TOWARD A MODEL OF ACTIVITY SCHEDULING BEHAVIOR

BY

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INTERDEPARTMENTAL DOCTORAL THESIS

MASSACHUSETTS INSTITUTE OF TECHNOLOGY

FEBRUARY 1979

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INTERDEPARTMENTAL THESIS

SUBMITTED TO THE

MASSACHUSETTS INSTITUTE OF TECHNOLOGY

ON 21 FEBRUARY 1979

IN PARTIAL FULFILLMENT OF THE
REQUIREMENTS FOR THE DEGREE OF
DOCTOR OF PHILOSOPHY IN TRANS-
PORTATION AND URBAN ANALYSIS

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ABSTRACT

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Submitted as an Interdepartmental thesis (Urban Studies and Civil Engineering) to the Department of Civil Engineering on 21 February 1979, in partial fulfillment of the requirements for the degree of Doctor of Philosophy.

The research presented here represents an attempt to learn more about choice in constrained temporal and spatial environments. The choices of interest are whether or not someone participates in an activity and for how long. The research proceeds through several steps in order to understand better and to predict this behavior. Building on other researchers' and the author's insights, a theoretical framework describing the environment of the choices "participation" and "duration" is constructed. This framework serves to structure the variables believed to operate causally with respect to choices observed. An operational model is then formulated so that the hypotheses embodied in the theory could be tested. The primary characteristic of this model is its treatment of participation (a discrete choice) and duration (a continuous phemonenon) as interrelated.

Using data from the Minneapolis/St. Paul area, exploratory analyses and econometric model estimations are conducted for five time periods. These periods are defined in relation to full time employees' working activities: (1) prior to the work trip, (2) on the way to work from home, (3) during the work activity, (4) on the way home from work, and (5) after the work trip. The results generally confirm the usefulness of the theoretical framework and contain the seeds of many potentially researchable questions, both of a more conceptual and a more applied nature.

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Acknowledgements

Two individuals were invaluable to me in the course of completing this thesis. First, Steven Lerman did much more than simply supervise. He encouraged me to explore uncharted territory and taught me an enormous amount about methodology and analysis. Despite an increasingly busy schedule he gave generously of his time. It was both a pleasure and a privilege to work with him. Second, Inge Damm-Luhr went well beyond the patience, love and moral support usually cited about spouses. Not only did she help me put the entire enterprise into proper perspective, but as a social scientist in her own right, she also provided a good share of professional criticism.

During various stages of the thesis a number of other people lent me important assistance. Eric Miller helped me work through several rounds of conceptualizing while Glen Weisbrod and Jesse Jacobson steered me clear of many computer programming problems during preparation of data. In response to several drafts of this document, Joel Horowitz made many constructive comments which have improved the quality of the final product. Members of my interdepartmental committee, Moshe Ben-Akiva, Ralph Gakenheimer, Marvin Manheim and Larry Susskind, also provided support and encouragement throughout the process. In addition, funding for the research reported in the thesis came in part from the U.S. Department of Transportation's Program of University Research (technical monitor was David Rubin of the Transportation Systems Center). Various drafts were typed by Nola Rezzo, Catherina Gentile and Mary Naus. To all these people I extend my warmest thanks.

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CHAPTER ONE

Introduction

1.1 Motivation

Among transportation analysts and planners the derived nature of travel demand is widely acknowledged. Nevertheless, relatively little progress has been made in the last decade toward understanding the sources from which this demand is derived. Even in the context of recent "behavioral" modeling of transportation-related choices, surprisingly little time has been spent trying to understand the highly interrelated nature of a person's activities and the resulting consequences for travel behavior. At the same time, an increasing number of public policy makers are discussing less capital intensive transportation schemes that will contribute to realizing energy conservation and pollution control objectives. One need think no further than the concept of flexible working hours to realize that the assessment of the impact of such schemes depends on our ability to understand and predict activity-related as well as travel behavior. In the absence of a solid theoretical explanation of the demand for activities and a related operational model which could be used to assess impacts, intelligent statements about alternative policies have not been abundant.

This thesis is geared primarily toward integrating analysis of activities into a larger scheme of understanding and forecasting travel behavior. It should become apparent, for example, that "accessibility" ought to be defined and measured with respect to where one is located and a specific time of day. (Accessibility levels with respect to a workplace at noon will usually be substantially different from those at midnight with respect to a home's location). This fact has important implications for the design of transportation policy since "accessibility" can be improved by many means other than expanding or constructing new facilities. A land use policy which encourages clustering of certain activities promotes more complicated trip making and offers greater accessibility to additional activities with a minimum of travel and energy consumption. Public policies could also be focused on altering the times during which activities are available. In short, the issues addressed are of interest to both analysts and policy makers.

For many traditional transportation analysts, a major stumbling block has been the conceptual framework within which they have operated. This framework is chiefly characterized by its focus on single links in a transportation network (e.g. one road between two cities). Even researchers whose frameworks include many links simultaneously are still largely prisoners of the need to predict the volume of traffic on particular links in a network. Because of such limitations, many of the ways which people adapt (i.e. change their behavior) to new situations cannot be understood. For example, as Stopher and Meyburg (1976) point out, "current trip generation models don't consider the possible trade-offs between making a trip to carry out a particular activity and substituting some other activity that can be carried out within the home." Similarly, "mobility" in the sense of realized travel (i.e. trips actually taken) is often studied with the implicit assumption that peoples' needs to participate in activities can only be better fulfilled with increased "mobility," i.e. more trips. If analysts better understood the factors which influence how people arrange their activities in time and space, then they would also be in a stronger position to recommend a much wider range of alternatives for providing for the needs which underlie the need to travel. Telecommunications already serve as a substitute for transportation facilities. For example, with a portable terminal and a standard telephone there is no reason today why a large portion of computer work cannot be performed at home (i.e. requiring no travel) instead of at some centralized office (requiring at least one round trip).

In another vein, it is ironic that transportation researchers are still exploring urban form as opposed to the forces which give rise to the form. As Chapin (1965) has pointed out, "planners have jumped directly into land use studies, essentially studying the effects of activity systems rather than seeking to define and understand activities themselves as producers of land use patterns." (p. 221) Urban form is a result of many other intervening and more important variables than "transportation." If we "seek to define and understand activities themselves", "transportation" is certainly among the critical variables we would need to isolate. In the context of the Urban Transportation Model System (UTMS), for example, using "land use" as an input into the trip generation stage is, therefore, just as mechanical and misleading as having no level of service feedback or behavioral components in any stage.[1] In short, as Jones (1977) has argued, it is time that a fully new approach be developed.

It should be evident that policies structured and implemented under the assumptions of models based on information about single links in a

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[1] See Stopher and Meyburg (1976) for a description of UTMS.

network without explicitly treating the demand for activities will necessarily lead to erroneous inferences and conclusions about the impact of alternative policies.

It has become patently clear that people's responses to transportation policies are, with few exceptions, vastly more complex than the simple behavioral shifts (*e.g.* from auto to transit) which most available empirical models would lead us to infer. Stearns (1976), for example, demonstrated that reduction in vehicle miles traveled observed during the 1974 gasoline shortage and price increase was due in large part to consolidation of trips rather than modal shifts. By ignoring more complex adaptions, such as trip consolidation, we run the serious risk of gross misprediction when analyzing alternative public policies. At the same time, if we are restricted to analysis based on concepts of welfare defined by number of trips made ("mobility"), target populations may be wrongly classed as "disadvantaged."

The rest of Chapter One will contain a guide to the thesis as a whole. Not only will the major features be outlined, but the context in which they exist will also be explained. Section 1.2 will have a statement about the unsuitability of prior approaches to the tasks of this thesis. In Section 1.3, the research design will be presented and evaluated. Next, the contributions of the present research to the state-of-the-art will be discussed, followed in Section 1.5 by a summary of the findings from the empirical work. Finally, the terminology encountered in the thesis will be explained in Section 1.6.

1.2 Why Are Conventional Approaches Unsuitable?

Although an increasing number of analysts are addressing the issue raised in Section 1.1, only a very few have succeeded in creating a balanced mixture of theoretical rigor, analytical sophistication and sensitivity to variables with which to parameterize the impacts of policies. For at least a decade, much of the theoretical discussion related to activity behavior has been characterized by what appears to be a dichotomy between "choice" and "constraints."[2] As we shall see, this dichotomy is more apparent than real; failure of most researchers to make a serious attempt to combine the two directions unfortunately has been the hallmark of research in this area. Furthermore, in their current formulations virtually all available models which incorporate concepts related to activity schedules suffer in that they often tell us alot about the nature of patterns but seldom enable us to predict and evaluate travel- and activity-related behavior.

While much of the prior research has been very useful as a source of hypotheses about activity-related behavior, only a small part of the information generated is of direct use to policy makers who need to be able to assess the impacts of alternative plans. One of the primary motivations behind this thesis is to forge beyond this more descriptive approach to activity research toward more theoretically rigorous, but also more widely useful models.

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[2] Some researchers (*e.g.* Hägerstrand) have focused exclusively on the constraints which limit a person's ability to reach a certain number of activities within a certain amount of time. He and his colleagues argue that analysis of people's choices (or "revealed preferences") cannot help to inform decision-makers about the impact of policies on people's welfare. Other researchers (*e.g.* Chapin) while not ignoring constraints, focus almost entirely on explanations of observed behavior, *i.e.* choices.

1.3 Research Design

The primary goal of this thesis is to understand better and to explain why people schedule their daily activities as they do. To the extent that it is possible, I will try to establish how the structure of activity schedules is related to socio-economic, demographic, residental locational and other variables. Often work in this area has been done by researchers who have given insufficient thought to practical application or operationalization of their concepts. As a result, a secondary goal of this thesis is to examine the extent that these decisions can be successfully represented by mathematical models. After an evaluation of prior research releated to activity schedules (Chapter Two), I will turn to the development of a theoretical framework for understanding the nature of causation in the observed behavior (Chapter Three). Next, the methodogical approach taken to developing multi-variate models of activity schedules is presented (Chapter Four). The data used to test the hypotheses implicit in the conceptual model of causation will be discussed in Chapter Five and then explored for any patterns or regularities which could indicate the extent of match between theory and reality (Chapter Six). The results from empirical estimation are laid out and evaluated in Chapter Seven. In order to give the reader a sense of the use of such models, Chapter Eight will contain a statement of what has been learned from the thesis, including the implications of the results for public policy.

This design suffers from several weaknesses. Since only one city (Minneapolis/St. Paul) is examined, the later part of the thesis takes on the character of a case study. In this sense, the results may not be directly transferable to other areas and conclusions about policies drawn on the basis of these results may have immediate relevance for no more than the city in question. Further the data used are cross-sectional, i.e. any given person's activity patterns are observed for one day only. It is unknown how behavior may have changed since the survey was done originally in 1970. In order to obtain a theoretically and analytically acceptable model, the sample was limited to workers who had a work trip on the day of observation.[3] While this is a defensible choice (see Chapter Five), the fact that the behavior of a sizeable fraction of the population was left unanalyzed certainly limits the generalizability of the results.

1.4 Contributions to the State-of-the-Art

It should become clear that this thesis makes at least five kinds of contributions to the state-of-the-art. First, in contrast to most studies of transportation-related behavior, activities are treated explicitly. Second, it will be shown that a more quantitative approach which combines aspects of both choice- and constraint-orientations is not only feasible, but also desirable. Third, the unique spatial and temporal environments in which people operate as they move through a day are considered. Since most analysts usually define accessibility only with respect to one's residential location, varying this measure depending on whether one is at home, at work, or moving between the two places, is a substantial innovation. Additionally, since we also expect such temporal attributes as opening hours of activities to vary over a

[3]See Section 5.4 for further explanation of this limitation.

day, the separation of decision-making into time periods becomes a necessity. Fourth, the models developed here embody an acknowledgement of the interrelatedness of daily scheduling decisions and reject the notion that a scheduling decision can be treated in isolation (as Markovian models do). Fifth, through the introduction of certain socio-economic variables, some of the interdependence among members of a household will be captured. These contributions translate not only into improved understanding of travel- and activity-behavior, but also into a stronger position from which to develop capabilities to forecast the impact of activity-related public policies.

1.5 Summary of Empirical Findings

In general, the results coordinate well with our prior judgement about the causal factors operating to influence the behaviors of interest: whether someone participates in an activity and if so, how long. Further, the empirical findings tend to support the division of the causal variables into the three categories of activity program/needs, temporal constraints and spatial constraints. One of the most unique features of the empirical analysis was the division of the day into five time periods, each with its own associated equations to be estimated. In order to capture the interrelatedness among decisions made in the different time periods, a variable "time spent in other periods" was defined. An important finding was that its coefficient seemed to perform as expected. That is, almost all of the coefficients of this variable were negative indicating the more time allocated to other periods, the less to the current period. It is clear that activity research which does not account for the interdependence of decisions over a day's time will be deficient. The results connected with the variables used to proxy the influence of familial and personal responsibilities on an activity program and schedule were not uniformly satisfying. However, as I did not begin the modeling with well established beliefs about their place in the conceptual scheme, this is not overly disappointing. As we shall see, these results are the seeds of many future research topics.

1.6 Making Sense of the Terminology

In the context of no widely accepted theory and often divergent approaches, it is useful briefly to make explicit the definitions of terms which appear in this thesis. In the literature, it is often the case that either disparate terms actually could be matched to a single concept or different meanings are ascribed to the same term. This section should therefore allow us to proceed to the following chapters on common definitional grounds.

The set of daily activities which people want to perform is referred to as an _activity program_ or _time budget_. A _total time budget_ is the latter plus travel time. Since people are necessarily limited as to the places and times or _time-space_ in which they can accomplish an activity program, there are a number of terms which all describe these limitations: _activity space_, _choice set_, _reach_, _prism_ and _potential paths_.

Given an _activity program_ which people need to accomplish in a day's time, they first need to decide when and where and for how long the program's activities should be performed. These decisions are not necessarily identical to or made simultaneously with travel decisions about how to connect these activities spatially. In this thesis, the traditional daily trip sequence will be turned inside out. Instead of focusing on what people do between activities, we will look at what people do between trips. In this vein, it seems more appropriate to speak of activity scheduling (of a program) especially since we assume that the activities themselves are more important than trips. Given an activity schedule, one can then begin to understand the nature of a travel pattern which is usually secondary to the activities to be performed.[4]

In close conjunction with 'pattern', many researchers have discussed linkage.[5] Though most have meant nothing more than a simple sequence of trips or even activities, it has never become clear whether such a term really expressed what appears to be connoted by the word. Why are two activities "linked"; merely because they follow each other temporally or happen to be within a particular distance? Is there a causal link or functional link? Very early in the development of this thesis, it became apparent that an understanding of linkages, whether "travel" or "activity" is outside the scope of this thesis. As a result, we will not refer here to "linked trips," but instead encourage separate exploration of them in the future.

In the course of moving away from a focus on single trips or activities, expressions combining multi- or multiple with destination, stage, journey, trip, link and sojourns have been employed. Unfortunately, it is unclear whether these terms were all meant synonymously (e.g. multi-

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[4] While the term 'journey structure' would be fitting in place of 'travel pattern', most authors tend to use the latter. Pattern has been used as an umbrella word for a collection of measures describing a person's trip making behavior over some time period: trip length and frequency are most often employed (e.g. Hanson and Hanson, 1979). At the same time, other researchers designate as a "pattern" the set of things people do in time and space (e.g. Chapin, 1974) or "path" which people follow (Hägerstrand/Lenntorp).

[5] Others have also used the terms transition, chain or sequence to express the same idea.

purpose may not be the same as multiple destination if all destinations visited are for the same general purpose category). The existing term complex tour does perhaps the most effective job of expressing the phenomenon in question, if we understand tour to be a series of trips beginning and ending at the same base. As will become apparent in Chapter Three, it is most fruitful to consider people with work trips and activities which act as pegs for organizing the rest of the day. If we take "home-work-home" as fixed, then it is of interest to examine how people add on non-fixed trips or activities. In the context of trip-making, the term 'complex tours' is quite adequate. However, if we want to address the derived nature of travel demand, i.e. demand for activities, we should think of deviations from an obligatory activity schedule. In this way, it will be possible to begin to understand the differences between people who simply go to work and those who, in addition to working, decide to participate at particular times and places in activities which could theoretically be performed elsewhere, at other times and for different durations.

CHAPTER TWO

Prior Research

2.1 Introduction

While a growing body of literature related to activity schedules has become available in the last decade, research in this area cannot yet draw on a coherent set of sources. Since the work conducted as part of this thesis covered new territory, prior research was useful primarily as a source of suggestions and hypotheses. In short, the directions taken in this thesis represent a weaving together of many threads gathered from the ideas and results of others. On the one hand, the available sources provide invaluable assistance in developing a solid theoretical basis for empirical work. On the other hand, there are many reasons why much of what is considered "state-of-the-art" simply illustrates the primative stage of much of our thinking.

Very early it became apparent that at least five types of weaknesses hindered our understanding of activity schedules and the travel patterns that they imply. First, there is a lack of operationalization of basic concepts, that is, definition in terms that can be easily paired with an empirical referent. For example, many authors used the concept 'linkage' so loosely as to be confusing (are linkages functional? causal? physical? behavioral?). Related to this first type of weakness is the fact that a large portion of the available source material has no conceptual grounding in anything which could be characterized as behavioral. The Markovian models are a good example. While many authors try to suggest the appropriateness of such models for representing sequences of decisions, they are hard-pressed to make the connection between a "memoryless" model and a causal model of people's activity scheduling behavior. Thirdly, many of the authors belabor the obvious by concentrating on descriptive approaches to research. Certainly a decade ago, descriptive studies were a vital necessity, given our then limited knowledge. However, we now have had the benefit of a wide range of tabulations and cross classifications on a variety of data for several years. Related to this criticism and fourthly, there is a marked lack of information on the theoretical as well as statistical interaction of key variables. Many researchers have brought to light interesting facts or generated hypotheses about single variables, but rarely tried, in a multivariate framework, to understand how sets of variables behave under various conditions. Finally, there is no available conceptual or theoretical framework which is suitable for analysis of activity schedules. This lack of generalized theory is perhaps the greatest stumbling block to significant progress in this area of research. The most rigorously obtained empirical results have little or no meaning in the absence of a theory which consistently ties together a set of hypotheses about people's behavior in time and space.

2.2 Approach to the Literature

One of the overriding goals of this thesis is to increase our understanding of the factors which influence or at least co-vary with the observed way in which people schedule daily activities. Very early in the course of pursuing this goal, I decided to test empirically a theoretical model of scheduling behavior. As a result, there were at least three criteria which were applied in sorting out the most relevant sources.

First, it was important to locate sources which aided in defining key variables. Some authors were able to do this conceptually, while others did so via empirical testing. Unfortunately, few were successful in both respects. Second, sources which systematically structured key variables were useful. One of the simpler, but no less important themes of this thesis is that activity scheduling behavior is vastly more complex than the behavior presumed to be captured in traditional models of modal choice for a single link in a transportation network. Consequently, those authors who have attempted to grapple with this complexity will receive special attention. Third, those sources which addressed methodological issues related to empirical tests of theoretical constructs pertinent to this thesis received careful consideration.

2.3 Review of Relevant Research

Although exhaustive review of sources related to activity research would surely serve worthy documentary aims, this chapter will be focused only on those sources which have had a bearing on the development of this thesis.[6] The next six sections will contain evaluation of research related to what have been defined as key issues. These are:

1. Spatial-temporal constraints
2. How activities are scheduled

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[6] There are a number of excellent general review of related literature. These are Anderson (1971), Ottensman (1972), Hautzinger and Kessel (1977), Hanson (1977) and Jones (1977). For review of recent work in Sweden, one should consult Kofoed (1970), Godkin and Emker (1976), Carlstein (1977) and Pred (1977).

3. How decisions made in time and space interact during a day

4. How members of a household interact

5. Isolation of critical variables

6. Multivariate modeling of choice in time and space.

2.3.1 Spatial-Temporal Constraints

The research of Hägerstrand (1970, 1974) and his team of social and economic geographers at the University of Lund (Sweden) extends the notion of constraint to both time and space simultaneously. Since they are primarily interested in how urban residents' choices are limited by constraints, their major effort has been to define the concept of 'reach'. They assume that each person has an "activity program" to be realized in the course of a given day. Since temporal and spatial constraints limit a person's set of feasible alternatives, they have asked themselves, "what are the possible paths which could be used to realize the activity program." (Lenntorp, 1976) It is important to point out that the Lund researchers have limited themselves to "objective" constraints, i.e. those which are physically measurable. The "reach" is, therefore, comprised of all events in which an individual can participate, whereas the 'physical reach' is the physically accessible part of the environment. In examining how people realize activity programs, they focus entirely on the potential rather than the actual set of alternatives which is available. This is parallel to work of Horton and Reynolds (1970) which uses an "objective spatial structure" to define the location of a household relative to the location of all potential activities. While focus on potential space does not shed light on decision-making in time-space directly, it nonetheless permits a better understanding of the kinds of constraints which operate to limit choice. Hägerstrand defines three types of constraints: coupling, capacity and authority.[7] The outcome of people's choices in time-space, given these constraints, leads to the continuous formation of "activity bundles" where people come together.

In this framework, the Lund group has defined 'path' to be a set of movements over both space and time. The logical results of this definition is the concept of 'prism' which means the "connected and continuous set of positions for which the probability of being included in an individual's path is grater than zero." Consequently, with a "prism" they have been able to develop the idea of 'potential path' which, when projected onto space gives an 'activity area' within which movements of a person must be confined.[8] As Lenntorp (1976b) has shown, "there is no time when the entire activity area is within reach." In addition, it ought to be clear that the definition of reachable activity area is heavily dependent on the mode of travel available. The extent of difference in reachable areas between modes is, in turn, dependent on the density of activities relative to one's current location. Using their theoretical constructs, one can easily move away from traditional analysis for example, of accessibility, in terms of an a-temporal home base. If one is at the

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[7] When forming "activity bundles" for production, consumption or social interaction, people face coupling constraints which determine the place, time of day and duration of these bundles. Capability constraints result from physical or physiological requirements (distance which can be covered with available technology or the daily sleep which one needs). Authority constraints arise from legal or institutional relationships which prescribe access to activities.

[8] Burns (1978) built on these concepts to develop theoretical measures of benefit which could potentially be used to assess alternative strategies which alter constraints.

work-place at 3:00 p.m., there are entirely different set of 'reachable' opportunities than if one is at home at 6:00 a.m.

Using the theoretical constructs described above, Lenntorp (1976a, 1976b) empirically defined the possible paths which could be used to realize a person's activity program within a set of objective constraints. In his simulation model PESASP (Program Evaluating the Set of Alternative Sample Paths), he developed an essentially deterministic algorithm with which to compute the number of paths depending on the temporal and spatial environment and the activity program to be accomplished. The "environment" is described by the locations of destinations relevant to the activities in the program, the opening hours of the activities as well as the design of the transportation system (geographic distribution and of service for public transport). The feasible paths are simply listings of alternative combinations of destinations and sequences with which a particular program can be realized. If a change is made in the "environment," then a new simulation shows its impact on the destinations which are reachable and the sequences which are feasible.

Lenntorp's application of PESASP to three suburbs of Stockholm is more manageable than previous models of sequencing since he restricted himself to shopping trips, in particular trips to food stores. Further, he limited the possible destinations to those which could be reached by several paths in time-space. By grouping possible paths he could identify activity sequences which are feasible.[9] One of his most interesting find-

[9] Apparently, his simulation was quite accurate in its correspondence to actually observed paths or sequences. For 90% of the sampled paths in one suburb nearly two-thirds came within 15 minutes of the total travel time observed.

ings was a confirmation of the hypothesis that type of mode used strongly influences the number of feasible paths. In particular, he found that public transit riders have the least complicated sequencing behavior.

A PESASP model was also developed exclusively for pedestrian and transit riders using data from the city of Karlstad (Lenntorp, 1976b).[10] Not only did he compare the city's existing environment with the simulated, but he also compared the simulation's results under present constraints with altered situations (changing the frequency of service, combining visits, adding a bus route, changing permissible travel time, and introducing new activities such as day care centers). The results of these experiments showed whether or not the set of feasible destinations for a person was altered. For doubling of the frequency of service on buses, Lenntorp determined the number of new locations from which it is possible to realize an activity program comprised of going to work and a post office. Given six alternative working place centers, he found that increased bus service led to four of these places being more accessible, but particuarly that in the town center. In contrast, the introduction of a circumferential bus line had little impact on the feasibility of various programs. By assuming the existence of two new day care centers in the periphery of Karlstad, improvements were found, but primarily for people both living nearby and working in the town center.

A noteworthy attempt to build upon and to extend the theoretical foundation laid by Hägerstrand and his colleagues was made by Stephens

[10] A PESASP model has recently also been developed using data from Vienna, Austria. Applying this model to two neighborhoods, Henseler and Ruesch (1978) calculated measures of the level of welfare as a function of the number of different possible paths and then considered the impacts of various policies on this level.

(1975), who hypothesized that "time-space constraints and levels of activity commitment are the critical determinants of activity sequences in time-space." "Level of commitment" was defined in terms of a person's judgement about the extent to which an activity could be perfomred at different times and/or different places. Using this definition, he constructed a measure of an activity's flexibility ranging from prearranged and fixed to unexpected and unplanned. The subjective measures were combined with objective constraints (i.e. those imposed by the person's environment) to develop hypotheses about people's time-space behavior which could be tested by simulation. With a survey of part of his University's community, he was able to gauge the extent people felt constrained by activities' times and locations.

Prior to actual simulation of activity patterns, Stephens grouped people based on their allocation of time to various activities as well as their observed daily sequence of activities. The result of this step was the realization that there were at least two distinct groups in his population, roughly those with highly structured and those with loosely structured patterns.

By grouping the population along these lines, the simulation model which Stephens constructed addressed many of the weaknesses which characterized previous work. His first step was to derive six probability distributions (frequency of activity occurence, duration, by constraint, locations, linkage and distance) to approximate activity structure. Using the "level of commitment" indicated by the respondents, he then isolated the most fixed activity or peg; and then used a Monte Carlo procedure to select activities, locations and durations which could be associated with a program built around the peg. The simulation then proceeded through the rest of the day from the next most fixed to the least fixed activity until a complete program was determined. As Stephens himself pointed out, "the simulation performed reasonably well in establishing activities to be associated with periods of high commitment and constraint, but failed in its ability to accurately estimate activity sequences over a day as a whole and for periods of low commitment and constraint in particular." (p. 280, Stephens, 1975) His recommenations were to: (1) use such a model for activities having a high degree of fixity (i.e. obligatory) and (2) not make a distinction between subjective and objective constraints.

For this thesis there were three major lessons learned from the literature which focused on temporal and spatial constraints:

1. Variables to account for differences in the environment of choice over time and in space were defined (e.g. accessibility, level of dependence on others in household).
2. Only objectively determined (i.e. physically measurable) constraints on people's scheduling were considered.
3. A person's day was considered as structured around activities which are fixed in time and space.

2.3.2 How Activities Are Scheduled

The first researchers to consider activity programs or schedules were those exploring time budgets without regard to spatial constraints. Sorokin and Berger (1938) asked questions about time allocating behavior with respect to an overall activity program or schedule. They began developing classes of activities, and, importantly, gained considerable insight into the psychological and social motivation behind time allocation with respect to an overall activity program or schedule. The work of Szalai (1972) and others of the Multinational Comparative Time Budget Project was monumental. Although there were too many specific findings to provide an adequate summary here, the key feature of this large project was the extension of traditional time-budget studies to include consideration not only of the duration of activities but also their frequency, timing (scheduling), sequential ordering (patterning), location and number of participants. As part of the same project Stone (1972) pointed out the need to use time budget data to segment a population according to similarity of activity patterns in order to make recommendations to policy-makers. Particularly the ideas of focussing on people's timing of activities and of trying to isolate homogeneous groups have been incorporated in this thesis.

There were also several authors who built on and extended the Lund researchers' concepts with respect to timing or scheduling of activities. Whereas Hägerstrand considers activities to be either fixed or not fixed, Cullen and Godson (1972) replaced the dichotomy with a range of gradations from completely arranged to unexpected. They rightly pointed out that people do not at all times "consciously balance priorities and constraints in a manner ... revealed by ... overt behavior." Cullen and Phelps (1975) and Stephens (1976) acknowledged this opinion by exploring attitudes when trying to understand how people relate to the context in which they operate.

Although the empirical tests conducted with both of these references did not match the authors' expectations (see Section 2.3.1 regarding Stephens), they nevertheless generated several very useful ideas. The major one of interest here is that "activities to which an individual is strongly committed and which are both space and time fixed tend to act as pegs around which ordering of other activities is arranged and shuffled according to their flexibility" (Cullen and Godson, p. 9).[11]

Jones (1977) and Heggie (1977) made several points which greatly influenced the course of this thesis. The first point is that "the twenty-four hour day has to be regarded as a series of separate and constrained time periods rather than a continuous block of time that affects choice in a marginal way." (Heggie, 1977, p. 19) As will be discussed in Chapter Three, separation of time periods within a day allows us better to understand the interdependence of a person's daily decisions in time-space. The second is that while most analysts acknowledge the derived nature of travel demand, few explicitly make use of this fact. The research at Oxford demonstrates why this prior work is incomplete. The choice facing a person is two-fold: (1) "participating in activities at the decision-maker's current location (i.e. no trip) or (2) participating in other activities which make use of facilities elsewhere (and hence

[11] Cullen and Godson administered a questionaire to 336 people in London College and were able to describe in detail: how much time people allocate to different activities, the charcteristics of "episodes" and their scheduling. In contrast to most of the other writers, they emphasize the apparent futility of studying overt behavior to understand how people balance priorities and constraints, especially since people "don't perceive constraints uniformly." Cullen and Phelps (1975) undertook a study analogous to that in London College in a working class community.

requiring travel)." Unlike prior authors, Jones (1977) realized that by ignoring in-home activities, the full potential of their approach is not reached.

A substantial body of literature builds on Markovian models of activity sequencing. These sources have served primarily as a counterpoint to the development of this thesis. Their associated theoretical underpinings were considered too mechanical and their resulting assumption about how people schedule activities unacceptable.[12] Using Markov chains to represent trip linkages, Horton and Shuldiner (1967) and Horton and Wagner (1969) were able to test the hypotheses about the probability that a person will travel from one land use type to another. Horton and Shuldiner (1967) constructed four matrices derived from data on trip origins and destinations in Waco, Texas: (a) observed relative frequency of trips between origin and destination (as defined by land uses), (b) a limiting matrix to define the expected percentage of tripmakers which will be found at a particular land use at a randomly chosen time of day, (c) transition probabilities, (d) expected variation in the expected number of stops at each land use. The authors then determined the degree of "linkage" among land uses which was seen as an indicator of the likelihood that multiple-stop trips will be made, since interaction among non-residential uses implies at least a second leg of a trip. Horton and Wagner (1969) broke the same data down by socio-economic and occupational classes. Within each class, travel behavior was analyzed and

[12] The key feature of Markovian models which is at issue here is the assumption that in a series of events any specific event occurs independently; the process which governs these occurances is said to be "memoryless."

transition probabilities were computed using trip linkage distributions generated by Markov chain analysis. Their results suggest significant differences between trip patterns of the three classes examined (high occupation, low occupation and housewife/student).

At about the same time, Hemmens (1970) analyzed data from Buffalo, New York, in the format of Markov process.[13] One state, "return home," was absorbing and all others were non-absorbing. This followed the logic of treating "each out-of-home journey as in effect a closed loop containing one or more activities and the whole day's travel as a series of such loops." Since Hemmens did not have data on transportation service, he was restricted to determining the number of trips before returning home (by family size, income and race) rather than analyzing the conditions under which activity links are formed. A contribution is to be found in his use of duration and type as well as sequence of activity in his simulation.

