NATIONAL COOPERATIVE
HIGHWAY RESEARCH PROGRAM REPORT 250

NEW APPROACHES TO UNDERSTANDING TRAVEL BEHAVIOR

TRANSPORTATION RESEARCH BOARD
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RESEARCH SPONSORED BY THE AMERICAN ASSOCIATION OF STATE HIGHWAY AND TRANSPORTATION OFFICIALS IN COOPERATION WITH THE FEDERAL HIGHWAY ADMINISTRATION

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TRANSPORTATION RESEARCH BOARD
NATIONAL RESEARCH COUNCIL
WASHINGTON, D C
SEPTEMBER 1982

NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

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NCHRP REPORT 250

Project 8-14A FY '77
ISSN 0077-5614
ISBN 0-309-03420-5
L. C. Catalog Card No. 82-61998

Price: $10.00

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Published reports of the

NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

are available from

Transportation Research Board
National Academy of Sciences
2101 Constitution Avenue, N.W.
Washington, D.C. 20418

Printed in the United States of America

FOREWORD

By Staff
Transportation Research Board

This report will be of interest to transportation analysts and policy planners in federal government, state transportation departments, and metropolitan planning organizations having expertise in urban travel demand analysis. Such persons will find guidance in using life-cycle variables, such as age distribution of household members, in trip generation models and in considering the effects of life-style changes, such as women entering the work-force or activity changes, on amounts of future travel. The use of life-style variables holds promise for improving the forecasting capabilities of such travel models and consequently improving travel demand forecasting. Researchers will find the results of an intensive investigation into quantifying the relationships between travel on one hand, and variables describing life-style and life-cycle on the other hand.

Decisions concerning transportation investment are based partially on forecasts of travel. These forecasts are generally made using models that relate travel time and cost, demographic characteristics, and transportation accessibility to travel. The distribution and assignment models used by most agencies are prime examples. There is no subsuming theory of travel behavior which generates those models; they are merely convenient formulations for expressing and forecasting travel and assume stable relationships. Disaggregate models, although offering significant advantages over present techniques, deal almost entirely with individual choices, thus ignoring basic household level and other processes that generate travel. A major deficiency in both approaches is their general insensitivity to policy options that are important today. Such options typically involve energy, lifestyles, and transportation service quality.

In recognition of this deficiency, Phase I of the research initiated development of a new approach to understanding travel behavior, concentrating on social and psychological relationships between individuals and their households as they exist in spatial layouts. A careful review and an evaluation were made of the transportation planning, economics, sociology, geography, and psychology literature to identify theoretical elements related to individual travel. This work was synthesized into a travel behavior theory comprised of two components—a microtheory and a macrotheory. The microtheory concept proposes that individuals in similar social status positions, in similar life stages, living in similar environments, will adapt in similar and partially predictable ways. Important to this theory are role patterns and attitude structures. The macrotheory is concerned with how the existence of activity opportunities and constraints modifies or reinforces behaviors specified in the microtheory. The microtheory deals with the individual's demand for activity opportunities; and the macrotheory, with the generation of the activity opportunity sets. A full summary of the Phase I research findings, by Boston College researchers, Fried, Havens and Thall, is included in Appendix G to this report.

Phase II of the research reported herein, conducted by Charles River Associates, identified three key elements relating to individual and household behavior, tested them, and determined how those elements might be incorporated into operational travel forecasting procedures.

The key elements (or concepts) tested include the following:

1. Activity and travel patterns can be related to demographic descriptors such as social class, ethnicity, life cycle, and lifestyle.
2. Intervening factors between activity and travel patterns include social roles and resource constraints.
3. Household activity choice, duration, scheduling, and location determine travel.

Structural equations were developed to test the relationships among these elements. In addition, trip frequency (trip generation) equations were developed as the basis for practical travel demand forecasting. The Baltimore Travel Demand Data Set was used for equation development. Resources did not permit the validation of these equations for other geographical areas nor did they allow for the incorporation of the equations in the Urban Transportation Planning System (UTPS). Nevertheless, analysts should be able to apply them to their own travel demand forecasting system for trial use.

The Phase I report entitled, "Travel Behavior: A Synthesized Theory," by M. Fried, J. Havens and M. Thall of Boston College, is available in microfiche form for $4.50 prepaid. Send check or money order, payable to Transportation Research Board, to Publications Office, Transportation Research Board, 2101 Constitution Avenue N.W., Washington, D.C. 20418.

The following unpublished working papers were written for Phase I and are available on a loan basis upon written request to the NCHRP:

1. "Classification and Evaluation of Social Science and Transportation Issues"; Marc Fried and John Havens.
2. "Preliminary Dimensions for Classification and Elevation", Marc Fried and John Havens.
3. "Toward a Mathematical Framework for Modelling Urban Travel Behavior"; John Havens.
4. "Issues in the Analysis of Attitudes (Attitude Theory)"; Marc Fried.
5. "Attitudes toward Transportation"; Marc Fried.
6. The Theory of Decision Dilemmas and Directions"; John Havens.
7. "Residential Mobility, Residential Location and Travel Behavior"; Matthew Thall.
8. "Spatial Cognition and Transportation", Deana D. Rhodeside.
9. "A Review of Temporal Cognition"; Daniel Rogan.

