrated using the limited dependent variable model presented in Chapter V; the models of travel time are estimated using ordinary least squares.

6.2 Specification of the Models

6.2.1 Models of Total Activity Duration

The purpose of this section is to formulate estimable models of total activity duration. In order to do this, it is necessary to assume specific functional forms for the theoretical relationships presented in Chapter IV and to select the set of independent variables that should enter the model specification.

Simplified Model of Activity Duration

The theoretical construct of the model of total activity duration presented in Chapter IV has not defined the functional form that relates variables such as utility, accessibility, travel time, etc. to the endogeneous variables. In order to obtain an estimable model, the functions have to be explicitly defined. However, even in the simplified case of the featureless plane presented in Appendix I, accessibility A_i, travel time tt_i, and travel cost tc_i are highly non-linear functions of T_i, the total activity duration, and the solution of the constrained utility maximization cannot be derived for the decision variables T_i. On a-priori grounds, nevertheless, it was hypothesized that the activity duration would be influenced by the ease of access to opportunities. Also individuals who participate more than average in a particular activity would reside closer to locations where the activity could be performed. The measure that was considered best adapted to represent the ease of access and the distribution of locations where activities can be performed, was accessibility. Accessibility, which is presented in detail in Appendix I, is sensitive to both changes in transportation level-of-service and to the changes in the availability of alternatives to perform a given activity. The proposed simplification is to use, as an explanatory variable, the expected accessibility given $T_i=\infty$. In theory, accessibilities to all activities should enter as explanatory variables to a given activity. Nevertheless, estimation of a model of activity duration with those explanatory variables did not yield reliable results, primarily because of the strong correlation between accessibilities for different activities. Thus it was decided to use, in the model for a given activity, only the accessibility to that activity, instead of all the accessibilities. Note that, because the accessibility measure developed in Appendix I is individual specific (it includes location and socioeconomic variables), the expected accessibility given $T_i=\infty$ is labeled $A^p_{i,\infty}$, where the superscript p refers to an individual.

It is necessary, at this point, to provide a stochastic structure to account for taste variation across the population. In fact, it should be recognized that different individuals decide differently on activity participation. It is assumed here that the difference in the outcome of the decision can be attributed to two factors, socioeconomic and demographic characteristics, (S^P) and idiosyncratic preferences, (ε^P_i). While accessibility varies for different individuals, thus explaining part of the taste variation, it is hypothesized here that activity duration is a direct function of S^P, and additive in ε^P_i. The general form of the model becomes:

$$T_i^P = g_i \ (A^P_{i,\infty}, S^P) + \varepsilon^P_i \tag{6.1}$$

It is assumed that the vector of variables S^P and the variable $A^P_{i,\infty}$ enter the function g_i in a linear fashion, so that the model can be written as:

$$T_i^P = \delta_1 + \delta_2 A^P_{i,\infty} + (S^P)' \ \tau + \varepsilon_i^P \tag{6.2}$$

where δ_1, δ_2 are scalar constants, τ is a column vector of constants, and $(S^P)'$ is the transpose of vector S^P.

<u>The Exogeneous Variables in the Models of Total Activity Duration</u>

Models for three types of non-work activities were estimated. The activity types are:

- Shopping
- Social/recreation
- Remaining Activities: Medical, Outdoor Recreation, Personal Business, and Serve Passenger

The model for shopping activity duration includes two measures of <u>shopping accessibility</u>. The first one is the home based accessibility, the second is the <u>home-work based accessibility</u>. The socioeconomic variables included in the shopping model are dummy variables for sex, driver's license, household size, age, work or (educational status), and the combined characteristics of work status, number of children in the household and age which describe the child rearing responsibilities.

The model for social/recreation activity duration includes social/recreation accessibility and socioeconomic characteristics. The socioeconomic characteristics include automobile ownership divided by household size, natural logarithm of household income and dummy variables for sex, age, driver's license and child rearing responsibilities of the individual. Note that the variable for child rearing responsabilities (role) is different for the shopping and the two other models. The role variable in the shopping model, contrary to the definition of the same variable in the two other models, changes value depending on whether the individual went to work (or school). The justification for the above difference is primarily due to the temporal characteristics of the activities. Typically, in fact, shopping and work (or school), occur during the same time period (the day), while social/recreation and activities such as outdoor recreation, personal business, occur on days or hours of the day during which work or school participation is not common.

The model of duration for the remaining activities includes the sum of the accessibilities for shopping and social/recreation. This variable is used as a proxy for locational attributes of the individual. The socioeconomic variables include all those appearing in the social/recreation model with the exclusion of the household income.

The exact definition of the variables for the three models described above is presented in Figures 6.1 and 6.2. The joint model of intra-household shopping activity duration has been estimated only for the shopping activity. It is composed of two equations, one for the male head of the household (the husband) and one for the female head of household (the wife). Both equations included the duration of shopping for the head of household of the opposite sex. The other variables included in the equations of the joint model were the same as those for the individual's shopping model with the exclusion of the dummy variables for sex and age, which are the dimensions of stratification of the models.

6.2.2 Models of Travel Time

The general form for the evaluation of the expected travel time to specific activities is written as:

$$E(tt_i) = \int_0^T tt_i \; P(T_i) \; dT_i \qquad (6.3)$$

where $E(tt_i)$ is the expected travel time to activity i, tt_i is the travel time conditional on T_i, and $P(T_i)$ is the probability of activity duration. The prediction of travel time by this functional form requires the integration of the function in equation (6.3). This approach, although theoretically attractive, was not feasible within this research because of computer budget constraints. It was decided, instead, to implement a simpler approach and only the expected value of T_i (instead of its distribution) was used in computing $E(tt_i)$. In order to do this, models for prediction of the share of total activity duration spent travelling were estimated. Three linear regression models were estimated for the three activity types (shopping,

Figure 6.1

Variables for the Shopping Person Model

Sex	1 if male 0 if female
Driver's License	1 no driver's license 0 has driver's license
Went to work or to school	1 yes 0 no
Household size	1 household size larger than two (excluding children under 5) 0 otherwise
Role	1 if age over 17, did not go to work and household has children 0 otherwise
Child	1 if age under 17 0 otherwise

Shopping accessibility for home based trips

Shopping accessibility for trips based on the home to work trip

Figure 6.2

Variables of the Social/Recreation Person Model

Variable	Definition
Autos owned/household size	
Natural logarithm of household income	
Sex	1 if male 0 if female
Child	1 if age under 17 0 otherwise
Role	1 if age over 17 and female or male head of household and household has children 0 otherwise
Driver's License	1 no driver's license 0 has driver's license
Went to work or school	1 yes 0 no
Social/recreation accessibility	

social/recreation and all remaining activities). The dependent variable of the models, the travel share, is the ratio of total travel time to reach the activity and the total activity duration. Total travel time includes in- and out-of-vehicle time; total activity duration is the sum of total travel time and net time spent performing the activity. Note that $tt_i \leq T_i$; therefore the ratio tt_i/T_i has to be always smaller than 1. Satisfying this condition can be guaranteed for any value of the independent variables by either simple truncation of the dependent variable (tt_i/T_i) between zero and one, or by predicting the value of the dependent variable assuming the underlying model is a limited dependent variable model with a lower limit at zero and an upper limit at one. The three regression models have T_i linear in tt_i because it was assumed that the ratio tt_i/T_i is constant for all T_i. The observations used for estimation of the models for each activity, include only individuals participating in that activity, since the travel share is undefined otherwise.

The variables included in the shopping travel share model are household income and accessibility for shopping trips. The social/recreation model similarly includes household income and accessibility for social/recreation trips. The model for the remaining activities includes a dummy variable for driver's license and the sum of shopping and social/recreation accessibilities.

6.3 Estimation Results

6.3.1 Models of Total Activity Duration

A) The Individual Activity Models

The individual models of total activity duration are estimated on a sample of 1431 individuals. The sample includes all individuals over five years of age in the 517 households which were randomly selected from the home interview survey.

The dependent variable, activity duration for each activity type, is always non-negative and, since the estimation sample is from a one day diary, it cannot be higher than 24 hours. These restrictions on the observed dependent variable are incorporated in the limited dependent variable estimation described in Chapter V. Summary measures of duration (travel and activity) for persons participating in activities are presented in Table 6.1, and statistics for accessibility measures are presented in Table 6.2.