The weaknesses of a model of Markov processes for representing activity patterns were recognized by Bentley, Bruce and Jones (1977). They used extensive data provided from week-long diaries gathered in 1969 in Watford, England (initial results of this survey is reported in Daws and McCulloch, 1974) to build a model with which the probability of continuing a tour could be calculated. The authors refer to trips which have "the potential to continue forward," but unfortunately never discuss the determinants of this potential. The parameters of their model relate

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[13] Readers unfamiliar with the logic and terminology of Markovian analysis are referred to Brown (1970) for an excellent review and discussion of their use in movement research.

entirely to observed number of trips which were continued and have no meaning connected to the individuals who made trips or the environment in which the trips were made. Nevertheless, the data base is of great interest for planners who could use the empirical material for exploring the relation of shopping and other activities to trip-making. Clearly, the location of urban facilities will be affected by and affects activity patterns.

Westelius (1972) developed a simulation model treating decisions to stop in a series of trips as Markovian processes. Despite the inability of such a model to account for interdependence, Westelius developed several important concepts regarding complex trip decision-making. His central focus in analyzing 1965 data from Uppsala, Sweden, was on the pattern of "substitutable" stops during a day (i.e. for activities which could be performed at more than one time or place). The hypothesis which Westelius explored was that such stops are influenced not only by the location of home but also by trips to and stops at other "fixed" places. In addition to confirming this hypothesis, by examining the spatial and temporal distribution of stops, he found that a person's decisions of whether or not to stop at different times of the day were strongly correlated with each other. Four of the hypotheses which he generated in his research are of direct relevance to this thesis. First, people combine stops in a day depending on their accessibility to potential activities; this accessibility varies depending on the time of day and place. Second, the greater the distance from home to the nearest point of supply, the greater the number of the stops which will be concentrated in a fewer number of chains. Third, people postpone stops more as it becomes more difficult to reach a point of supply. Embodied in this hypothesis is the notion that needs accumulate until some threshold value has been reached, at which point a stop will be made. Finally, a hierarchy in the pattern of travel is determined by the properties of the activities and transportation networks.

2.3.3 How Decisions Made in Time and Space Interact During a Day

Vidaković (1971, 1974, 1977) developed models which are critically different from the Markovian type. Most importantly, he questions the idea of sequences of trips as governed by memoryless behavior and posits an alternative model with which to examine the interaction of all trips and stops in an individual's schedule. He has reported models of the relationship (1) between frequency of arriving someplace besides home and the size of a trip chain (*i.e.* the number of trips in a sequence beginning and ending at home), and (2) between distance traveled between activities (stops) and chain size.[14] The feature of these models which is most important to this thesis is that all decisions in time-space are treated as an integrated whole. That is, all decisions are influenced by both prior actions and future intentions. Just as Cullen and Godson (1975) pointed out, "the decision ... is no longer taken in a purely theoretical action space surrounding the individual's residence, but is taken in terms of a highly specific time-space prism." (p. 61)

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[14] Tested on a 1% sample from Amsterdam, Vidaković's model produced a distribution of chains over different sizes which indicated no significant difference between expected and observed values at the .05 level.

Recent work by Pipkin (1974) illustrates that an activity decision is vastly more complex than anything suggested by prior research. Pipkin drew the conclusion that the existence of multi-purpose travel implies that it is unreasonable to seek direct relationships between a household's aggregate visit frequencies to sites and any single measure of their overall 'utility' (p. 3). In the context of this thesis, it is important to realize that the utility of activity sites continually varies with the decision-maker's current location and "trip history." This means that separable, but interdependent, equations should be used to model the utility to be derived at different times and places in a person's day.

2.3.4 How Members of a Household Interact

Perhaps one of the most neglected aspects of research related to people's activities is the dependence of individuals on the schedules of others in his/her household.[15] Building on the concepts developed by Hägerstrand and his colleagues, Jones (1977, 1979), Heggie (1977) and other researchers of the Transport Studies Unit have begun to address this aspect with their Household Activity - Travel Simulator (HATS), a technique which "involves the use of display equipment in a group, in-depth interview." (Jones, 1979, p. 7) Of great importance is their including activities which occur at home as well as outside activities reached by any mode; in short, they can represent a "continuous picture of daily behavior." With this interactive gaming device they are able to observe

[15] Recent work at Charles River Associates (1978) contains a review of many sources which shed light on decision-making in the family which relates to travel-activity behavior.

how a household's interviewees represent their patterns under varying environmental conditions (e.g. opening hours, bus schedules). As a result of actual use of HATS Heggie suggests that a change in travel conditions could lead to a rearrangement of tasks among household members. That is, the time-space decisions of household members are interdependent and further, that besides changes in frequency, destination, mode and route, a person often has a wide range of substitutable arrangements within a household which may be perfectly acceptable.[16,17]

2.3.5 Isolation of Critical Variables

Our primary interest in this section is the variables which previous researchers have considered important. The interactions between variables are also of interest, especially since the direction of causation in the theoretical models is anything but clearcut. The literature in this section can be divided into two parts: tabulations with no explicit theoretical basis and preliminary models based on some set of behavioral assumptions.

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[16] It should be noted that "HATS was able to improve considerably on intuitive forecasts of the impact of the change." Jones (1977, p.25). In addition, it "will be used ... to assist in he formulation of realistic decision rules" (Jones, 1977, p. 30) as part of an extension of a formal activity-based model to forecast changes in journey structure (using mathematical programming techniques) to be developed by the Transport Studies Unit. Through these interviews, they have learned, for example, that "it may be necessary to include information on in-home activities in some cases because of the role they play in influencing the timing, nature and location of out of home activities and travel." (Heggie and Jones, 1978). In addition, Heggie and Jones (1978) developed a systematic framework with which to judge the appropriateness of alternative theoretical models of movement in time-space. Their four "domains" can be represented by a two-by-two matrix whose cells are some combination of independence and/or a reference group. These are (1) independence, (2) space-time linkage, (3) interpersonal linkage and (4) both (2) and (3).

[17] In a multivariate context, Jacobson (1978) has developed models of the interaction between husbands and wives in terms of allocation of time to various activities.

Under the leadership of F. Stuart Chapin, researchers at the University of North Carolina have generated insights into which variables could explain urban activity patterns. Leaving aside questions of constraints, he hypothesized about the set of factors which lead urban residents to choose daily activity patterns. From the perspective of this thesis, one of Chapin's major conceptual advances is his broadening the notion of accessibility, which has traditionally reflected only spatial measures. He suggested indicators of temporal and income ("social") accessibility as means to evaluate the set of opportunities actually available to an individual.

Employing such tools as correlation analysis and cross-tabulation on national survey data, Brail (1970) made a detailed outline of the variables which may help explain what activities people choose, how long, when and where they choose them. Chapin (1974) conducted a more detailed analysis of data from two neighborhoods of Washington, D.C. While Chapin did not attempt to join the key variables into a comprehensive model, he sorted out many of the socio-demographic factors which seem to explain the differences in different people's patterns of daily activities. He isolated "role structure" (as embodied in sex, family responsibilities and working status) as a critical variable. Brail and Chapin (1973) concluded that work is a "major structuring element" of these patterns.

Closely parallel to Chapin's work is Kutter's (1972, 1973a, 1973b) research. Kutter performed a factor analysis to separate out those groups in the population which seem to have similar activity patterns. The typology which he developed for his "individual-factor-model" could be helpful when considering possible ways to segment the population. He found that respondents in his sample fell into distinct groups which showed significant differences in frequency and duration of activities (especially along class, gender and working status dimensions). Kutter, just as several previously mentioned authors, used the notion of "main activities" which influence the rest as part of his analysis.

An important by-product of many of the tabulations has been an increased sensitivity to segments of a population whose behavior may be quite distinct from that of an "aggregate". Some of the recent analyses of activity patterns along the dimension of gender not only give us insights into the behavior of selected groups, but also aid in our attempt to specify general models.

Palm and Pred (1979) for example explored alternative situations in which working women were constrained by children and/or household responsibilities or lack of automobile. Drawing heavily on the framework developed by Hägerstrand, they outlined the way in which various constraints might limit the "action space" within which such women make decisions about allocating their time. Two other sources give credence to the belief that an undifferentiated analysis of "women" across all activities leads at best, to marginally useful knowledge and that a multivariate framework is appropriate. Chapin (1974) in his study of activity patterns in Washington, D.C., calculated the mean number of hours of weekday "discretionary" time (i.e. devoted to activities in which participation is chosen) for working men and women. His results showed no significant difference between the means of each group. However, when he broke each group into the components "presence of a child under thirteen years old" or "no presence," he found an increase in the difference of means between the men and the women whose households had a child under thirteen. This seems to imply that, at least in Chapin's sample, the presence of younger children reduces women's disposable time more than men's. Such differences appear even more obvious when samples are split along lines of occupational status or class. In a study reported by the U.S. OMB (1973), the average time spent on personal and family care was computed for men and women within the classes blue and white collar. In both classes, females spent a considerably larger share of time than males (white collar: 6.1 vs. 3.8 hours; blue collar: 7.1 vs. 4.1 hours). Again, even those women holding full time jobs seem to carry a greater share of the household responsibilities than their male counterparts.

Hanson and Hanson (1979) demonstrated the need also to differentiate activities in which people participate. Using longitudinal household survey data from Uppsala, Sweden, they examined four indices of "daily activity-travel behavior". Their analysis of the frequency of participation in different activities, for example, showed that individual responsibilities within the family are not equally shared. "While fully employed men use 'more time' for their own leisure pursuits, fully employed women are occupied with individual household duties." (Hanson and Hanson, p. 220) Clearly, these authors point toward the need for further investigation not only of the factors which relate to household responsibilities but also of the interaction of these factors with other socio-economic variables.

2.3.6 Multivariate Modeling of Choice in Constrained Time and Space

Despite the meager results of most of the exploratory studies and the as yet weak theoretical foundations, research has emerged using methodologies developed in the fields of operations research and of econometrics. Researchers have drawn heavily on theories of choice such as utility maximization to estimate multi-variate models.[18] Such models have the obvious advantage that they can be used to assess the impacts of alternate policies. To the extent that the assumed distributions (of the error terms) hold or nearly hold, we can estimate coefficients and make predictions about people's future behavior, given changes in the activity or transportation system or in socio-economic characteristics.

Adler (1975, 1976) helped to clarify the problems associated with understanding and modelling complex round trips by making a strong case for the need to examine entire patterns of behavior rather than individual trip links. As he pointed out, "choices are clearly made on the basis of attributes of complete round trips when the decision is made to travel for a given purpose. Categorization by trip links leads to behavioral misclassification in many cases." (Adler, 1975, pp.15,27) Given that one cannot assume independence of decisions between links of a tour, Adler's discussion of the trade-offs between the chaining of sojourns and single-stop round trips is particularly interesting. In agreement with Westelius (1972), Adler points out that "the desire to combine needs into a single tour is affected by the levels to which the needs have accumulated at that point in time." (Adler, 1976, p.33) As a result, he treats the

[18] Utility theory and its application in this thesis will be covered in Chapter Three.

basic decision as one between combining purposes into a multi-stop tour and a single-stop tour. In this way, he suggests that people, in effect, make a utility maximizing joint choice of mode, destination and frequency, conditioned on scheduling convenience, travel expenditures, attributes of the set of destinations in the pattern and the socio-economic characteristics of the household.[19] Although he did not explicitly account for it in his thesis, Adler makes special note of the existence of a "fixed pattern" of travel which may consist simply of a single work chain or ... may be composed of other unavoidable and set patterns of travel for school or for additional workers." (Adler, 1975, p.55)

In his empirical work, Adler (1975, 1976) used household interview survey data from Washington, D.C. (1968) to estimate two multinomial logit choice models.[20] The first model (Adler, 1975) represented a joint choice of mode, destination and frequency of non-work travel. The second model (Adler, 1976) used the daily household travel pattern as the choice alternative and represented this pattern "by the number and characteristics of destinations chosen for non-work activities, the modes used to travel to those destinations and by the number of tours used to travel to the set of destinations."[21] Using the

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[19] An alternative approach was taken by Nystuen (1967) who developed a theory relating travel behavior to the spatial arrangement of urban facilities, i.e. multiple purpose shopping trips to the arrangment of stores in centers. Nystuen's work is especially interesting since he developed the notion of "out-of-home utility," meaning that duration of trips will increase until "home utility" is greater and the tour terminates.

[20] This model is also discussed in Adler and Ben-Akiva (1979).

[21] A tour is a series of trips starting and ending at home.

"accumulation of needs" concept developed by Westelius (1972), Adler defined a new variable type, "scheduling convenience." With this, he postulated that people would most like to combine stops with the worktrip when the needs threshold has been reached but don't always do this because of the associated inconvenience. In this way, Adler was able to develop a multivariate (logit) choice model of "travel pattern" as a function of this convenience in addition to net non-home activity duration, remaining income after travel expenses, attributes of destinations and households' socio-economic characteristics.[22] While this formulation allowed us for the first time to model travel pattern decisions in a joint or interdependent fashion, several issues remain unclear. First, the process by which people compare alternative patterns for an entire day is not obvious. Do people actually try to maximize their utility for an entire day, pattern or just for certain trips? Second, it is not certain how utility associated with single stop tours (which imply a greater separation of activities in time and space) is compared to the utility of multi-stop tours. Finally, we are still in the dark about how people evaluate marginal increases in travel time associated with additional stops on an obligatory work trip versus stops made before or after the work trip is even begun.

Horowitz (1976, 1979) also used data from Washington, D.C. to examine hypotheses about the frequency of non-work auto travel and the demand for multi-destination auto travel. In particular, he used utility maximizing models to test the significance of travel time and

[22]Because choice of "travel pattern" is actually a very complex joint choice of several things modeled for an entire day, the changing attributes of a person's location in time-space during the day were not considered.

auto operating costs on the frequency and demand mentioned above. The empirically based results demonstrate that at least one element of transportation level of service affects frequency of travel (i.e. trip generation) and the way households structure their travel (tours and sojourns). In contrast to Adler, Horowitz considered the set of destinations actually chosen rather than the full set of potentially available travel patterns. In Horowitz (1979), it was clearly shown that it is possible to develop a utility maximizing model which forecasts non-work tour frequencies and destination choice when multi-destination travel but not the detailed structure of travel patterns is considered.

Although Oster (1977, 1978a, 1978b) worked in a simple regression framework and does not account for interdependence of decisions (within a day or within a household), his operationalization of several concepts is noteworthy. First, he calculated spatial accessibility measures for both the residence and the workplace in recognition of the importance of work as a fixed base from which to add discretionary activities. Second, Oster used the incremental travel costs of adding stops to a home-work trip. Finally, he defined aggregate measures of a "pattern" with which to analyze the impacts of alternative policies. Here it is crucial to mention that not only were trip length, travel time and distance but also activity time at stops included as measures. His empirical results (using number of stops as the dependent variable) showed that at least in his formulations, very little variation in the data is explained by either household or locational attributes (number in household older than 16 was one of the exceptions).

The total duration of various activities in a day was the central focus of Bain (1976). Observing that available behavioral models included only attributes of travel and socio-economic characteristics of individuals, he called for consideration of the attributes of the activities for which trips are made. His model treated total daily activity plus associated travel time as the variable to be explained and drew on the theoretic econometric work of Tobin (1958) to take account of the fact that the choice is twofold: whether to participate and how long.[23] Since Bain's models of "shopping and personal business" and "social-recreation" do not account for interdependence of the durations of single activities in a day, it is impossible to determine why a particular sequence of stops occurs. Nevertheless, Bain's work provides a good basis from which to expand our understanding of activity schedules and travel patterns. Most recently, Jacobson (1978) also estimated multivariate models of the total time allocated to specific activities in a day. Of particular interest is his estimation of such a model for an individual simultaneously with his or her spouse.

2.4 What Does the Literature Tell Us?

Despite the relatively underdeveloped state-of-the-art in modelling "what people do in time and space," prior research provides a rich source of hypotheses. While some of these hypotheses have already begun to be examined in some way, others remain unexamined. The most promising hypotheses generated from the literature survey fall into three groups:

[23] Readers interested in elaboration on this type of model are directed to Chapter Four of this thesis.

(1) constraints on choices in time, (2) constraints on choices in space and (3) the socio-economic environment in which constrained choices are made.

It became evident that research based on assumptions of independence of decisions misrepresent the choice process of most people. At least three types of hypotheses should consequently be tested to address this fact, each relating to the nature of interdependence:

- a person's daily decisions to participate in activities are interrelated;
- the temporal-spatial decisions of a member of a household are dependent on the decisions of others in the household;
- a person's temporal-spatial decisions are dependent on decisions of people in non-household reference groups (*e.g.* at work).

Researchers have also told us that decisions made in time and space are rarely unconstrained. That is, virtually everyone has a limited amount of time to reach a limited number of opportunities in space. That research which has looked exclusively at revealed preferences or observed choices without explicit treatment of constraint has misrepresented the reality under which those choices were made. The resulting hypotheses to be tested should be obvious:

- the density of opportunities in space influences activity scheduling behavior
- since density of opportunities varies with a person's location, such density varies in its impact on behavior
- whether activities are open for participation influences scheduling behavior.

The set of socio-economic variables and corresponding hypotheses which has been suggested by prior research is enormous. On the one hand, many of these variables could give us insights into the constraints under which people make activity scheduling decisions. That is, many variables relating to familial and work-related roles and responsibilities actually tell us about the limits put upon an individual's discretionary time. Hypotheses of the two following forms could be applied to most of the "household level" variables: (1) the number of children in a family influences the number and extent of tasks to be performed in a household, and (2) the number of non-working adults influences the extent to which a household's tasks can be performed by someone other than a full time worker. In short, there seem to be at least two forces which influence the familial constraints actually experienced by a person; the first originating from people who generate needs and the second from those who can meet these needs.

Within the set of socio-economic variables are also a wide range of implicit hypotheses to be tested about individuals, independent of their familial context. These relate primarily to whether or not homogenous groups can be defined in the population. Such groups are sometimes referred to as market segments and can be indicated by descriptors of a person as gender, income and age. Although these variables cannot be said to be "causal" in terms of directly influencing a decision whether or not to participate and for how long, they can nonetheless help us to explain the observed variation with respect to activity schedules.

In summary, the review of the literature has generated three lessons to be learned. First, an entire day's activity decisions should be considered as interdependent. Second, activities which are fixed and the resulting fixed schedule should be considered as bases around which the rest of a day's activities are chosen. The work activity and corresponding "home-work-home" schedule appear to lend themselves well to this requirement. Third, the analysis should be multi-variate. At this time, there are sufficient numbers of tabulations and cross classifications with which to move on to a more complex set of techniques, presumably those leading to parametric, multi-variate models.

CHAPTER THREE

Theoretical Framework

3.1 Introduction

The purpose of this chapter is to outline the casual mechanisms which appear to explain how people schedule activities in time and space. At issue, then, is the way in which best to represent these mechanisms. We would like to approximate as closely as possible people's decision processes as they evaluate alternative arrangements of activities in a day. However, we would also like to design a set of theoretical constructs which lend themselves to operational definition and thereafter to empirical estimation in form of an analytical model. Despite simplifying assumptions which reduce the degree of correspondence between reality and any model, a statement is then possible about the causation believed to operate when people schedule activities. Without such a statement no empirical work can go beyond the bounds of statistical correlations. The framework described here will not only provide a vehicle for synthesizing the many sources of inspirations discussed in Chapter Two, but will also be operationalized so that the most promising hypotheses embodied in the framework can be tested against observed behavior.

At the outset an ideal or full system of concepts with which to explain people's behavior in time and space will be developed. While not all concepts are ultimately amenable to being matched to a single measurable variable, sketching out the full theoretic system provides an excellent means of later uncovering confounding or intervening variables which affect the observed behavior. The next section will contain an evaluation of alternative constructs with which to explain how the set of "causal factors" relate to the dependent variables of "whether or not to participate in an activity" and "for how long." Part 3.4 will then include a discussion of how principles of utility maximizing provide a useful framework within which to develop a quantitative analysis of activity scheduling decisions. This will be the foundation on which an operational model to be used in empirical tests of the theory will be constructed. The assumptions and structure of this model are the subjects of Chapter Four.

3.2 Causal Model Postulated

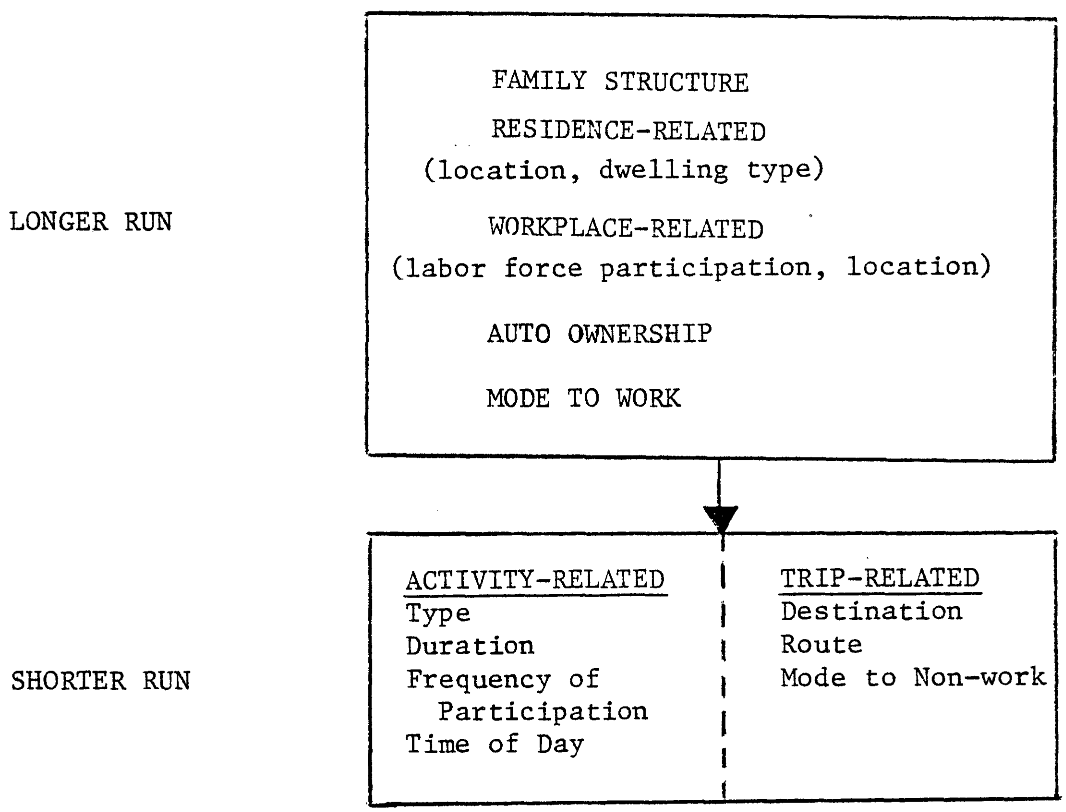
At the heart of any construct useful to this research is the notion that travel is derived from the need to participate in activities. It is instructive at the outset to differentiate activities by the level of fixity associated with each. Participation in a work-related activity, for example, is clearly more fixed for most people than, say, participation in a recreational activity. In the usual case, the worker's place and time of employment can be considered fixed. Together with the person's place of residence and timing of home-related activities (sleeping, eating, etc.) we can describe the basic schedule of activities of any given weekday. For a sizeable segment of the population we will observe a pattern of home-work-home on a typical work day. However, for that segment of a population which does not simply go from home to work and back, we have very little understanding of their decision-making. The primary focus of this thesis is, consequently, to understand and predict full time workers' decisions to deviate from this basic schedule. In other words, we would like to know what combination of circumstances seems to "cause" such workers to add one or more activities to an otherwise obligatory schedule.

Fortunately, prior researchers (Bain, 1976; Jacobson, 1978) have attempted to place demand for activity participation in an overall scheme of time-space decisions. Figure 3.1 draws on this research to show the position of activity scheduling relative to decisions which range in time from very long (participation in the labor force) to very short (which cinema to visit). It should become evident that in fact, not all scheduling of activities falls into the same position. For example, scheduling "work" or "sleep" tends to involved much longer run decisions than scheduling "social visits."

While a number of authors have explicitly treated the demand for activities as part of an analysis of travel patterns, no one has attempted to develop a general theoretical foundation with which the nature of movement between places over time could be understood in the context of a person's full set of daily activities. Most of the available analyses of activity demand, being closely derived from those of travel demand, use theories which treat only out-of-home activities. Particularly with respect to recreational or social activities, one could imagine that in fact, people often choose between staying home and going out. Bain (1976), in describing his "hierarchy of choice models" included "in-home activity supply" as a factor influencing decisions related to participation and duration. Unfortunately, he did not elaborate on the effect of this supply on the utilities derived from participation in particular activities.

FIGURE 3.1

GENERAL CHOICE HIERARCHY FOR TIME-SPACE DECISIONS



For example, why would anyone want to leave home when the transportation costs of staying home will always be zero?

Explicit in the approach taken by several authors (Bentley, et al., 1977) is the notion of ending a series of stops in a tour by returning back home. Those researchers who used Markovian models also developed their work by treating "home" as the absorbing state, i.e. that which ends a series or chain of trips. However, none of these modelers attempts to understand the tradeoffs which may have been made in decisions to return home or stay outside home. Because of either the lack of a general theoretical basis or the nature of the analytical tools available, very little progress has been made toward consideration of in-home activities in the context of activity schedules and the resulting travel patterns. Although the causal mechanisms postulated in Figure 3.2 only indirectly treat activities in the home, by focusing on the decision to participate in non-home, non-work activities, it is implicitly included.

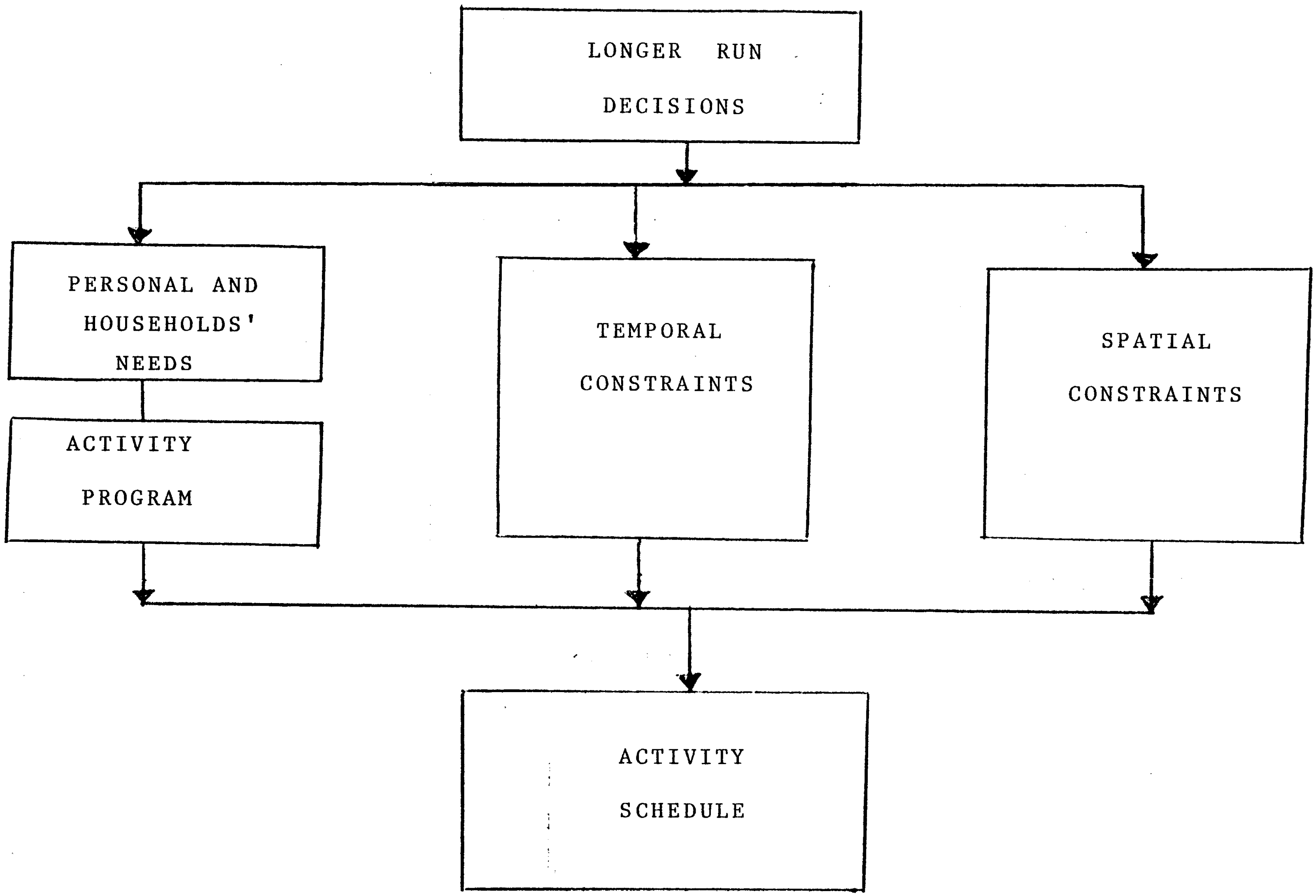
This implicit treatment of in-home activities can be understood by considering the organizational scheme which emerges from focus on workers with a work trip. If we take the activities at home and at work to be fixed in time and space, we can view a person's day as effectively divided into five time periods with respect to these two fixed activities. They are:

1. prior to the work trip
2. during the trip from home to work
3. during work
4. during the trip from work to home
5. after the work trip.

One decides to participate in non-home/non-work activities for a specific duration, given a decision to participate at all. A decision not to "participate" is an implicit choice to continue at one's current location in Periods One, Three and Five to do nothing more than travel between home and work in the case of Periods Two and Four. As we shall see in Section 3.4 it can follow quite plausibly that a person evaluates the utility derived from not leaving home just as much as the utility derived from leaving home to take part in an outside activity. The framework developed here embodies recognition of the fact that some in-home activities are actually discretionary in nature and compete with out of home or what has traditionally been called "non-work" activities for a piece of an individual's total time budget or activity program.

The causality implied in Figures 3.2 through 3.6 reflects a collection of many threads, from both _a priori_ understanding and work conducted by other researchers. At the top of Figure 3.2 are the set of factors about which an individual and people in his/her household decide or at least consider over a longer period of time. Very few people decide about their participation in the labor force or car ownership level on anything less than a yearly basis. Similarly, the division of roles in a household is only occasionally the subject of debate among its members. These factors are then seen to influence collectively the three sets of factors immediately below. In broad terms, the factors can be thought of as demand (needs/program) and supply (constraints). Given this "demand" and "supply" we then observe an activity schedule which is represented here by the decision of whether or not to participate in an activity (_i.e._

Figure 3.2: Summary of Factors Influencing Activity Scheduling



deviate from an obligatory schedule and if so, for how long.

Descriptors of factors which are direct manifestations of the distribution of roles in a household are elaborated on in Figure 3.3. On the one hand, each member generates both personal and household-level needs to be met by participating in activities outside the home. On the other hand, only some members of the household are in a position to fulfill such needs, either their own or for others. Depending on the particular mix of roles in a household, any observed individual will have a certain number of out-of-home responsibilities to take care of which meet the needs of the household as a unit (e.g. grocery shopping). In the same way, the lifestyle, employment status and role of an individual, together with a myriad of other economic and psychological factors combine to influence the needs which an individual experiences apart from the household's context. Both these familial and personal needs together produce an activity program which a person would like to complete over some time frame.