CONTENTS

ACKNOWLEDGMENTS

The research reported herein was performed under NCHRP Project 8-14A by Charles River Associates Incorporated (CRA)

Peter M Allaman, Senior Research Associate, CRA, was the Principal Investigator during the second half of the project He succeeded Frederick C Dunbar, then Program Manager for Urban Development, CRA, now Senior Consultant with National Economic Research Associates Incorporated Other members of the project staff who have contributed to the work reported herein include the following persons Alex Bardow, Research Assistant, CRA, Kim Honetschlager, Research Associate, CRA, Pamela Marshall, then Research Associate, CRA, now graduate student, MIT, Katherine K O'Neil, Research Associate, CRA, Danny Steinberg, then Senior Research Associate, CRA, now Analyst, Abt Associates, and Timothy J Tardiff, Senior Research Associate, CRA Allaman, Bardow, Dunbar, Marshall, and Steinberg were the principal staff for the individual-level modeling, Allaman, Honetschlager, and Tardiff were the principal staff for the household-level modeling David Rubin, Senior Planner, COMSIS Corporation, performed some initial processing of the household-level data, and provided a critique of Chapter 3 under subcontract to CRA Other former staff members who participated earlier in the project include Ricardo Dobson and Edward Kuznitz

Several consultants also participated in the early stages of the project These included Jacqueline Allaman, consultant to CRA, Brian Berry, Professor of City and Regional Planning, Harvard University, Vincent Breglio, Executive Vice President, Decima Research, Allen Liska, Professor of Sociology, State University of New York, Albany, and Shalom Reichman, Associate Professor of Geography, Hebrew University

The work was performed under the general supervision of Harrison Campbell, Vice President and Officer in Charge of the project, who supplied useful guidance, input, and critique Daniel Brand, Vice President, also contributed valuable guidance and input to the project

NEW APPROACHES TO UNDERSTANDING TRAVEL BEHAVIOR

SUMMARY

The objectives of this study were to improve the understanding of travel behavior and to enhance practical transportation forecasting models by investigating and applying fundamental concepts from the social sciences. After extensive reviews of the literature in Phase I and the early part of Phase II, three concepts were selected for in-depth investigation.

Lifestyle, which can be defined as how individuals and households allocate time to alternative activities such as work, in-home time, and recreation, has become increasingly prominent in travel behavior research. The emphasis on activities is also consistent with a stratification of travel by trip purpose. *Life cycle,* typically defined in terms of the ages of the adult members of a household and the number and ages of children, was also selected for investigation. *Household structure* is a closely related concept, especially relevant in light of the ongoing changing size and composition of households. The life cycle and household structure concepts suggest that the number of household members, a variable typically used in standard trip generation models, might not adequately capture the characteristics of households that affect travel demand.

The standard urban transportation demand forecasting system consists of four components: trip generation, trip distribution, modal choice, and route assignment. In order to avoid duplication of other major research projects, and to use this project's resources in a cost-effective manner, the research team and the NCHRP advisory panel determined that enhancement of the trip generation models would be the major practical focus.

The research team approached the research with the general orientation that the social circumstances in which an individual (or household) lives should have considerable bearing on the opportunities and the constraints that he or she faces in making activity choices. Whether one lives alone or with others will affect the opportunities for coordination and economies of scale regarding necessary household activities as well as travel instrumental to other pursuits. A married couple with a young preschool child (or children) will generally find itself less mobile than a similar couple without children or with older children who do not require as much care. Elderly and retired persons who live with younger adults are likely to be more active outside the home than elderly persons living with persons roughly their own age or living alone. A single parent will face both the reduced opportunities for coordination with other household members of the adult living alone and the added constraints on mobility of the presence of children. The number of children and the number of adults living together in a household will have an effect on the broad pattern of travel and time use of the individual.

Analyses were performed in three major areas. First, the effects of life cycle, household structure, and other sociodemographic variables on the allocation of time to specific activities by individuals were examined. Second, the usefulness of life cycle, household structure, and residential location characteristics in trip generation models was explored. Third, structural equation methods were used to analyze simultaneously the interactions among measures of mobility such as travel time, travel distance, and trip frequency.

Findings—Time Allocation by Individuals

For the analysis on how individuals allocate time to particular activities, and the other analyses described below, the Baltimore Travel Demand Data Set, collected by FHWA in the spring of 1977, was used in model development. Since,

unlike most other urban travel data sets, the Baltimore data describe both nonvehicular and vehicular travel, the analysis described in this report includes both types of travel.

The model of activity time allocation of individuals comprises equations for in-home time, travel time, and ten other categories of out-of-home activity. One set of hypotheses to be tested is whether the major break points in the life cycle of individuals signal major changes in time allocation. A household typology, based on the age of the youngest and eldest member of the household, is thus developed. In an attempt to look at within-household interactions, information on spouse employment status is also included. A wide variety of other characteristics of the person is also employed to investigate the impact of other socioeconomic characteristics of persons on their time allocation patterns

Principal findings relate to the effects of life cycle, employment status, and other sociodemographic characteristics.

The research verified that such life-cycle effects as having preschool children present, having the youngest child reach school age, and progressing to other points in the life cycle do indeed prompt changes in time allocation. The presence of preschool children has little effect on the behavior of men, nor is there a detectable difference between time use patterns of not-employed women with children and without children. For employed women, however, the transition to having a young child prompts less time in pleasure travel and more time spent in shopping. The decreased demands of caring for young children prompted by the youngest child reaching school age has a stronger effect, with employed women spending more time at work and less time at home and shopping. Not-employed women with children spend fewer hours at home and more time visiting friends. Employed members of households without children tend to spend more time taking meals away from home than do employed members of households with children and, with increasing age, spend less time working. Not-employed members in households without children also spend more time eating out, at home, and in pleasure travel; less time is spent serving passengers and in outdoor recreation, relative to not-employed members of households with children.