Shopping Activity Duration

Several specifications were tried for the model of individual shopping duration. The final model specification is partly obtained from prior knowledge of the variables that should appear in the model, and partly from empirical considerations derived from estimation of preliminary models. In particular, the set of socioeconomic and demographic variables which appear in the model specification is obtained from current literature on activity pattern research. Included are variables such as sex, age, work or school status, household size, child rearing responsibilities, and driver's license status. Among the variables that were considered for inclusion in the model, but were excluded because of statistical problems, are income and autos owned. In particular, these two variables were found not to add any explanatory power to the model. The coefficient of income was statistically insignificant and correlated with the driver's license dummy variable when

TABLE 6.1

Average Total Activity Duration For Persons Participating in the Specific Activity

Activity	Percent Participants	Activity Duration (*)	Travel Time to Activity(*)
Shopping	.194	61.2708 (101.03)	23.7331 (18.6)
Social/Recreation	.175	143.856 (144.02)	32.0843 (24.5)
Medical	.020	57.931 (35.65)	24.8276 (23.7)
Outdoor Recreation	.055	125.772 (104.13)	27.2569 (25.4)
Personal Business	.137	85.8367 (112.18)	26.8955 (24.8)
Serve Passenger	.052	40.48 (50.26)	29.9244 (23.0)

Sample Size: 1431

(*) In parenthesis is the standard deviation.

TABLE 6.2

Statistics for Accessibility Measures

Statistics for Home Based Shopping Accessibility

Mean =	-22.8138
Std. dev. =	3.28772
Median =	-22.6

Statistics for Home Based Social/Recreation Accessibility

Mean =	-4.52342
Std. dev. =	1.21579
Median =	-4.26

the latter was included. Similarly, the coefficient of driver's license was significant and correlated with autos owned by the household and autos owned per household member when the latter was included. Moreover, when the driver's license variable was left out of the specification of the model, the coefficient of the automobiles owned variable (either the "by household" or the "per household member" measure) had low statistical significance, and was affecting the values of coefficients of other variables in the model.

All the coefficients that were included in the final model specification have the expected sign (Table 6.3). Specifically, the coefficient of the dummy variable for participation in non-discretionary activities (work and school) has a negative sign, suggesting that, as expected, workers (or students) allocate less time to shopping than non-workers (or non-students). A zero-one variable for participation was used instead of the duration of participation for non-discretionary activities. It was in fact found that the likelihood of the model was higher with the zero-one variable, than with the duration variable. A preliminary model was estimated with both variables (duration and dummy variable), but the duration coefficient was highly correlated with the coefficient of the dummy variable and had a positive sign, which is inconsistent with expected behavior. The role variable, which represents the child rearing and household care responsibilities, has a positive sign. This suggests that adults who don't go to work in a family with children tend to spend more time shopping than other individuals. Typically this market segment includes housewives who don't do any work outside the home (14.9% of the population), and fathers on their weekday off (4.9% of the population).

TABLE 6.3

Individual Shopping Duration Model

Variable	Unrestricted Model	Restricted Model
Constant	-40.6864 (.83943)	-155.884 (13.9372)
Sex {1 male, 0 female}	-22.2465 (1.63719)	
Driver's License {1 no, 0 yes}	-84.1696 (3.7099)	
Went to work or school {1 yes, 0 no}	-11.789 (.63419)	
HH size over 2 {1 yes, 0 no}	-41.0053 (2.55676)	
Role {1 if age over 17, did not go to work and HH with children, 0 otherwise}	32.2118 (1.6272)	
Child {1 if age under 17, 0 otherwise}	-14.3746 (.50474)	
Home based shopping accessibility	2.01161 (1.01637)	
Home-work based shopping accessibility [for individuals that went to work]	1.02554 (.77098)	
Standard Deviation	170.164 (20.715)	176.619 (20.5422)
- Log Likelihood	2227.7	2268.33
Likelihood ratio test	81.3	
ρ^2	.018	

(In parenthesis is the ratio of coefficient over its asymptotic standard error).

Dependent Variable: Total Shopping Duration

Sample Size: 1431

No. of participants in shopping activity: 281

The coefficient for the household size dummy variable is negative. The negative sign indicates that within larger families the task of shopping is shared by the members of the household, with corresponding time savings for each individual. Both the home based and the home-work based accessibilities have positive coefficients. This implies that higher accessibility leads to both more frequent and longer shopping durations. Note that the home-work based accessibility is defined only for individuals that went to work. This implies that, for workers, the value of the dependent variable of the model is affected both by an intercept effect (the dummy variable for participation in non-discretionary activities) and by a slope effect (the home based accessibility). For school children, only the intercept effect appears.

Social/Recreation Activity Duration

The specification of the model of social/recreation duration is similar to the specification of the model of shopping duration. The coefficients for the final specification of the social/recreation activity duration model all have the expected signs (Table 6.4). The variable which impacts the most on activity duration is the dummy variable for driver's license status. Specifically, a change in driver's license status shifts activity duration more than a change in work status or role in the household. The lack of a driver's license has, as expected, a larger negative effect on social/recreation duration than on shopping or the remaining activities. Also negative is the effect of the participation in the work or school activity and the child rearing and household care responsabilities. The coefficient of the natural logarithm of income is positive and indicates that individuals

TABLE 6.4

Individual Social/Recreation Duration Model

Variable	Unrestricted Model	Restricted Model
Constant	-420.924 (2.15143)	-289.633 (13.2984)
Autos owned/HH size	8.03613 (.165453)	
ln(HH income)	39.9866 (2.1076)	
Sex {1 male, 0 female}	-39.9632 (1.62808)	
Child {1 if age under 17, 0 otherwise}	49.5106 (.994965)	
Role {1 if age over 17, and female or male hd of hh, and hh w/child. 0 otherwise}	-34.3341 (1.23797)	
Driver's License {1 no, 0 yes}	-185.281 (3.95456)	
Went to work or school {1 yes, 0 no}	-56.8308 (2.16153)	
Accessibility social/recreation	31.162 (2.44725)	
Standard Deviation	307.587 (19.2883)	318.25 (19.1810)
- Log likelihood	2254.4	2279.97
Likelihood ratio test	51.1	
ρ^2	.011	

(In parenthesis is the ratio of coefficient over its asymptotic standard error).

Dependent Variable: Total Social/Recreation Duration

Sample size: 1431

No. of participants in social/recreation activity: 261

in wealthier households tend to allocate more time to social/recreation. The logarithmic transformation of income was chosen because it is assumed that there is a decreasing marginal effect of income on activity duration. The coefficient of accessibility has a large positive effect on activity duration. A small change in level-of-service to social/recreation destinations, for example, causes significant changes in the predicted time allocation. The variable of automobile ownership per household member (a measure of car availability) has a positive coefficient. The coefficient's low statistical significance is due primarily to the correlation of this with the coefficient of the driver's license status. Although the statistical significance of the coefficient is low, it was decided to include the car availability variable in the model because this variable is, on a priori grounds, believed to be a significant determinant of activity participation, particularly in the case of the most discretionary of the non-work activities, (social/recreation, personal business, outdoor recreation, etc.). Note that the car availability variable already appears in the measure of social/recreation accessibility.

Activity Duration for the Remaining Activities

The coefficients of the model for the remaining non-work activities all have the expected sign (Table 6.5). The role dummy variable, which represents the child rearing and household responsibilities, has a positive coefficient, suggesting that individuals in families with children allocate more time to non-work activities such as outdoor recreation, medical visits, etc. Note that the coefficient of automobiles owned per household member is larger than

TABLE 6.5

Individual Remaining Activities Duration Model

Variable	Unrestricted Model	Restricted Model
Constant	-138.637 (2.34924)	-159.245 (13.2520)
Driver's License {1 no, 0 yes	-93.0428 (4.51015)	
Went to work or school {1 yes, 0 no	-28.9148 (1.71031)	
Sex {1 male, 0 female	25.5746 (1.59557)	
Autos owned/HH size	69.7321 (2.22319)	
Role {1 if age > 17 and female or male head of HH and family w/ child. 0 otherwise	47.4211 (2.72956)	
Accessibility shopping + Accessibility social/recreation	1.39524 (.729734)	
Standard Deviation	219.301 (23.1776)	226.312 (23.0666)
- Log likelihood	2845.87	2880.19
Likelihood ratio test	68.6	
ρ^2	.012	

(In parenthesis is the ratio of the coefficient over its asymptotic standard error).

Dependent Variable: Total Activity Duration for Medical, Outdoor Recreation, Personal Business and Serve Passenger Activities

Sample Size: 1431

No. of participants in other activities: 354

the coefficient for the same variable in the social/recreation model, suggesting the added importance of car availability for the most discretionary activities such as personal business, serve passenger (activities which clearly cannot be performed without having an automobile available), and outdoor recreation.

Summary of the Estimation of the Individual Activity Models

The three models presented above all have the expected sign for the different variables. However, for some coefficients, the asymptotic standard error is relatively high. It is hypothesized that the above is due mainly to the nature of the process modelled, the type of observational data, and the small size of the data.