In Figure 3.4, the notion of temporal constraint is represented. The duration of one's work- and home-centered activities (which is partly determined by one's chosen lifestyle) has a direct impact on the time available for completing a program of discretionary activities, i.e. a limiting one. The temporal fixity of obligatory activities is also partially determined by one's lifestyle and other longer term decisions such as those related to profession. A person who is required to be at work during prescribed hours and is strongly expected by others to be home for a meal at a set time will probably have an activity schedule

Figure 3.3: Detailed Representation of Activity Program's Influences on Scheduling

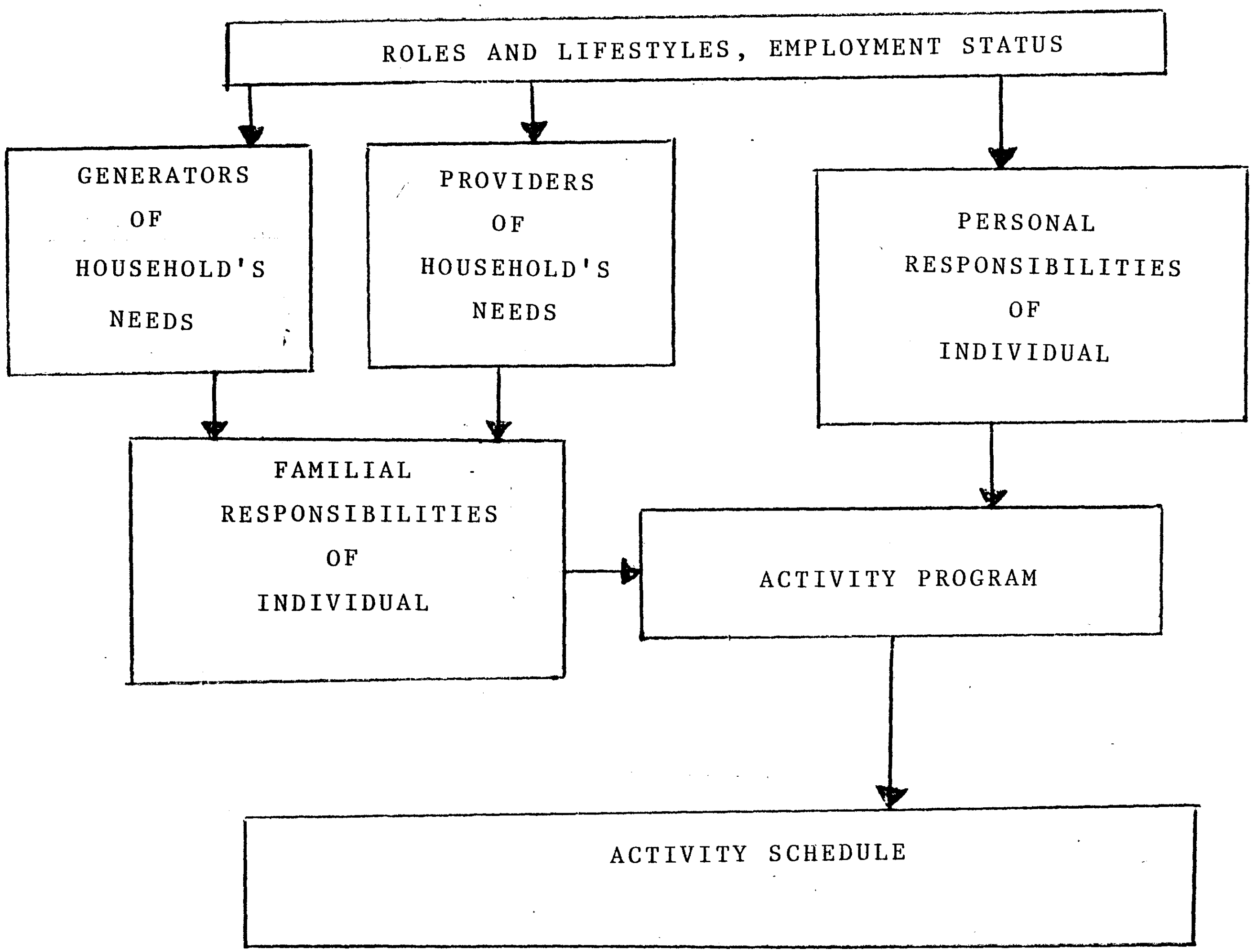
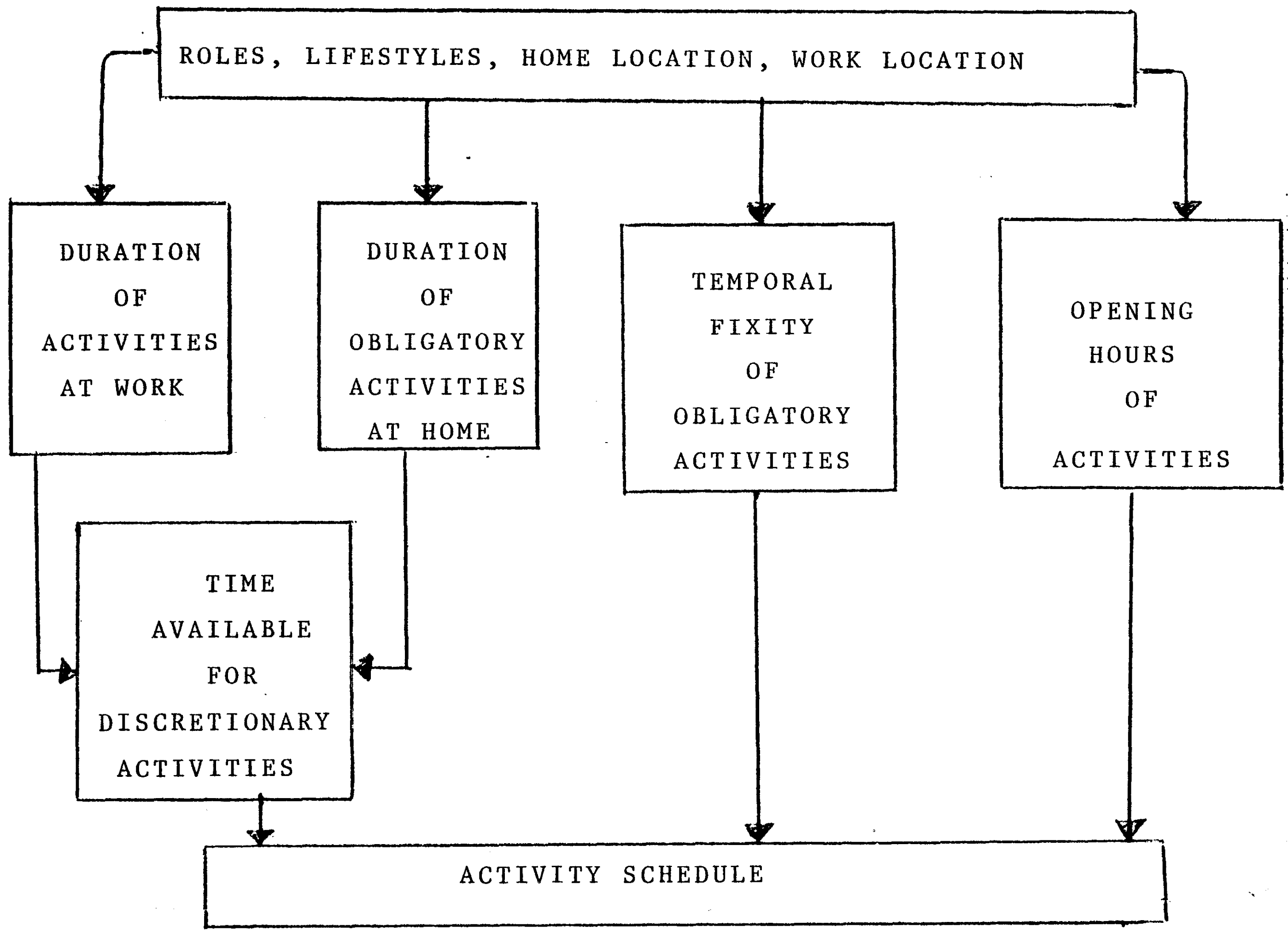


Figure 3.4: Detailed Representation of Temporal Constraints Influencing Activity Scheduling



very different from people who don't experience such requirements. The hours during which various activities are opened provide another substantial source of constraint on the decision-making of full-time workers. Though out of direct control by most people, the set of activities whose hours would be of concern to the person observed are predetermined by the longer run decisions of residential and job locations.

In Figure 3.5, the components represent constraints upon but also potential for reaching activities in space. First, there are two factors which represent more perceptual influences on scheduling behavior: (1) familiarity with surroundings at home and (2) spatial fixity of the workplace. One assumes that people whose workplace is not fixed in space (e.g. construction workers) will be less familiar with potential nearby opportunities and hence have a different activity schedule than people whose workplace is in one location over the long run. It should be clear that the transportation facilities available to a person directly affect his/her ability to overcome the barriers of space. Likewise, the characteristics of the spatial environment (i.e. the density of activities) which one encounters during a day of work have an immediate bearing on the set of potential opportunities which could be included in an activity program. These characteristics are embodied in an accessibility level. Aside from the abstract "accessibility" which a person encounters in various locations, the mode taken to work directly affects one's capability to reach activities in space.

Finally, in Figure 3.6, the activity program and constraints are collapsed into one package which influences the decision of an individual to participate in an activity during a particular time period. If the

Figure 3.5:Detailed Representation of Spatial Constraints Influencing Activity Scheduling

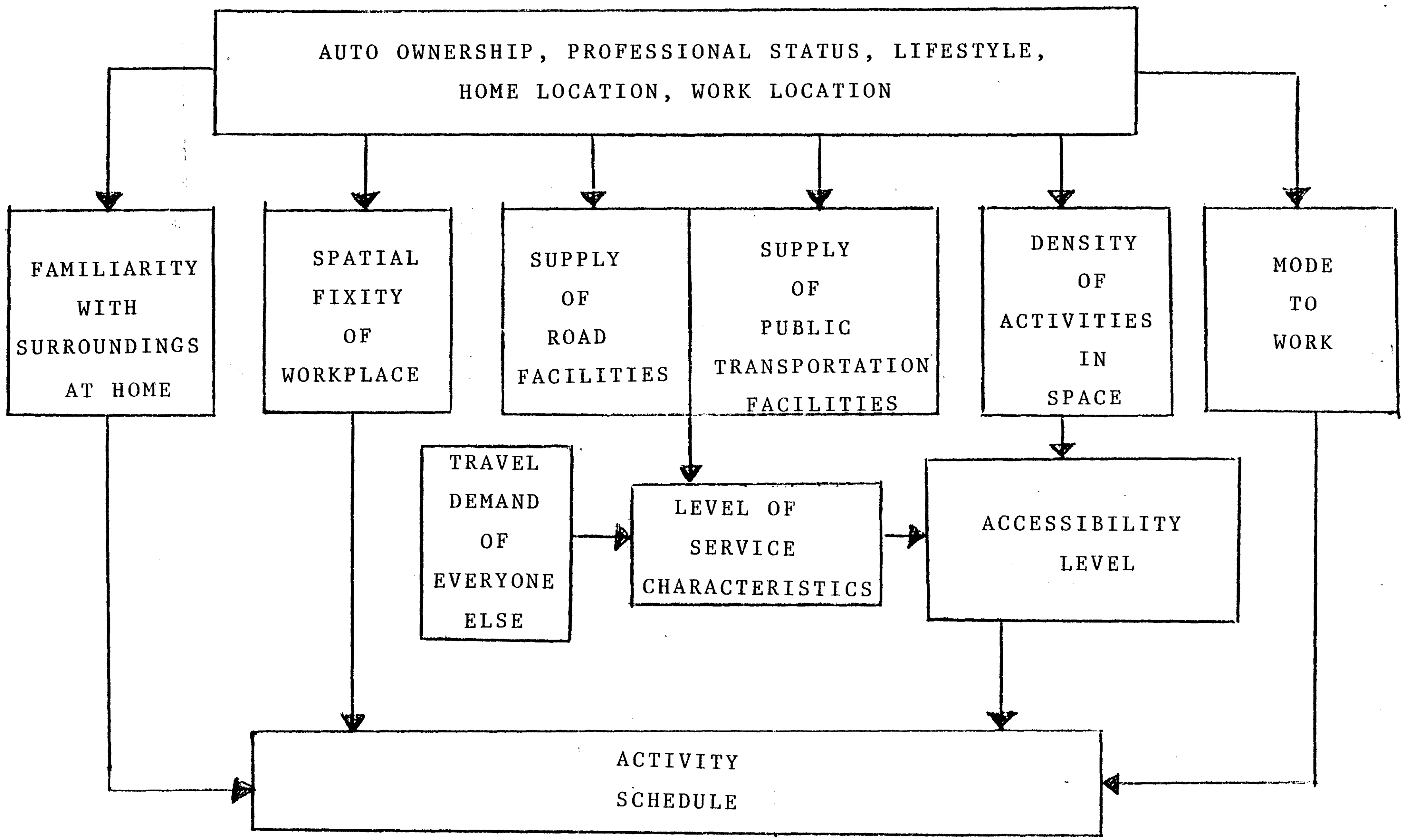
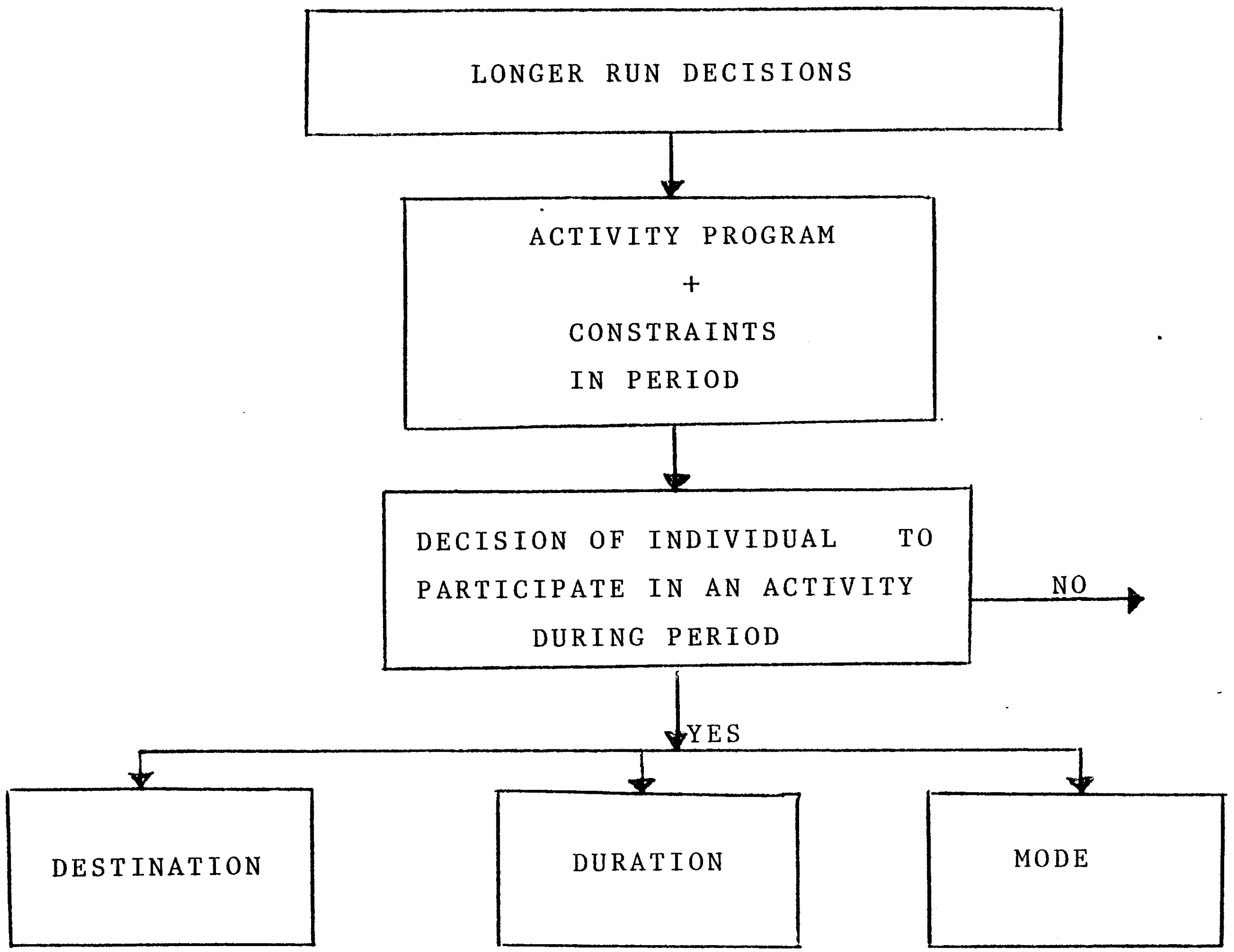


Figure 3.6: Detailed Representation of Activity Scheduling Decisions



outcome of the decision is positive then there are at least three decisions which are made: where participation will occur, by what mode the activity will be reached and for how long participation will last.

The concepts of prism and potential activity area developed by the Lund researchers are useful at this juncture in understanding the two dimensional nature of scheduling behavior (i.e. in both time and space).[24] Consider Figure 3.7 reprinted from Lenntorp (1976a) on the following page. To this figure have been added labels identifying the person's location and the time period which would correspond to that defined in this thesis. As an individual moves through a day and between home and work, the temporal and spatial constraints vary, and hence, the potential area which can be reached at a given time and place. In this way, we can readily see the virtues of treating intervals before, during and after work separately. Because these prisms only describe the maximal area within which a deviation from a fixed schedule can be made, we need to devise a more specific framework for analyzing the actual choices which people make. It is to the alternative theories of choice which we now turn.

3.3 Alternative Theories

A number of well developed theories about choice already exist expecially in the field of economics and psychology. While these theories have often been used to good advantage in research of transportation issues

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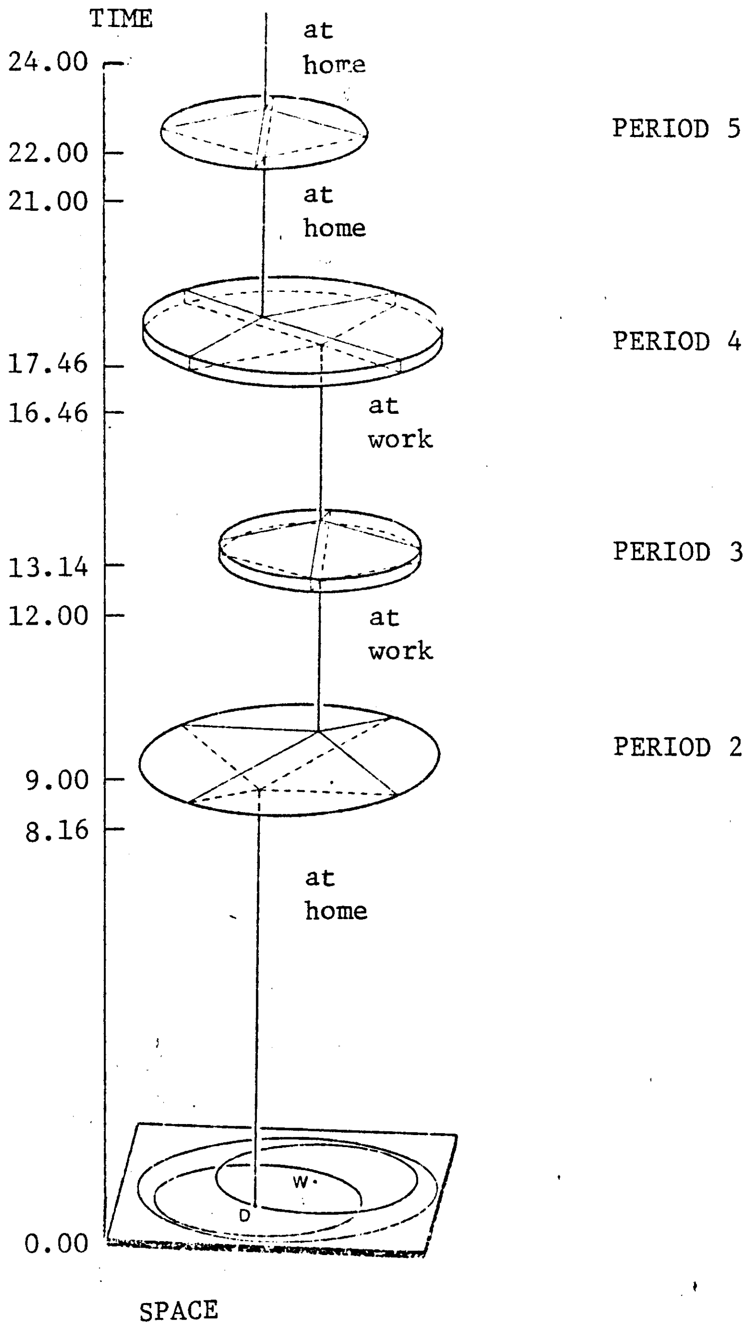
24 For a discussion of the concept of prism, see Chapter Two, pp 23-26

Figure 3.7: An Example of Prisms in an Individual's Daily Program*



*Drawing and concept taken from Bo Lenntorp (1976a). As he points out, "The activity areas for the two prisms which start at 08.16 and 16.46 hours respectively coincide completely in space. D denotes the location of the dwelling and W that of the workplace. Four possible individual paths are followed over the 24-hour period."

as modal choice, it is not obvious how these theories are appropriate for explaining activity scheduling behavior. For the most part, the available "choice theories" (e.g. elimination by aspects, satisficing, optimization under constraint) have been applied to choice situations in which alternatives are easily identified by their attributes. In terms of scheduling activities, the set of alternatives from which people choose is not immediately evident. Unlike modal choice, the scheduling of activities embodies choice along many dimensions: time of day, destination, duration as well as mode.

Implicit in most choice theories is the notion of "trade-offs" and the closely related concept of "substitutability." That is, in choosing one mode over another, a person may be trading off lower travel time against higher cost (auto versus bus). In deciding about how to realize an activity program, such clear cut trade-offs do not exist. One may well evaluate time and cost of "alternative" schedules; but is time always to be weighed against cost? (For participation in some activities, e.g. social or recreational, more time may be preferred but only up to some point. For others, e.g. grocery shopping, lower time may be better in any case.) A further complication is that scheduling involves more than discrete (or nearly discrete) alternatives like "peak" versus "off-peak." A decision to participate in an activity is directly linked to choice of duration which, as a continuous variable, cannot be well explained with available choice theories.

Based largely on optimizing versions of choice theory, a growing body of transportation research reflects the tendency to view decision making as either maximizing or minimizing some quantity. In order to collect an evaluation of many diverse attributes into one package, transportation theorists have postulated that travelers choose alternatives based on some ordinal ranking of the utilities associated with each discrete alternative. In its pure form, the resulting model is effectively deterministic since we can perfectly predict outcomes if we have information on the alternatives' attributes and utility functions. If we admit that, in fact, there is not only a systematic but also a random component involved in people's evaluation of alternatives, our resulting model is probabalistic. The "chosen" alternative is postulated to produce greater utility than any other "non-chosen" alternative. Adler (1976) and Horowitz (1979), for example, tried to apply this utility maximizing framework to the topic of "trip-chaining", or combining two or more stops into one tour.[25]

In his research, Adler hypothesized that people vary in their willingness to let out-of-home needs accumulate, and hence vary in observed frequency of making multi-versus single-stop tours. In addition to maximizing utility via conventional factors such as level of service, people evaluate "scheduling convenience" associated with multi- or single-stop tours. Nevertheless, several points remain unclear with regard to the use of a utility maximizing framework for trying to understand activity participation decisions. Because there was no explicit treatment of activities in Adler's formulation, he was able to avoid a number of critical issues. The "choice set" was simply the range of stops per sojourn.

[25] This research is descrbied more fully in Chapter Two.

Duration of a stop and time of the day of a stop (or stops) were not considered. Unfortunately, it is neither obvious that people actively choose a level of stops/sojourn nor clear that a certain value of stops/sojourn at one time for one person is equivalent to the same value at another time for the same person. The end effect of such a theory is to provide a causal framework for the traditionally correlative trip generation models. However, there is still no certainty that making a number of stops per sojourn, is actually a "behavior" which should be represented with a maximization framework. The present research will attempt to show that "trip-chaining" or consolidating is much better understood when activities are explicitly treated. Moreover, we will see that given sufficient modifications activity scheduling behavior can be adequately represented with utility theory.

Several authors (including Jones, 1977,and Burnett and Hanson, 1979) have contended that new theories of complex behavior in time-space are warranted. They believe that especially since decisions are not made "at the margin," it is inappropriate to speak of optimizing anything. Since no such "new theory" which would be more appropriate to the explicit treatment of activity participation is yet available, one task of this will be to evaluate the adequacy of the existing utility theory in helping us to understand how people decide to participate in activities and for what duration.

3.4 Utility Theory and Activity Schedules

Because basic principles and their general applications to transportation phenomena has been adequately detailed elsewhere

(Domencich and McFadden, 1975), extensive discussion of utility theory will be omitted. Instead, this section will contain the three following parts: (1) description of the complete 24-hour time budget and the place of an activity schedule within it; (2) creation of a generic utility model for activity scheduling; (3) development of a simple example of this model. In this way, we will then be in a position to operationalize the causal structure described in Section 3.2 so as to allow empirical testing of the hypotheses embedded in it.

Recalling that we have defined five periods of time during a full-time worker's day, we can let:

Q_p = the total time available in period p

It obviously follows that:

$$\sum_{i=1}^{5} Q_p = 24 \text{ hours} \tag{3.1}$$

While many activities fall on a continuum between the extremes of discretionary-obligatory, for purposes of initial development, we can let:

T_p = the discretionary time available to an individual in period p

S_p = the obligatory time which an individual faces in period p

Obligatory time includes time spent at work or at home as well as the minimal path travel time between these two points. Knowing that

$$Q_p \equiv T_p + S_p \tag{3.2}$$

implies that

$$T_p = Q_p - S_p \tag{3.3}$$

Since T_p is the variable of central interest in this research, it is useful to separate it into its three observable components; namely let:

a_p = time spent away from a fixed place or path in period p in an activity

tt_p = travel time used to go away from the fixed place or path in period p

b_p = time spent in non-obligatory activities at a fixed place.

Consequently,

$$T_p = Q_p - S_p = a_p + tt_p + b_p \tag{3.4}$$

In the same fashion we can separate S_p into its components. Let:

c_p = time spent in an obligatory activity

d_p = time spent in travel between the obligatory activities

such that

$$S_p = c_p + d_p \tag{3.5}$$

In summary form Table 3.1 shows the "schedule" which we observe for an individual over a day's time, i.e. over the five time periods. The value of all variables is greater than or equal to zero.

In any given time period then, we can postulate that a person evaluates that set of conditions associated with participation in such an activity and that set associated with non-participation (i.e. staying in the current obligatory activity or not deviating from a minimal path, depending on the period). In this thesis we postulate that there exists a utility, U, derived from either participation or non-participation and that this U can be expressed as a function of the conditions used in a person's evaluation.

Let:

$$U = [\rho(a + tt), b] \tag{3.6}$$

subject to the constraint:

Table 3.1 : Components of an Activity Schedule

Period \ Component	Obligatory Time (S_p) c_p	d_p	Discretionary Time (T_p) a_p	tt_p	b_p	Σ Q_p
1 (H-O-H)	c_1	0	a_1	tt_1	b_1	Q_1
2 (H-O-W)	0	d_2	a_2	tt_2	0	Q_2
3 (W-O-W)	c_3	0	a_3	tt_3	0	Q_3
4 (W-O-H)	0	d_4	a_4	tt_4	0	Q_4
5 (H-O-H)	c_5	0	a_5	tt_5	b_5	Q_5
						Σ=24 hours

c_p = time in an obligatory activity

d_p = time in travel between obligatory activities

a_p = time away from a fixed place or path in an activity

tt_p = travel time used to go away from a fixed place or path

b_p = time in non-obligatory activities at a fixed place or path

p = subscript defining period.

$$T_p = \rho_p\ (a_p + tt_p) + b_p,\ \forall_p \tag{3.7}$$

where:

$$a + tt = \{a_1 + tt_1,\ a_2 + tt_2, \ldots a_N + tt_N\}$$

$$b = \{b_1, b_2, \ldots b_N\}$$

$$\rho = \{\rho_1, \rho_2, \ldots \rho_N\}$$

$\rho_p = \begin{cases} 1, \text{ if a discretionary activity scheduled away from a fixed place in period } p \text{ (\underline{i.e.} } \rho_p = 1 \text{ if } a_p \geq 0) \\ 0, \text{ otherwise} \end{cases}$

N = total number of time periods

T_p = total discretionary time in period p

An activity schedule consists of those a*'s and b*'s which maximize the utility, U. Since entries in ρ can take only values of 0 or 1 (corresponding to participation and non-participation), then there are 2^N possible combinations of binary variables which define $a + tt = 0$ and $a + tt > 0$. For example, if we have five time periods, there are 32 such combinations. The highest utility (U*) of a set of alternative activity schedules can be derived by maximizing the utility function above, $U[\rho(a + tt),b]$. As we believe that decisions in the various time periods are interdependent, the ideal approach to finding a U* for any invididual would be to evaluate the utility associated with each of the thirty-two combinations. This approach would entail extremely complex functions and a procedure for solution which would be computationally expensive.

A more tractable approach would be to assume initially that decisions are made for each time period separately and attempt in later stages to define attributes of single time periods which are functions of characteristics of all other periods. Using this approach we obtain:

$$U^*(\rho) = U^*[\rho_1(a_1 + tt_1, b_1)] + U^*[\rho_2(a_2 + tt_2, b_2)] + \ldots U^*[\rho_N(a_N + tt_N, b_N)] \qquad (3.8)$$

In order to simplify the theoretical discussion we will consider a two period model which can be easily translated to any multi-period situation.

In this way we can begin to postulate a decision process which people use when evaluating alterntive schedules. For example, in the two period case, we would like to maximize the function:

$$U[\rho(a + tt,b)] = (a_1 + tt_1)^{\rho_1\delta_1} b_1^{\delta_2}(a_2 + tt_2)^{\rho_2\gamma_1} b_2^{\gamma_2} \qquad (3.9)$$

subject to the constraints:

$$T_1 = \rho_1(a_1 + tt_1) + b_1 \qquad (3.10)$$

$$T_2 = \rho_2(a_2 + tt_2) + b_2 \qquad (3.11)$$

where:

$\delta_1, \delta_2, \gamma_1, \gamma_2$ = parameters

$$\rho_1, \rho_2 = \begin{cases} 1, & \text{if participation} \\ 0, & \text{otherwise} \end{cases}$$

$a + tt, b \geq 0$

If we attempt to maximize U given a ρ to obtain a $U^*(\rho)$, there are four "best" solutions, depending on the value of ρ. The cases in which solutions could occur are as follows:

<u>Case 1</u> $\rho_1 = 0, \rho_2 = 0$

$$\begin{array}{ll} a_1 = 0 & a_2 = 0 \\ b_1 = T_1 & b_2 = T_2 \\ tt_1 = 0 & tt_2 = 0 \end{array}$$

<u>Case 2</u> $\rho_1 = 0, \rho_2 = 1$

$$\begin{array}{ll} a_1 = 0 & a_2 > 0 \\ b_1 = T_1 & b_2 = T_2 - a_2 - tt_2 \\ tt_1 = 0 & tt_2 > 0 \end{array}$$

<u>Case 3</u> $\rho_1 = 1, \rho_2 = 0$

$$\begin{array}{ll} a_1 > 0 & a_2 = 0 \\ b_1 = t_1 - a_1 - tt_1 & b_2 = T_2 \\ tt_1 > 0 & tt_2 > 0 \end{array}$$

<u>Case 4</u> $\rho_1 = 1, \rho_2 = 1$

$$\begin{array}{ll} a_1 > 0 & a_2 > 0 \\ b_1 = T_1 - a_1 - tt_1 & b_2 = T_2 - a_2 - tt_2 \\ tt_1 > 0 & tt_2 > 0 \end{array}$$

The necessary conditions for maxima in each case where $a > 0$ can be derived by taking the partial derivities of the Lagrangian with respect to the variables a_1, b_1, a_2 and b_2, setting the derivatives equal to zero and solving.[26] By using the resulting expressions for time allocated in the two periods, we can then evaluate the utility functions in each of the four cases to solve for $U^*(\rho)$, the maximum:

[26] Where $a=0$, the solution is completely determined. These correspond to corner solutions to the maximization.