Employment status, of course, has an enormous impact on weekday activity, but not all of the time spent working is drawn from time at home, other activities are cut back as well. Employed women spend 1.3 hours less and employed men 1.9 hours less time in activities that the not-employed engage in outside the home. The largest time reductions come from visiting friends less, shopping less, and foregoing personal business. A smaller but statistically significant reduction occurs in pleasure traveling. There are differences in these patterns between men and women

A common effect of employment on both sexes is to increase total travel time by about 15 min. Since the average trip to work in the sample is about 35 min, the extra total travel is not nearly enough to get a person to work and home again. Therefore, substantial travel substitution, or perhaps greater trip chaining and better planning of trips, also appears to take place when a person works in the marketplace.

With respect to other sociodemographics, differences between males and females were found to be significant for unmarried blacks but not for white unmarried persons. Employed unmarried black men tend to spend more time at work and traveling and less time at home and food shopping than employed unmarried black women. Employed males with working spouses tend to spend more time at work and travel, but less time at home and shopping than do employed women with working spouses. The differences between black men and women in time spent at work, travel, and shopping are more pronounced than the differences between white men and women for these activities. Among persons whose spouses do not work, the differences between men and women are much less sharp, but are similar in direction to those already noted.

For the employed, time at work tends to peak in terms of age in the early 40s, time spent at home reaches a minimum in the late 30s, and most other activities reach a minimum at some later age. For most employed persons, the household income variable tends not to be a significant predictor of time allocation. For not-employed persons, higher income implies more time spent at home, in pleasure traveling, and in entertainment and less time spent shopping, visiting friends, and serving other persons. Income tends not to affect travel time significantly for either the employed or unemployed.

Education is not significant in any of the equations for the not-employed. For the employed, increasing education implies decreased time at work, and increased time eating away from home, in entertainment, and in travel time. As age and income have been controlled for, it appears that the educated employed enjoy a distinctive lifestyle.

Techniques are developed for predicting changes in time allocation, in the long run, as the composition of the population changes. The key demographic trends are an increased labor force participation rate for women, an older population, and a greater proportion of single-person households. These trends are expected to have some impact on time allocation in the aggregate, but various effects, such as aging versus increasing income, tend to cancel each other out. Perhaps the greatest impact on time allocation in the future will come from the increasing labor force participation rate among women. At the traffic analysis zone level, however, large shifts may occur as specific changes in population composition take place.

Findings—Household Trip Generation Models

A major focus of the research was the exploration of whether concepts such as life cycle have implications for trip generation modeling. Classification of trips by the purpose (or activity) at the destination follows naturally from the analyses of time allocations by purpose. In this scheme, trips to home would be a separate category. This classification is referred to as activity-based. In contrast, standard trip generation models are based on a classification of trips into home-based and nonhome-based. Home-based trips have one trip end (either origin or destination) at home; consequently, home is not a separate purpose category. Household trip generation models were developed separately for both activity-based and home-based classifications.

Activity-Based Models. Trip generation models were developed by adding variables describing household structure, age structure, and location characteristics to standard trip generation models. Findings on the usefulness of these variables in enhancing trip generation models are described in the following.

Because the trip generation models were developed for potential practical applications, the household structure used in the individual time allocation modeling was modified to facilitate compatibility with classifications used in other data sources, such as census data projections of demographic variables.

There are three distinct groupings of households from the point of view of trip frequency. These are groupings of individuals without children present (unrelated individuals, couples, and adult families without children); families with children present (nuclear families, single-parent families, and adult families with children); and single individuals.

The household type with the greatest trip frequency per person is that of unrelated individuals. Although the household size of unrelated individuals is only slightly larger than that of couples, households of unrelated individuals take almost 1.2 more trips per day than households of couples. This indicates that family relationships have an impact on trip frequency behavior Households composed of roommates tend to pursue their own schedules of activities and interests and are much less tied to the activities of other household members than are persons with a greater degree of commitment to a relationship.

Single-parent households' total trip rates are marginally higher than those of nuclear families when their vehicle ownership patterns, age structure, and residence patterns are accounted for. Adult families with children have the highest differential in total trip frequency of the families with children (after accounting for the other variables). This greater frequency seems to be related to the presence of extra adults, as it is the increased frequency of work/school, personal business, entertainment, and visiting trips—all adult-oriented activities—that contributes to the higher rate.

Of the single-person households, single males are more mobile than single females. This is due principally to a higher frequency of entertainment trips and return-home trips.

The major finding is that trip generation rates decline with age For example, household members under 35 account for approximately 0.5 more trips per weekday than do people aged 35 through 64 and about 2 more trips than those 65 and older.

It is important to note that the differences in trip generation by age may in part reflect cohort effects. Older people may travel less because they always did, rather than because of their age The cohort effect is likely to be largest for those over 65; the declining trip generation rates for other age groups likely reflect a real decreasing travel propensity.

The presence of one or more preschoolers has a strong inhibiting effect on the frequency of total weekday travel. This reduced frequency comes principally from personal business and serve-passenger trips. The presence of grade schoolers has a slight positive effect on trip frequency principally in the serve-passenger and entertainment areas

Population density is negatively related to total trip frequency This has long been observed in trip generation models The reasons for this finding suggest potential lifestyle variations. Frequency of work, shopping, and entertainment trips significantly increase with decreasing residential density. Conversely, visiting trips are positively related to increasing net residential density, perhaps indicating a greater degree of socializing within the neighborhood in denser areas Another location-related effect is the reduced frequency of entertainment and visiting trips for households with residences within the Baltimore City limit. Again, this would appear to be a lifestyle effect Duration of residence does not have a significant effect in any of the equations for weekday travel, except that short-term residents are marginally more likely to make personal business trips.