Specifically, the choice of activity duration is a process whose day by day outcome has very high variability, although over a longer time period it might be fairly stable. Typically, if an individual engages in a given activity every other day, on a given day there is a 50% probability of observing his participation. This probability distribution however, might be totally irrelevant over longer time periods (say a week), when the individual might be observed devoting a constant number of hours to the given activity.

The data used in the estimation of the models discussed here is composed of a day's diary. This implies that the activity durations show high variability both in the observed values and in the model predictions. As discussed above, this is not necessarily due to the model's misspecification, but in large part to the sampling procedure.

Note, however, that averaging activity participation of individuals over a longer period of time is not desirable. Although using averages improves the statistical fit of the model, the inherent variability of the process is lost. Moreover, with the "averages" it would be impossible to estimate a frequency (or generation) model.

Overall, it should be pointed out that in the estimated models, most of the variation in the activity duration is explained by the choice of whether to participate in a given activity or not. Probability of participation and how long to participate, are decisions which are assumed to be made jointly and should thus be estimated as a joint model. The hypothesis of jointness of the two decisions (participation/duration) was further validated by limited tests on the estimation of sequential models of probability of participation and duration given participation. Specifically, ordinary least squares estimation of activity duration given participation, using only observations on individuals who participated in the given activity, yielded wrong signs for the coefficients of some of the independent variables of the model. The joint model (the limited dependent variable estimator), with the same set of independent variables, however, yielded correct signs.

A different joint model was tried for the models of activity duration. This model (Westin, 1975), discussed in detail in Chapter V, is a generalization of the limited dependent variable estimator proposed by Tobin (1958). It assumes that the decisions of participation and duration given participation are made jointly, but can be a function of a different set of independent variables. Westin's model was, however, unacceptable because the actual model calibration yielded statistically unreliable estimates.

Although the models presented are statistically valid, it is suggested, for future work, to use a larger sample. A larger sample was available for this research, but it was reduced to limit the computational expense of the estimation. A larger sample would yield lower variance of the coefficients and would probably yield acceptable estimates for the general model of choice proposed by Westin. The transportation policy and socioeconomic implications of the individual activity duration models is presented in Chapter VII.

B) The Joint Activity Model

The hypothesis of intrahousehold task sharing is explicitly tested by the estimation of a joint limited dependent variable model forthe total shopping activity duration of male and female heads of households. The individual activity duration models include some measure of intrahousehold jointness of decision, particularly through the dummy variable for household size. The joint activity model explicitly tests the jointness by estimating simultaneous equations. The estimator adopted is the two stage least squares equivalent proposed by Nelson and Olson (1977) and presented in detail in Chapter V. Coefficients obtained using this estimator are compared to the coefficients obtained by estimating two single equation limited dependent variable models for the two household heads. The two equations for the male and for the female head of household include, as one of the explanatory variables, the shopping activity duration of the spouse. In the case of the simultaneous estimation, the shopping activity duration of the spouse is assumed to be an endogenous variable; in the case of the single equation estimation, it is assumed exogenous. By analogy to the simultaneous regression model, it is hypothesized that the coefficients of the limited dependent variable single equation estimation are inconsistent. The comparison of the coefficients of the simultaneous and the single equation joint models can thus provide insight on the existance of "strong" or "weak" simultaneity. For comparative purposes, coefficients are estimated also for an additional reduced form specification which does not include the companion's shopping activity duration. The joint and reduced form model estimated with data from 342 male heads of household and as many females belonging to the same households. The sample of 342 households is a subset of the of the original 517 households; households which did not have both male and female heads were excluded. The variables of the model include the spouse's shopping activity duration, and the variables of the individual shopping duration model with the exclusion of sex, age and school participation.

For reasons discussed in Chapter V, the two-stage limited dependent variable (2SLDV), procedure proposed by Nelson and Olson (1977) was used for estimating the coefficients of the joint equation model. The results of the estimation are presented in Tables 6.6 and 6.7.

Model for the Male Heads of Household

The statistical significance of the model coefficients if low for all the coefficients except home-work based shopping accessibility. It is hypothesized that the low statistical significance of the estimated coefficients is due to two primary reasons. First, the estimator of the model, as discussed above and in Chapter V, is not entirely appropriate for the problem at hand. Second, the sample size of 342 observations is probably small for modelling activity duration, given that less than 20% of the individuals participate in shopping the day recorded in the interview.

TABLE 6.6

Model of Shopping Activity Time for Male Head of Household

Variable	Reduced Form Model	JOINT MODEL	
		Simultaneous Estimation	Single Equat. Estimation
Constant	-213.482 (1.57787)	-178.185 (1.21611)	-195.264 (1.46773)
Driver's License {1 no, 0 yes}	-64.7825 (.606463)	-53.0577 (.488703)	-48.2226 (.447938)
Went to work {1 yes, 0 no}	3.5062 (.06372)	-1.79656 (.031917)	1.6287 (.029473)
HH size over 2 {1 yes, 0 no}	-36.6386 (1.07048)	-30.294 (.848836)	-15.7426 (.462064)
Role {1 if household with children, 0 otherwise}	-4.55442 (.074681)	-7.75775 (.126738)	-7.63769 (.125932)
Home Based Shopping Accessibility	-2.84731 (.54008)	-1.87322 (.340974)	-.20311 (.038713)
Home-Work Based Shopping Accessibility [if went to work]	4.83937 (1.6573)	4.72401 (1.61924)	4.67524 (1.6226)
Shopping Activity Time Female Head	-	.217736 (.603286)	1.14978 (3.75125)
Sigma	231.286 (11.5492)	230.955 (11.5515)	225.392 (11.6307)
-Log Likelihood	661.887	661.703	654.627

(In parenthesis is the asymptotic t-statistic)

Dependent variable: Total Shopping Activity Duration

Sample size: 342

TABLE 6.7

Model of Shopping Activity Time for Female Head of Household

Variable	Reduced Form Model	JOINT MODEL: Simultaneous Estimation	JOINT MODEL: Single Equat. Estimation
Constant	-110.038 (1.88485)	-185.445 (2.33412)	-117.285 (2.02164)
Driver's License {1 no, 0 yes}	-105.923 (4.40125)	-115.061 (4.58934)	-104.445 (4.37311)
Went to work {1 yes, 0 no}	-63.3797 (2.07929)	-65.4912 (2.16486)	-62.9707 (2.08265)
HH size over 2 {1 yes, 0 no}	-36.4711 (2.6244)	-48.1024 (2.59257)	-34.6973 (2.19567)
Role {1 if household with children, 0 otherwise}	7.49386 (.3693442)	3.4992 (.17238)	5.95977 (.296225)
Home Based Shopping Accessibility	-4.28355 (1.79037)	-5.2572 (2.1229)	-4.45562 (1.87856)
Home-Work Based Accessibility [if went to work]	-2.42379 (1.24295)	-2.12696 (1.09414)	-2.48061 (1.283)
Shopping Activity Time Male Head	-	-.371556 (1.4247)	.17922 (2.59333)
Sigma	113.182 (12.6938)	112.07 (12.6911)	111.793 (12.7181)
-Log likelihood	766.7	765.695	763.305

(In parenthesis is the asymptotic t-statistic)

Dependent variable: Total Shopping Activity Duration

Sample size: 342

Despite the poor statistical properties of the model, it is possible to derive some useful insight from the estimation. In particular, it should be noted that the simultaneous and the single equation estimation of the joint model yield somewhat different coefficient estimates. This would suggest the existance of at least a "weak" simultaneity in the process. Also note that the coefficient of the shopping time of the wife has a positive coefficient, indicating that husbands tend to shop more when their wives shop more. This phenomenon is probably due to the face that typically Saturday shopping is done by all the members of the household together.

Model of the Female Heads of Household

The same statistical caveats apply for the model of female head of household as for the model of male head of household. However in this model all the coefficients of the socioeconomic variables have the expected sign and, except for the role variable, are significant at the 95% confidence level. Note that the coefficient estimates for the two accessibilities are negative and fairly stable for the reduced form and joint models. It is interesting to note also that the coefficient for the shopping activity time of the husband is negative for the simultaneous equation and positive for the independent estimation. Since, as suggested earlier, it is hypothesized that single equation estimation of one equation in a simultaneous equation system yields inconsistent results, the simultaneous estimation is a priori deemed more reliable. The negative coefficient of male shopping activity time indicates that the husband's shopping has a negative effect on shopping activity duration of the wife. This suggests that wives substitute their own shopping time for their husbands shopping time;that is, wives do not have a strong preference to going themselves or to sending their husbands. On the other hand, as shown by the male head of household model, husbands prefer to shop with their wives and thus shop more if their wives shop more.