Case 1 is trivial. Since the only values of interest are b_1 and b_2, the maximum is given by:

$$U^* \ (\rho_1=0,\rho_2=0) = T_1^{\delta_2} \ T_2^{\gamma_2} \qquad (3.12)$$

For Case 2, we have:

$$U[\rho(a + tt, b)] = a_2^{\gamma_1} \ b_2^{\gamma_2} \ T_1^{\delta_2} \qquad (3.13)$$

Since we already included the first constraint in Equation 3. by T_1, we can form the Lagrangian as:

$$L = a_2^{\gamma_1} \ b^{\gamma_2} \ T_1^{\delta_2} - \lambda[T_2 - a_2 - tt_2 - b_2] \qquad (3.14)$$

Taking the partial derivatives and then setting them equal to zero, we have:

$$\frac{\partial L}{\partial a_2} = \frac{\gamma_1}{a_2} a_2^{\gamma_1} \ b_2^{\gamma_2} \ T_1^{\delta_2} - \lambda = 0 \qquad (3.15)$$

$$\frac{\partial L}{\partial b_2} = \frac{\gamma_2}{b_2} a_2^{\gamma_1} \ b_2^{\gamma_2} \ T_1^{\delta_2} - \lambda = 0 \qquad (3.16)$$

By adding through by λ in both equations, we have expressions which are equivalent and can be set equal to each other. Since the term $a_2^{\gamma_1} \ b_2^{\gamma_2} \ T_1^{\delta_2}$ occurs on both sides of the equation we obtain:

$$\frac{\gamma_1}{a_2} = \frac{\gamma_2}{b_2} \qquad (3.17)$$

Since we know that $b_2 = T_2 - a_2 - tt_2$, we can substitute it into equation 3.17 and solve for a_2, the out-of-home activity time, getting:

$$a_2 = \frac{\gamma_1}{\gamma_1 + \gamma_2} (T_2 - tt_2) \tag{3.18}$$

Returning to the original utility function, we obtain an expression for the maximum:

$$U^*(\rho_1=0,\ \rho_2=1) = \left[\frac{\gamma_1}{\gamma_1 + \gamma_2}(T_2 - tt_2)\right]^{\gamma_1} \left[\frac{\gamma_2}{\gamma_1 + \gamma_2}(T_2 - tt_2)\right]^{\gamma_2} T_1^{\delta_2} \tag{3.19}$$

Case 3 can be solved in exactly the same way as Case 2 as shown in equations 3.13 through 3.19. These are:

$$U[\rho(a + tt,\ b)] = a_1^{\delta_1} b_1^{\delta_2} T_2^{\gamma_2} \tag{3.20}$$

$$L = a_1^{\delta_1} b_1^{\delta_2} T_2^{\gamma_2} - \lambda(T_1 - a_1 - tt_1 - b_1) \tag{3.21}$$

$$\frac{\partial L}{\partial a_1} = \frac{\delta 1}{a_1} a_1^{\delta_1} b_1^{\delta_2} T_2^{\gamma_2} - \lambda = 0 \tag{3.22}$$

$$\frac{\partial L}{\partial b_1} = \frac{\delta_2}{b_1} a_1^{\delta_1} b_1^{\delta_2} T_2^{\gamma_2} - \lambda = 0 \tag{3.23}$$

$$\frac{\delta_1}{a_1} = \frac{\delta_2}{b_1} \tag{3.24}$$

$$a_1 = \frac{\delta_1}{\delta_1 + \delta_2} (T_1 - tt_1) \tag{3.25}$$

$$U^*(\rho_1=1,\rho_2=0) = \frac{\delta_1}{\delta_1+\delta_2}(T_1 - tt_1)^{\delta_1} \frac{\delta_2}{\delta_1+\delta_2}(T_1 - tt_1)^{\delta_2} T_2 \gamma_2 \tag{3.26}$$

Though Case 4 involves more terms than the previous cases, its solution is no less straightforward. This is:

$$U[\rho(a + tt,b)] = a_1^{\delta_1} b_1^{\delta_2} T_1^{\delta_2} a_2^{\gamma_1} b_2^{\gamma_2} T_2^{\gamma_2} \tag{3.27}$$

$$L = a_1^{\delta_1} b_1^{\delta_2} T_1^{\delta_2} a_2^{\gamma_1} b_2^{\gamma_2} T_2^{\gamma_2} - \lambda_1(T_1 - a_1 - tt_1 - b_1) \tag{3.28}$$

$$- \lambda_2(T_2 - a_2 - tt_2 - b_2)$$

$$\frac{\partial L}{a_1} = \frac{\delta_1}{a_1} a_1^{\delta_1} b_1^{\delta_2} T_1^{\delta_2} a_2^{\gamma_1} b_2^{\gamma_2} T_2^{\gamma_2} - \lambda_1 - \lambda_2 = 0 \tag{3.29}$$

$$\frac{\partial L}{a_2} = \frac{\gamma_1}{a_2} a_1^{\delta_1} b_1^{\delta_2} T_1^{\delta_2} a_2^{\gamma_1} b_2^{\gamma_2} T_2^{\gamma_2} - \lambda_1 - \lambda_2 = 0 \tag{3.30}$$

$$\frac{\partial L}{b_1} = \frac{\delta_2}{b_1} a_1^{\delta_1} b_1^{\delta_2} T_1^{\delta_2} a_2^{\gamma_1} b_2^{\gamma_2} T_2^{\gamma_2} - \lambda_1 - \lambda_2 = 0 \tag{3.31}$$

$$\frac{\partial L}{b_2} = \frac{\gamma_2}{b_2} a_1^{\delta_1} b_1^{\delta_2} T_1^{\delta_2} a_2^{\gamma_1} b_2^{\gamma_2} T_2^{\gamma_2} - \lambda_1 - \lambda_2 = 0 \tag{3.32}$$

$$\frac{\gamma_1}{a_1} = \frac{\gamma_2}{b_2} \quad \text{and} \quad \frac{\delta_1}{a_1} = \frac{\delta_2}{b_1} \qquad (3.33) \text{ and } (3.34)$$

$$a_1 = \frac{\delta_1}{\delta_1+\delta_2} (T_1 - tt_1) \qquad (3.35)$$

$$a_2 = \frac{\gamma_1}{\gamma_1+\gamma_2} (T_2 - tt_2) \qquad (3.36)$$

$$U^*(\rho_1=1,\rho_2=1) = \frac{\delta_1}{\delta_1+\delta_2} (T_1 - tt_1)^{\delta_1} \frac{\delta_2}{\delta_1+\delta_2} (T_1 - tt_1)^{\delta_2} \cdot \qquad (3.37)$$
$$\frac{\gamma_1}{\gamma_1+\gamma_2} (T_2 - tt_2)^{\gamma_1} \frac{\gamma_2}{\gamma_1+\gamma_2} (T_2 - tt_2)^{\gamma_2}$$

If the parameters δ and γ are configured as:

$\delta_2 > \delta_1$ and

$\gamma_2 > \gamma_1$,

then we can unambiguously state that the maximum is indicated by $\rho_1 = 0$ and $\rho_2 = 0$; this is a situation in which a person doesn't leave his/her current location in either time period (Case One).

If the parameters δ and γ are configured as:

$\delta_1 >> \delta_2$ and

$\gamma_1 >> \gamma_2$,

then the maximum is indicated by $\rho_1 = 1$ and $\rho_2 = 1$; that is, Case 4 pertains.

Until now we have developed a deterministic framework within which to understand people's decisions of whether or not to participate in discretionary activities. Nonetheless, we can extend the general concepts developed above to include a probabilistic notion, i.e. the utility function is actually composed of both systematic and random components. Reformulating our model we get:

$U^* = V + \varepsilon$ where

U^* = the random utility of an activity schedule

V = the systematic part of U^*

ε = additive random disturbance

Since the original formulation of the model assumed complete interdependence of decisions across time periods, it is first necessary to assume that $U^*(a + tt, b)$ is transformable to a function with additive terms. This would give us a function which conforms to our model of decisions separable by period. If we think of the indicator variable ρ as determining the conditions under which U^* is evaluated, we can express the maximal utility of participation in each time period:

$$U^*(\rho) = U^*(\rho_1) + U^*(\rho_2) + U^*(\rho_3) + U^*(\rho_4) + U^*(\rho_5) \tag{3.38}$$

In probabilistic terms this expression becomes:

$$U^*(\rho) = V_1(\rho_1) + V_2(\rho_2) + V_3(\rho_3) + V_4(\rho_4) + V_5(\rho_5) + \varepsilon_1(\rho_1) + \varepsilon_2(\rho_2) + \varepsilon_3(\rho_3) + \varepsilon_4(\rho_4) + \varepsilon_5(\rho_5) \tag{3.39}$$

For a particular time period, for example the first, the probability that someone participates in a discretionary activity is:

$$Pr(D_1) = Pr[V_1(\rho_1 = 1) + \varepsilon_1(\rho_1 = 1)$$

$$> V_1(\rho_1 = 0) + \varepsilon_1(\rho_1 = 0)] \qquad (3.40)$$

Returning to the two period example developed above, we can derive the same expression with specific variables. In order to maintain the separability of time periods and obtain a function with additive terms, the utility of outside participation in period one can then be formulated as:

$$U_1(\rho_1 = 1) = \ln[a_1^{\delta_1}(T_1 - tt_1 - a_1)^{\delta_2}] + \varepsilon_1(\rho_1 = 1) \qquad (3.41)$$

In parallel fashion, the utility of no outside participation in period one is given by:

$$U_1(\rho_1 = 0) = \ln(T_1^{\delta_2}) + \varepsilon_1(\rho_1 = 0) \qquad (3.42)$$

Since we have an expression for a_1 in equation (3.35), we can define:

$$a_1 = \frac{\delta_1}{\delta_1+\delta_2} (T_1 - tt_1) \qquad (3.43)$$

We can, therefore, express the probability of participating in an outside activity as:

$$\Pr(D_1) = \Pr\ \ln\left(\left[\frac{\delta_1}{\delta_1+\delta_2}(T_1 - tt_1)\right]^{\delta_1} \cdot \left[T_1 - tt_1 - \frac{\delta_1}{\delta_1+\delta_2}(T_1 - tt_1)\right]^{\delta_2}\right.$$

$$+\ \varepsilon_{10} - \varepsilon_{11} \geq \ln(T_1^{\delta_1}) \tag{3.44}$$

where:

$$\varepsilon_{10} = \varepsilon_1\ (\rho_1{=}0) \quad \text{and} \quad \varepsilon_{11} = \varepsilon_1(\rho_1{=}1)$$

In words, this expression states that the probability of participating is defined by the probability that the maximal utility to be derived from participation $U^*(\rho_1{=}1)$ is greater than the maximum utility to be dervied from non-participation $U^*(\rho{=}0)$.

When we assume that the ε terms are distributed as normal with zero mean and a variance of 1, then we can use this equation to calculate the actual probability of a person's participating in an outisde activity for a given period via a probit choice model. If we linearize the entire expression for T_1 in the parameters and consider the tt_1 term as a generalized cost (i.e. the costs of overcoming environmental constraints), we are then in a position to develop empirically tractable and testable models of activity scheduling behavior.[27]

[27] While the above discussion has used only two time periods, it should be evident that we could easily extend it to the five periods postulated in the present research.

CHAPTER FOUR

Developing An Operational Model

4.1 Introduction

To be considered in Chapter Four are the most appropriate procedures for achieving the twin goals of being able to (1) represent accurately the causal model postulated in the previous chapter and (2) conduct tractable empirical analyses. There are a number of assumptions which need to be made explicit as we move from the theory developed in Chapter Three to an operational model and then on to empirical analysis. In Section 4.2, an attempt will be made to translate the abstract concepts of the previous Chapter into working definitions. In addition, there is need to explore the most appropriate functional forms with which to express the hypothesized causation. Of particular interest to those pursuing activity scheduling models is the discussion of the types of models considered and those ultimately chosen. In Section 4.3, we address the general structural issues associated with the models. In particular, arguments are put forth on the merits of a two component modeling system which has been brought to light by Westin (1975) and Westin and Gillen (1978).

4.2 Assumptions of the Operational Model

This phase of the research probably involves the point of greatest compromise of the entire research process; many theoretically very appealing concepts must be dropped in favor of others which can be relatively painlessly transferred to an operational world. There are many possible theories for why people participate in out-of-home activities in a time period, but only a small subset of these can be operationally so constructed as to permit empirical tests of their implicit hypotheses. The purpose of this section is to develop that set of operational concepts.

First, discretionary activities will not be differentiated despite the probable differences in their degree of fixity or substitutability. Though this assumption will surely obscure variation in scheduling behaviors, it will allow us temporarily to disregard the complicated interactions of decisions to schedule different activity types. Second, and related to the first, we assume that both minimum and maximum worthwhile participation time are identical across activity types for all people. This is necessary since people often decide to participate if they perceive the available time as adequate for carrying out a particular activity. In the absence of data on people's perceptions of what constitutes an "adequate" length of time, it is useful to assume that an objective definition of adequate exists. Third, the process by which all people decide about participation is identical (i.e. some utility is maximized) and the decisions within time periods are made simultaneously over a day. If we have several periods we can in fact characterize the entire decision process as falling on a continium along the line between sequential and joint. Since it is not clear from prior research how daily temporal-spatial decisions are made, it will be useful to assume one or the other extremes and then with our empirical results, reject or not reject the relevant hypothesis on a period by period or daily basis. Fourth, a deviation from the fixed, obligatory schedule is not qualitatively altered by the number of stops made in a period. This is, of course, a strong assumption since being able to or having to make many stops in a period changes the relative "attractiveness" of other periods for scheduling all or part of an activity program. Nonetheless, without any a priori beliefs about the relation between number of stops and "attractiveness", this assumption will enable us to proceed to empirical tests. Within the operational model, multiple stops can be handled by designating an activity as "primary." Though a number of criteria could be applied to this designation, using duration of activity appears to be the most plausable. Fifth, participation in several different activities at one stop does not substantially alter the nature of the stop. This assumption is required because of the summary nature of most activity/travel diaries, i.e. that only one "purpose" is usually listed per stop, despite the fact that more than one type of activity (each chosen by different processes) may well be included. Sixth, the supply or level of service variations at different times of the day do not affect peoples' choices of when to schedule an activity. Just as in traditional transportation demand analysis, we know that the supply characteristics of the relevant system affect and even constrain alternative behaviors. Congestion in a particular activity location (e.g. sold-out concert) may well deter actual participation despite all other "demand" circumstances. However, because of the lack of the relevant data, consideration of equilibration in the activity system is a task which is simply infeasible for this thesis. Last, because the decision processes underlying activity scheduling are so poorly understood, the operational model will reflect only duration as conditional on whether or not someone participates. The destination and mode used will be considered effectively fixed.

With these restrictions on the theoretical model we are in a position to develop a set of operational definitions with which we can conduct an empirical case study. Although many of the concepts formulated in Chapter Three will be at best indirectly represented in these definitions, the basic principles being tested will not be lost.

4.3 Structural Issues

The key topic to be considered in this section is the modeling framework to be used. We are fortunate to be able to draw on a growing body of literature related to problems of modeling both discrete and continuous phenomena together. It is to this literature and its use in the present thesis to which we will now turn.

As discussed in Chapter Three, the phenomenon to be evaluated directly is an amount of time spent by a worker in a non-home/non-work activity in each of the five time periods. Implicit in this observation is of course a second phenomenon, whether or not to participate. Observing no time spent in a period obviously means not participating whereas spending any time means the opposite. If we were to apply a standard ordinary least squares (OLS) regression model with duration as the dependent variable we violate the assumptions of this model since there is a bunching of some observations at a value of zero (when no participation occurs). Further, if we were to simply ignore observations with zero values, the resulting estimators would be inefficient (i.e. not having the smallest variance among all unbiased estimators) if we try to explain the probability of observing both zero as well as positive values.

As an alternative Tobin (1958) proposed a "limited dependent variable" model, i.e. a regression which allows truncation at either lower or upper limits or both. In this way, his model permits us to account for the fact that the postulated explanatory variables will affect both the probability of observing a duration of zero and non-zero values.

4.3.1 Tobin's Model and Its Potential in This Thesis

Tobin's model can be approximately represented as:

$$t = \begin{cases} X\beta + \varepsilon, \text{ if } X\beta + \varepsilon > 0 \\ 0, \text{ if } X\beta + \varepsilon \leq 0 \end{cases} \qquad (4.1)$$

where X represents the set of variables which would be used to explain variation among individuals' observed durations, given that they would participate in a non-home, non-work activity, β is a vector of coefficients which corresponds to the variables used in estimation, and ε is a vector of random disturbances or unexplained variation. The dependent variable, t, would take a value of zero if no participation were observed. Although the model structure proposed by Tobin is a vast improvement on the standard linear regression model for the type of problem posed in this thesis, it has several drawbacks. By collapsing the two decisions of participation and duration, it assumes implicitly that only one "decision" is made, i.e. that the two are made jointly. Upon reflection it should be evident that in many cases the same set of variables does not affect "participation" and "duration" identically. For example, whether or not someone has a driver's license will have a greater impact on a person's decision to participate than on the choice of how long to spend. Equally as serious a drawback is the fact that the equation which would result from a "tobit" model is necessarily biased. Since we have no information on what durations would have been observed for non-participators, our estimates are not centered around their "true" values. This is particularly debilitating in the case of prediction. In light of the above considerations, a more appealing approach is to separate the two events "participation" and "duration," and choose a modeling structure which accounts for both the conditionality and the implicit bias described above. Westin and Gillen (1978) and Westin (1975) present just such an approach in their work on mode choice and parking location.

4.3.2 Allowing for Endogenous Attributes in Discrete Choice Models

Westin and Gillen postulate that the costs paid at a chosen parking location affect the mode picked (in their case, auto versus transit), but that a model of mode choice is biased due to only being able to record a parking location and costs for those who chose auto. While the interested reader is directed to the relevant sources for the details of this approach, its outline in the context of this thesis will be presented.

First, we would like to model the decision of person i to participate in an activity in time period t:

$$B_{it} = \propto \pi^*_{it} + Z_{it}\gamma + \mu_{it} \qquad (4.2)$$

where:

B_{it} = utility derived from participation

α = a scalar coefficient

Z_{it} = a row vector of variables believed to be related to participation in period t

γ = a vector of constants (coefficients of explanatory variables)

μ_{it} = an unobserved random variable assumed to be distributed with mean zero and variance 1, i.e normal.

Second, we would also like to represent the length of time spent in time period i, given that one has decided to participate:

$$\pi^*_{it} = X_{it}\beta + \varepsilon_{it} \qquad (4.3\ )$$

where:

π^*_{it} = duration we would observe if person i were to participate in time period t.

X_{it} = row vector of variables which "explain" variation in observed duration

β = vector of constants associated with X_{it}

ε_{it} = an unobserved random variable distributed $N(0,\sigma^2)$

While the details of the estimation procedure used by Westin and Gillen (1978) are given in Appendix C, several aspects of their work merit more general discussion.[28] As these authors did, we can separate out the two dependent variables "participation" and "duration" into different equations, and then be in a position to make a direct connection to the utility theory discussed in Chapter Three. That is, we will assume and model people's comparison of the utilities of participating and not participating.

[28]See also Miller (1978) for discussion of this procedure.

At the same time, by estimating a separate equation for duration (for those who participate), we can then infer the length of time which all people in the sample would have participated, regardless of their actual observed decision. The vector of expected (or mean) values of duration can then be used as an exogenous variable in the model of participation, working under the premise that that decision is influenced by the length of time which people would like or need to spend if they were to participate. Westin and Gillen would recognize, however, that the value of duration observed for participators misstates on the average the value which we would observe were duration available for everyone. Consequently, our analysis includes a correction for "selectivity bias" in order to obtain statistically consistent estimates. By having separate estimations for the two dependent variables it is also possible to separate out the direct and indirect effects of variables which we feel belong in both equations 4.2 and 4.3.

CHAPTER FIVE

The Data

5.1 The Ideal and the Reality: Alternative Sources

In effect, there are two types of datasets which could have been used in the empirical work of this thesis: time budget and home interview survey. Before beginning statistical tests of the hypotheses generated in the course of developing the theory discussed in Chapter Three, these types of datasets were scrutinized against several criteria. First, the data should contain information on the duration of all daily out-of-home activities of a person observed. Second, an identifier for a person's work status should be present. Third, transportation level of service as well as land use data is necessary. Fourth, description of the socio-economic characteristics of the person's household are required.

While these four criteria were considered a minimal set, there are of course many items which would have ideally also been available. Since we are uncertain about the temporal frame in which decisions are made, it would be useful to have travel or activity diary information for periods longer than one day. Additionally, data on people's time allocation within the home would allow us to explore the full range of trade-offs which are being made in time-space. Complete information on the characteristics of activities would permit us to examine the role which observable attributes of activities play in influencing decisions about participation. Having data on opening hours, admission charges, capacities and other such related attributes would encourage putting the activities themselves into the center of the research. It would, of course, also broaden the scope of the research to be able to have data from several cities, especially those with differing spatial structures. As anyone involved in "activity" research quickly discovers, compromises with these ideals are inevitable.

Applying the above criteria unfortunately led to elimination of nearly all the first types of data, as most had no associated information with which to develop measures of a person's spatial accessibility (i.e. transportation level of service and land use). The outstanding exception was data collected by F. S. Chapin, Jr., in Washington, D.C. Although this dataset could have been augmented appropriately and had an exceptionally detailed classification of activity purposes, it too was rejected because of the limited nature of its population. Only two neighborhoods were sampled and both contained a disproportionate share of lower-middle income families. Among home interview surveys available in 1977, that from Minneapolis/St. Paul, Minnesota, both met the minimal criteria and was most easily accessible within reasonable time constraints.[29]

5.2 Description of the Chosen Database

There are four major components of the Minneapolis/St. Paul dataset used in this thesis: (1) vehicular travel diary for one day, (2) level of service, (3) spatial density of activities, and (4) socio-economic characteristics. The data was collected between April and July, 1970, as part of the Travel Behavior Inventory (TBI) sponsored by the Metropolitan Council of the Twin Cities and conducted by Mid-Continent Surveys, Inc.

[29] The data collected in Baltimore under the auspices of the U.S. Federal Highway Administration would apparently have been a superior choice. Unfortunately, it was not available until December, 1978.

From a 1% random sample of households in the metropolitan area, 15,416 persons collectively from 5009 households were obtained. Within the survey, data was gathered in hierarchical fashion from the household to the person to the trip levels. Like most such surveys, the travel diary recorded for each person covered a twenty-four hour period (4 a.m. of the day preceeding the survey to 3:59 p.m. of the interview day). For this thesis, it is important to mention the classes of purposes of activities at the destinations of trips recorded in the survey: in-home, work, school, shopping, outdoor recreation, other social or recreational, medical, personal business (banking, legal, etc.), and serving a passenger.

In conjunction with the travel survey, land use data was collected on 1058 zones of varying size. From this data comes a major input into the calculation of spatial accessibility measures: density of activities or opportunities with respect to a person's current location.[30] There are three groups of data within this file: (1) type of business, (2) acreage by use, (3) zonal distribution of household's income, size and automobile ownership.

Separate level of service information was collected for highway and transit travel and recorded as a matrix of origins and destinations. These matrices represent information taken from coded networks or "skim trees." In particular, a matrix exists for in-vehicle time and out-of-vehicle time as well as number of transfers and fare for transit.

[30] The details of this calculation are given in Appendix B.

5.3 Using Secondary Data Not Collected for the Analysis of Activity Schedules

Almost invariably, non-experimental research is fraught with problems associated with data. Information is collected in situations most of whose variables cannot be controlled in any meaningful sense. In the current research, an additional layer of problems was encountered because the Minneapolis/St. Paul data was not collected for purposes of testing any of the hypotheses (i.e. postulated theory). That is, because many issues were never intended to be addressed, compromises were necessarily made. The overriding problem was the trip rather than activity-focus of the home interview survey. Non-motorized vehicular movements (e.g. on foot or bicycle) were not recorded. As will be discussed in Chapter Seven, the results of models of participation in discretionary activities during a person's working hours are distorted by this omission. Particularly in the central business district, we often observe many people making trips on foot. At the same time, the level of service information used was averaged over a twenty-four hour period. This is potentially damaging for calculation of accessibility, because the decision to add or not to add a discretionary activity to a fixed schedule may well be influenced by congestion levels or parking costs at various times of a day. Whereas engineering or physically measured travel times are embodied in the skim trees, the activity duration (a dependent variable) is derived from the travel times reported in the diaries (e.g. the beginning time of trip t+1 minus the ending time of trip t). Since we have no reason to assume that the reporting errors are distributed with a mean of zero, bias in addition to loss of statistical efficiency will probably result.

In deciding whether to participate in an activity, a person probably will sometimes weigh the alternative of accomplishing the purpose at home (*e.g.* for a recreational activity) instead of outside the home. In the general case, a person could simply decide not to travel from his/her current location, but actually begin a new activity. The available survey data is particularly weak with respect to information on the nature of the activities themselves. Many quite dissimilar activities are lumped into a single category (*e.g.* shopping, personal business). In addition, there is no information on the extent to which participation in certain activities is dependent on the schedules of others. Some researchers (*e.g.* Hanson, 1977) have also suggested that many decisions to participate in activities are made over a period longer than a single day. Although it is still unclear which temporal framework is most appropriate for which activity, to the extent that periods longer than a day are in fact used, additional uncertainty is introduced into the model to be estimated. Parallel to the transportation network, the "activity systems" also exhibit congestion which is unaccounted for in the available data. One can imagine, for example, a sold-out concert or movie influencing someone's decision to participate. Likewise, the opening hours of activities constrain an individual as to when participation is feasible over a particular time-space. While it is certainly possible to create proxy variables for the effect of opening hours and congestion of activities, lack of explicit data is definitely a shortcoming.

Finally, there are several pieces of data which, while not directly critical to this research, would possibly enlarge the potential of the equations discussed in Chapter Seven. Like many similar surveys, that from

Minneapolis/St. Paul has information on the number of years a household has lived at its current location. Unfortunately, the analogous data for a worker's employment location is not available. One imagines that a worker's level of familiarity with spatial and temporal opportunities and, hence, likelihood of taking part in activities will be related to this variable. At the same time, a worker's occupational or professional status presumably also influences the degree to which certain activities are perceived as socially accessible or desireable (e.g. a yacht club versus a bar in an ethnic neighborhood). Information on this factor was also unavailable.

5.4 Sampling from the Sample

In order to use the Minneapolis/St. Paul data for testing the hypotheses in the theoretical phase of this research, it was necessary to apply two types of criteria to sifting of the data: person-related and trip-related.[31] With respect to persons only those who were recorded as working full-time (defined as more than sixteen-hours per week) entered the sample.[32] For full-time workers, trip records were examined to see if reported trip-making information could be used in the context of models oriented to activities. The results of the screening process are given in Table 5.1.[33] Workers would have to have not only traveled that day but also had a work trip. The trip diary allowed persons to have

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[31] For a complete statistical summary of the items in the database, see Appendix A.

[32] See Section 3.2 for elaboration of this point.

[33] It should be noted that this process was imposed sequentially (i.e. an observation fell into a category it was no longer considered; as a result, the numbers do not reflect whether an observation fell into several categories).

Table 5.1: Summary Tabulations of Excluded Observations

Reason	Number	% of Sample
No trips made	281	6.2%
No work trips	411	9.1%
Trips outside survey area	372	8.3%
First origin not home	209	4.6%
Last destination not home	259	5.8%
Misplaced work destination	310	6.9%
Misplaced home destination	233	5.2%
Sampling or coding problem	79	1.8%
Estimation sample size	2345	52.1%
Total in Survey	4499	100%

traveled to areas outside the 1058 traffic analysis zones in the course of the day. Unfortunately, as level of service data does not exist for these zones and no information was available on the location of the outside area, no person was included in the final sample who had at least one trip to or from such an area. Because of the central importance of the notion of fixity of the home and work activities as pegs around which discretionary trips are planned, persons whose schedule did not begin and end at home were excluded from the estimation sample. Similarly, there were instances when individual's trips did not fit into a schedule which suggested fixity of the home and/or work activity. For example, persons who went home between the trip to and from work or who had two or more work trips in a row (probably salespeople) were excluded. Finally, in a few cases coding errors or missing information in the skim trees, led to a record's being deleted. The resulting sample to be used in estimation contained 2345 observations or 52.1% of all observations in the original full sample. As the Travel Behavior Inventory was not created for the purpose of conducting research on activity scheduling, this percentage seems reasonable. In some cases individuals have been excluded who simply have unconventional behavior in time-space. To this extent the results of the empirical models will be slanted toward people whose behavior fits into a conventional daily survey. Nonetheless, it was not felt that this skewness would be a major barrier to innovative research.

CHAPTER SIX

Exploratory Data Analysis

6.1 Introduction

The primary objective of exploratory analysis is to begin to examine the data for regularities which could give us insights into the causal model postulated in Chapter Three. Toward that end, we will first examine the sample selected for analysis and descriptive tabulations of trip-making and activity-participating within this sample. Second, tabulations of scheduling types will permit inference to be made about the inter-dependence of decisions in different time periods. Finally, correlations between pairs of variables will be scrutinized for clues about overlapping of factors and possible multicollinearity. Since the socio-economic descriptors of individuals in the sample are not directly "causal" in relation to participating/scheduling decisions, an attempt will also be made to define homogenous segments or groups in the population. By obtaining loosely structured evidence about possible causal relationships and thereby gaining an intuitive grasp of the data, we will be in a better position to make inferences about the validity of the hypotheses to be tested.

6.2 General Descriptive Tabulations[34]

The estimation sample obtained from the Minneapolis/St. Paul data set contained no surprises. While some of the variables were skewed

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[34] As the present analysis is "activity-abstract", a complete display the distribution of activity purposes by time periods is also given in Appendix A.

toward either a lower bound (e.g. presence of a working spouse) or one category (e.g. male head of household, single family owner-occupied dwelling), none appeared to be radically different from the values we would expect to find in the general population of working people.

Table 6.1 shows the distribution of the number of trips taken by a person, i.e. often the "dependent variable" in a trip generation equation. The fact that the even numbers of trips have higher frequencies than neighboring odd numbers (in most cases) probably indicates that more trips are made with respect to a single base. That is, fewer people make additional trips on the way to home or work than those who travel from home or work and then return in one circuit. Although we can also see that the frequency of observation and number of trips per person is strongly related, there is an enormous amount of information buried in the numbers which cannot be recovered. When did the 3-plus trips occur in relation to the work trip? For what duration did people stop before beginning another trip?

Moving into the framework set up in Chapter Three, we can begin to realize the marked contrast between traditional trip generation and the present analysis. Consider Figure 6.1. The distribution of deviation types is clearly not uniform across time periods, but rather skewed toward later in a worker's day, when presumably larger blocks of disposable time are available and temporal constraints are more relaxed. With respect to durations of deviations from the obligatory home-work-home schedule, Tables 6.2 and 6.3 likewise show that participation varies considerably depending on the position of the deviation relative to the work activity.