The trip frequency equations reveal distinct patterns with respect to vehicle ownership and income. In terms of total trip frequency for all purposes, number of vehicles owned has a strong positive contribution, adding approximately one trip per vehicle per day to the household's travel pattern, other things being equal Number of vehicles owned is positively related to all categories of travel by purpose except for personal business and entertainment. Income is not a significant determinant of total trip-making behavior, although it has marginal positive impact in the work and entertainment purposes, and a negative relationship to visiting trip frequencies (these are the sorts of activities one might expect to be associated with higher income)

Home-Based Trip Productions Equations for trip frequency by the six home-based trip purposes are estimated The variance explained tends to be higher for home-based trip making than for activity-based trip making. The overall patterns of the coefficients also were similar, although the age structure is more important for home-based trips. It is reasonable that variables describing the household and its residential environment are more effective in predicting home-based trips than in predicting activity-based trips, because the home-based concept focuses more sharply on the household and its residential setting than does that of activity-based trip making, which includes nonhome-based trips and defines the trip by activity at the destination When number of household members employed is added to the equations, the results indicate a lessening of the importance of vehicles owned and a shifting of the importance of household structure variables for predicting overall trip frequency.

To illustrate the capabilities of the general approach for forecasting purposes, the home-based trip generation models developed in this study were compared to standard trip generation models Two exampls are presented First, the alternative models were applied to five hypothetical households, representing different life cycle stages Whereas the standard trip generation models generally showed very little difference in trip generation estimates, the enhanced models indicated that trip frequency would change substantially with changes in life cycle.

Second, the alternative models were used to forecast travel based on illustrative 1990 values for key independent variables for the Baltimore area. In this case, the forecasts differed only moderately These examples suggest that the models developed for this study may be most useful in analyzing trip generation rates for households or homogeneous zones. Differences between the enhanced and standard models are likely to be less substantial in applications to heterogeneous groups of households, primarily because the averaging of household characteristics probably obscures the sharper differences found in more homogeneous applications.

Findings—Structural Equation Models

A set of structural equations was estimated using the two-stage least squares method. The system first estimates precursors of mobility such as vehicles owned, relates this and household descriptors to activity time allocations, and in turn relates time allocation to trip frequency, travel time, distance, and fuel consumption

The pervasive influence of vehicles owned on activity and trip-making behavior is evident; that is, vehicle ownership is strongly related to several mobility measures. Time at home and work are substitutes for each other, but other out-of-home activities are complementary with time spent at home. Total travel time and trip frequency are complementary; that is, total travel time increases with trip frequency, and vice versa.

There are several findings for out-of-home travel by purpose. The negative relationship between activity time and trip time for out-of-home activities may indicate a time budget for the activity / travel bundle and a consequent tradeoff of the two. In contrast, travel frequency is positively related to activity time. Similarly, the greater the amount of time spent at an activity, the further the distance traveled (in person miles) to the activity. The contrast between travel time and person miles traveled suggests that higher speeds may be involved in traveling to activities at which more time is spent. However, travel distance is generally not traded off against trip frequency. Only in the case of entertainment is there a tradeoff between travel frequency and distance traveled.

Fuel efficiency, measured as gallons per mile averaged over each household's fleet of vehicles, is also estimated The more vehicles the household owns, the greater the average fuel economy; a larger number of young adults and residence within the Baltimore city limits also promote fuel efficiency. Fuel efficiency tends to decrease with the following factors: when the household is nonwhite and when the number of male adults and the total miles traveled for household-owned vehicles increase.

Implications

The importance of measures of household structure and residential location argue for their inclusion in existing travel forecasting procedures. Their importance is shown by the fact that, of two variables commonly used in travel forecasting, income and vehicles owned, only vehicles owned adds explanatory power over and above measures of household structure. This may be because vehicle ownership patterns capture preferences for a certain type of lifestyle which one cannot measure with existing household interview data. When one has accounted for household structure and vehicle ownership patterns, income adds little explanatory power to trip generation analysis.

Because most of the variables used in the trip generation models developed in this project are available in standard transportation data sets, estimation of similar models for particular regions should be straightforward. All illustrated by the forecasting examples, inclusion of household structure and residential location variables can be quite important in some cases.

Problems in predicting these household structure variables for the purpose of travel predictions are real, but not impossible to overcome. At the aggregate level, the future age structure of the population, which is of major importance in trip generation models, is known today. Table 20 in Chapter Three presents estimated changes in age structure for 1990.

Prediction at the traffic analysis zone level is more problematic, of course. However, estimation at the small-area level of the variables considered here is no more arbitrary than forecasting vehicle ownership or income levels—it simply means a reorientation of existing efforts. Further, land-use models that deal with the sorts of variables considered in this report exist, and the application of their output to trip generation questions is feasible. Also, although NCHRP Project 8-24, "Forecasting the Basic Inputs to Transportation Planning," focuses on more traditional trip generation models, some of the forecasting procedures are relevant to applications of the trip generation models in this report For example, that project presents methods for projecting population, including age-specific estimation procedures.