Summary

The joint model discussed in this section is a first attempt to explicitly explain simultaneity in intrahousehold task sharing. Additional research should be devoted to the development of a behavioral theory of the joint process which recognizes the substitutability and ccmplementarity of the household heads' activity time. Ih addition to the theoretical issue, it is also suggested 1) to develop an improved estimator for simultaneous limited dependent variables models, possibly using FIML (full information maximum likelihood), and 2) to use larger samples.

6.3.2 Models of Travel Time

Three models of travel time were estimated for the three activity types: shopping, social/recreation and remaining activities. The models predict the share of total activity duration devoted to travel. The models were estimated using ordinary least squares on observations with non-zero travel times.

Model of Travel Time to Shopping Destinations

The coefficients of travel time to shopping destinations have the expected signs (Table 6.8). A decrease in accessibility implies an increase in the share of total activity duration devoted to travel.

Dependent variable: Share of total shopping activity duration spent travelling

Mean = .34571

Sample size :281

R^2=.02847 $\bar{R}^2$ = .02148

σ = .1771

	Coefficient	t-statistics
Constant	-.18529	.99379
ln (household income)	.04653	2.59488
Accessibility shopping	-.00412	1.30157

TABLE 6.8

Model of Travel Time to Shopping Destinations

Specifically, if the cost of travel increases individuals will travel a longer amount of time to destinations which have lower travel costs associated with them. If in- or out-of-vehicle time increases, individuals will have to travel a longer amount of time to get to activities and the share of total activity duration they will devote to travel will increase. Income is also positively related to the share of travel since wealthier people can allocate a larger monetary budget to travel.

Model of Travel Time to Social/Recreation Destination

Because of problems with the software used for estimation of the travel time models, it was not possible to evaluate directly the share of total activity duration devoted to travel. Instead, the dependent variable of the model was chosen to be the travel time to social/recreation destinations, and all the independent variables were multiplied by total activity time for social/recreation. The estimation of such a model yields results which are different from the model which would have as a dependent variable the share of total activity duration devoted to travel, since different assumptions are made on the unobserved error term of the regression. However, unbiased predictions of the share of total activity duration devoted to travel can be obtained by dividing the right and left hand side of the regression by total activity duration. It should be added that the relative efficiency of the estimated model with respect to the model whose dependent variable is the share of total activity time spent travelling, clearly depends on the underlying distribution of the unobserved error term. Note that the R^2 and $\overline{R}^2$ are not reported because they are not available; the software used for estimation, in fact, does not compute R^2 or $\overline{R}^2$ correctly for the model specification used.

Dependent variable: Travel time to social/recreation destinations

Mean : 32.08430

Sample size :261

R^2 = n.a. $\bar{R}^2$ = n.a.

σ = 24.8804

Definition: T = total social/recreation duration

	Coefficient	t-statistics
Constant x T	-.39115	3.30622
ℓn (household income) x T	.04514	3.86574
Accessibility social/ recreation x T	-.02355	2.16992

TABLE 6.9

Model of Travel Time to Social/Recreation Destinations

Model of Travel Time to the Remaining Activities Destination

This model was estimated, in a fashion similar to the social/recreation travel share model, using as dependent variable travel time to remaining activities, and by multiplying the independent variables by the total duration of remaining activities (Table 6.10). Similar caveats apply to this model specification as to the model of travel time for social/recreation activities. A different specification than the one used in the shopping and social/recreation model was, however, chosen, because it is assumed that travel to the remaining activities is most sensitive to the possession of a driver's license. Travel to activities such as personal business and/or outdoor recreation has, in fact, characteristics which are significantly dependent on the possession of the license. Accessibility for shopping and social/recreation has a positive sign indicating that when travel cost (or time) increases, the share of travel to remaining activities decreases. In this model, accessibility and the driver's license possession acts only as a proxy for desired vehicular mobility. It is thus reasonable to expect a positive effect on activity duration of increased accessibility and possession of a driver's license.

Summary

The specification of the models of travel time estimated here is a simplification of the form presented in equation (6.3). It was however decided to adopt this simplification in order to streamline the estimation and prediction phases of the research, and to remain within the allocated analysis budget.

Dependent variable: Travel time to remaining activities

Mean: 33.59890

Remaining activities: Medical, outdoor recreation, personal business, serve passenger.

Sample size: 354

R^2 = n.a. $\bar{R}^2$ = n.a.

σ = 25.1284

Definition: $\bar{T}$ = total duration of remaining activities

	Coefficient	t statistics
constant x T	.30230	5.05435
T x Driver's License {1 no, 0 yes}	-.06011	3.02851
(Accessibility shopping + accessibility social/recreation) x T	.00320	1.43756

TABLE 6.10

Model of Travel Time to the Remaining-Activities Destinations

Accessibility has a negative sign in the shopping and social/recreation travel share models indicating that a decrease in transportation level-of-dervice (increase in cost, in-vehicle travel time or out-of-vehicle time) would cause an increase in the share of total activity time spent travelling. For the remaining activities, the sign of the coefficient of the accessibility measure is positive, suggesting that the travel share of remaining activities would decrease in case of a decrease in transportation level-of-service.

CHAPTER VII

IMPLICATIONS OF THE ESTIMATED MODELS

7.1 Introduction

In order to clarify some of the implications of the activity pattern models, this chapter analyzes aggregate predictions derived from the models. Two general types of model predictions are discussed. The first presents the impact of level-of-service policies on predicted activity duration and travel time. The second analyzes the change in aggregate activity duration due to changes in socioeconomic characteristics, with specific focus on current trends in female labor force participation and possession of a driver's license.

7.2 Activity Patterns for Transportation Level-of-Service Changes

The models presented in Chapter VI are sensitive to level-of-service. Specifically, a change in out-of-pocket costs, or in travel time to destinations, will have an effect on the predicted activity patterns, *i.e.* on activity duration and travel time to the activities. It is the purpose of this section to report the impact of transportation level-of-service changes on aggregate activity patterns.

The policies tested included changes in automobile operating costs, and in out-of-vehicle and in-vehicle time. No attempt is made to investigate the destination and mode choice implications of the changes. Rather, the emphasis is on the shifts in total activity duration and the travel time to activities. In particular, changes in travel time are an indication of changes in vehicle-miles travelled, or combustion emissions. In order to simplify the analysis, and to limit the analysis cost, only automobile related policies are tested. The models are however sensitive to public transportation policies, and such policies could be tested. The three level-of-service policies discussed in this section are, among the automobile related policies, those which are the most often considered by transportation planners (and politicians). Schemes for implementation of these policies include added gasoline or roadway taxes, parking restrictions, signallization, speed limits, one-way streets, etc.

In order to simplify the computation of the predictions, changes in the value of the endogenous variables are predicted only for a limited number of market segments. All the prediction values were computed from the estimated models using a programmable pocket calculator. For level-of-service policies, predictions are computed for only one "average" individual. Moreover, it was assumed that there is only one destination available for each alternative activity. The values of level-of-service and land-use characteristics used refer to that single destination and are sample averages. Home-work based shopping accessibility for workers is, for simplicity, assumed constant across all policies and equal to the average value observed in the sample. The values of the variables (socio-economic, level-of-service, and land-use) for the base case are listed in Table 7.1. The results of the policy predictions measures, and their definition is:

1) Activity duration given participation is the predicted activity duration, conditional on participation in the activity.

2) Probability of participation is the probability that activity duration for the activity will be non-zero.

3) Unconditional activity duration is the predicted duration independent of the probability of participation.

Table 7.1

Base Values for the Exogenous Variables of the Activity Duration Models for Use in Level-of-Service Policy Predictions

Socioeconomic

Dummy for sex = .5; Dummy for driver's license = .4; Dummy for travel to work or school = .5; Dummy for household size = .6; Household size = 1.85; Dummy for child = .1; Dummy for role = .2; Automobiles owned = 1.3; Income = $13,500/year.

Level-of-service for Shopping Travel

Dummy for automobile mode = .9; Out-of-vehicle time = 2 minutes; In-vehicle travel time = 6 minutes; Out-of-pocket travel cost = 30¢; Distance = 3 miles.

Land-use for shopping travel

Retail employment density = 30 retail employees per net commercial acre; Retail employment = 200 employees; Home-work based shopping accessibility = -4.8 .

Level-of-service for Social/Recreation Travel

Dummy for automobile mode = 1; Out-of-vehicle time = 3 minutes; In-vehicle travel time = 10 minutes; Out-of-pocket travel cost = 50¢; Distance = 5 miles.

Land-use for Social/Recreation Travel

Population = 900; Total zonal employment = 100 employees; Vacant area = 5.0 acres.

4) Travel time given participation is the travel time to the activity derived from the activity duration given participation in the activity.

5) Unconditional travel time is the travel time to the activity derived from the unconditional activity duration.

6) Total unconditional travel time is the sum of the unconditional travel times for all the activities modelled. (Table 7.2).