Table 6.1: Distribution of Person Trips

Number of Trips	Frequency
2	1044
3	122
4	558
5	192
6	218
7	64
8	69
9	20
10	26
11	13
12	6
13	6
14	3
15	1
16	1
17	1
18	1

Sample Size = 2345

Figure 6.1 : Distribution of Deviation Types Across Time Periods*

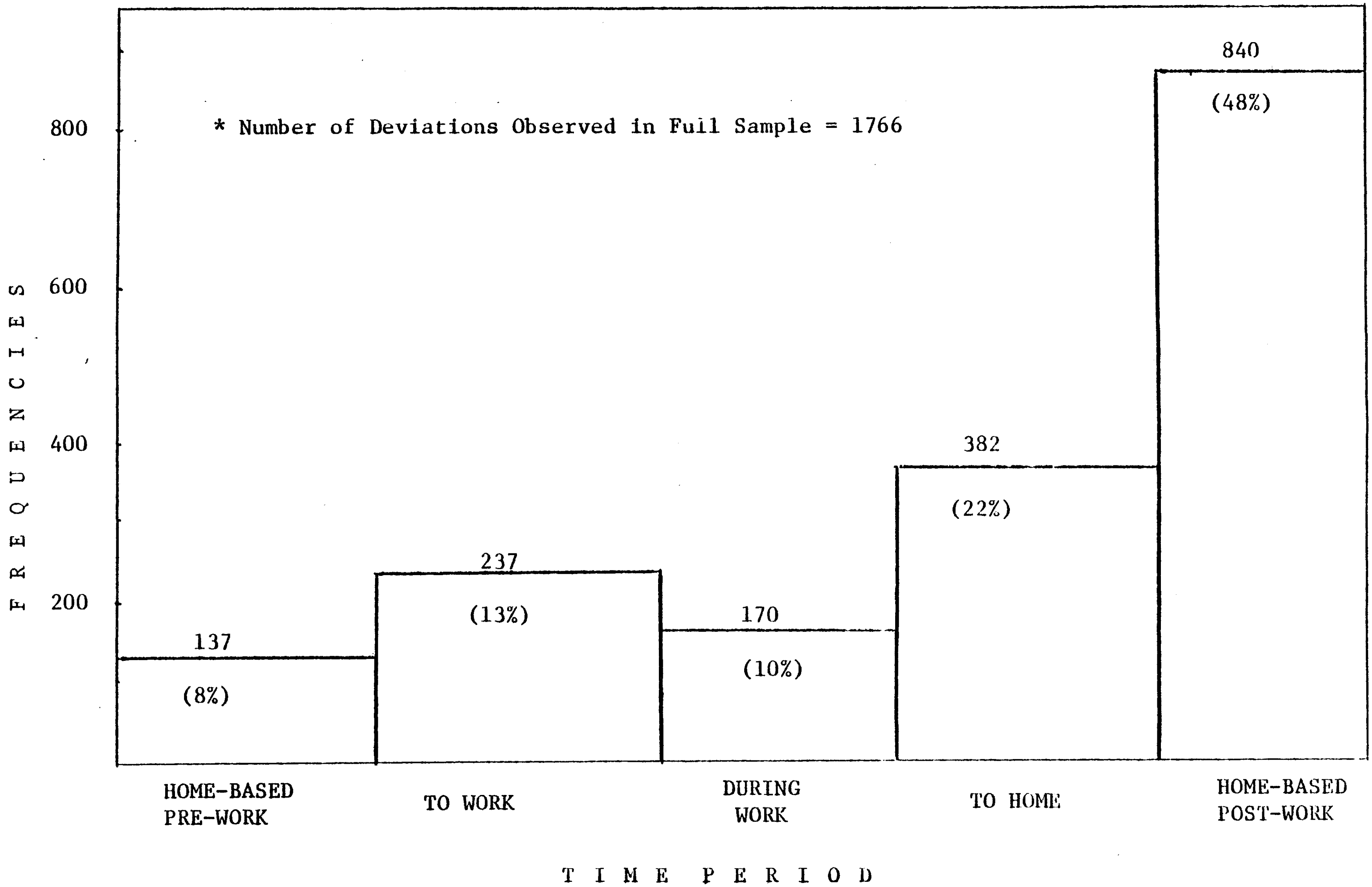


TABLE 6.2: Summary Statistics for Durations (in minutes)

Type \ Period	1			2			3			4			5		
	$\bar{x}$*	σ**	range	$\bar{x}$	σ	range	$\bar{x}$	σ	range	$\bar{x}$	σ	range	$\bar{x}$	σ	range
Activity Duration	65	66	6-390	19	52	6-600	49	39	6-288	66	109	6-732	87	77	6-396
Travel Duration	30	21	4-113	11	11	0-102	23	15	4-76	13	14	0-114	25	17	4-105
Total Duration (a + b)	95	74	10-424	30	57	6-635	72	44	14-358	79	115	6-771	112	86	10-465

* $\bar{x}$ denotes mean or average observed duration in a time period

** σ denotes standard deviation

Table 6.3 : Cumulative Distributions of Total Durations by Deviation Type

Time Constraint / Deviation Type	% ≤ 12 MIN.	% ≤ 30 MIN.	% ≤ 60 MIN.	% ≤ 120 MIN.
1 H-O-H NOBS = 137	1%	17%	41%	69%
2 H-O-W NOBS = 237	38%	79%	92%	96%
3 W-O-W NOBS = 170	1%	11%	48%	89%
4 W-O-H NOBS = 382	15%	50%	67%	79%
5 H-O--H NOBS = 840	.2%	6%	26%	53%

Table 6.2 indicates that deviations made prior to beginning the trip from home to work, last longer (in total time) than all others except those in Period 5. That the variance of the duration of stops made during work is the lowest of all periods corresponds to our intuition: most people take about an hour for lunch break.

Table 6.3 also provides strong evidence why separate models for each time period ought to be developed. In Period Two, a high percentage (79%) of activities have been completed within a half hour and nearly all within two hours. (A large proportion of deviations in this period are for serving passengers). On the other hand, barely half of the deviations in Period Five are completed after two hours. This suggests that especially for activities chosen for participation after having come home from work tend to have a longer minimum worthwhile duration. Table 6.4 also supports the general line of reasoning above. Whereas the modal split for Periods Two and Four is virtually identical, that in Period Five is quite different. In direct connection with the work trip, driving alone is clearly the preferred mode, while after work, shared ride predominates by nearly two to one. This fact will most certainly be reflected in the coefficients of mode-related variables in the multivariate models.

Figure 6.2 shows a composite of the distribution of ending times for deviations made in the five time periods.[35] Compare Period One with the other periods. That its peak lies beyond that of Period Two seems to point to

[35] See Appendix D for the separate distribution of ending times for each period as well as those for the home-work and work-home trips.

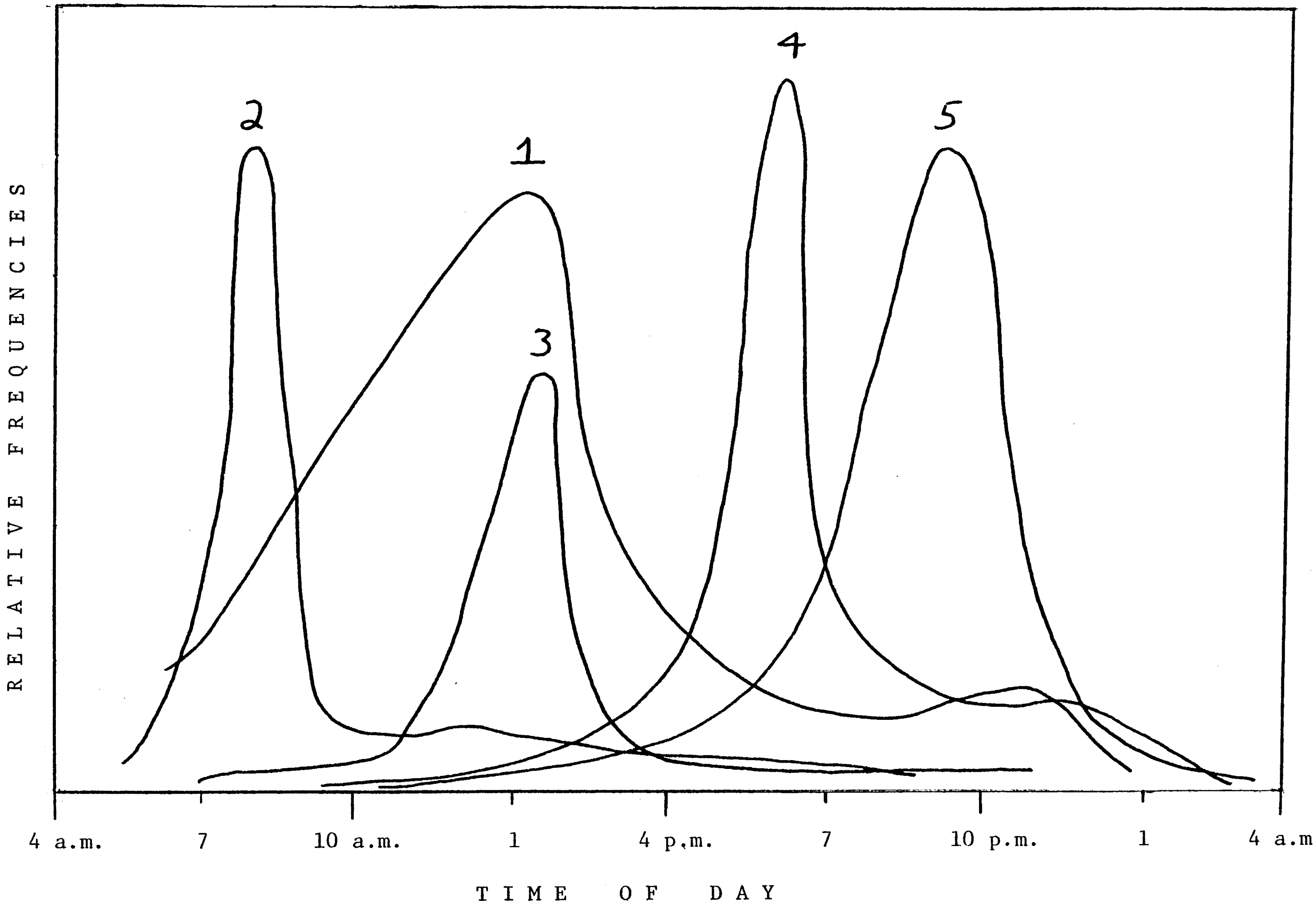
Table 6.4 : Distribution of Observations Across Periods by Mode

period \ mode	drive alone auto	shared ride auto	public transit	school bus	taxi passenger	drive alone truck	shared ride truck	motor-cycle	more than one mode
1. H-O-H (NOB=137)	70 (51%)	60 (44%)	3 (2%)	0	0	0	0	1 (1%)	0
2. H-O-W (NOB=237)	149 (63%)	67 (28%)	5 (2%)	0	0	10 (4%)	6 (3%)	0	0
2a. H-W* (NOB=2345)	1664 (71%)	384 (16%)	171 (7%)	1 (.04%)	1 (.04%)	94 (4%)	17 (1%)	5 (.2%)	8 (.3%)
3. W-O-W (NOB=170)	80 (47%)	77 (45%)	1 (.6%)	0	0	8 (5%)	4 (2%)	0	0
4. W-O-H (NOB=382	241 (63%)	113 (30%)	3 (.8%)	0	1 (.3%)	16 (4%)	6 (.2%)	2 (.5%)	0
4a. W-H* (NOB=2345)	1653 (70%)	400 (17%)	164 (7%)	1 (.04%)	4 (.1%)	98 (4%)	15 (.6%)	6 (.3%)	4 (.2%)
5. H-O-H (NOB = 840)	292 (35%)	511 (61%)	4 (.5%)	0	1 (.1%)	14 (2%)	15 (2%)	3 (.4%)	0

* Modal splits for periods 2 and 4 were also calculated for the full sample (2345), regardless of whether a respondent made a stop.

NOB = Number of Observations

Figure 6.2: Composite Distribution of Ending Times Periods 1-5



point to the existence of substantial numbers of people who start work later in the day and don't have the standard nine to five business hours. In any case, by treating time blocks as distinct, we will be able to account for the different environments in which choice is made.

6.3 Tabulations of Scheduling Types

With information on the distribution of persons across the 32 ($=2^5$) possible scheduling configurations, we can begin to make inferences which will be directly useful in the development of multivariate models. Table 6.5 shows the complete breakdown of scheduling types. Note that as the configurations become more complicated, the frequencies decrease. Figure 6.3 shows that in fact, virtually no one deviated in more than three time periods during a work day. Of particular interest, however, is the fact that more than half of the sample had at least one deviation from the basic home-work-home schedule. In many cases, this indicates the presence of much more complicated behavior than most prior single trip-oriented research would allow us to infer. Additionally, the virtue of considering the entire day's activities rather than those directly linked to the work activity becomes more evident. With nearly 33% of observations in the sample, those types with deviations in either Period One or Five or both exclusively account for a large proportion of the total. Not to treat these "home-based non-work deviations" explicitly is to lose a sizable proportion of information of worker's activity behavior. Tables 6.6 through 6.9 show further that decisions to deviate in one period do not appear to be fully independent of decisions made in the other four periods.

TABLE 6.5: Distribution of Scheduling Types*

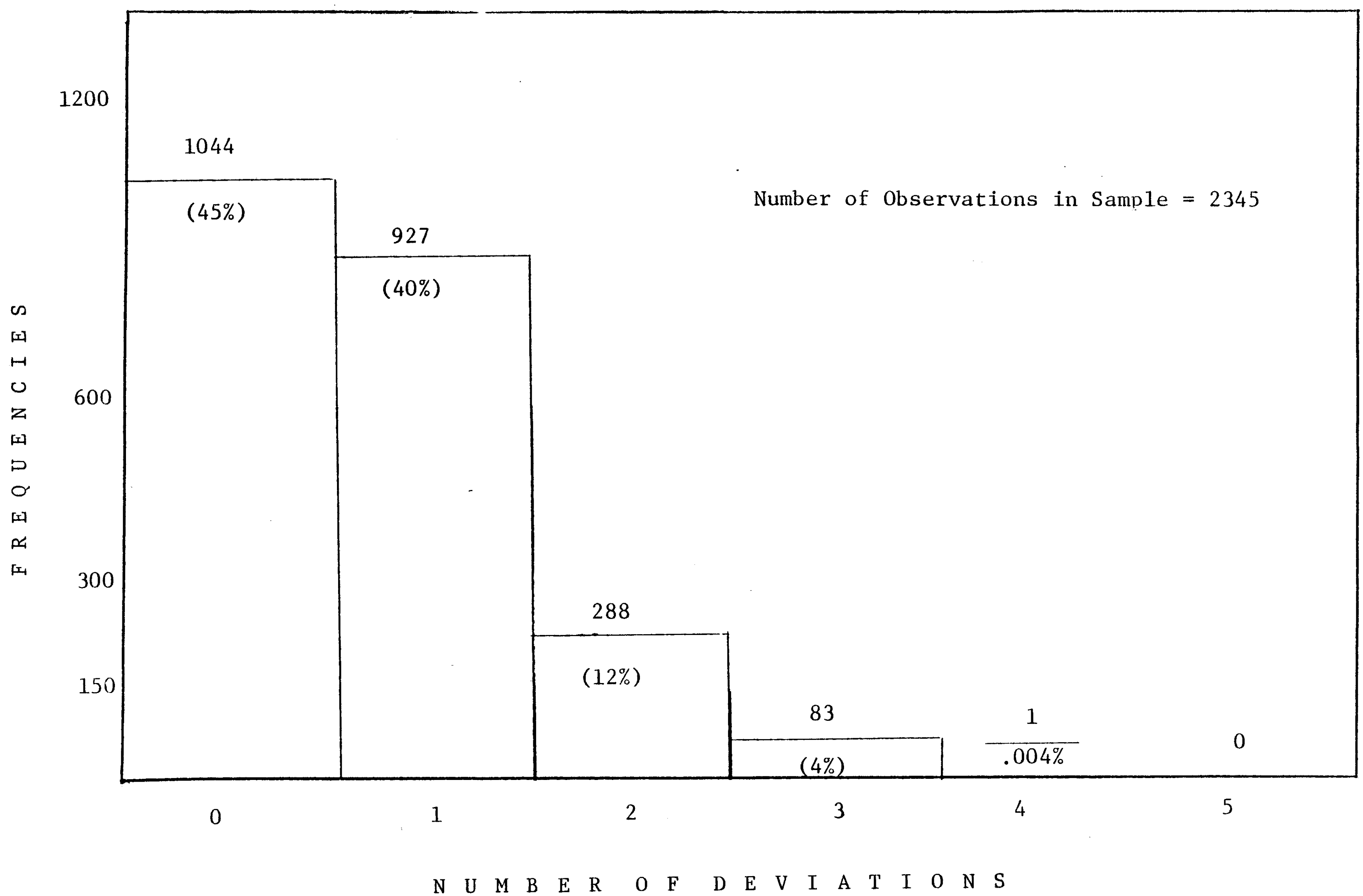
NUMBER	SCHEDULING CONFIUGRATION**	COUNT OF OBSERVATIONS	NUMBER	SCHEDULING CONFIGURATION**	COUNT OF OBSERVATIONS
1	W-H	1044 (45%)	17	O-H-O-W-O-W-H	0
2	O-H-W-H	93 (4%)	18	O-H-O-W-H-O-H	1 (.04%)
3	O-W-H	44 (2%)	19	O-W-O-W-O-H	5 (.2%)
4	W-O-W-H	65 (3%)	20	O-W-O-W-H-O-H	7 (.3%)
5	W-O-H	136 (6%)	21	W-O-W-O-H-O-H	6 (.3%)
6	W-H-O-H	589 (25%)	22	O-H-O-W-O-H	9 (.4%)
7	O-H-O-W-H	3 (.1%)	23	O-H-W-O-W-O-H	0
8	O-H-W-O-W-H	0	24	O-H-W-O-H-O-H	4 (.2%)
9	O-H-W-O-H	9 (.4%)	25	O-W-O-H-O-H	47 (2%)
10	O-H-W-H-O-H	15 (.6%)	26	O-H-W-O-W-H-O-H	4 (.2%)
11	O-W-O-W-H	9 (.4%)	27	O-W-O-W-O-H-O-H	0
12	O-W-O-H	66 (3%)	28	O-H-W-O-W-O-H-O-H	0
13	O-W-H-O-H	41 (2%)	29	O-H-O-W-O-H-O-H	1 (.04%)
14	W-O-W-O-H	22 (1%)	30	O-H-O-W-O-W-H-O-H	0
15	W-O-W-H-O-H	50 (2%)	31	O-H-O-W-O-W-O-H	0
16	W-O-H-O-H	73 (3%)	32	O-H-O-W-O-W-O-H-O-H	0

Number of observations in sample = 2345

* All schedules begin at the respondent's home.

** W = WORK ACTIVITY H = HOME ACTIVITY O = SOME ACTIVITY OUTSIDE OF HOME OR WORK

Figure 6.3 : Distribution of Deviation Frequencies



Using Periods Two and Four (deviations directly associated with the work trip) as references, the breakdown within each of the four scheduling types is summarized in Table 6.6 . If one agreed with the Markovian assumption that decisions in a time period are dependent only on the immediately proceeding period then one would expect approximately uniform proportions be observed in the conditional probability,

Pr (deviate in 1,3 or 5|outcome in 2 or 4).

While the range of values of this conditional probability for Period One is relatively small (.04 - .08), those for Periods Three and Five are large enough to make a good case for the lack of independence among decisions in the five time periods. In short, a simultaneous modeling structure seems most appropriate to capture the interdependence nature of daily scheduling decisions.

6.4 Correlation Coefficients

Correlation coefficients were used in this thesis for three purposes:

(1) to flag those explanatory variables whose effect may be covered by other variables (multicollinearity);

(2) to begin to make inferences about the most appropriate variables and functional forms to be used in the multivariate models;

(3) to begin to sort out the socio-economic segments in the sample which seem to have similar daily activity schedules.

Because the dependent variable in each of the five equations is truncated at zero (i.e. no negative durations allowed), the standard product moment correlation coefficients are necessarily of only limited usefulness.

Table 6.6: Distribution of Deviation Types with Respect to Home-Based Work Deviations

SCHEDULING TYPE * (periods 2 & 4)	FREQUENCY	% TOTAL	% WITH PRE-WORK TRIP DEVIATION (period 1)	% WITH WORK-BASED DEVIATION (period 3)	% WITH POST-WORK TRIP DEVIATION (period 5)	% HOME-BASED NON-WORK DEVIATIONS (periods 1 & 5) combined
1. W-H	1858	79%	6%	6%	35%	41%
2. O-W-H	105	4%	4%	15%	47%	50%
3. W-O-H	250	11%	5%	13%	35%	38%
4. O-W-O-H	132	6%	8%	4%	36%	43%
TOTAL	2345	100%	6%	7%	36%	41%

* All schedules begin at the respondent's home.

Table 6.7: Distribution of Pre-Work Trip Deviations (Period 1)

Scheduling Type *	Frequency	% of all such deviations	% of all home-based work deviations
1. O-H-W-H	110	80%	6%
2. O-H-O-W-H	4	3%	4%
3. O-H-W-O-H	13	9%	5%
4. O-H-O-W-O-H	10	7%	8%
TOTAL	137	100%	6%

Number of observations in sample = 2345

* All schedules begin at the respondent's home

Table 6.8: Distribution of Work-Based Deviations (Period 3)

Scheduling Type*	Frequency	% of all such deviations	% of all home-based work deviations
1. W-O-W-H	117	69%	6%
2. O-W-O-W-H	16	9%	15%
3. W-O-W-O-H	32	19%	13%
4. O-W-O-W-O-H	5	3%	4%
TOTAL	170	100%	7%

Number of observations in sample = 2345

* All schedules begin at the respondent's home

Table 6.9: Distribution of Post-Work Trip Deviations (Period 5)

Scheduling Type*	Frequency	% of all such deviations	% of all home-based work deviations
1. W-H-O-H	656	78%	35%
2. O-W-H-O-H	49	6%	47%
3. W-O-H-O-H	87	10%	35%
4. O-W-O-H-O-H	48	6%	36%
TOTAL	727	100%	36%

Number of observations in the sample = 2345

* All schedules begin at the respondent's home

As a result, the values computed for the correlation between the observed durations and individual explanatory variables can be interpreted as no more than suggestive.

This phase of the analysis revealed several sets of variables which appeared to overlap considerably and hence, be subject to omission or redefinition in the multivariate phase. The variables "number of person trips" and "number of household trips" were, of course, strongly collinear (product moment coefficient, r = .53). Since the "number of person trips" is, in fact, a function of the dependent variables in the model, its use on the right hand side of an equation is inappropriate. It is also unclear what causal effect the number of "household trips" could have on the observed person's propensity to add discretionary activities to an obligatory schedule. These considerations led to defining a third variable to reflect the frequency of trip making by other household members. In defining this variable, we presume that there is a set of duties in any household (e.g. shopping) which need to be performed. The number of trips which other members of a household make could then be a proxy measure for the extent to which these duties do not have to be performed by the respondent (# household trips - # person trips). In a similar vein, another group of variables exhibit a high degree of collinearity. These are the numbers of: (1) workers, (2) children, (3) non-working adults, as well as (4) household size. Estimation of preliminary ordinary least squares (OLS) regression equations confirms that fact and points to the need for judicious weighing of the various combinations of them.

Despite the limited nature of the correlation coefficients, several points seem quite evident. If we assign the nine alternative modes to the three classes:

(1) high independence (drive alone truck and auto, motorcycle);

(2) medium independence (shared ride auto and truck);

(3) low independence (public transit, school bus);

and define dummy variables (0-1) for a person's falling into a class or not, we find that the dummy variables for classes one and three are strongly correlated with the dependent variables (i.e. .52 and .72 respectively). However, because these two groups were always mirror images of each other (0/1 and 1/0), only one of the three at a time should be included in equations of duration or participation so as to avoid problems of overspecification.

The number of stops made in a period was strongly related to total duration of activities as might be expected (.78, .48, .78, .62, and .70 for the Periods One through Five respectively). Interestingly enough, the number in Periods Two and Four had relatively strong correlation (.35), indicating that people may tend to plan stops in these periods jointly (e.g. serving the same passenger).

The length of time spent at the workplace appears to be one of the more important of the exogenous variables, except in Period Five. Correlations between duration of participation and time spent at the workplace were -.14, -.17, -.11, -.15, and -.04 for Periods One through Five respectively. This seems to indicate that decisions to participate in activities in Period Five are made with much less regard to constraints associated with workplace. Once again, the virtue of treating time blocks within a day separately becomes evident. Unfortunately, it is much more difficult to differentiate types of workplaces. Dummy variables for each of the nine employment categories (1 digit SIC codes) were defined, but every one failed to show a correlation with any duration of more than 0.1.

6.5 Summary of Findings

The preliminary analysis conducted on the estimation dataset has produced a number of insights into activity scheduling behavior as well as the framework which has been developed here to explore this behavior. In general, the following statements appear to be supported by the exploratory analysis:

1. Treating scheduling decisions in terms of separate time period is warranted.

2. Analyzing activity-related behavior over the entire day (rather than only connected to the work activity) captures an essential element of complexity missing from prior research.

3. Decisions made in one time period are dependent on decisions made in other periods, but not uniformly.

CHAPTER SEVEN

Estimation of Multivariate Equations

7.1 Introduction

The primary purpose of estimating equations in this thesis is to confront the theoretical structure presented in Chapters Three and Four with data reflecting observed behavior. Many approximations had to be accepted in the process of building models which could be confronted with empirical fact. This, combined with the tentativeness of the conceptual model, impose limitations on the conclusiveness of the results. In some cases the outcomes of estimation were unequivocal and a clear inference could be made. In other cases, however, outcomes were either contradictory or ambiguous enough to make inference a tenuous enterprise. Nonetheless, the results discussed here provide a useful foundation for future hypothesis testing about the nature of activity scheduling behavior.

Section 7.2 will contain a discussion of the empirical procedures used in the thesis. This will include mention of the basic philosophy applied in the analysis, the variables chosen to proxy the elements of the conceptual model and the issue of econometric simultaneity. In Section 7.3, the empirical findings will be presented and interpreted. The implications of these results will be discussed in Chapter Eight.

7.2 Procedures Used in the Analysis

The main idea was to separate the systematic from the random components so that some probabilistic statement could be made about the behavior of different groups in the population. Toward that goal, this stage became an iterative learning process, in which the final equations were the result of several reformulations. Having used statistical methods, we can, however, do no more than report covariation. To the extent that our theoretical model is sound and we have reduced error as much as possible, we can make inferences about the population's "true" parameters, *i.e.* about the causality in operation. The outcomes of hypothesis tests should lead us to a re-thinking of the theoretically based causal models and to recommendations for additional research.

7.2.1 The Philosophy Behind the Analysis

The basic philosophy of modeling paralleled that outlined in DeNeufville and Stafford (1971), *i.e.* that the "correct model should be "chosen through a joint use of statistical tests and *a priori* theoretical considerations" (p. 280). For example, a variable was not dropped from a particular equation simply because its t-statistic was not above a certain value. Generally, a variable was omitted according to two criteria: (1) its theoretical position was doubtful (*i.e.* prior evidence or theory only weakly suggested causation) and its t-statistic suggested no significant difference of the variable's coefficient from zero at any reasonable level of confidence (*i.e.* 90% or above) and/or (2) its effect on the dependent variable appeared largely to be represented already by some other variable. Though care was taken not to exclude variables which covary with those included, the approximate nature of the equations used in estimtion should provide warning to the future researchers who might specify models based on these results.

7.2.2 Choice of Variables Used

The variables used in estimation of equations are defined in Table 7.1 A direct match between all elements of the conceptual model postulated in Chapter Three and the data from Minneapolis-St. Paul was the ideal case. While in some cases, particular elements could be closely paired with observed data, compromises were in other cases the only alternative to total omission of what was postulated to be an explanatory variable. Referring to Figures 3.2 through 3.6, the extent of match between concept and their empirical referents can be seen.

The dependent variables were, of course, directly "observable" since the beginning and ending times of all of a person's daily trips were available. For virtually all factors hypothesized in Chapter Three to have causal influence on the observed activity schedule (i.e. whether and for how long someone participates in discretionary activities in a day), the variables for which data was available are necessarily approximate. The group representing a "cause" (such as "temporal constraints") is either incomplete or only indirectly corresponds to the intent of the original concept.

The activity program shown in Figure 3.3 is simply the set of things which a person needs to do in a day's time. Since this is, in effect, a scheduled "activity schedule", we need some way of explaining how this set of needs is generated in the first place. At the household level, several variables proxy the factors which determine the familial responsibilities with which the observer worker might be confronted. The number of children aged 5 to 15, for example, partially

Table 7.1: Definition of Variables[36]

Dependent Variables

(1) Participation in an Activity (indicated by a positive duration)
  - = 1, if participation observed
  - = 0, if no participation observed

(2) Duration of a Deviation (activity plus travel time)

Explanatory Variables

I. Temporal Constraints

- arrive at work after 9 a.m.
  - = 1, if condition met
  - = 0, if not met
- leave work after 6 p.m.
  - = 1, if condition met
  - = 0, if not met
- proximity to the weekend
  - = 1, if observation made on Friday
  - = 0, otherwise
- discretionary time spent in other periods (predicted for each of the other four periods and then summed)
- duration of work

II. Spatial Constraints

- Fixity of Workplace
  - = 1, if destination of work trip not identical to workplace
  - = 0, if identical
- Accessibility ("expected utility") or "generalized cost")[37]
- Driver's license
  - = 1, if person has a driver's license
  - = 0, otherwise

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36. See Appendix A for summary statistics for all of these explanatory variables.

37. See Appendix B for a fuller discussion of the accessibility measure used here.

Table 7.1: Definition of Variables (Continued)

- Mode to work $\begin{cases} = 1, \text{ if drive alone auto or truck} \\ = 0, \text{ otherwise} \end{cases}$

- logarithm of years lived at residence

IIIa. Socio-Economic: Person Level

- age

- sex $\begin{cases} = 1, \text{ if male} \\ = 0, \text{ if female} \end{cases}$

IIIb. Socio-Economic: Household Level

- logarithm of disposable income (=income – $800* household size)

- number of children aged 5-15

- number of non-working adults (adults are older than 18)

- work status of spouse $\begin{cases} = 1, \text{ if working full-time} \\ = 0, \text{ otherwise} \end{cases}$

- number of daily trips made by others in household, per person

- drivers per cars in household

- access of non-workers to a car $\begin{cases} = 1, \text{ if number of cars} > 1 \text{ and number of drivers} > 1 \text{ and number of non-working adults} > 0 \\ = 0, \text{ otherwise} \end{cases}$

represents the level of needs which will be generated in a household. Parallel to this are such variables as the number of non-working adults, access of non-workers to a car, or work status of spouse which partially indicate the extent to which people other than the observed worker can meet the needs generated at the household level for activities outside the home. The number of daily trips made by others in the household (an average per person), is to some extent a proxy for both "generators" and "providers," since the propensity to travel could correspond to "activeness" (and hence more needs to be fulfilled) but also to readiness to travel in service of others' needs. Finally, the variables age, sex and disposable income serve as indirect measures of the differences we observe in people's personal as well as familial responsibilities. Although there is no information on the less obvious, but certainly important psychological "causes" of either the generation of or provision for needs to participate in activities, the available data are adequate for testing exploratory hypotheses about the influence of socio-demographic factors on someone's observed activity schedule.

Being the least understood of all the causal factors and having the fewest obvious empirical referents, the temporal constraints (as shown in Figure 3.4) are also the most tenuously represented. Although two people may have identifical activity programs, they may have quite different amounts of time available for carrying out such a program. Since we have postulated "work" as a peg or key activity around which discretionary time is planned, the "duration of work" is clearly a good measure of temporal limitation. At this point, the shortcomings of the traditional home interview survey data become apparent. The duration of obligatory activities at home are surely as important as those at work in imposing constraints on one's disposable time. However, because data was gathered only on trip-making outside of the home (and only vehicular travel at that), no empirical referent could be defined for this theoretical concept.[38] Similarly, we of course have no data on total discretionary time available to a person, but rather only on the time allocated to non-home, non-work activities. As the model was conceived as splitting the day into five time periods, we can use this information to create a variable representing the time allocated to discretionary activities in periods other than the one being evaluated. It is possible in this way to proxy the effect of various activities "competing" for the scarce time one has to dispose of. In addition, this variable allows us to test the hypothesis that decisions over time periods are interdependent.