CHAPTER ONE

INTRODUCTION AND RESEARCH APPROACH

This chapter describes the overall research approach Specific findings are treated in Chapter Two Appraisal of these findings as well as specific plans to implement them are discussed in Chapter Three

OBJECTIVES

The principal objective of this study was to identify behavioral science concepts potentially useful in understanding travel behavior A more detailed discussion of the concepts thus identified is provided in Appendix A A major part of the research involved the formulation of models that describe the interaction between the lifestyle of individuals and households and travel behavior These models can be implemented from existing transportation data sets and incorporate important sociodemographic determinants of behavior (including relationships within the household as well as characteristics of the person) A major objective is to link the general theoretical propositions developed in Phase I of this project (*1*) to practical forecasting techniques. In order to do this, it is necessary to proceed in an incremental fashion, using the types of data that are currently available to transportation planners

The efforts of this project were thus directed at the following specific objectives.

- To model lifestyle as the allocation of a person's or a household's time to various categories of activities
- To examine the impact that such activity allocations have on travel behavior
- To produce operational definitions of household structure and incorporate them into the modeling process
- To incorporate other sociodemographic characteristics, thus providing a richer description of the individual and household than is typically used, and providing proxies for other unmeasured attributes
- To implement these models using the types of data currently available to transportation planners, such as travel surveys

An important issue in applying the theoretical concepts to practical forecasting problems is how the traditional four-step process of (1) trip generation, (2) trip distribution, (3) modal choice, and (4) route assignment can be improved by incorporating fundamental behavioral concepts. It was decided early in the project to focus on improvements in trip generation models Because modal choice models have received considerable attention in numerous other projects, including projects sponsored by NCHRP and the U S Department of Transportation, they were not emphasized here However, the research team did examine how trip generation relations varied by mode Although concepts such as lifestyle and activity time allocation may have important implications for trip distribution, project resources did not permit an in-depth analysis of potential improvements in trip distribution models. Finally, because the theoretical concepts of interest in this study do not appear to be particularly germane to route selection, no attempt was made to improve route assignment models

This project had the dual objectives of advancing the state of the art in travel behavior and in improving practical models As such, its emphasis was different from that of recent projects that have focused on better approaches for applying existing methods For example, Sosslau et al (*2*) illustrate quick-response manual approaches to the traditional 4-step travel demand sequence, and CRA (*3*, *4*) demonstrates how disaggregate travel demand models, particularly modal choice, and related elasticities can be applied in a quick-response context John Hamburg and Associates (*5*) are examining methods for predicting the input variables in traditional trip generation models By contrast, NCHRP Project 8-14 emphasizes the development and application of travel demand models, primarily trip generation, that have been enhanced by the introduction of fundamental behavioral science concepts.

APPROACH

The major hypothesis of the research is that the social circumstances in which an individual lives should have a considerable bearing on the opportunities and the constraints that he or she faces in making activity choices and that these activity choices lead to differing travel behavior. Whether one lives alone or with others will affect the opportunities to coordinate and trade off activities with others to achieve economies of scale regarding necessary household activities as well as travel instrumental to other pursuits. A married couple with a young preschool child (or children) will generally find itself less mobile than a similar couple without children or with older children who do not require as much care. Elderly and retired persons who live with younger adults are likely to be more active outside the home than elderly persons living with persons roughly their own age or living alone. A single parent will face both the reduced opportunities for tradeoff of the adult living alone and the added constraints on mobility provided by the presence of children. The number of children and the number of adults living together in a household may also have a bearing on the broad pattern of time use of the individual members.

At the household level, different types of households would likewise be expected to exhibit different behavior Households of unrelated individuals would be expected to pursue a schedule of activities less influenced by the presence of other members of the household than would similar-sized households of related individuals, with similar age and other demographic characteristics. More frequent trips might result, both because of the reduced coordination among household members and because the activity patterns of the members might involve fewer home-centered activities.

One way of introducing such notions into a modeling framework is to develop a set of household types that captures these distinctions and add this measure to the equations predicting individual or household behavior. The research team has experimented with two different typologies of this sort. One is based entirely on the age of the youngest and eldest members of the household and is thus an extension of a suggestion by Heggie (*6*). This is used at the individual level. For modeling households' travel behavior, a typology is developed that can be implemented on existing transportation data sets for inferring a relationship-based household typology more closely aligned with typical Census definitions (nuclear family, unrelated individuals, etc) This was done because the age structure of the household is introduced explicitly and there is less of a need for an age-based household typology.

The approach also considers the lifestyle of individuals and households. Recent work investigating travel behavior has been increasingly broadening in scope as it has begun to view travel behavior as part of the larger allocation of time (and money) to activities across separate locations. This is a generalization of the idea that travel is a "derived demand" and is performed in the service of other needs of the individual or household, rather than as an end in itself. The approach operationalizes the concept of lifestyle as the allocation of varying amounts of time to different activity purposes both within and outside the home; of course, travel is a part of this time allocation.

It is important to look at activity allocation questions for several reasons. As noted above, it is the demand for activity that produces the demand for travel, this suggests that because activity logically precedes travel in the causal sequence, it is behaviorally more sound to introduce the concept of activity allocation prior to the modeling of travel behavior. In addition, the time allocation (or lifestyle) of individuals appears to vary systematically across various segments of the population, with different segments of the population having clearly identifiable differences in lifestyle. This is true of race, sex, and marital status. Lifestyle seems to vary systematically with changes in age. Clearly, employment status is a crucial determinant of how persons allocate their time Different household structures place different demands on individuals, and this should be reflected in differing time allocations.

The lifestyle concept is important both from the standpoint of identifying stable groups (such as race or sex) with differing activity schedules and demands for travel as well as being able to trace systematic changes which occur based on overall demographic shifts (such as changes in age structure, employment status, or marital status). Numerous demographic trends of significance for travel behavior have recently received extensive attention. (See, for example, Hartgen (*7*) and Spielberg, et al (*8*).)