7.2.1. Doubling Out-of-Pocket Costs

The policy of doubling out-of-pocket (operating) costs does not have a major effect on activity duration, or travel time, for any of the three activity types. This is due to the relatively small effect of travel cost on the accessibility. The doubling of automobile operating costs decreases the probability of participation in shopping and social/recreation activities by .6% and .8% respectively. Expected duration and travel time for the same two activities, however, changes by smaller percentages. Note that, for shopping and social/recreation, travel time given participation increases, while unconditional travel time decreases. This indicates that participation in activities will require longer travel times, since individuals will choose different destinations with lower access costs. However, the reduced frequency of activity participation will cause an overall decrease in travel time (-.3% and -1.2% for shopping and social/recreation trips, respectively).

7.2.2 Doubling Out-of-Vehicle Time

The doubling of out-of-vehicle time has a much more significant effect on activity patterns than the doubling of cost. Most significant are the changes in travel time and in the probability of participation in activities.

Measure		Policy: Base			Double out-of-vehicle time			Double in-vehicle time			Double out-of-pocket cost		
	Activity	1	2	3	1	2	3	1	2	3	1	2	3
Activity duration given participation	Expected value [min]	92.19	150.98	128.38	91.31	145.75	127.82	90.11	140.32	126.55	92.06	150.69	128.72
	Change with respect to base case [%]	-	-	-	-1.	-3.5	-.8	-2.2	-7.1	-.8	-.1	-.2	-.1
Probability of participation	Expected value [%]	17.9	11.9	23.8	17.3	10.0	23.2	16.4	8.3	22.4	17.8	11.8	23.7
	Change with respect to base case	-	-	-	-3.6	-15.4	-2.5	-8.4	-30.2	-5.9	-.6	-.8	-.4
Unconditional activity duration	Expected value [min]	16.52	17.92	30.66	15.77	14.64	29.65	14.80	11.62	28.60	16.41	17.73	30.56
	Change with respect to base case [%]	-	-	-	-4.5	-18.3	-3.3	-10.4	-35.2	-7.4	-.7	-1.1	-.4
Travel time given participation (*)	Expected value [min]	31.33	29.03	24.88	31.82	31.33	23.43	32.48	33.67	21.61	31.40	29.16	24.72
	Change with respect to base case [%]	-	-	-	1.6	7.9	-5.8	3.7	16.0	-13.1	.2	.4	-.6
Unconditional travel time (*)	Expected value [min]	5.6	3.5	5.9	5.5	3.1	5.4	5.3	2.8	4.8	5.6	3.6	5.3
	Change with respect to base case [%]	-	-	-	-1.8	-9.3	-8.2	-5.0	-19.1	-18.3	-.3	-1.2	-1.1
Unconditional travel time (*) (cumulative)	Expected value [min]		15.0			14.0			12.9			14.9	
	Change with respect to base case [%]		-			-6.4			-14.1			-.9	

(*) Includes out-of-vehicle time and in-vehicle time.

Activities: 1. Shopping

2. Social/Recreation

3. Remaining activities: Medical, Outdoor Recreation, Personal Business, Serve Passenger.

Table 7.2
Measures of Activity Duration and Travel for Level-of-Service Policies

Particularly sensitive to out-of-vehicle time is the social/recreation activity; this policy causes a 15% decrease in the participation rate with a 9% decrease in the total travel time generated by social/recreation trips. Shopping is less sensitive to the policy, and the decrease in total travel time is 2%.

7.2.3 Doubling In-Vehicle Travel Time

The policy of doubling in-vehicle travel time has a significant effect on activity patterns. Note that the largest change is predicted in the probability of participation in social/recreation trips, a drop from 11.9% to 8.3%. Also the unconditional expected travel time decreases from 3.5 to 2.8 minutes, a drop of 19%. The predicted decrease in unconditional travel time to the remaining activities is 18%.

7.2.4 Summary

The changes in non-work activity duration due to level-of-service policies all have the expected sign. A cost or time increase causes activity duration for all activities to decrease. Note that the pricing policy yields changes in predictions which are much smaller than the changes in prediction due to travel time policies. For all non-work activities the travel time changes due to the pricing policy is negligible. However, the out-of-vehicle time policy decreases non-work travel time by 6.4% and non-work participation 5.8%. The in-vehicle time policy decreases non-work travel time by 14.1% and trip generation by 12.1%.

7.3 Future Changes in Activity Patterns

This section illustrates the effect of socioeconomic and demographic variability on activity duration. Sensitivity of expected activity duration to socioeconomic and demographic characteristics is tested by varying the values of the relevant independent variables in the models. Furthermore, specific emphasis is placed on two relevant trends, the increased participation of females in the labor force, and the increased desire of individuals for vehicular mobility, as represented by the increased rate of issuance of driver's licenses.

7.3.1 Implications of Socioeconomic Characteristics

In order to test the implications of the socioeconomic characteristics on activity duration, a segmentation of the population into relatively homogeneous markets is performed. The dimensions of stratification used are four: sex, work (or school) travel, possession of a driver's license and age. The share in the population of the 12 markets derived from the proposed stratification is illustrated in Table 7.3. Note that, by definition, children (under 17 years of age) do not possess a driver's license. This implies that the market segments of children with driver's license are void. The value of the independent variables which were not used in the stratification is assumed to be the average value of that variable in the corresponding market segment. The predictions which were derived from the above classification (for the three activity types across the twelve market segments) are presented in Tables 7.4, 7.5 and 7.6.

The effect of a single variable on the activity duration of the population as a whole is tested by modifying the base case share of the market segments. As an example, in order to test the effect of an increase in the possession of driver's licenses, the share of individuals with driver's licenses is increased by 1% with respect to the base case.

Sex	Work or School Status	Driver's License	Age	Frequency in the Population	Market Segment Number
Male	Went to work or school	Yes	Under 17	-	
			Over 16	.2034	1
		No	Under 17	.0263	2
			Over 16	.0071	3
	Did not go to work or school	Yes	Under 17	-	
			Over 16	.1181	4
		No	Under 17	.1174	5
			Over 16	.0114	6
Female	Went to work or school	Yes	Under 17	-	
			Over 16	.0818	7
		No	Under 17	.0249	8
			Over 16	.0171	9
	Did not go to work or school	Yes	Under 17	-	
			Over 16	.2091	10
		No	Under 17	.1195	11
			Over 16	.0640	12

TABLE 7.3
Definition and Frequency of the Market Segments in the Population

Measure \ Market Segment	1	2	3	4	5	6	7	8	9	10	11	12	Weighted Sum (*)
Expected duration given participation [min]	92.33	80.13	77.51	106.31	76.72	88.08	101.01	104.67	81.25	112.41	80.40	92.67	95.3058
Probability of participation	.1802	.0974	.0822	.2870	.0778	.1496	.2461	.2744	.1043	.3340	.0990	.1827	.206642
Unconditional expected duration	16.64	7.80	6.37	30.51	5.97	13.18	24.85	28.72	8.47	37.54	7.96	16.93	20.8664

(*) Weighted by the frequency in the population

TABLE 7.4

Base Measures of Shopping Duration

Measure \ Market Segment	1	2	3	4	5	6	7	8	9	10	11	12	Weighted Sum(*)
Expected duration given participation [min]	155.8	133.1	126.3	160.1	141.8	129.3	163.6	139.1	131.8	168.2	148.5	135.1	153.78
Probability of participation	.136	.062	.045	.153	.088	.052	.167	.079	.058	.186	.110	.067	.1316
Unconditional expected duration	21.2	8.2	5.6	24.5	12.4	6.7	27.3	11.0	7.7	31.2	16.3	9.1	20.71

(*) Weighted by the frequency in the population

TABLE 7.5

Base Measures of Social/Recreation Duration

Measure \ Market Segment	1	2	3	4	5	6	7	8	9	10	11	12	Weighted Sum (*)
Expected duration given participation [min]	131.46	110.56	111.87	152.14	116.17	128.00	125.45	105.94	107.17	144.72	111.18	122.22	129.61
Probability of participation	.254	.134	.141	.376	.164	.233	.218	.110	.116	.333	.137	.199	.2438
Unconditional expected duration	33.36	14.79	15.74	57.28	19.09	29.83	27.33	11.67	12.46	48.21	15.24	24.31	32.83

(*) Weighted by the frequency in the population

TABLE 7.6

Base Measures of Remaining Activities Duration

The relative shares of the three other dimensions (sex, work or school travel and age) is maintained constant. In general, in order to maintain the relative shares of the other stratification dimensions constants, an iterative procedure is required. As an example, increasing the share of the market segments for individuals that possess a driver's license (market segments 1, 4, 7 and 10) would, if not adjusted, increase the share of male in the population. The prediction results for a 1% increase in the male population share and an identical increase in the share of individuals going to work or school and in the share of individuals possessing a driver's license are reported in Table 7.7. Note that the increase in male population share has a negative effect on shopping and social/ recreation duration and a positive effect on remaining activities duration. This suggests that men devote more time than women to activities such as personal business, serve passenger, etc. Somewhat surprising is the small changes caused by an increase in the share of workers (or students) in the population. This suggests that individuals who do not work (or do not go to school) allocate, at least during a weekday, most of their extra "leisure" time not to more out-of-home activities but to more in-home activities. As expected the increase in the share of individuals possessing a driver's license has a large positive effect on the duration and frequency of participation of all the activity types.