Whatever the exact amount of time one may have available, it is also important how flexible one's obligatory "schedule" is. For example, a person working on an assembly line cannot usually deviate from the prescribed working hours, whereas a self-employed carpenter may be free to begin and end working whenever he or she pleases. The closest proxy which could be defined to this variable was two dummy variables for whether a person began or ended work outside of conventional hours (after 9 a.m. or 6 p.m.). At the same time, these variables served as proxies

[38] It is conceivable that some of the socio-demographic variables "capture" some of the effect of duration of obligatory activities at home.

for the effect of being able to take advantage of conventional opening hours of many commercial establishments. The presumption here is that most businesses are opened between 9 a.m. and 6 p.m. and that people whose work doesn't coincide with these hours will be constrained differently than those whose work does. Finally, a dummy variable for temporal proximity to the weekend was defined according to the day of the week to which the diary information corresponded. Some activities are "open" on the weekend (of which Friday is a part); consequently, the temporal constraints experienced will at least vary along this dimension.

Parallel to the temporal are the spatial constraints which limit the "activity space" in which a program can be performed. Because of the more extensive prior development related to these constraints and the nature of the database, the match between concept and empirical referent was relatively close. An accessibility metric was calculated to represent the ease with which a person can reach opportunities (i.e. potential activities) from either home or work or both combined. Because this metric is generalized over both auto and transit, a variable was also created for the mode chosen to go to work, which presumably captures the effect of limitations imposed by having to travel either together with others in a car or in a bus with its fixed route and schedule. A dummy variable for whether or not someone has a driver's license also indicates one's ability (i.e option) to travel alone. Two additional variables defined to capture the effect of spatial constraints on activity scheduling behavior were of a more experimental nature. Whether the location of work and actual destination of work coincided was an indicator of the fixity of one's workplace. The hypothesis here is that for people who didn't have such a coincidence, there would be less knowledge of the options in area and hence less likelihood that time would be spent on non-work activities. Likewise, the variable "years lived at residence" was defined to proxy for a person's familiarity with alternative activities with respect to the home. The logrithmic form was to indicate that the additional knowledge or information gained decreases with tenure (i.e. the amount gained in the first year is greater than that in the tenth year).

Collectively, then, these variables serve as proxies for all the elements (shown in the figures in Chapter Three) which are postulated as having a causal effect on activity scheduling behavior. Five equations were developed to capture the effect of these variables on whether or not someone decides to participate in an activity in a time period. Since we are trying to estimate the probability with which a person will participate, the coefficient of a variable indicates the degree to which a person would be likely to participate. A negative sign indicates less likelihood, all other factors held constant, and the magnitude times, say, the mean value of the variable in the sample gives us a clue to the relative contribution of the factor to the final predicted probability (-.08 being a much lower contribution than -.12). The five equations for duration were estimated only with data on people who actually participated in an activity in a particular time period. These equations measure the statistical effect of variables on the actual observed duration. If, for example, we multiply the average value of a variable (as duration of work) times its coefficient, the product is the relative contribution of the variable to the duration we would observe if participation were also observed.

7.2.3 Econometric Simultaneity

Because five time periods were defined for every observed person's day, there were ten equations developed to reflect the unique temporal and spatial environment in each period. Since it is a central hypothesis of this thesis that decisions made in different time periods are not independent, the way to represent this fact takes on major importance. A number of alternative approaches seem plausible. An obvious econometric answer would be to estimate the ten equations as a complete simultaneous system, leaving at least one of the ten equations as an identity. This procedure is not clearly appropriate because the solution of a system in which there are in fact five pairs of equations (participation and duration) is hardly a traditional "simultaneous system" as econometricians know the concept. Another approach would be simply to use a standard single equation method. As Kmenta (1971, p. 573) points out, this method of estimation leads "to estimates that are consistent but in general not asymptotically efficient."[39] The alternative approach used here is to define explanatory variables for the models in each time period which reflect some characteristic of the other four periods. When we are trying to explain duration, for example, it is useful to know how much time a person spent in other time periods, since to the extent that

[39] This is because of the disregard of correlation of disturbances across equations and prior restrictions in other equations in the model. Inefficiency would result in the present case because a reduced form model has been used.

decisions across periods are interrelated, time will be allocated more jointly than sequentially.[40]

7.3 Presentation and Interpretation of Findings

The results will be presented first period by period, then summarized over all periods for the models both of duration and of participation. Four kinds of results will be discussed. First, there were variables about which the author had strong prior beliefs which were in effect "confirmed" by the findings (e.g. we could reject the hypothesis that a variable's coefficient was not significantly different from zero at the 90% level of confidence). Second were the reverse cases in which counter-intuitive results occurred. Third, there were cases in which no strong belief existed about behavior in particular time periods but the results were clear enough (in a statistical sense) to lead to relatively strong hypotheses to be tested in future work. Fourth and finally were variables which were more experimental in nature. The findings in this category were ambiguous such that a coefficient could be interpreted by little more than speculation. As we shall see, particularly these results could bear the seeds of productive future research.

In most cases, a variable was not included in an equation if its t-statistic did not indicate that its coefficient was not virtually zero

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[40]Because including an exogenous variable which is actually a composite of the endogenous variables of the other four durational models violates the assumptions of OLS, it is necessary to implement a two stage least square estimation procedure. First, durations are estimated for everyone without a "simultaneous" term and the expected (mean) values for people who actually participated are used to calculate the time spent in other periods. In this way, we avoid risking correlation of the error terms and explanatory variables in each model.

at the 0.1 level of significance. The author's judgement was, however, exercised in a few cases in favor of inclusion regardless of the t-statistic, if strong a priori grounds existed. In the context of strict hypothesis testing, there would consequently be several variables dropped which are nevertheless reported here. It is hoped that future work in this field can closely scrutinize such variables. Summary measures of the overall "fit" of the data to the model are given along with the results of each equation. Because these measures were not used to judge the "best" equation, discussion of them is omitted.[41]

7.3.1 Results of Period One

As already indicated by the ending times of trips to discretionary activities in Chapter 5, Period One is unique in that most people who participate in an activity before even beginning the work trip start working well after the majority of people in the sample. As one can see in Table 7.2, the coefficients of variables related to duration of work and whether a person begins work after 9 a.m. are statistically significantly different from zero at the .01 level (as $t>2.33$). It is also apparent that younger workers have a strong tendency to make such trips as shown by the sign on the coefficients for age. In the equation for duration, the relatively large magnitude of the coefficient of "sex" indicates that if we observe participation men will spend considerably less than their female counterparts.

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[41] For the regression equation, $\bar{R}^2$ is used to indicate the proportion of variation in the dependent variable explained by the equation, corrected for the number of explanatory variables used. In the probit equations, ρ^2 is used. It is calculated as:

$$1 - \frac{\text{log likelihood of the equation before estimation}}{\text{log likelihood of the equation after estimation}} .$$

Table 7.2 : Results of Estimations of Equations for PERIOD 1 (H-O-H)

PARTICIPATION

VARIABLE NAME	VALUE (t-statistic)
constant	-0.008 (-.17)
duration of work	-.007 (-3.61)
time spent in other periods	-.003 (-3.85)
Friday	.12 (5.36)
arrive at work after 9 a.m.	1.20 (11.79)
accessibility (home)	.08 (2.20)
trips per others in household	.04 (1.19)
drivers per car in household	-.12 (-2.05)
driver's license	.14 (2.03)
number of non-working adults	.25 (2.95)
log (disposable income)	-.05 (-1.52)
log (years at residence)	-.03 (-.89)
age	-.01 (-3.26)
predicted duration	.0004 (.14)
ρ^2	.76

DURATION

VARIABLE NAME	VALUE (t-statistic)
constant	2.19 (2.12)
duration of work	-.44 (-1.65)
time spent in other periods	-.26 (-2.50)
accessibility (home)	-7.47 (-1.93)
trips per other household members	11.94 (3.59)
number of children 5-15	6.75 (1.48)
sex	-36.21 (-1.91)
selectivity bias correction	-.32 (-.45)
$\bar{R}^2$	.17

That the coefficient for trips taken by others in the household is positive and also significant at the .01 level suggests that many of the trips are made with others, presumably for some household errand like shopping or serving a passenger. The other household-level variables also appear to show the effect of interaction with family members, but the results do not always point in any obvious direction. In the participation equation, the coefficent of number of non-working adults has a positive sign and strong significance whereas in the duration equation its sign is negative. "Number of children (5-15)" was not a statistically good explainer of whether someone was likely to participate but was relatively good in the equation of duration. Competition for automobiles among members of a household is registered by the variable "drivers per car"; its negative sign coordinates well with our intuition that more drivers per car means lower likelihood of observing participation.

7.3.2 Results of Period Two

Despite the lack of distinction between types of activities, a large portion of explanation of the results for Period Two (see Table 7.3) undoubtedly is to be found in the high percentage of "serve passenger" trips (67%). Since it was decided to omit exploration of the process by which specific kinds of activities (e.g. shopping, recreation, etc.) are chosen, only a few tests of separate types of activities were conducted. The few tests which were run show, for example, that the coefficient of "fixity of workplace" in the equation of duration was significant at the .05 level in a sample which excluded "serve passenger", whereas in the mixed sample one would be unable to reject the hypothesis of no significant difference from zero, even at the .10 level. One suspects

Table 7.3: Results of Estimations of Equations for PERIOD 2 (H-O-W)

PARTICIPATION

VARIABLE NAME	VALUE (t-statistic)
constant	-.22 (-3.55)
duration of work	-.03 (-5.06)
time spent in other periods	.002 (3.12)
Friday	-.27 (-4.58)
arrive at work after 9 a.m.	.51 (6.35)
accessibility (home-work)	.07 (4.14)
trips per others in household	-.05 (-2.71)
mode to work	-.55 (-6.19)
access of non-workers to a car	.10 (1.44)
driver's licence	.49 (3.87)
number of non-working adults	-.14 (-3.96)
log of disposable income	.20 (2.97)
sex	.73 (6.45)
predicted duration	-.03 (-5.18)
ρ^2	.57

DURATION

VARIABLE NAME	VALUE (t-statistic)
constant	.21 (1.11)
duration of work	-1.1 (-6.23)
time spent in other periods	-.11 (-1.87)
trips per other household members	-2.89 (-1.64)
access of non-workers to a car	12.40 (1.58)
log of disposable income	6.54 (1.27)
selectivity bias correction	.41 (2.39)
$\bar{R}^2$	.23

that the counterintuitive sign of time spent in other periods in the equation for participation could be similarly explained. Likewise, the negative sign on "mode to work" appears to indicate that people who share rides (and therefore, be more likely to "serve a passenger") will be more likely to participate in an activity on the way to work. This is obviously uncharted territory which should be explored in future research.

In addition to the problem of activity purposes, the variable which represents whether non-workers have access to an automobile merits note. In the equation of participation its coefficient's sign is positive and significant at the .01 level. Since the original intent of this variable was to capture the effect of having others in a household to take care of familial responsibilities, this result is clearly counter-intuitive. Similarly, the positive sign in the equation of duration seems to raise questions about our theoretical model or at least the use of this variable to represent a part of it. If non-workers have such access the observed person would be expected to have fewer obligations and, hence, need to spend less time (i.e. a negative sign would be the norm).

For the most part, however, the results conformed to prior judgement about likely outcomes. That only five variables were statistically significant in the equation of duration points toward the need for more detailed examination of particular activity purposes; many of the variables which showed up in other periods were effectively washed out by the pre-dominance of "serve passenger" purposes.

7.3.3 Results of Period Three

People's behavior in Period Three is characterized by a high degree of independence from other household members as well as from decisions made in other time periods. This seems intuitively reasonable since the work activity is usually the least connected to the activities of others in a household. In the equation of duration (see Table 7.4), the variables having the best explanatory power are generally those describing the person (e.g. sex) and the person's workplace (e.g. duration of work). At the same time, household variables such as "access of non-workers to a car" or "number of children (5-15)" are only weakly significant. Since a high percentage of activities in this period are "personal business" (62%), it was decided to keep these variables in the equation so that future research might explore their effects on duration of activities other than "personal business."

Several variables exhibited behavior which is not immediately explainable. "Disposable income" (of the household) is strongly significant in both equations. While one could readily believe that higher earners are more likely to use their cars during work (e.g. to drive to a restaurant), it is not clear why such people would stay on the average longer than lower earners, given that participation is observed. (Do they have more autonomy in scheduling activities related to work?) It is also difficult to understand why "driver's license" should have a negative coefficient (i.e. possession of one indicates likelihood of going out).

Table 7.4: Results of Estimations of Equations for PERIOD 3 (W-O-W)

PARTICIPATION

VARIABLE NAME	VALUE (t-statistic)
constant	-4.56 (-4.83)
duration of work	-.006 (-2.07)
accessibility (work)	.03 (1.21)
fixity of workplace	-.19 (-1.27)
trips per others in household	.04 (2.31)
mode to work	.28 (2.50)
driver's license	-.45 (-2.72)
working spouse	-2.31 (-4.92)
log of disposable income	.43 (3.60)
predicted duration	.002 (.55)
ρ^2	.65

DURATION

VARIABLE NAME	VALUE (t-statistic)
constant	-1.23 (-1.76)
duration of work	-1.00 (-3.76)
time spent in other periods	-.07 (-1.35)
accessibility (work)	-4.94 (-2.60)
fixty of workplace	-24.80 (-1.86)
mode to work	18.20 (1.67)
access of non-workers to a car	-6.43 (-0.92)
log of disposable income	41.58 (2.21)
number of children 5-15	-2.58 (-1.22)
sex	22.95 (1.81)
selectivity bias correction	-0.74 (-1.37)
$\bar{R}^2$	.19

7.3.4 Results of Period Four

The most striking aspect of the results in Period Four (see Table 7.5), are the high magnitudes of two variables in the equation for duration which proxy the level of responsibilities a worker faces at work (duration) and at home (working spouse). The presumption in the latter case is that persons in a dual career relationship tend to shoulder more general responsibilities for a household than their single career counterparts. The signs of each of these variables indicate the direction of constraint on time spent in non-home, non-work activities.

Except for the coefficient of "accessibility" (in the duration equation), all other variables' results conformed to the *a priori* beliefs held before estimation. The positive sign of accessibility tells us that as this variable increases in value, a person will spend more time (since most values of access are negative). As travel and activity time are components of time spent, we expect that as activities are on the average located further away from a place, more time will be spent in order to "participate". Since the accessibility metric for Period Four is actually a composite of home- and work-oriented measures, possible explanations may be related to the "marginal" nature of adding activities onto a schedule in this period (or Period Two). That is, activities in this period are an integral part of the travel between home and work and usually require only a slight or marginal increase in travel expenditures. In any case, this result should provide interesting thoughts about future research.

Table 7.5 : Results of Estimations of Equations for PERIOD 4 (W-O-H)

PARTICIPATION

VARIABLE NAME	VALUE (t-statistic)
constant	.02 (.70)
duration of work	-.008 (-5.40)
accessibility (home-work)	.03 (2.35)
fixity of workplace	-.24 (-2.74)
trips per others in household	.06 (4.90)
mode to work	-.09 (-1.37)
driver's license	.27 (1.82)
number of non-working adults	-.17 (-3.54)
age	-.006 (-2.35)
predicted duration	-.0002 (.28)
ρ^2	.38

DURATION

VARIABLE NAME	VALUE (t-statistic)
constant	.64 (4.45)
duration of work	-1.55 (-6.51)
time spent in other periods	-.33 (-3.98)
access of non-workers to a car	23.47 (2.04)
accessibility (work-home)	2.67 (1.34)
log of disposable income	11.04 (1.70)
working spouse	61.15 (1.52)
age	-1.57 (-3.77)
selectivity bias correction	-.42 (-9.13)
$\bar{R}^2$	.29

7.3.5 Results of Period Five

Period Five (see Table 7.6) resembles the third period in that its duration equation did not appear to be influenced by the time allocated to activities in other periods. This suggests that once someone decides to go out, the length of stay is determined independently of decisions made earlier in the day. The particular day of the week on which an observation was made had its most pronounced effect in this period, with the dummy variable "Friday" being significant in both equations. The fact that the coefficient of "trips per others in household" has a relatively high matnitude and is strongly significant in both models, together with our knowledge of modal split (37% drive alone, 63% shared ride, 1% other modes) leads us to infer that decisions made about spending time outside home in this period are highly interrelated with other members of one's household. The positive sign and high level of significance of the coefficient for number of children (aged 5-15) in the model of participation also support this notion of interdependence among household members, despite the fact that the nature of this interaction is not obvious with the present results. The same variable's coefficient in the model of duration had a negative sign and was not significantly different from zero at any reasonable level. One supposes that there are counteracting forces at play here; more children mean having to spend more time satisfying their activity needs but at the same time, if children are left at home, their parents will be less able to stay out for a longer time. The interpretation of the income variable is likewise clouded; its coefficient's being negative suggests that richer people stay out less

Table 7.6: Results of Estimations of Equations for PERIOD 5 (H-O-H)

PARTICIPATION

VARIABLE NAME	VALUE (t-statistic)
constant	.08 (.18)
duration of work	-.005 (-2.84)
time spent in other periods	-.004 (-5.75)
Friday	.23 (2.78)
leave work after 6 p.m.	-.85 (-8.30)
accessibility (home)	.02 (1.22)
trips per other household members	.17 (12.38)
driver's license	.40 (2.33)
number of children 5-15	.08 (3.89)
log of years lived at residence	.03 (.93)
age	-.01 (-3.38)
predicted duration	-.002 (-1.0)
ρ^2	.17

DURATION

VARIABLE NAME	VALUE (t-statistic)
constant	1.12 (5.30)
duration of work	-.39 (-2.25)
Friday	16.89 (2.19)
accessibility (home)	-2.08 (-1.29)
trips per others in household	5.00 (2.62)
log of disposable income	-3.70 (-1.20)
age	-.38 (-1.53)
sex	-39.84 (-4.14)
selectivity bias correction	-.15 (-1.08)
$\bar{R}^2$	.05

time, although we have no prior knowledge why this should be the case. Finally, the opposite signs of accessibility's coefficient in the two equations illustrate the conflicting phenomena embodied in this variable. On the one hand, we expect denser opportunities around the residence to encourage more frequent activity participation (hence the positive sign in the model of participation). On the other hand, more frequent participation tends to promote shorter trips and time spent in activities (as represented in the negative sign in the model of duration).[42]

7.3.6 Results Across Time Periods

Tables 7.7 and 7.8 show the results from all periods for participation and duration respectively. By comparing across periods we can begin to see regularities which were not apparent in the context of a single time frame. In order to systemize this discussion, variables were grouped to correspond to the scheme laid out in Table 7.1.

In the group of temporal variables, the result of "duration of work" confirmed the theoretical hypothesis that the larger the block of obligatory time the less the likelihood of including discretionary activities in a schedule and, clearly, the lower the amount of time spent even if one participates. "Time spent in other periods", the variable which proxies interrelation of temporal-spatial decisions in a day, was not uniform in its result as was initially expected. In the first and fifth periods of the participation equations, the signs were negative, but in the second it was positive and statistically significant at the .05 level.

[42] Any model formulation which collapsed the two phenomena, participation and duration into one "decision" would, of course, fail to capture this reality.

Table 7.7: Comparison of Participation Equations Across Time Periods

Variable \ Period	1 (H-O-H)	2 (H-O-W)	3 (W-O-W)	4 (W-O-H)	5 (H-O-H)
constant	-.008 (-.17)	-.22 (-3.55)	-4.56 (-4.83)	.02 (.70)	.08 (.18)
duration of work	-.007 (-3.61)	-.03 (-5.06)	-.006 (-2.07)	-.008 (-5.40)	-.005 (-2.84)
time spent in other periods	-.003 (-3.85)	.002 (3.12)			-.004 (-5.75)
Friday	.12 (5.36)	-.27 (-4.58)			.23 (2.78)
leave work after 6 p.m.				-.10 (-1.69)	-.85 (-8.30)
arrive at work after 9 a.m.	1.20 (11.79)	.51 (6.35)			
accessibility	.08 (2.20)	.07 (4.14)	.03 (1.21)	.03 (2.35)	.02 (1.22)
fixty of workplace			-.19 (-1.27)	-.24 (-2.74)	
log of years lived at residence	-.03 (-.89)				.032 (.93)
mode of work		-.55 (-6.19)	.28 (2.50)	-.09 (-1.37)	
driver's license	.14 (2.03)	.49 (3.87)	-.45 (-2.72)	.27 (1.82)	.40 (2.33)
access of a non-worker to a car		.10 (1.44)			
drivers per car	-.12 (-2.05)				
working spouse			-2.31 (-4.92)		
number of children 5-15					.08 (3.89)

Table 7.7: Comparison of Participation Equations Across Time Periods (continued)

Variable \ Period	1 (H-O-H)	2 (H-O-W)	3 (W-O-W)	4 (W-O-H)	5 (H-O-H)
number of non-working adults	.25 (2.95)	-.14 (-3.96)		-.17 (-3.54)	
trips per others in household	.04 (1.19)	-.05 (-2.71)	.04 (2.31)	.06 (4.90)	.17 (12.38)
log of disposable income	-.05 (-1.52)	.20 (2.97)	.43 (3.60)		
age	-.01 (-3.26)			-.006 (-2.35)	-.009 (-3.38)
sex		.73 (6.45)			
predicted duration	.0004 (.14)	-.03 (-5.18)	.002 (.55)	-.0002 (-.28)	-.002 (-1.0)
ρ^2	.76	.57	.65	.38	.17

Table 7.8: Comparison of Duration Equations Across Periods

Variable \ Period	1 (H-O-H)	2 (H-O-W)	3 (W-O-W)	4 (W-O-H)	5 (H-O-H)
constant	2.19 (2.12)	.21 (1.11)	-1.23 (-1.76)	.64 (4.45)	1.12 (5.30)
duration of work	-.44 (-1.65)	-1.10 (-6.23)	-1.00 (-3.76)	-1.55 (-6.51)	-.39 (-2.25)
time spent in other periods	-.26 (-2.50)	-.11 (-1.87)	-.07 (-1.35)	-.33 (-3.98)	
friday					16.89 (2.19)
accessibility	-7.47 (-1.93)		-4.94 (-2.60)	2.67 (1.34)	-2.08 (-1.29)
fixity of workplace			-24.80 (-1.86)		
mode to work			18.20 (1.67)		
access of non-workers to a car		12.40 (1.58)	-6.43 (-0.92)	23.47 (2.04)	
log of disposable income		6.54 (1.27)	41.58 (2.21)	11.04 (1.70)	-3.70 (-1.20)
number of non-working adults	-16.89 (-2.43)				
working spouse				61.15 (1.52)	
number of children 5-15	6.75 (1.48)		-2.58 (-1.22)		
trips per others in household	11.94 (3.59)	-2.89 (-1.64)			5.00 (2.62)
age				-1.57 (-3.77)	-.38 (-1.53)
sex	-36.21 (-1.91)		22.95 (1.81)		-39.84 (-4.14)

Table 7.8 : Comparison of Duration Equations Across Periods (continued)

Variable \ Period	1 (H-O-H)	2 (H-O-W)	3 (W-O-W)	4 (W-O-H)	5 (H-O-H)
selectivity bias correction	-.32 (-.45)	.41 (2.39)	-0.74 (-1.37)	-.42 (-9.13)	-.15 (-1.08)
$\bar{R}^2$	.17	.23	.19	.29	.05

While the coefficients of this variable in equations of duration are negative when at all significant statistically, the fact that it is virtually equal to zero in Period Five implies that this period tends to be planned more separately in terms of allocation of time in a total activity program. The other temporal variables, whether or not the observation was Friday and the arrival and departure times at work were, for the most part, good explainers of the variation on the left hand side of the equation only in specific periods. Understandably in Period Five, the "Friday" variable was among the strongest. For less obvious reasons, it was positive in the first and negative in the second period in the model of participation. Exactly as expected, the coefficient for arriving after 9 a.m. was positive in the first and second periods, whereas for that of departing after 6 p.m. negative in the fourth and fifth periods, all in the models of whether or not a worker goes out. Since these cutoff times were not systematically chosen, it is left to future research to examine alternative specifications using other arrival or departure times.

Of the spatially oriented variables, "fixity of workplace" performed according to initial expectation with respect to the sign of its coefficient. That is, in periods directly associated with the work activity, its coefficient was negative. This result strongly supports the notion that the workplace is a or perhaps the major peg around which a worker schedules daily activities. People who go to a place other than their regular "workplace" are less likely to go out and even if they do, for less time. Surprising was that in neither equation for Period Two was the coefficient of "fixity" statistically different from zero. "Accessibility" also did not have a uniform and significant coefficient as initially expected in both equations. In the equations for duration, its coefficient in Period Two was virtually zero and in Period Four positive. These results could relate directly to the fact that activities during these periods are visited on the way to an obligatory activity. Since these "on-the-way" activities are secondary to getting to home or to work, their duration will not be greatly affected by accessibility levels, however high. The mode to work dummy was negative in both Periods Two and Four in the equation of participation. Since a large proportion of trip purposes in these periods is "serve passenger this result should not be surprising. Likewise, the positive sign on this variable's coefficient for Period Two can be understood by realizing that one could drive alone to work but go out during work either alone or with others. Though one would apparently have no reason to doubt the hypothesis that possession of a driver's license would tend to predispose a person to participation in an outside activity, this corresponding coefficient was not significantly different from zero in Period Two and negative in Period Three. Speculation and further hypothesis testing could possibly uncover the reasons behind these counter-intuitive findings. This is even more true with respect to the experimental variable "years lived at residence," whose results are reported despite the inability to reject the hypothesis of its coefficient being virtually zero. While this variable could simply be a poor measure of a theoretical construct, the opposite signs of the coefficient in Periods One and Five (the home-oriented periods) may be clues to the particular effect that familiarity with one's spatial surroundings has an activity participation at different times of the day. In any case, additional research is clearly warranted.

In may cases, the socio-economic variables are weakly significantly different from zero, especially in the models of duration.[43] While the demographic descriptors "sex" and "age" cannot be interpreted in a directly causal sense, the results of their use in the equations gives insight into possible segments or sub-groups in the population which could be fruitful subjects of future research. In the equations of whether or not someone went out, women appear to have a lower probability than men of participating in Period Two. With regard to duration, women, on the one hand, apparently tend to spend more time in activities in Periods One and Five. During the work activity, on the other hand, we would predict men as having longer durations in outside activities. The coefficient of "age" showed no such variation. Its value was consistently negative, prompting the idea that younger people are more active outside the home. In Periods One and Five in the participation equations, it is strongly significantly different from zero. (This could be understood when one considers the child-related duties which younger parents perform). That its coefficient in Period Four's duration equation was substantially higher than those of other variables might simply reflect the tendency of younger people to satisfy more social-recreational needs outside of the residential domain).

The results of the socio-economic variables at the household level are less than definitive in terms of rejecting or failing to reject

[43] Given that these models were estimated only on persons actually participating, lower precision is to be expected.

initial hypotheses. The initial hypothesis about the variable "trips per others in household" was that it would be a proxy for the extent to which others perform duties at the household level and hence, the extent to which the observed person would be freed of chores to take care of. Contrary to this expectation this variable's coefficient was positive in every case in which meaningful statistical significance was reached (.10 level). In all but Period Two, greater likelihood of participation is indicated when the other members of the household travel more. At the same time, the two variables which proxy the effect of competition in a family for cars (drivers per car in Period One, access of non-workers to a car in Periods Two, Three and Four) illustrate the extent of interdependence in a household. In Period One, for example, the negative sign is proof that the more competitors for fewer cars, the less likely a person will go out -- as it is to be expected. In Periods Two and Four in the model of duration, the reverse seems to be true; that is, if a car is available to a non-working adult, then the worker will tend to spend more time in an activity once she/he has gone out. In this case, an observed person would seem to be freed from home-related chores to spend more time in discretionary activities.

One of the most striking results is that no variable in the socio-economic group was statistically significant in all periods; rather, people tended to be influenced more by household traits in Periods having "home" as the peg or reference point (One and Five) than in the Periods with work as either the sole or joint peg. In the equation of participation, for example, the coefficient of "number of children 5 to 15" was significant (and positive) only in the fifth period. Whereas the sign of this variable accords with prior expectation, the positive sign of "number of non-working adults" in Period One is an implicit call for further investigation of the unique nature of activities visited during this time and of the related scheduling behavior. Its negative sign in the second and fourth periods is as we expect; when there are other people to perform household duties, the observed worker will deviate from the obligatory schedule with less likelihood. "Income" appeared to have a positive effect in the two periods associated with work (2 and 3). The experimental variable "working spouse" still needs further work in the context of the participation equations. The "working spouse" was strongly negative in the third period, a result that is difficult to interpret.

Likewise, one can only speculate about the extent to which and how the socio-economic factors explain variation observed in duration of activities. "Number of non-working adults" performed as expected, being negative, but significant statistically only in the first period. The coefficient of "number of children 5 to 15" was positive in the first, but negative in the third period. Income appears as positive in periods Three and Four, but negative in Two and Five. It seems evident that more information on in-home activities and opportunities as well as finer breakdown of purposes would permit more precise inference.

Finally, it is worth commenting on the variables which were primarily by-products of the modeling procedure developed in Chapter Four.

7.3.7 Results of the Use of Variables for "Selectivity Bias" and "Predicted Duration

As discussed in Chapter Four, the modeling approached selected for this thesis entailed using two variables besides usual explanatory variables. The first was for the duration predicted for everyone in the sample and used to estimate the effect of duration on participation decisions. The hypothesis implicit here is that one decides about participation and duration jointly rather than sequentially. The second, a corrector for the bias caused by the hypothesized simultaneity of choice of participation and duration decision, was used in duration equations. Referring to Table 7.7, one can see that except in Period Two, the coefficients for "predicted duration" are not significantly different from zero at the 0.1 level. Because of the predominance of the "serve passenger" purposes in Period Two, the t-statistic should be considered with some skepticism. In any case, these results cast doubt on the hypothesis that decisions about participation and duration are made simultaneously.

The results for "selectivity bias" in the equation for duration are not uniform, as should be evident in Table 7.8. In Periods One and Five, its coefficient is virtually zero at the 0.1 level of significance, whereas its coefficient in Periods Two, Three and Four is statistically significant.[44] The importance of this variable is further confirmed by comparing the estimation results of the corrected with the uncorrected equations of duration. Table 7.9 shows the uncorrected equations and Table 7.10 gives a direct comparison of the differences in Periods Two and Five with and without a variable for selectivity bias. These results

[44] Although estimations with the available data did not so indicate, it is possible that one or more variables omitted in Periods Two, Three and Four are strongly correlated with the variable correcting for selectivity bias. This possibility clearly merits further exploration.