One of the most significant trends for predicting travel behavior is the changing ratio of households to population. Although the rate of population growth is falling, the rate of household formation is increasing. This is due, among other reasons, to dramatic increases in the number of single-parent households and the number of persons who are setting up individual households. Travel forecasting methodologies that assume stable ratios of households to population (this is often an implicit assumption) may thus be dramatically affected by this structural shift in the demographic composition of the society. This suggests that it is not sufficient for planners and policy makers simply to use aggregate counts of population or households as a basis for policy decisions.

Another much-discussed trend is the overall aging of the population. Because age tends to be associated with a decline in mobility and a change in lifestyle, the changing age structure also has profound implications for transportation behavior.

It is important to note that the differences in trip generation by age may in part reflect cohort effects. Older people may travel less because they always did, rather than because of their age The cohort effect is likely to be largest for those over 65, the declining trip generation rates for other age groups likely reflect a real decreasing travel propensity.

The dramatic increase in the proportion of working women is yet another trend that has great significance for transportation forecasting. Its significance derives from two effects One is simply a straightforward employment effect, where time allocation (and its associated travel behavior) are profoundly impacted by the requirements of being employed. A more subtle difference is introduced via the nature of role relationships within the household and the lifestyle impacts (particularly on women) that occur when both spouses work and children are present.

A further complication for travel forecasting practice is that the processes of demographic change may occur at differing rates in different parts of a metropolitan area The overall changes that have been described would have an effect on trip-making behavior for the area as a whole. Individual areas may change their composition more or less rapidly than the area as a whole and thus exhibit more or less change in the derived transportation behavior than would be expected on average For example, "bedroom communities" with a fixed stock of dwellings suitable for households with a traditional nuclear family structure may remain rather stable in their composition and, hence, travel characteristics On the other hand, areas that, because of changed supply and demand conditions, undergo rapid shifts in the composition of the population may change their travel characteristics dramatically within the span of a few years Thus the spatial dimension (including patterns of land use and dwelling unit occupancy) must be accounted for at the local level for meaningful incorporation of these concepts into existing transportation planning and forecasting practice

The approach incorporates the use of the Baltimore Travel Demand Data Set (Appendix A describes this data set) This data set has much in common with traditional travel behavior data sets, although it also contains novel features For the most part, only the types of data that are available in standard travel data sets are utilized in order to relate more closely to existing practice and potential applications Where appropriate, the research team has devised methods of generating household type and activity time measures from such travel diary data sets The approach followed here is one that could be implemented using one of a number of the travel surveys that have been conducted in various cities at various points in the last 20 years

The methodological approach is to use ordinary least squares regression analysis to predict the allocation of time to various activities as well as to predict trip generation and the other travel-related measures previously discussed Two sets of estimations are performed One is at the level of the individual and is an initial exploration of the determinants of activity time allocation and differences across sociodemographic groups The second set of analyses is conducted at the household level and comprises analyses of household time allocation, trip frequency, travel time, miles traveled, and related measures of travel behavior An attempt is made to assess the relative importance of various sets of determinants within the regression framework. Ordinary least squares regression analysis is used in order to simplify the computational requirements and to improve the chances of successful transferability of the resulting models

REPORT ORGANIZATION

The body of the report is organized as follows The substantive findings of the research into the determinants of individual and household activity time and travel behavior are reported in Chapter Two Chapter Three appraises these findings and describes how they may be used in a practical context The household trip generation models are of primary interest in Chapter Three because they can be readily adapted to current transportation planning applications Chapter Four summarizes the report and presents recommendations for further research These chapters are written on a general level and are intended to provide an overview of the research, they are not intended to comment on specific techniques or details of the analysis

The appendixes detail the research that was conducted Appendix A covers background issues and provides a brief discussion of the Baltimore area and the data set used for the analysis Appendix B discusses the individual-level modeling of activity time allocation Appendix C addresses questions of long-run forecasting utilizing the system of equations fit at the individual level Appendix D discusses the definitions used and the data processing performed for the household-level analysis Appendix E addresses preliminary analyses of the household-level data, particularly the differences found among household types This appendix also discusses the analysis of trip linkages Appendix F details the household-level modeling and its results Appendix G summarizes the final report from Phase I of this study

CHAPTER TWO

FINDINGS

This chapter summarizes the substantive findings on the determinants of individual and household activity time and travel behavior The chapter is written at a general level, the detailed findings from the research are contained in Appendixes B through F of this report Because the initial analyses of the determinants of time allocation for individuals were performed before the analysis of household-level data, it is natural to divide this chapter into sections dealing with each

INDIVIDUAL-LEVEL ANALYSIS

As noted in Chapter One, the orientation in the individual-level modeling is to examine the effect of the social circumstances of the individual on his or her activity pattern, and to do this in a way that can be readily implemented using an existing transportation data set First, a brief discussion is provided of the model as formulated, then the principal findings are discussed, and, following this, the forecast experiments are described The first two topics are pursued in greater depth in Appendix B; forecast experiments are described in detail in Appendix C.

The Model

The time allocation (in hours) of individual travelers was modeled for activities at home, ten types of activities away from home that generate a need for travel, and total travel time The major classes of explanatory variables are the individual-level variables of marital status, employment status of self and of spouse (if married), age, sex, race, and education and selected combinations (interaction terms) of these variables. Household-level contextual variables are household type and income Activity time for each of the 12 activities is predicted as a function of this set of independent variables Table 1 defines the dependent variables, and Table 2 defines the independent variables

The model is as follows.

$$Y = XB + E$$

where

Y is an ($n \times 12$) matrix of activity times (n persons, 12 activity purposes),
X is an ($n \times 21$) matrix of exogenous variables;
B is a (21×12) matrix of coefficients to be estimated, and
E is an ($n \times 12$) matrix of residuals.