7.3.2 Implications of Socioeconomic Trends

This section examines the implications of two major socioeconomic trends: the increase in the female labor force participation and the increase in the possession of driver's licenses. The two trends are

	Activity	Shopping			Social Recreation			Remaining Activities		
	Measures	1	2	3	1	2	3	1	2	3
Sex effect	Expected Value	95.3	20.6	20.8	153.7	13.1	20.7	129.6	24.4	32.9
Sex effect	Change with respect to base case [%]	0.0	-.1	-.2	0.0	-.1	-.2	0.0	.1	.1
Work or school travel effect	Expected Value	95.3	20.	20.8	153.9	13.2	20.7	129.6	24.4	32.8
Work or school travel effect	Change with respect to base case [%]	0.0	0.0	-.1	0.0	0.0	-.1	0.0	-.1	-.1
Driver's license effect	Expected Value	95.4	20.8	21.0	153.9	13.2	20.8	129.8	24.5	33.0
Driver's license effect	Change with respect to base case [%]	.1	.5	.6	.1	.4	.4	.1	.4	.5

Measures:
1. Activity duration given participation [min]
2. Probability of participation [%]
3. Unconditional activity duration [min]

TABLE 7.7

Effect of Socioeconomic Characteristics on Activity Duration.

analyzed separately, and net of any other socioeconomic trend. It is assumed that the representative trends were those observed to have occured in the period 1969 to 1974. All the predicted changes in activity duration reported in this section refer to the expected change over this "typical" five year period.

The trends are derived from national data collected and tabulated by the U.S. Bureau of the Census (1975). It was also assumed that national trends would be valid in predictions for the Minneapolis-St. Paul metropolitan area.

Female Labor Force Participation

While the growth in participation of men in the labor force is parallel to the growth in the adult population (9.67% vs. 9.88%), the growth in women's participation is more pronounced. Between 1969 and 1974, the increase in female labor force has been 17.09%.(*) This is 7.12% above the adult population growth.

In order to compute the predicted activity duration for this scenario, the frequency of females over sixteen who went to work(**) is increased by 7.21%. The frequency of females over sixteen who did not go to work is decreased accordingly. The results of the predictions are reported in

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(*) The 17.09% increase includes both employed and unemployed women. However, in 1974 because of the very bad employment prospects, many women had effectively dropped out of the labor force, and do not appear in this increase. The true long run rate of increase of the femal labor force participation might thus be underestimated by the 1969 to 1974 trend.

(**) This includes the entire market segments 7 and 9.

Table 7.8. Note that, although work has a negative effect on activity duration, the model predicts an increase in activity duration for shopping and social/recreation. This is due to the fact that the frequency of working women with driver's licenses (market segment 7), within the class of working women, is much higher than the frequency of non-working women with driver's licenses within the class of non-working women. Assuming the new entrants into the labor force acquire licenses in the same proportion as their already working counterparts, this implies that an increase in the proportion of working women would increase the frequency of individuals in possession of a driver's license. Thus the decrease in shopping and social/recreation duration due to more working women is offset by the stronger effect of increased proportion of drivers. For the remaining activities, however, the negative impact of work on activity duration is not completely offset by the positive effect of driver's license. The effect on non-work activities of increased female participation in the labor force on the population as a whole is a decrease in the probability of participation of .04% and a decrease in the unconditional duration of .03%. These changes in aggregate predictions are very small, but it should be remembered that the fraction of the population which is affected by the trend represents only 10% of the total population.

Driver's License Possession

Statistics show that the share of adults possessing a driver's license is increasing. The increase in share appears, for all practical purposes, only in the group of adult women. The rate of increase of possession of driver's licenses in this group over the typical five year

TABLE 7.8

Activity Program Changes for Increased Female Labor Force Participation (*)

Activity	Shopping	Social/ Recreation	Remaining	Total
Duration given participation	.0175	.0204	-.041	-
Probability of participation	.0526	.053	-.127	-.04
Unconditional duration	.0408	.116	-.175	-.03

(*) Measures are percent changes with respect to base case period (1969 - 1974), net of population growth, is 13.8%. In order to compute the predicted activity duration due to this trend, the share of adult women with a driver's license is increased by 13.8%. The share of adult woemn without a license is decreased according. The results of the predictions are reported in Table 7.9. All the predicted changes have the expected sign.

The increase in the share of women drivers over non-drivers has the effect of increasing the proportion of adults and workers in the population. Note that, while work has always a negative effect on activity duration, the effect of adult age is positive on the shopping duration and negative on social/recreation duration (the age variable does not appear in the model of remaining activities). The negative effects of work and adult age (on social/recreation only) have not, however, altered the directionality of the changes in activity duration for any of the three activity types. The effect on all non-work activities of the increased possession of driver's licenses is an increase in the probability of participation of 2.8% and in the unconditional duration of 3.4%.

7.3.3 Summary

The changes in non-work activity duration caused by changes in socio-economic characteristics all have the expected sign. In particular, the possession of a driver's license and sex are the most important determinants of activity duration. Moreover, it is interesting to point out that the results of the models suggest that the effect on activity duration of going to work or school is very small. This implies that, if in the

TABLE 7.9

Activity Program Changes for Increased Possession of Driver's License (*)

Activity	Shopping	Social Recreation	Remaining	Total
Duration given participation	.951	.639	.799	-
Probability of participation	3.239	2.715	2.498	2.8
Unconditional duration	4.066	3.196	3.070	3.4

(*) Measures are percent changes with respect to base case future the work duration of individuals were to decrease, people would devote only a fraction of the additional time available to them to out-of-home activities; most of the additional time would be devoted to in-home activities.

The two scenarios of increased female participation in the labor force and increased possession of driver's licenses also have the expected effect on activity duration. A .9% increase in unconditional activity duration is predicted for the latter trend and a .03% decrease is predicted for the former, both over a five year period.

CHAPTER VIII

SUMMARY AND CONCLUSIONS

8.1 Summary

This research has addressed the theoretical and empirical issues in modelling the duration of non-work out-of-home activities. The primary objective of this research is to advance the state-of-the-art in non-work travel demand modelling. Specifically, past research has neglected to regard travel demand as demand derived from basic commodities such as activities. The decision to travel is, in almost all cases, not generated by the pleasure of driving, or sitting in a bus, but primarily by expectations on the activity to be performed at the destination of the trip.

The theoretical approach proposed here is derived from conventional consumer theory. It explicitly recognizes the impact of transportation level-of-service and land-use on activity duration. However, because of the complexity of the problem, it was not possible to solve analytically the proposed theoretical model. Nevertheless, based on the implicit solution and a priori considerations, it was assumed that accessibility, a composite measure of level-of-service and density of opportunities, should appear explicitly as a variable in the models of activity duration. Other variables which have been proposed in the current literature as determinants of activity patterns have also been included in the models. These variables are socioeconomic and demographic characteristics and include sex, work status, age, household size, child rearing responsabilities and income.

The shifts in non-work activity programs due to transportation level-of-service changes are significant, primarily for travel time policies (in- and out-of-vehicle times). In particular, a decrease in the speed of travel decreases activity duration for all the activities modelled and decreases the total time individuals spend travelling. The effect of the cost policy (out-of-pocket cost) is an order of magnitude smaller than the effect of the travel time policies. This is due, primarily, to the low importance individuals attach to travel cost when deciding on participation in discretionary activities. Note that a change in activity duration corresponds, in the framework developed for this research, to a change in probability of participation in the activity. Although a rigorous relationship between probability of participation and trip generation has not been developed, nevertheless it can be reasonably assumed that, everything else being equal, a decrease in the probability of participation in a given activity corresponds to a decrease in trip generation, and viceversa. Thus, among other things, by showing that non-work activity programs are sensitive, at least in the short run, to the level-of-service of the transportation system, it is possible to infer that trip generation is also sensitive to level-of-service.

The importance of socioeconomic characteristics is also significant. Specifically, the possession of a driver's license, which represents the desire for vehicular mobility, has a large impact on activity duration. While the percentage of adult women who have a driver's license has been increasing at a rate of approximately 2.7% per annum. This trend applied to the estimated models suggest that, in the future, more time is going to be spent in non-work out-of-home activities.