Table 7.9 : Comparison of Duration Equations without Correction for Selectivity Bias

Variable \ Period	1	2	3	4	5
constant	1.89 (2.35)	.12 (.61)	-.37 (-1.17)	.47 (2.97)	1.01 (5.41)
duration of work	-.37 (-1.71)	-1.24 (-7.18)	-.73 (-4.07)	-1.75 (-6.68)	-.35 (-2.10)
time spent in other periods	-.24 (-2.62)	-.09 (-1.52)	-.09 (-1.80)	-.54 (-6.17)	
Friday					14.64 (1.96)
accessibility	-7.99 (-2.17)		-4.24 (-2.31)	1.49 (0.58)	-2.35 (-1.48)
fixity of workplace			-20.32 (-1.57)		
mode to work			9.90 (1.08)		
access of non-workers to a car		6.57 (.85)	-.03 (-1.06)	2.68 (0.22)	
log of disposable income		12.85 (2.71)	17.24 (2.66)	9.42 (1.31)	-3.57 (-1.16)
number of non-working adults	-17.51 (-2.58)				
working spouse				44.57 (1.01)	
number of children 5-15	6.85 (1.51)		-2.69 (-1.17)		
trips per others in household	11.6 (3.59)	-1.69 (-.98)			3.39 (2.88)
age				-1.00 (-2.20)	-.31 (-1.30)

Table 7.9: Comparison of Duration Equations without Correcting for Selectivity Bias (continued)

Variable \ Period	1	2	3	4	5
sex	-36.94 (-1.96)		22.62 (1.78)		-42.01 (-4.46)
selectivity bias correction	---	---	---	---	---
$\bar{R}^2$	.18	-	.18	.14	.05

Table 7.10: Comparison of Uncorrected and Corrected Duration Equations for Periods 2 and 5

Variable	Period 2 Uncorrected	Period 2 Corrected	Period 5 Uncorrected	Period 5 Corrected
constant	.12 (.61)	.21 (1.11)	1.01 (5.41)	1.12 (5.30)
duration of work	-1.24 (-7.18)	-1.10 (-6.23)	-.35 (-2.10)	-.39 (-2.25)
time spent in other periods	-.09 (-1.52)	-.11 (-1.87)		
Friday			14.64 (1.96)	16.89 (2.19)
accessibility			-2.35 (-1.48)	-2.08 (-1.29)
trips per others in household	-1.69 (-.98)	-2.89 (-1.64)	3.39 (2.88)	5.00 (2.62)
access of non-workers to car	6.57 (.85)	12.40 (1.58)		
log of disposable income	12.85 (2.71)	6.54 (1.27)	-3.57 (-1.57)	-3.70 (-1.20)
age			-.31 (-1.30)	-.38 (-1.53)
sex			-42.01 (-4.46)	-39.84 (-4.14)
selectivity bias correction		.41 (2.39)		-.15 (-1.08)
$\bar{R}^2$	.22	.23	.05	.05

tentatively indicate that at least in the periods directly connected to the work activity, prediction of duration would be significantly biased were we not to account for the fact that we have data only for people who actually participate in an activity. Since this finding is in contrast to that of most other researchers who have explored selectivity bias, further research into possible underlying factors (*e.g.* omitted variables which may be strongly correlated with "selectivity bias") appears warranted. For the time being, its coefficient in Period Two indicates that the actual durations are on average lower than those which would be observed if everyone in the sample had participated in an activity. In effect, the results in this equation are "pulled up" to correct for this. Its coefficient in Periods Three and Four serves the opposite function, *i.e.* to "pull down" the equation because durations are on average higher than those which would be observed in the full sample.

CHAPTER EIGHT

What Has Been Learned?

8.1 Introduction

From both the empirical and conceptual research conducted in this thesis, there have been at least three types of insights gained. First, there are a number of more practical implications of this work useful to those engaged in analysis of alternative public policies. Second, there are implications for the causal model postulated in Chapter Three. Third, the empirical results have given us clues about the possible directions to take in modeling activity scheduling behavior. In addition, the research conducted in this thesis bears the seeds of several new approaches to urban transportation analysis and planning. A discussion of what could potentially be done with more advanced research into activity schedules is the basis of the concluding section.

8.2 Implications for Public Policy Analysis

Because the operational model and empirical equations in this thesis were developed primarily as tools of exploration into activity scheduling behavior, the results presented in Chapter Seven must be used indirectly to analyze alternative public policies. With further development of the research presented here, such a model and set of equations could eventually be adapted to the more general needs of public policy analysts.

8.2.1. Types of Policies or Changes

As Jones and Heggie (1978) have showed, the majority of "operational travel demand models" operate as if one's observed behavior were independent of others' behavior and one's own temporal-spatial decisions made at other times and/or places. "There are clearly instances where this may be an appropriate simplification, as when the policy change is small, or the affected individuals have very simple travel patterns, but equally there are other occasions when it is an oversimplification." (Jones, 1979, p.19). The operational model presented in this thesis can be considered a first step toward being able to assess the impact of policies on complex travel/activity behavior. In particular, where independence of events in a person's day or among people seems strong, a model of the kind presented here may be appropriate. Generally, there are four categories of policies which could be analyzed:

(1) those which loosen constraints

(2) those which tighten constraints

(3) those which shift constraints

(4) those which change the activity program which people want to realize.

Many policies which have only recently been given serious consideration would fall in one or more of the first three categories. For example, instituting a four-day work week in certain industries would tighten temporal constraints on the working days but loosen them on the extra non-working day. Flexible working hours would loosen the constraints experienced, whereas straggered hours would shift the constraints in time. In addition, changes in socio-demographic characteristics (e.g.income, age, proportion of women in the labor market) will have an effect on the activity programs which are to be realized. To analyze the impact of any of these policies or demographic changes, models which account for complex adaptation to a changed environment are warranted. If someone can arrive at home at 6:30 p.m. instead of 5:00 p.m. at the latest (because of longer or staggered hours), the schedules of others in the household and possibly the distribution of familial responsibilities will be affected. Using traditional travel demand models to assess the impact of such policies will probably misrepresent people's likely responses as choices are usually assumed to be made independently of other people.

8.2.2. Examples of the Analysis of Policies' Impacts

Despite the fact that the empirical work served more exploratory aims, the final specification presented in Chapter Seven can be used to indicate magnitude and direction of the impacts of some of the types of policies discussed above. Given the appropriate modifications to the specifications, a much wider range of policies could be analyzed.

Down the left-hand side of Table 8.1 are three measures of impact in each period, the values of which represent the average computed when the predictions for the sample or relevant subsample has been enumerated. The probabilities of participation were calculated using the estimated coefficients from the participation equations and evaluating the cumulative distribution function. The conditional durations were derived from the estimated coefficients of regression equations, whereas the unconditional durations were taken from the product of the first two items. The last item can be interpreted as the average duration we would observe in the sample regardless of whether we knew if participation had taken place. The data used were in all cases drawn from the sample used for estimating the equation.

Across the top of Table 8.1 the base case (i.e. current values) are followed by four changes:

- 20% increase in working time overall
- 20% increase in working time for those in manufacturing
- 15% increase in real income overall
- reduction in car ownership levels by 1 per household (if number of cars ≥ 1).

The first two changes could be expected on a working day if a four-day week were implemented. The third change might be expected if the region were to

Table 8.1: Comparison of Impacts Using Estimated Equations

Period	Policy Change / Measure*	Base Case	Work Time +20%	Work Time +20% (MFG.)	Real Income +15%	Cars Owned -1
1 (H-O-H)	Pr(participation	.06	05 (-17%)	.06 (-.3%)	.06 (-.4%)	.03 (-50%)
	conditional duration**	94.4	86.7 (-8.2%)	91.9 (-2.6%)	--	--
	unconditional duration	5.9	4.6 (-22%)	5.5 (-6.8%)	5.8 (-1.7%)	2.8 (-52.5%)
2 (H-O-W)	Pr(participation)	.07	.04 (-43%)	.06 (-14%)	.07 (0)	.07 (0)
	conditional duration	24.3	5.1 (-79%)	18.0 (-26%)	22.2 (-9%)	20.8 (-14%)
	unconditional duration	2.5	1.2 (-52%)	2.1 (-16%)	2.6 (+4%)	2.2 (-12%)
3 (W-O-W)	Pr(participation)	.08	.07 (12.5%)	.08 (0)	.09 (+12.5%)	--
	conditional duration	62.3	44.8 (-28.1%)	56.6 (-9%)	68.1 (+9.3%)	64.1 (-2.9%)
	unconditional duration	4.1	3.8 (-7%)	5.1 (+24%)	6.9 (+68%)	6.0 (+46%)
4 (W-O-H)	Pr(participation)	.16	.13 (-18.8%)	.15 (-6.3%)	--	--
	conditional duration	71.1	44.1 (-38%)	62.3 (-12.4%)	72.3 (+1.4%)	64.5 (-9.3%)
	unconditional duration	11.3	6.0 (-47%)	9.6 (-15%)	11.5 (+1.8%)	10.2 (-9.7%)
5 (H-O-H)	Pr(participation)	.36	.33 (-8.3%)	.35 (-2.8%)	--	--
	conditional duration	111.7	104.8 (-6.2%)	109.5 (-2.0%)	111.2 (-.4%)	--
	unconditional duration	40.6	35.3 (-13.1%)	38.8 (-4.4%)	40.4 (+.5%)	--
Σ unconditional duration		64.4	50.5 (-22%)	61.2 (-5%)	67.2 (+4%)	61.8 (-4%)

*All values are means for the sample; parentheses show the percentage change from the base case.

**All durations are in minutes.

experience a boom in economic growth relative to the nation, requiring a great deal of overtime work. The last change is extreme but not inconceivable given the projected increases in fuel prices and other costs of owning and operating an automobile. It should be noted that the forecasts were made for a week day on which a person works. Further development is required to expand the analysis to weekend or at least non-working days.

There are two main points to be noticed about these examples. First, aside from the first "policy", the change from the base of the sum of the unconditional durations over the time periods falls within ± 5%. Second, even for the same change the impacts are not uniform across time periods. In Period Four, increasing working time by 20% for manufacturing employees would decrease unconditional duration by 15% whereas in Period Five a decrease of about 4.5% would be predicted.

The above examples are meant to be illustrative of one way in which the impacts of alternative policies could be analyzed. Clearly, for an analysis to be genuinely useful to a public decision-maker, further research is necessary, especially into the best way to represent policies with the variables used in each equation.

8.3 Implications for Theory

In spite of the many compromises made in defining variables to capture the influence of factors on activity scheduling behavior, a number of insights have crystalized as a result of the empirical tests. It appears to be useful to group the causal factors into the three types applied here: needs/activity program, temporal constraints and spatial constraints. Because of the rough match between many of the variables used in their corresponding theoretical constructs, future research should most certainly concentrate on the definition of variables which more closely capture the effects intended by the abstract model. This recommendation holds particularly in the case of variables related to temporal constraints and interaction of household members. This task would, of course, be made easier if traditional travel diary information were augmented with the following items of data:

(1) in-home activity duration and purpose

(2) number of participants for each activity and their relation to person observed

(3) opening hours of major activities in major locations

(4) all relevant data on activities reached by non-vehicular modes

(5) degree of flexibility of arrival and departure times at work and at home

As a result of adding these items to the database, some of the apparent anomalies reported in Chapter Seven will probably be better understood. For example, with data from items (1) and (2) the socio-economic variables (e.g. working spouse, number of non-working adults) could be examined more closely. Likewise, by including all modes, specific periods' equations (especially those from Three) might produce results different from those reported here. The above items are a minimal set for improving the correspondence of empirical referents to theoretical constructs.

There are a number of other ways in which the state-of-the-art could be advanced. Two of these relate to the nature of the sample chosen for empirical work. Since the dataset used in estimation reflected only the realities of the Minneapolis/St.Paul area in 1970, the generalizability of the results from this thesis could be examined by:

(1) conducting a study of activity scheduling behavior in another metropolitan area, and

(2) using more recent data from the Twin Cities with the same modelling approach.

An assumption implicit in the present research has been that activity scheduling decisions are made on a daily basis. Because there may actually be temporal cycles other than the daily, it would be useful to explore scheduling behavior over either weekly or monthly cycles. Of particular interest would be the trade-offs made between times of the week or month. One imagines that especially working people often decide about participation between a weekday and a weekend. Finally, to the extent possible, types of activities should be isolated and analyzed in the general framework developed here. It should be noted, however, that using specific activities may require some modification in the functional forms of particular variables (e.g. duration may be better represented in logarithmic form) or in the operational model (e.g. a "discrete" logit or probit). As it has already been suggested, Periods Two and Three would be excellent candidates for an analysis of particular activities. Since information on the "land use" classification is also available for the destination in a person's travel diary (from the Twin Cities' Travel Behavior Inventory), it is conceivable that "purposes" (which indicate type of activity) could be further broken down and possibly re-grouped into more homogeneous segments.

8.4 Implications for the Modelling Approach

Because of the ambiguity of the results of variables connected to the modeling procedure outlined in Chapter Four, which approach is most appropriate for representing the theory remains an open question. Potential alternative approaches are to estimate:

(1) the participation and duration questions as a simple sequential decision process

(2) one 32-alternative choice equation (logit or probit) and then one separate equation for total activity time[45], or

(3) one choice equation (logit or probit) per time period in which the choices are discrete intervals of time spent in participation.[46]

The third alternative has merit in light of the results for the "predicted duration" variable. As it was entered into the equation for participation, duration was implicitly assumed to be a linear function. Given the "activity abstract" formulation used in this thesis, there was no strong prior belief about the nature of this variable, e.g. at what duration the utility associated with participation begins decreasing, if at all, and at what rate. The third approach could be used to good advantage if specific activities were analyzed; we could examine empirically which length of time individuals consider optimal for participation.

In addition to the alternatives which could be pursued, there are several extensions to the approach used in this research whose realization could go a long way towards increasing our understanding of activity scheduling behavior. First, it would be useful to explore ways to integrate the choices of mode and destination into the modeling system. Since the results of the "mode to work" variable were explainable but not entirely coordinate with our prior beliefs, it is far from clear what conditionality, if any, exists between participation and modal choice decisions. Finally, and most obviously following from the empirical results, a breakdown of activities by type would allow research geared toward understanding of the choice process behind participation. Since some of the activities (e.g. shopping) treated as "discretionary" are often more obligatory, it might then be possible to relax the strict definition of "fixed pegs" used here to explore possible hierarchies of activity types which underlie scheduling behavior.

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[45] Suggested by Moshe Ben-Akiva

[46] Suggested by Joel Horowitz

8.5 Place of Thesis in Larger Context

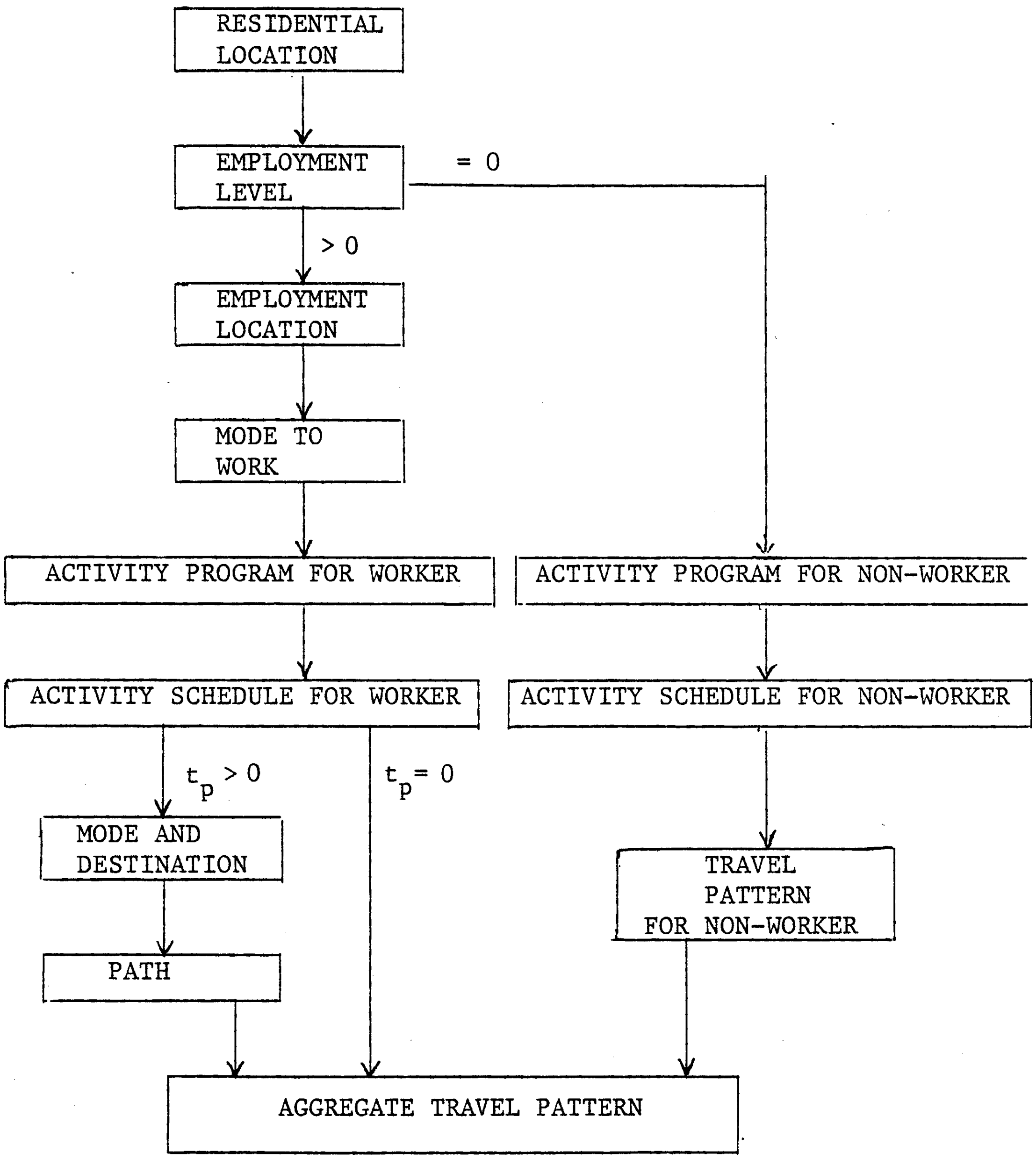
Beyond the more immediate benefits of better understanding of and predictive capability for activity scheduling behavior, there is a wide range of potential implications for the general issues of transportation analysis and planning. While a good deal of effort is still required before most of the concepts can be directly applied in practical situations, I am confident that the final result will be well worth the effort.

One of the dominant themes of this thesis has been that activities should be treated explicitly in transportation analysis. If we want, for example, to include activities for which travel is not required for participation (e.g. doing something at home), then the traditional "trip-generation" analysis is hardly suitable. Demand for recreational activities (and associated travel) will most certainly be increasingly affected by the supply of home entertainment centers (video recorders, two-way cable TV, etc.) as well as gasoline prices. In short, an "activity-generation" analysis will need to become a tool of the practicing planner.

Taking this line of reasoning further, a reformulation of an entire system of demand models so that activities could be fully integrated would be desirable. At the present time, activities are only vaguely represented in such systems by terms such as "land use." As should be clear from this thesis, simply reporting the use of a piece of land or the number of employees in a certain area tells us precious little about the ability of a person to actually participate in something at the site (and hence generate "activity" and possibly a trip). Whether someone's time is flexible, and whether an activity is open for participation when a person has good physical access to the site ("land use") are probably more important than some rough designation like "retail use." At the same time , once destination and modal choice were also integrated into a system of activity participation and duration equations, then activity-oriented analysis could become standard part of transportation planning practice. In Figure 8.1 the structure of an integrated system of demand models is illustrated. Given a decision to participate in the labor force (i.e. have an "employment level" greater than zero), one presumably makes decisions which fix the location of work and by what mode that location is reached from home. Both the worker's and non-worker's decisions could be modeled in parallel with respect to activity program and schedule. The outstanding difference between these two types of individuals are, of course, that the worker arranges his or her activities around the job. Consequently the worker's travel pattern can be represented in segments, t_p (where t is the time spent in period p). By means of some sampling procedure it should therefore be possible to determine the travel pattern which we expect to observe in a particular place over a certain time.

In conjunction with a reformulated system of demand equations, an expanded approach to transportation policy would also emerge. With a growing curiosity about the impact of changes in activities on travel behavior there will be a corresponding need to conceive of planning and management of the urban system in a larger framework. The currently discussed "transportation systems management" (TSM), for example, would have to be rethought so that policies as changed opening hours, flexible working hours or a four-day work week could be used more consciously to achieve political goals as reduced vehicle kilometers traveled (VKT) or lower congestion levels. One could imagine an "activity systems management" supplementing or even replacing TSM. The set of equations developed in this thesis could be used to isolate prob-

Figure 8.1: Structure of a Reformulated System of Demand Models



lems which occur during particular times of the day, for example the evening or the middle of the day. They represent, in any case, the beginning of a more realistic and useful approach to urban transportation demand analysis.

Appendix A: General Statistics Related To Dataset Used In Empirical Part of Thesis

1. Summary Statistics for Continuous Variables
2. Summary of Sample Values for Categorical Variables
3. Distribution of Deviation Purposes (bar graph)
4. Distribution of Activity Purposes (table)
5. Total Daily Activity Time

Table A.1: Summary Statistics*

Variable	Mean	Standard Deviation	Range
duration of work	$8\frac{3}{4}$ hrs	0.9	$0\text{-}16\frac{3}{4}$
Friday	0.16	0.36	= 1, if Friday = 0, otherwise
arrive at work after 9 a.m.**	.14	.35	= 1, if condition met = 0, otherwise
leave work after 6 p.m.**	.13	.33	= 1, if condition met = 0, otherwise
home based accessibility[47]			
• for shopping	-2.6	0.4	-4.2 to -1.4
• for social/recreational	-6.2	2.0	-17.9 to -2.4
home-work accessibility[47]			
• to shopping	-2.1	0.4	-3.8 to -0.7
• to social/recreational	-4.5	2.2	-12.6 to 1.92
work-based accessibility[47]			
• to shopping	-2.6	0.3	-4.3 to -1.4
• to social/recreational	-6.3	1.8	-15.3 to -2.1
fixity of workplace	0.10	0.31	= 1, if workplace not same as work destination = 0, otherwise
trips per others in household**	2.18	2.25	0-20.8
mode to work	0.75	0.43	= 1, if mode drive alone = 0, otherwise

Table A.1: (continued)

Variable	Mean	Standard Deviation	Range
access of non-workers to a car**	.34	.47	= 1, if # of drivers > 2, # of cars > 1, # of non-working adults > 0 = 0, otherwise
drivers per car**	1.62	1.6	0-30
number of drivers in household	2.1	0.9	0-6
number of autos in household	1.5	0.8	0-6
driver's license	.95	.21	= 1, if yes = 0, if no
presence of working spouse	0.01	0.1	= 1, if yes = 0, if no
household size	3.4	1.7	1-14
number of children age 5-15	1.0	1.4	0-9
number of non-working adults	1.1	0.7	0-5
number of workers in household	1.3	0.6	1-6
income	$12,525.	$5490.	$2000-$28,500
disposable income	$9842.8	$5285.6	$1-$27,700
number of years at current residence	8.8	8.4	1-62
sex	1.1	0.3	= 1, if male = 2, if female

Table A.1: (continued)

Variable	Mean	Standard Deviation	Range
age	39.5	13.2	15 - 78
total household trips	8.9	7.0	2 - 49
total person trips	3.8	2.1	2 - 18

*Total number of observations = 2345

**Variable created from original data (i.e., not in original survey)

[47] For a discussion of these accessibility measures, see Appendix B.

Table A.2 : Summary of Sample Values for Categorial Variables

DAY OF THE WEEK

Monday:	503
Tuesday:	508
Wednesday:	486
Thursday:	480
Friday:	368

STAGE IN THE FAMILY CYCLE

with children

youngest child under 5:	627
youngest child 5 - 18:	746
youngest child over 18:	171

without children

married, over 45:	301
married, under 45:	202
unmarried, over 45:	111
unmarried, under 45:	187

HOUSING TYPE

single family-own:	1642
single family-rent:	121
two family-own:	56
two family-rent:	122
multi-family-own:	8
multi-family-rent:	396

RELATION OF RESPONDENT TO HEAD OF HOUSEHOLD

male head/husband:	1931
female head/wife	193
child of head:	129
parent of head:	3
other relative:	23
other non-relative:	65
visitor:	1

TYPE OF EMPLOYMENT (1 DIGIT SIC CODE)

agricultural, mining, construction:	179
manufacturing:	747
trade - wholesale:	105
transportation, communication:	222
trade - retail:	271
finance, insurance, real estate:	129
hotels, services:	261
medical, education, legal:	211
government:	220

Figure A.1 : Distribution of Deviation Purposes (% for all periods)

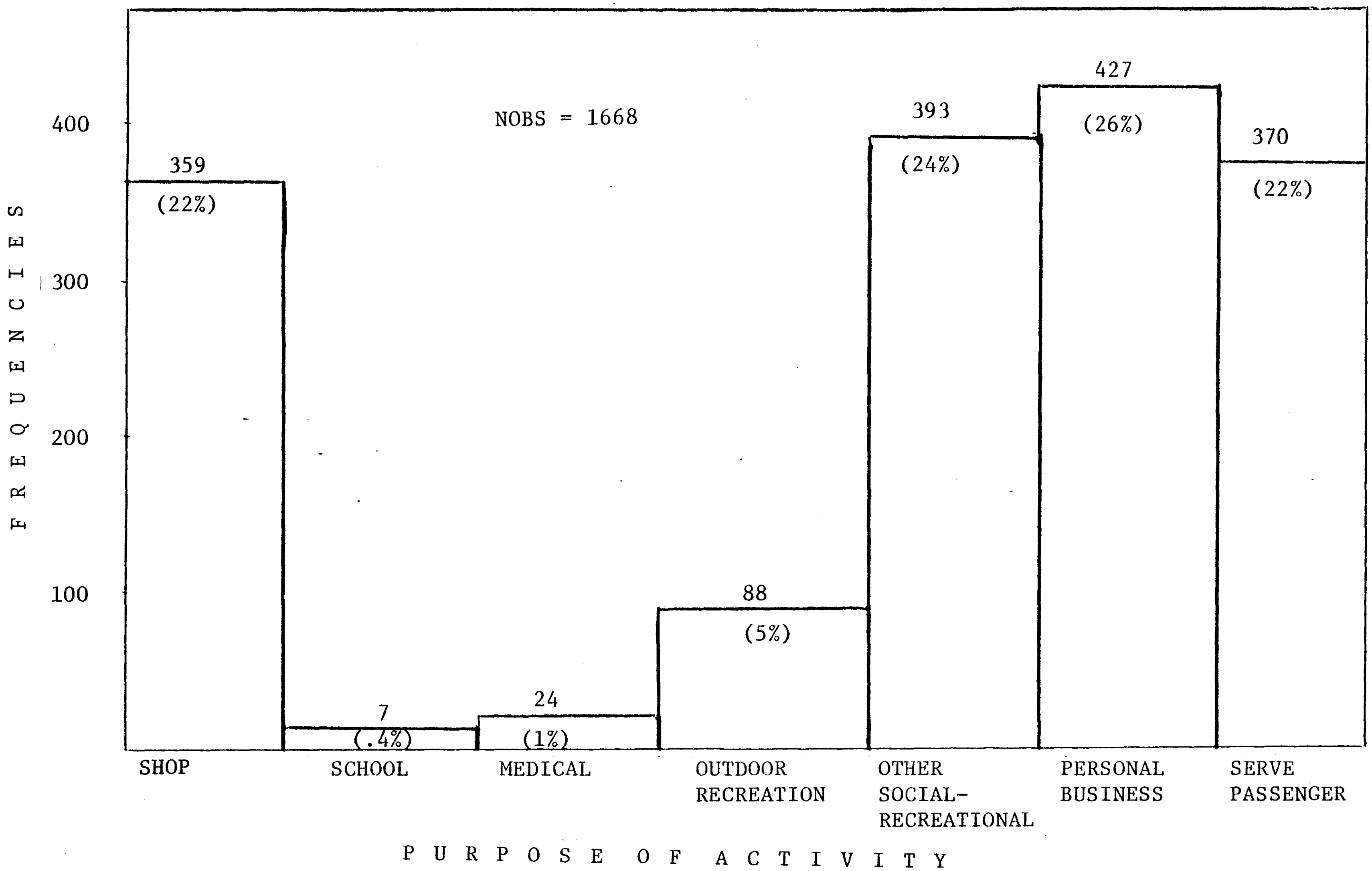


Table A.3: DISTRIBUTION OF ACTIVITY PURPOSES

(% of trips in time period)

time period \ purpose	shop	school	medical	outdoor recreation	other social-recreation	personal business	serve passenger	all purposes
1. (before work trip) H-O-H	45 (34%)	2 (1%)	6 (4%)	4 (3%)	17 (13%)	35 (26%)	25 (19%)	134 (100%)
2. (to work) H-O-W	9 (4%)	1 (.4%)	2 (.8%)	1 (.4%)	18 (8%)	47 (20%)	159 (67%)	237 (100%)
3. (during work) W-O-W	11 (7%)	0	2 (1%)	2 (1%)	38 (25%)	93 (62%)	5 (3%)	151 (100%)
4. (to home) W-O-H	69 (18%)	1 (.3%)	7 (2%)	15 (4%)	66 (17%)	103 (27%)	121 (32%)	382 (100%)
5. (after home trips) H-O-H	219 (29%)	3 (.4%)	7 (.9%)	66 (9%)	254 (34%)	149 (20%)	60 (8%)	758 (100%)
All Periods	359	7	24	88	393	427	370	1668

Table A.4: Total Daily Activity Time

Interval in Minutes FROM	TO	NUMBER OF OBSERVATIONS
0.	38.55	272.
38.55	77.1	312.
77.1	115.65	198.
115.65	154.2	157.
154.2	192.75	106.
192.75	231.3	86.
231.3	269.85	62.
269.85	308.4	31.
308.4	346.95	16.
346.95	385.5	20.
385.5	424.05	18.
424.05	462.6	7.
462.6	501.15	6.
501.15	539.7	2.
539.7	578.25	3.
578.25	616.8	0.
616.8	655.35	2.
655.35	693.9	0.
693.9	732.45	0.
732.45	771.	3.

Appendix B: Procedure Used to Calculate Accessibility Measures

Since the concept of accessibility and its translation to an exogenous variable are not obvious, it is useful to elaborate on its origins and use in the present thesis. In a general sense, we would like to measure the ease with which an individual in the sample can reach activities. Using information on the spatial density of activities as well as transportation level of service with respect to some place of reference, it should be possible to construct such a metric. In keeping with the behavioral orientation of this thesis, we would like to incorporate some notion of the utility associated with a person's choosing particular destinations at which to take part in particular activities. Prior work done by Ben-Akiva and Lerman (1977) suggest to us that the measure most appropriate to this approach is that of the expected (or mean) value of the maximum of the utilities of alternative destinations. This measure "refers to some composite measure which describes the characteristics of a group of travel alternatives as they are perceived by a particular individual." (Ben-Akiva and Lerman, 1977)

This can be formalized as:

$$A_t = E[\max_{i \varepsilon c_t} (U_{it})]$$

where:

A_t = accessibility of person t

U_{it} = the utility of alternative i to person t

c_t = set of feasible travel alternatives.

If we consider the utility U_{it} to be composed of both a systematic and a random component, an analytic expression can be derived for accessibility. Within the framework of a multinomial logit model, this expression is:

$$A_{c_t} = \log \sum_{i \varepsilon c_t} e^{V_{it}}$$

where:

V_{it} = the systematic component of utility

The entire term on the right hand side of the equation is sometimes known as the logarithm of the denominator of a multinomial logit model.

The calculation of the actual accessibilities was conducted parallel to that of Jacobson (1978). Because of budgetary constraints, joint destination/mode choice models already estimated by Adler (as reported in Adler and Ben-Akiva, 1976) for Washington, D.C., provided the coefficients of the level of service variables in the utility equations. The coefficients for the other variables were obtained by re-estimation of the utility equations using data from Minneapolis/St. Paul. With respect to location of someone's home or work, fifteen destinations were chosen at random from the 1058 zones of the Minneapolis/St. Paul metropolitan area. Separate calculations were done for shopping and for social-recreational activities, and if a "destination" of the fifteen contained no such activity its utility was set so that $e^{V_{it}} = 0$. The value calculated for $e^{V_{it}}$ for all fifteen destinations was then summed and then multiplied by 1058/15 in order to compensate for destinations which were not sampled.

In this thesis, three types of accessibility measures were computed: home-based, work-based and a composite home and work. For the first two, the vaues for level of service were the one-way mode-specific travel time and cost from either home or work. For the third measure the time and cost were the marginal values, i.e. those corresponding to what someone would expend above and beyond the obligatory trip home-work (or work-home).

The analysis conducted in this thesis is "activity-abstract," i.e. without respect to specific types of activities. It was, therefore, decided to add together the accessibility measures obtained for shopping and social-recreational purposes. As a result, the variables used to proxy the effect of "accessibility" are in fact composites. Future analyses which are "activity-specific" should, of course, use the corresponding accessibility measures.