In summary, the approach involves the development of 12 equations that explain how individuals allocate time to 12 activities. Each equation contains the same explanatory variables that are of three basic types (1) the age and size composition of the individual's household, (2) the individual's marital and employment status, and (3) other sociodemographic variables such as age, income, race, and education

Activity time is defined as the elapsed time between consecutive trips Travel time to an activity is distinguished from activity time except in the case of serving passengers and pleasure traveling, where travel time may be logically considered a part of activity time The activity types employed are time spent at home, at work, in personal business, eating meals away from home, grocery shopping, other shopping, out-of-home entertainment, visiting friends or relatives, outdoor recreation, and all travel (except that spent serving passengers and pleasure traveling).

As noted, the modeling includes numerous independent variables describing the person In order to test the importance of household structure in determining individuals' activity patterns, the household types that are employed are defined by the age of the youngest and eldest members of the family and they also identify single-person households. The age categories used in the household typology were chosen to correspond to the transition points in the life cycle. Ten life-cycle types are defined, as detailed in Table 3. These include a progression from living in a household consisting totally of young adults, to having preschool-age children present, to having the youngest of school age, and to older

Table 1 The dependent variables

THOME	Time spent at home in the 24-hour period, obtained as a residual, the difference between time available and total time spent outside of the home.
TWORK	Time spent at work, or work-related business.
TPERSON	Time spent in visiting the doctor or dentist. auto-related purpose, or personal business not otherwise specified.
TEAT	Time spent to eat a meal away from home.
TPLEAS	Time spent in pleasure walking, riding or driving or accompanying someone else on a trip (includes both travel time and time at destination).
TFOOD	Time spent grocery shopping.
TSERVE	Time spent in serving a child or an adult (includes both travel time and time spent at the destination).
TSHOP	Time spent in shopping other than food shopping.
TENTAIN	Time spent in entertainment, civic, cultural, or religious activities.
TVISIT	Time spent visiting friends or relatives.
TOUTDR	Time spent in outdoor recreation.
TOTTRAV3	Time spent in all travel except that part of TSERVE and TPLEAS which is also travel.

NOTE: All variables are expressed in hours.

Table 2 Exogenous variable definitions

Household Structure[1]

PRESCHLF	- presence of a preschool child and respondent is female; adults of any age
YADULTG	- household composed entirely of adults between the ages of 20 and 34
ADULTMIX	- youngest member between 20 and 34, and oldest 35 or over
ADLT3555	- youngest member between ages 35 and 54
ADLT5565	- youngest member between ages 55 and 64
SENIOR	- all members age 65 or over, including seniors living alone
ALONEF	- woman under age 65 living alone

Marital Status and Spouse Employment[2]

MARSPW	- married, spouse works, respondent male or female
HUSNTWKW	- married woman, spouse does not work
WORKWIFH	- married man, spouse works, the interaction of MARSPW and SEX

Other Demographics

SEX	- takes the value 1 for males, 0 for females
RACE	- takes the value 1 for whites, 0 for blacks
RACESEX	- white male, the interaction of RACE and SEX
SENSEX	- male age 65 or over, the interaction of SENIOR and SEX
INC	- household income midpoint[3] centered[4]
INCSQ	- square of INC
AGE	- age centered[4]
AGESQ	- square of AGE
EDUCY	- years of education midpoint[5] centered[4]
EDUCYSQ	- square of EDUCY

[1]Categories defining the following have been omitted males with preschool child present, adults of either sex with youngest member age 6-19, and males under 65 living alone

[2]Omitted categories are: not married of either sex; married man with spouse not working.

[3]Household income was defined as the midpoint of 19 grouped income classes.

[4]Variables were centered at the means of their respective sample (total sample, employed persons, not employed persons) for the appropriate set of equations.

[5]Education was defined as the midpoint of nine grouped education classes.

households without children with the youngest adult being progressively older (35–54, 55–64, and 65 plus) As described in Appendix B, the age categories were selected to account for transition points throughout the life cycle

The interdependence between adults that is modeled is whether or not a respondent's spouse was employed, this distinction is included in the definition of marital status, which includes not married, married/spouse working, and married/spouse not working Employment status is specified as employed or not employed, students were eliminated from the sample before estimation. Sex was included both as a main effect and in interaction terms with other variables in the model to test its importance in time allocation Race was split between white and nonwhite persons. Age and education of the person and household income were also included in the models

In the estimation, the same set of independent variables for each of the 12 activity equations is used in an attempt to assess the importance of a common set of factors for each type of activity, to constrain the system in such a way that the sum of activity times will always be 24 hours, and to ensure efficiency of estimation.

Three sets of equations are estimated one set of equations for employed persons for 12 activity types, another set for not-employed persons for 11 activity types (excluding time at work); and a final set of 12 equations for the pooled sample using a dummy variable for employed / not employed and one for employed males. Tables 4 through 6 provide a summary of the results; actual coefficient estimates are given in Tables B-9 through B-11 of Appendix B.