A major trend, which offsets somewhat the previous, is the one that indicates that more and more women are entering the labor force. While the pure effect of work participation is a decrease in activity duration for all activities, it is expected that working women would possess relatively more driver's licenses than non-working women, and thus would have higher travel mobility. The combined effect of increased work duration and driver's license possession due to this trend is an increase in shopping and social/recreation duration. Another major finding of this research indicates that a work duration decrease would not increase significantly the duration of weekday non-work activities. In particular, it is suggested that, in the future, if work hours were to decrease, the "new" leisure time available would not be devoted primarily to more out-of-home activities, but mostly to in-home activities.

The estimation of the simultaneous shopping duration model for the two heads of household has not been entirely satisfactory. This is due primarily to the large standard error for the estimated coefficients, and to the model form assumed (Nelson and Olson, 1977), which, although the best available at present, is not well adapted for the problem at hand. It was, nevertheless, possible to derive some preliminary conclusions. In particular, the estimated models suggest that the equation for the male head of household (the husband) should include the shopping activity duration of the female head of household (the wife).

Also the results of the models for heads of household suggest that estimation of models of activity duration for different population groups would yield coefficient estimates which can be significantly different from those estimated on the full cross-section of the population.

8.2 Recommendations and Directions for Further Research

8.2.1 Near Term Recommendations

The results of this research have provided useful insights in the modelling of activity duration and participation. Nevertheless, issues and problems, which for various reasons were not addressed, have surfaced both during the research, and in the analysis of the results. It is the purpose of this section to provide guidance to future researchers in this field, so that they might continue the work presented here, extending it, and avoiding some of the problems that were encountered.

The primary issue regards the size of the estimation sample. Strict budget constraints for this research have dictated a significant reduction in the sample size for model estimation. This, combined with the high variability of the observed activity durations and participation is assumed to be the major cause of the somewhat poor statistical properties of the estimated models. It is suggested, for future research, to use a larger sample of observations (>5,000 individuals). Note however that the costs of estimation of limited dependent variable models with such a sample size can be very high (>$100 per model).

A second important issue is the improvement of the models for prediction of travel time. The models presented in this research are multivariate regressions which predict the share of total activity duration which is devoted to travel for each given activity. A better model, which was not adopted for this research because of the limited computer budget available, is based on the explicit use of travel demand models such as a destination and mode choice model. This model derives directly from the models of activity duration and a travel demand model conditional on activity duration and does not require any additional model estimation.

Some of the empirical results also have suggested some areas in which further investigation seems appropriate. In particular, the issue of joint travel of members of the household has not been investigated. This was primarily due to the potential computational problems that could have been generated by the sorting of joint household travel from individual-level trip information. In fact, trip information is recorded at the individual level and the recorded data does not permit to identify explicitly the members of the household (or friends) with whom a trip might have taken place. It is however possible, by matching information such as trip origin and destination, start and end time, and mode, to determine whether a given trip was made with one or more household members. Data, nevertheless, cannot be obtained on friends or other individuals who might share a ride in the vehicle but who are not members of the household. Neglecting joint travel causes an evident overprediction of the value of time, since it is expected that actual travel costs are lower than those used for model estimation. Travel costs for an automobile trip to a shopping mall with two occupants in the vehicle are double-counted in the individual activity duration model. An additional issue which was considered secondary to this research is the impact of vehicular mode choice on activity patterns. It is hypothesized that individuals choosing public transportation for their mode to work are less likely to participate in descretionary activities than individuals choosing private automobile. This is primarily due to the fixed nature of the route and fare structure of the transit system, which does not favor deviations on the home-work, work-home trip.

With regard to the estimation of the econometric models, two issues are of interest. First, it is suggested to estimate the model form proposed by Westin (1975) with a larger sample size. It is hypothesized that the larger sample size would improve the reliability of the estimates and thus yield acceptable coefficients. A Westin type model was estimated with the smaller sample size available for this research. The coefficient estimates were, however, highly unreliable. This problem is discussed in more detail in Chapter V. Second, it is suggested to develop an alternative to the simultaneous limited dependent variable model developed by Nelson and Olson (1977) which is used in this research to estimate joint activity duration models. Two possible estimation procedures could be developed. One is the full information maximum likelihood (FIML), which is to be considered a technique of last resort, since it involves the repeated evaluation of the cumulative multivariate normal distribution for which no close form solution exists. A second procedure would require the development of an equivalent of the two stage least squares estimator for the simultaneous limited dependent variable model. For experimental purposes the first procedure (FIML) is to be preferred because it yields estimates with all the desirable statistical properties. For repeated model estimation, however, the development of a limited information maximum likelihood estimation procedure is required in order to reduce model development costs.

8.2.2 Long Term Recommendations

The most important long term recommendation involves the data. In particular, the framework developed within this research is based primarily on the duration constraint; however little or no data is available on the scheduling and temporal distribution of the constraint. For example, if an individual works from nine o'clock to five o'clock every weekday, it will be impossible for him (or her) to go to the bank, or to a store, that has those opening hours. Thus, this individual will not be observed participating in any of the above activities, not because of limited time available to him, but primarily because of scheduling conflicts. Other components of activity duration modelling that require additional investigation, but cannot be analyzed because of the limitations of currently available data, include the determinants of intra-household task sharing and activity scheduling, and the determinants of activity duration. Negligence of the above components could give rise to a significant misinterpretation of the "causal" determinants of activity duration. Thus it is suggested here that, in order to avoid important biases in the analysis and the prediction, the data to be collected for future research include more relevant information than currently available in typical urban transportation surveys.

Another area in which further research is recommended is the development of improved theoretical and econometric models. It is believed that the development of an improved theoretical model will permit better understanding of the activity pattern decision process. And, in order to best exploit the improvements in the theoretical model, it is probable that a new econometric approach would have to be developed to evaluate the parameters.

APPENDIX I

THEORY OF ACCESSIBILITY

This appendix presents both the theoretical justification for the specific functional form adopted, and the empirical application for actual evaluation of accessibility.

Accessibility in the context of this research, is a measure which is directly related to the travel choices of decision makers. Specifically, as Ben-Akiva and Lerman (1977) write "... accessibility... refers to some composite measure which describes the characteristics of a group of alternatives as they are perceived by a particular individual." Clearly accessibility depends on the set of alternatives being evaluated by the decision maker, and on the characteristics of the decision maker. Ben-Akiva and Lerman formalize the concept of accessibility as being "the outcome of an operation on a set of travel alternative". Under the common assumptions of utility theory and disaggregate demand modelling, a decision maker t will choose, out of the set of his available travel alternatives C_t, the one with the highest utility. However, since utility is (at least from an observer's perspective) a random variable, the utility of the most desirable alternative cannot be measured. Ben-Akiva and Lerman suggest, as an alternative to this measure, the expected value of the maximum of the utilities of the travel alternatives which is written as:

$$A(C_t) = E[\underset{i \varepsilon C_t}{\text{Max}} (U_{it})] \qquad (I.1)$$

where $A(C_t)$ is called accessibility, and U_{it} is the utility of alternative i to individual t. Assume a multinomial logit model of choice of the form:

$$P(i|C_t) = \frac{\exp(V_{it})}{\sum_{j \varepsilon C_t} \exp(V_{jt})} \qquad (I.2)$$

where $P(i|C_t)$ is the probability that individual t will choose alternative i given C_t, and V_{it} is the systematic component of the utility function U_{it} (with $U_{it} = V_{it} + \varepsilon_{it}$ where ε_{it} is the random utility component). Given the assumed model of choice, the accessibility can be derived in closed form as:

$$A(C_t) = \ln \sum_{i \varepsilon C_t} e^{V_{it}} + \text{Constant} \qquad (I.3)$$

The first term on the right hand side of (I.3) is the natural logarithm of the denominator of the multinomial logit model, the constant term can be omitted since only changes or relative values of $A(C_t)$ are of interest. The final expression for accessibility derived from the above assumptions is thus:

$$A(C_t) = \ln \sum_{i \varepsilon C_t} e^{V_{it}} \qquad (I.4)$$

Assuming that average utility function V_{it} is linear in the unknown parameters, it is written as:

$$V_{it} = \beta_i' x_{it} \qquad \forall i \qquad (I.5)$$

where x_{it} is a column vector of explanatory variables, and β_i' is a column vector of parameters to be estimated. It is necessary at this stage to extend somewhat the analysis to include the specification of C_t, the set of alternatives available to individual t. When modelling travel demand, one has to account for the multiple dimensions of choice with which decision makers are faced. Specifically, the relevant decisions include not only all travel choices such as mode, route, destination, etc., but also travel-related choices such as auto ownership, residential location, work place, etc.