The models used to compute accessibilities are as follows:

(1) Shopping

utility = 8.134*AC + 3.672 *[-.0593*(OVTT/DIST) - 2.422* log(OVTT+IVTT)
- .01905*(COST/INCOME)] + .7291*AUTOS - .001761*REMPD
+ log (REMP)

(2) Social-recreational

utility = 2.554*AC + 1.828*[-.207*(OVTT/DIST) - 1.94* log(OVTT+IVTT)
- .004*(COST/INCOME)]

where:

AC = auto constant

OVTT = out of vehicle travel time

IVTT = in-vehicle travel time

DIST = distance

AUTOS = number of autos in household

REMPD = density of retail employees

REMP = number of retail employees

Appendix C: Technical Description of the Modeling Procedure Used in Estimation

The purpose of this Appendix is to describe in more technical fashion the results of using the five step procedure suggested by Heckman (1976) and modified by Westin and Gillen (1978). Since Westin and Gillen provide an excellent detailed outline of this procedure in their article, the emphasis here will be on the intermediate results and their implications for econometric issues. As discussed in Chapter Three, we have an equation for "participation" (discrete) and one for "duration" (continuous). They are:

$$B_{it} = \alpha \pi^*_{it} + Z_{it} \gamma + \mu_{it} \tag{C.1}$$

$$\pi^*_{it} = X_{it}\beta + \varepsilon_{it} \tag{C.2}$$

Referring to these equations, the five stage procedure can be summarized as follows:

<u>One</u>: Estimate a marginal probit equation using all exogenous variables believed to influence either "participation" or "duration" or both, <u>i</u>.<u>e</u>.

$$\Pr[B_{it} \geq 0] = \Phi \; \frac{X_{it}\beta + Z_{it}\gamma}{\sqrt{1 + \alpha^2\sigma^2}} \tag{C.3}$$

$$= \Phi \; (\theta_{it}) \tag{C.4}$$

where Φ indicates the cumulative univariate standard normal distribution function. This should provide consistent estimates of the coefficients (the set is denoted by θ_{it}).

Two: Compute a correction factor for selectivity bias using the estimates of the coefficients from Stage One. This is the probability density function of the estimates divided by the cumulative density function of the estimates:

$$\frac{\phi(\theta_{it})}{\Phi(\theta_{it})} \tag{C.5}$$

where $\phi(\cdot)$ stands for the univariate standard probability density function. Then, using this correction factor as an additional exogenous variable, run a regression (OLS) on the deviation equation using those people who actually participated in an activity. This can be expressed in terms of expected (or mean) value:

$$E[\pi^*_{it} | B_{it} \geq 0] = X_{it}\beta + \frac{\alpha\sigma^2}{\sqrt{1 + \alpha^2\sigma^2}} \frac{\phi(\theta_{it})}{\Phi(\theta_{it})} \tag{C.6}$$

Three: Having coefficient estimates from those whose duration was positive, estimate the duration for the entire sample, regardless of observed length of participation:

$$\hat{\pi}^*_{it} = \beta_0 + X_{it} \hat{\beta} \tag{C.7}$$

where ^ denotes an estimated value. Using the values obtained ("predicted duration"), re=estimate the probit equation using only those variables which are believed to influence whether or not someone participates, obtaining:

$$\hat{\theta}_{it} = \frac{\alpha\ \hat{\pi}^*_{it} + Z_{it}\ \gamma}{\sqrt{1 + \alpha^2\sigma^2}} \tag{C.8}$$

<u>Four</u>: Multiply the estimated coefficient of $\phi(\theta_{it})/\Phi(\theta_{it})$ from Stage Two by the estimated coefficient of $\hat{\pi}^*_{it}$ from Stage 3 to get an estimate of ρ^2. Compute new values for the correction factor for selectivity bias from the probit equation in Stage Three then, re-estimate the equations for "duration" by weighted least squares in order to correct for heteroscedasticity (<u>i</u>.<u>e</u>. unequal variances).

<u>Five</u>: To obtain final coefficient estimates from the probit equation, calculate a factor of proportionality with which to divide the coefficients from Stage Three.

There are two developments which should be discussed in regard to using this five stage procedure in this thesis. First, Stage Four appears to be required in order to correct for heteroscedasticity, especially for Periods Two and Three. As a firstcut approximation, only the analyses of Stages One, Two and Three were conducted. Noticeable was the high magnitude of the coefficient of the variable representing "selectivity bias." For Periods Two and Three, the calculation of the scaling factor used to obtain final estimates (which is a partial function of the coefficient of selectivity bias) resulted in a complex number. When Stage Four was appended to the procedure in these equations, the magnitudes of the selectivity bias coefficient was greatly reduced (<u>e</u>.<u>g</u>. from 235 to 0.4) and a real number was obtained for the scaling factor.

The second development is closely related to the first. Once the full five-stage procedure was implemented for all periods' equations, the resulting scaling factors were all virtually equal to one (e.g. 1.000085). Because of the exploratory spirit of this thesis, the coefficients for the estimations of the probit equations in Stage Three were therefore considered final.

Other than the two developments described above, the estimations reported in Chapter Seven closely parallel those performed by Westin and Gillen (1978).

Appendix D: Distribution of Ending Times

Figure D.1: Distribution of Ending Time, Period 1

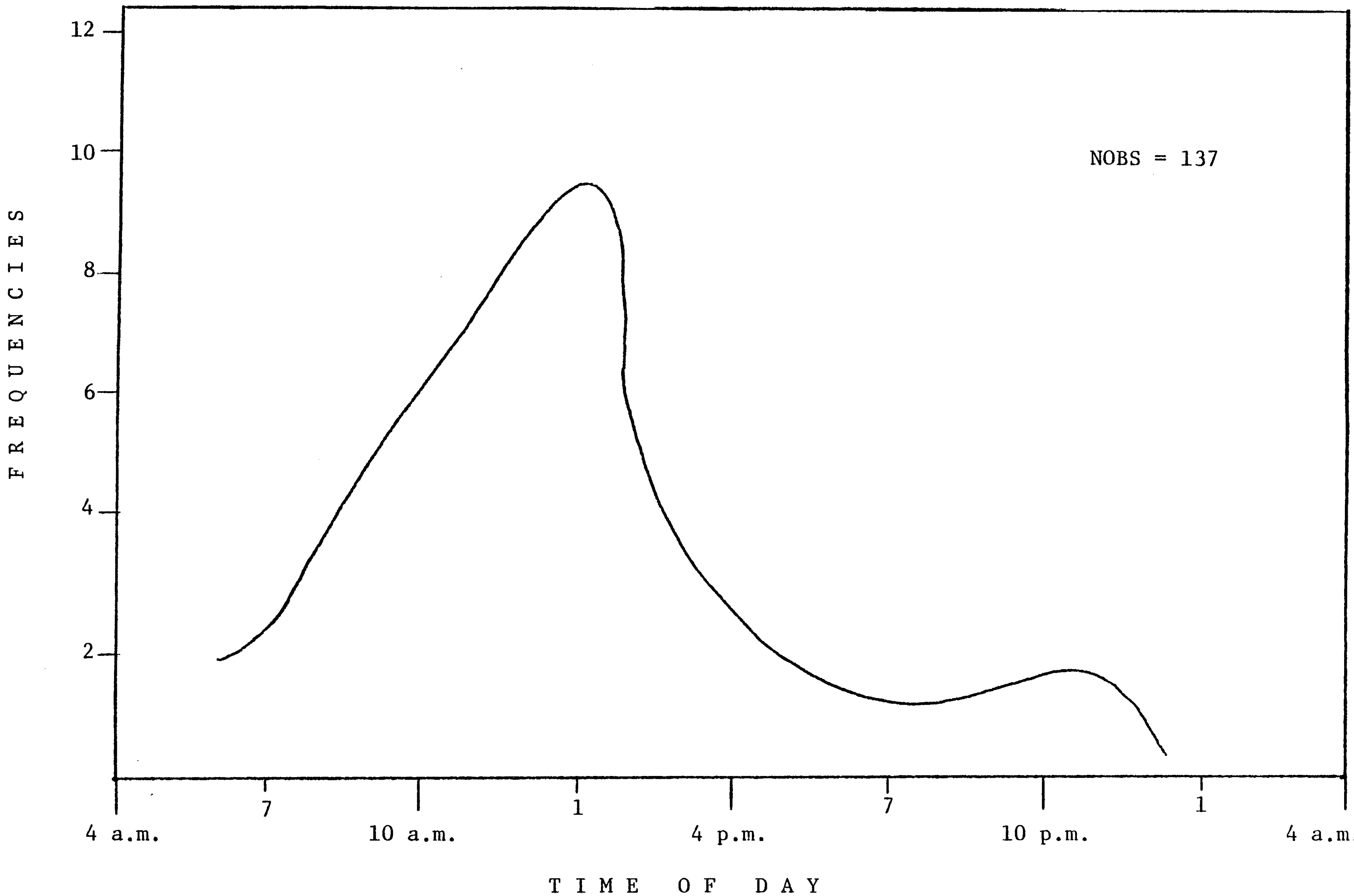


Figure D.2: Distribution of Ending Times, Period 2

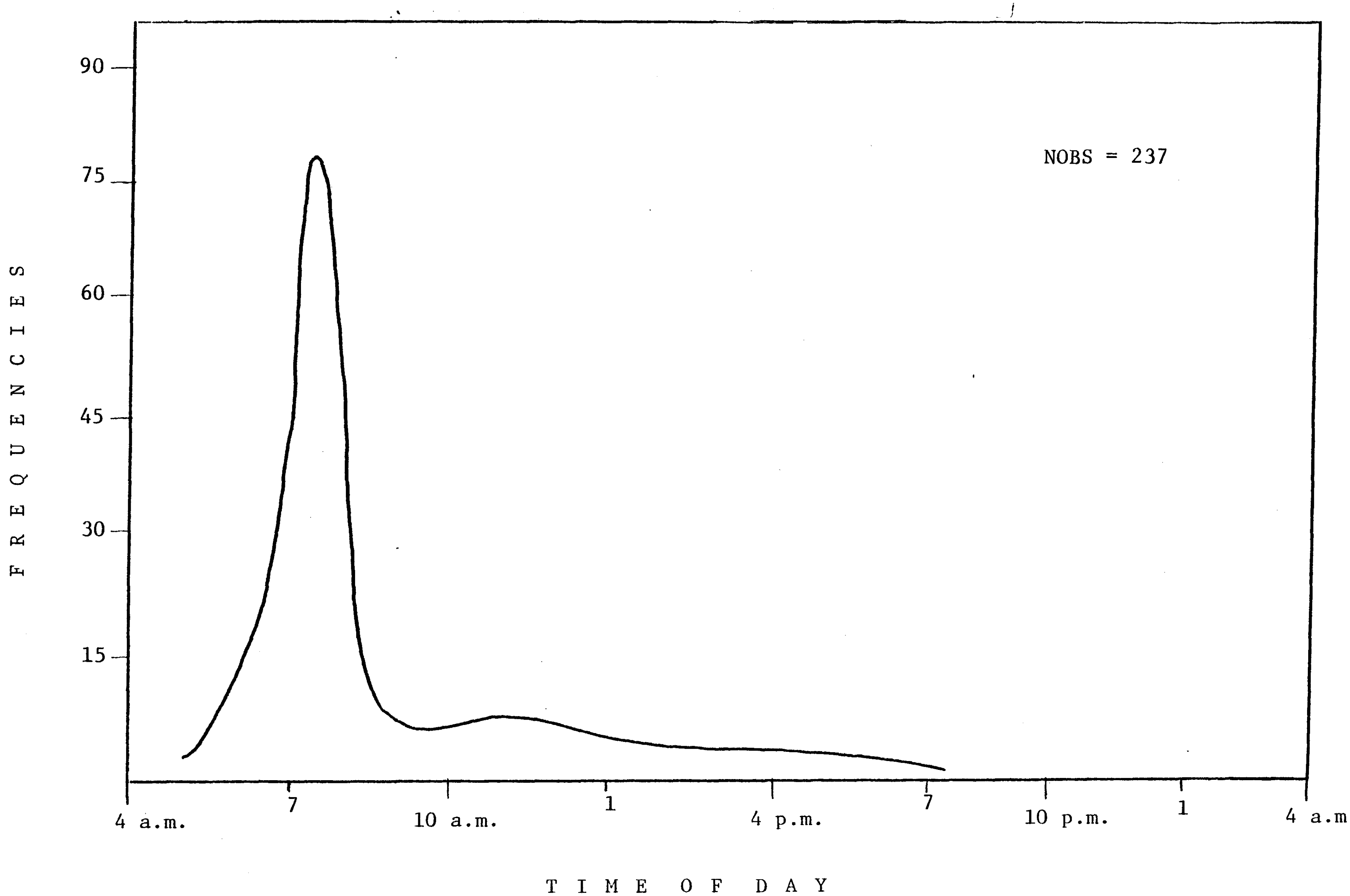


Figure D.3 : Distribution of Ending Times, Period 3

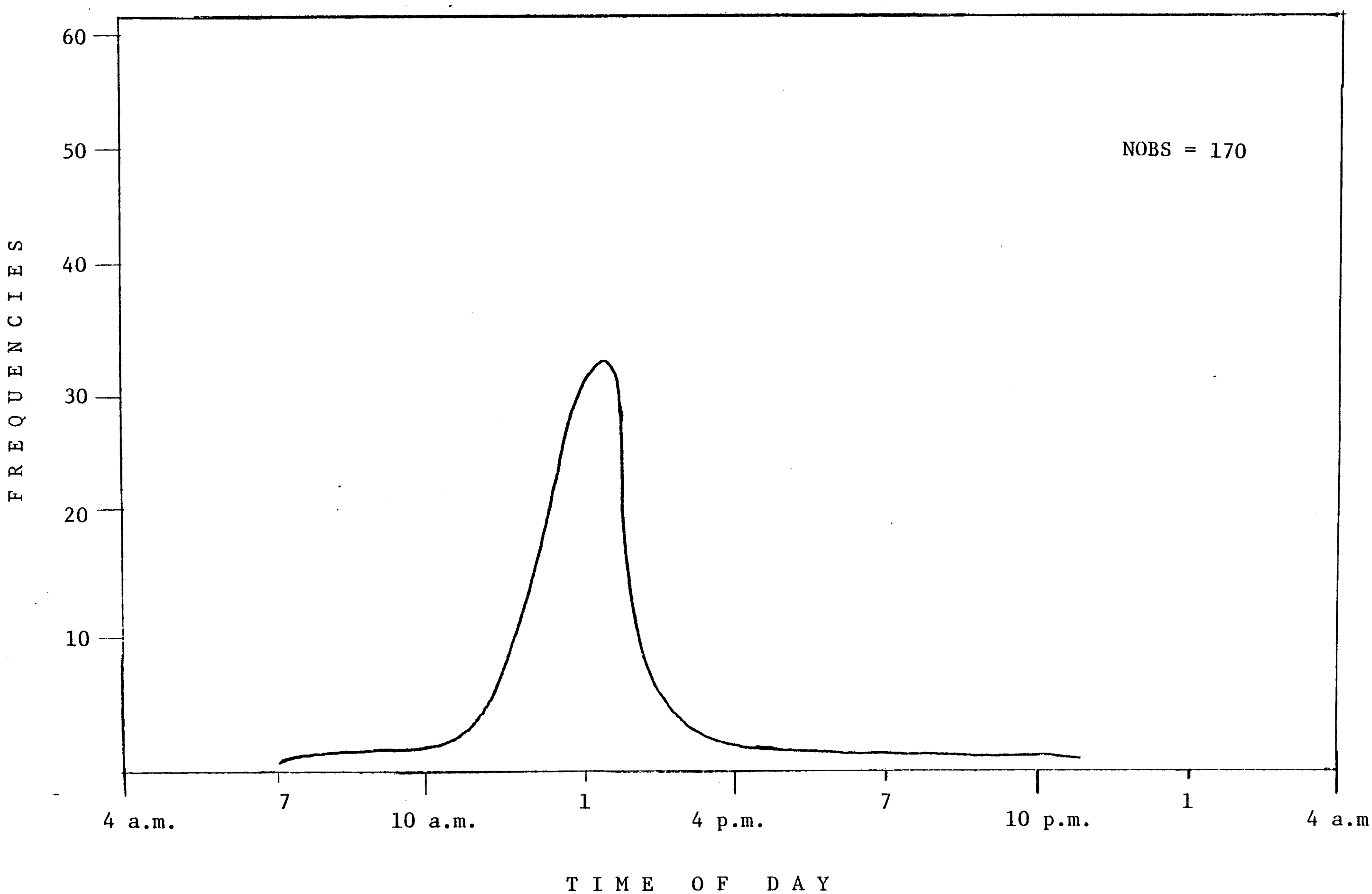


Figure D.4: Distribution of Ending Times, Period 4

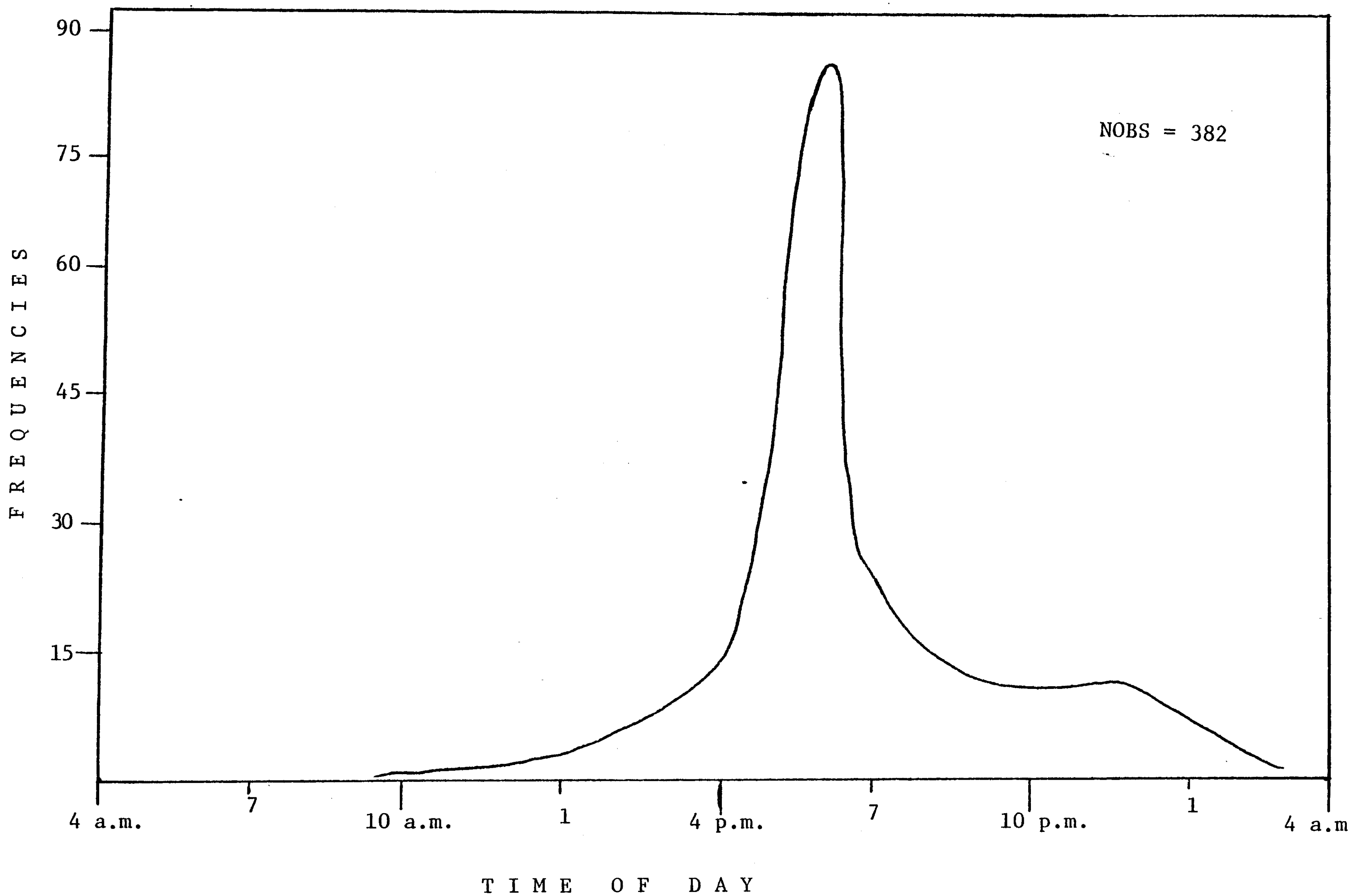


Figure D.5 : Distribution of Ending Times, Period 5

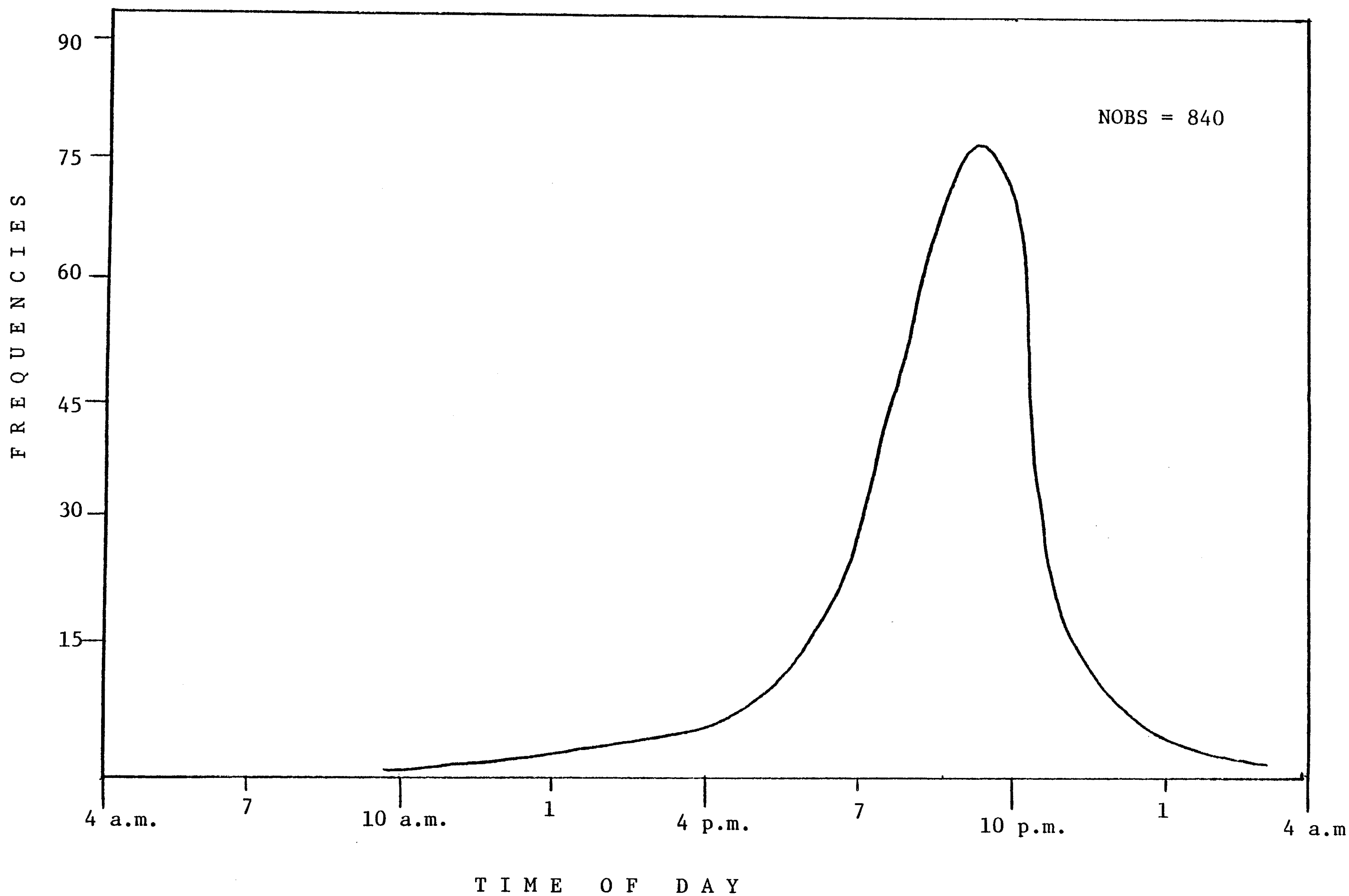


Figure D.6 : Distribution of Ending Times, Work Trip (home-work)

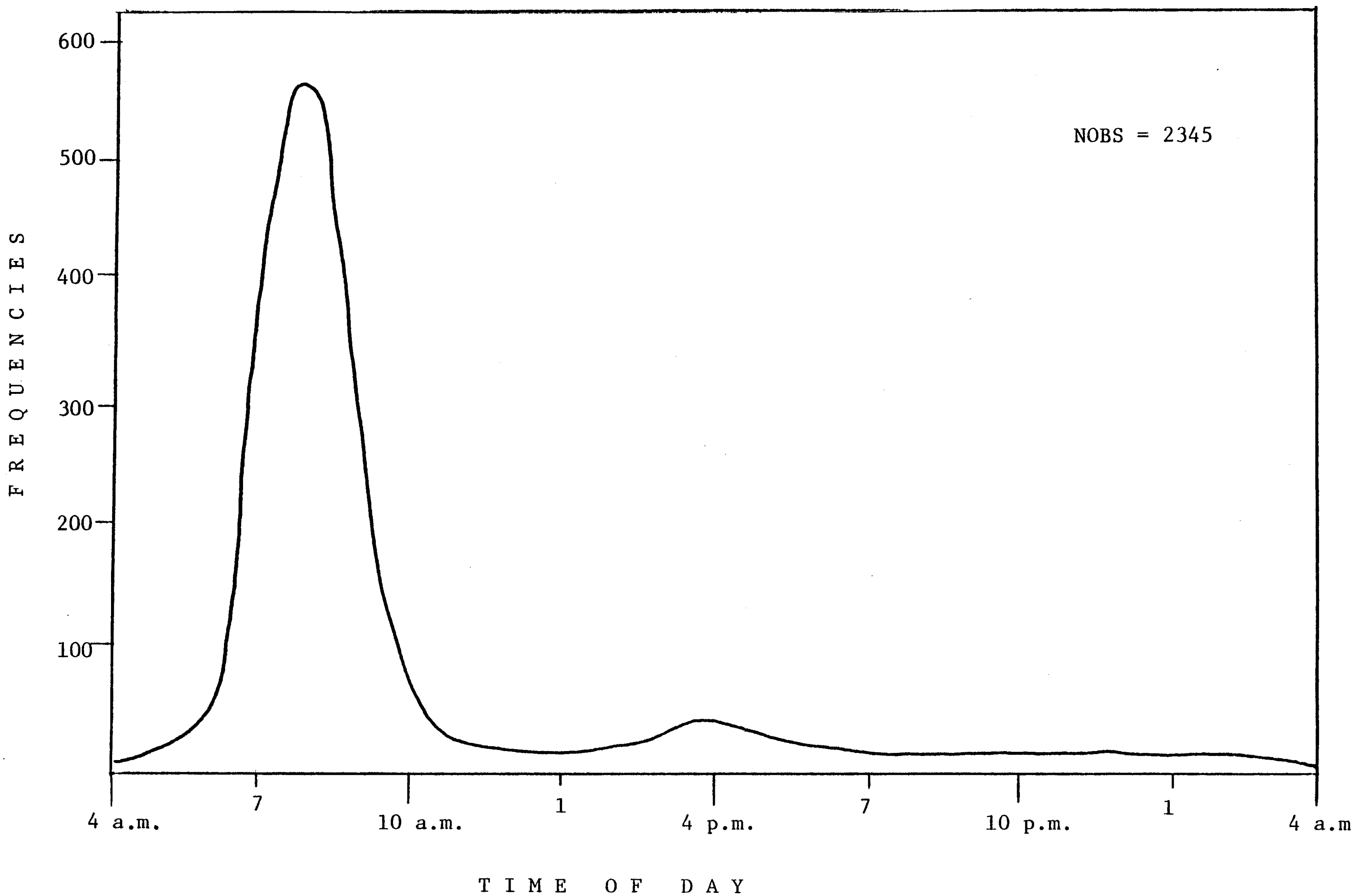
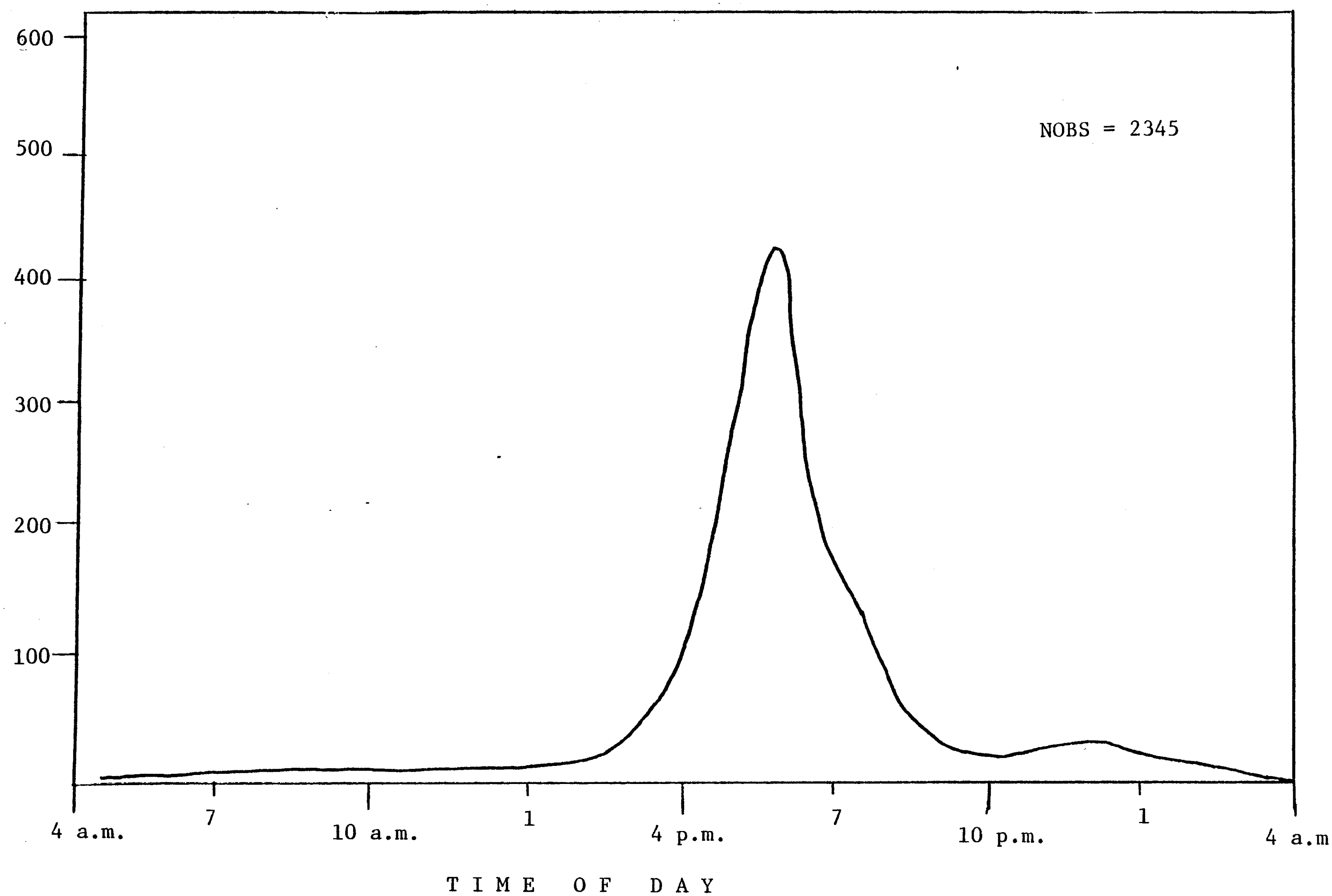


Figure D.7: Distribution of Ending Times, Work Trip (work-home)



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