For modelling activity patterns, it is assumed that work hours, the mode to work, residential location, and automobile ownership are fixed. Specifically, it is assumed that non-work activities and the related travel patterns are short-run decisions, while work, residential location and automobile ownership are long-run decisions. The distinction between short and long-run decisions is formalized in the concept of the "hierarchy of choices".(*) Long-run choices, also termed mobility decisions, are at the top of the hierarchy. The short-run decisions, also termed <u>non-work activity duration/travel patterns</u>, are made <u>conditional</u> on the long-run decisions (Figure I.1).

We will hypothesize a similar hierarchy of choices within the short-run decisions. It is assumed that consumers first decide on activity duration, and then, <u>conditional</u> on activity duration, choose their travel

(*)See Ben-Akiva (1973), Lerman (1975) and Adler (1976) for discussions of alternative choice hierarchies.

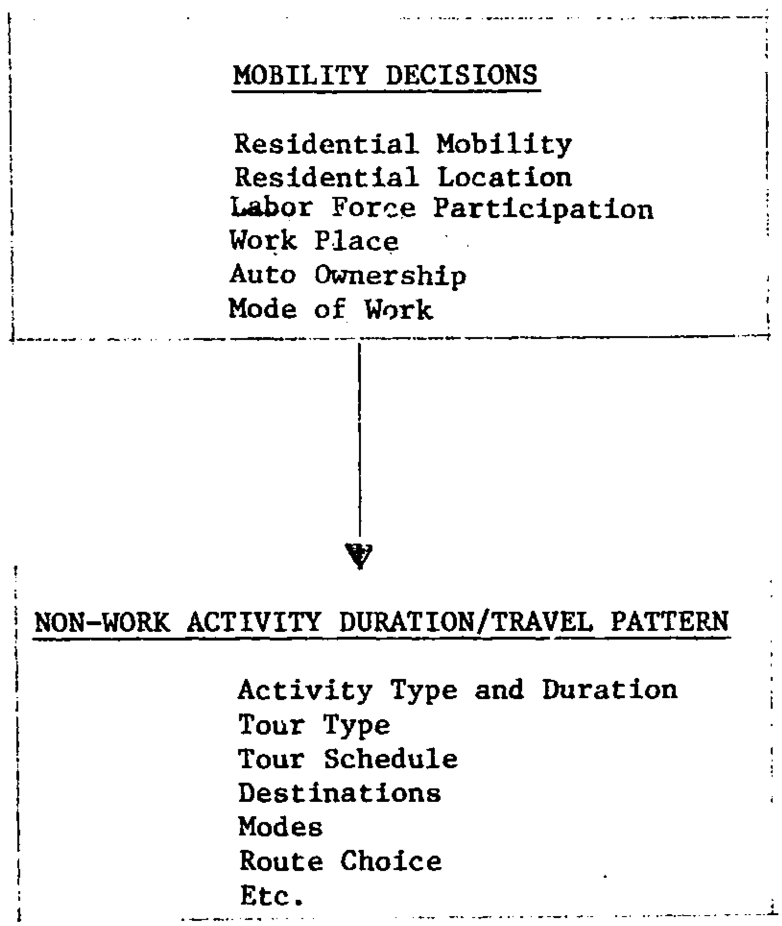

Figure I.1

BASIC CHOICE HIERARCHY

pattern[*] (Figure I.2). The above theoretical assumptions imply that, when individuals decide on the activity duration, their travel pattern is indeterminate. It is thus impossible to write the utility for a specific alternative. It is possible, nevertheless, to define a composite measure, such as accessibility, that describes the characteristics of the travel pattern for a given activity.

It is assumed that individuals' choice of destination and mode alternatives vary with the activity performed at the destination. Thus, in order to compute the accessibility for a particular activity, different models of destination and mode choice have to be estimated for each activity type. In the present study three activities are modelled: shopping, social/recreation and the remaining non-work activities (medical, outdoor recreation, personal business, and serve passenger). Accordingly three different accessibility measures need to be developed for the three activities. Destination/mode-choice models for shopping and social/recreation activities have already been estimated by Adler and Ben-Akiva (1976) and Ben-Akiva and Adler (1975) for Washington, D.C.; no model has been estimated for the remaining activities. It was not feasible (because of budget constraints) to estimate a completly new model for the remaining activities. Therefore only two joint destination and mode choice multinomial logit models were estimated using the model specification already available from the two studies mentioned earlier. The

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(*)While the scope of the present research is limited to the modelling of activity duration, a related research currently in progress (Damm,1978) is investigating the issues involved in the scheduling of activities and travel.

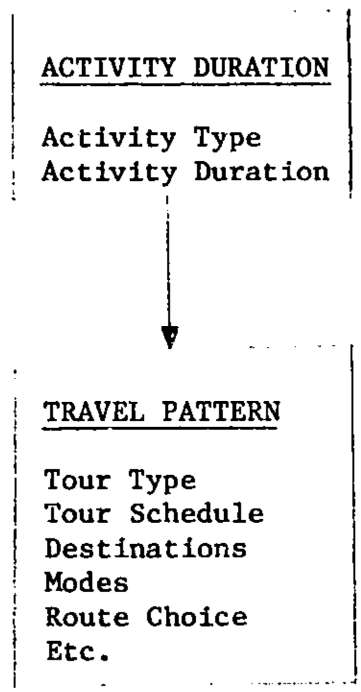

Figure I.2

NON-WORK CHOICE HIERARCHY

The sum of the shopping and social/recreation accessibilities is used in the remaining-activities duration model as a proxy for the accessibility which could not be estimated.

From the reduced sample, home based shopping and social/recreation trips were sorted. This yielded 128 observations for the estimation of the shopping model and 77 for the estimation of the social/recreation model. The preliminary models estimated yeilded a high value of time (>$100/hour). This was assumed to be due to the small estimation sample. It was thus decided to constrain the value of time to a smaller value, and this procedure yielded the estimated coefficients in Tables I.1 and I.2.

Accessibility from the estimated models was then computed using equation (I.4). Because the total number of alternative destinations available to each individuals is assumed to be 1058 (the number of zones coded for the Twin Cities metropolitan area), for computational simplicity it was decided to draw a random sample of alternative destinations for the computation of accessibility, instead of enumerating all the alteratives. A maximum of forty destinations and two modes were selected for each individual. Note that a selected zone was not considered an alternative destination in the computation of the shopping or social/recreation accessibility if, respectively, no stores or no social/recreation opportunities were available in that zone. If transit were not available to a given destination, only the automobile mode was considered. Furthermore, the automobile mode was assumed to be non-available for household or individuals who didn't own a vehicle.

TABLE I.1

Shopping Destination Mode Choice Model

Variable	Coefficient
Auto const. [for auto mode only]	-8.134 (2.597)
Autos owned [for auto mode only] (by the hh)	.7291 (.4258)
Ret. emply. density [retail employees/ net commercial acreage]	-.001761 (.5866)
ln retail employment [employees]	1.00 (NA)
-.05 x ovtt [min. one way]/dist [miles one way] + -2.4 x ln (ivtt [min. one way] + ovtt [min. one way]) + -.02 x optc [¢ one way]/ hh income [code*]	3.672 (6.360)

(t-statistics)

*1 = 0 - 2,999
2 = 3,000 - 3,999
3 = 4,000 - 5,999
4 = 6,000 - 7,999
5 = 8,000 - 9,999
6 = 10,000 - 11,999
7 = 12,000 - 14,999
8 = 15,000 - 19,999
9 = 20,000 - 24,999
10 = 25,000 +

Sample Size: 128

TABLE I.2

Social/Recreation Destination-Mode Choice Model

Variable	Coefficient
Auto constant (for auto mode)	2.554 (.3884)
ln(Weighted Attraction Variable) = ln(.00018 x population + .00096 x total zonal employment+ .00036 x vacant area [1/10 acre])	1.00 (NA)
-.21 x ovtt[min. one way]/dist[miles one way] + -1.9 x ln (ivtt [min. one way] + ovtt [min. one way]) + -.004 x optc [¢ one way]/hh income [code*]	1.828 (6.850)

*See Table I.1 for income codes.

(t-statistics)

Sample size: 77

The level-of-service used for the evaluation of accessibility (except for the home-work based shopping accessibility) is the one-way mode-specific travel time and cost from home to each of the forty destinations. The home-work based accessibility is the accessibility of destination and mode alternatives, given that the destinations are reached by a deviation from the home to work or work to home trip. Since home to work and work to home trips are assumed exogenous (i.e. they would be performed anyhow), the travel time and cost to the activities reached by such a deviation is equal to only the incremental and not to the full travel time and cost of the tour which includes home, the workplace and the destination.

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