Overview of Findings

For *employed persons,* some household-type variables are significant, while age, sex, income and education, and presence of working spouse are significant in several equations. The household-type variables have the strongest influence on time spent eating and pleasure traveling, with marginal effects in the other shopping and entertainment equations. Age, sex, income, and the presence of a working spouse have strong and opposite effects on the time spent at home and the time spent at work. These equations were both very strong in terms of variance explained. Age, race, and sex have strong influences on amount of time spent food shopping. Age and education have marginal effects on time spent in entertainment and total travel time, while age has a significant negative relationship to time spent visiting and time spent outdoors Equations with little predictive power apart from the mean include personal business, pleasure traveling, serve passengers, other shopping, entertainment, and outdoor recreation.

For *not-employed persons*, the household-type variables enter into several equations with significant coefficients and enter into a number of others with marginal significance. Sex, income, and age tend to have the strongest significant effects among the personal characteristics. Time spent at home is positively related to presence of a preschool child for females, income, age, and living in a household consisting exclusively of young adults Income has a positive relationship to pleasure traveling, but a negative relationship to other shopping and visiting Not-employed males tend to eat out less and to spend less time in entertainment than women. Increasing age tends to inhibit outdoor activities as well as (marginally) total travel, time spent in visiting, entertainment, and pleasure traveling Equations with little predictive power above the mean include time spent in personal business and serving passengers.

When the equation system was estimated with the *entire sample* of employed and not-employed persons, the variables with the greatest predictive power include employment status, sex, income, and age, with education and presence of a working spouse and certain household-type variables being significant in particular equations. Again, the variables that stimulate time at home depress time at work.

It should be noted that more equations for the employed than the not-employed had negligible predictive power above knowing the mean rate for the subgroup. This means that knowing a person's demographic characteristics does not help predict time spent in personal business and serving passengers for the not-employed, and may indicate fixed time budgets for such activities. For the employed, many of the discretionary activities are poorly estimated by knowing the person's demographics; this may point to the pervasive constraining influence of time spent at work on other activity time allocation.

Table 3 Table of household types defined by ages of youngest and oldest members and sex of respondent

PRESCHLF	- presence of a preschool child and respondent is female, adults of any age
PRESCHLM	- presence of a preschool child and respondent is male, adults of any age
YOUTH	- presence of children between age 6 and 19, adults of any age and sex
YADULTG	- household composed entirely of adults between the ages of 20 and 34
ADULTMIX	- youngest member between 20 and 34, and oldest 35 or over
ADLT3555	- youngest member between ages 35 and 54
ADLT5565	- youngest member between ages 55 and 64
SENIOR	- all members age 65 or over, including seniors living alone
ALONEF	- woman under age 65 living alone
ALONEM	- man under age 65 living alone

NOTE Variable has value of one if the individual is in a household type, zero otherwise.

In the regressions YOUTH is the left-out category and hence does not appear in the regressions. In test regressions, men living alone under age 65, and men with a preschool child in the household were not found to behave differently from men from YOUTH household type. Accordingly, ALONEM and PRESCHLM were also left out of the equations. The left-out category is properly the union of YOUTH, ALONEM, and PRESCHLM groups.

A single-parent category for this data set was not created because there were only 44 such families with weekday travel. The effect can be picked up by a total adult variable, but this variable was found not to be significant in prior tests.

Specific Findings

Employment Status

Obviously, employment status has an enormous impact on weekday activity, causing a considerable shifting of time from most activities to the workplace. Both men and women draw most of their working time from time that would otherwise be spent at home, but the substitution is not complete. Employed women draw 1 3 hours and employed men 1 9 hours from activities that the not employed engage in outside the home, as can be seen from Table 7. Both recreational and household maintenance activities are reduced, with the largest time reductions coming from visiting friends less, shopping less, and forgoing personal business. A smaller but statistically significant reduction occurs in pleasure traveling

Men tend to spend more time eating out and less time serving passengers; the direction of change is similar for women but not statistically significant. Men reduce personal business, visiting, and outdoor recreation and increase travel time more than do women. And while women reduce time at food shopping and at entertainment when they work, there is no such reduction for men.

A common effect of employment on both sexes is an increase in total travel time by about a quarter hour. Since the average trip to work in the sample is 35 min, the extra total travel is not nearly enough to get a person to work and home again Therefore, when a person works, time allocated to other purposes, including travel time, is reduced. This reduc-

Table 4 Estimation results—employed persons (n = 737)

DEPENDENT VARIABLE \ INDEPENDENT VARIABLE	INTERCEPT	PRESCHLF	YADULTG	ADULTMIX	ADLT3555	ADLT5565	SENIOR	ALONEF	MARSPW	HUSNTWKW	RACE	SEX	INC	INCSQ	AGE	AGESQ	EDUCY	EDUCYSQ	WORKWIFH	RACESEX	SENSEX	R^2	$\bar{R}^2$	Significance of Regression
THOME	+	(+)							+			-	-	(+)		+			-	(+)		.100	.083	.0001
THWORK	+	(-)							-			+	+		+	-		(-)	(+)	(-)		.121	.096	.0001
TPERSON																						.013	0.0	.977
TEAT					+	+				(-)						(+)	+	(+)				.101	.076	.0001
TPLEAS			+																			034	.007	.188
TFOOD	+					(-)	(-)	+		(-)	-	-			+					+		.057	.031	.002
TSERVE	(+)																					.011	0.0	.993
TSHOP	+	(+)		(-)		(+)																.033	.006	224
TENTAIN			(-)		(-)					(+)						(+)	(+)	(+)				.024	0.0	.603
TVISIT	+														-	(+)						.044	.017	.040
TOUTDR			(-)								(+)				-							.022	0.0	.723
TOTTRAV3	+							(+)				(+)			(-)		(+)	(+)	(+)	(-)		.046	.019	.028

NOTE: A + or - indicates the sign of the coefficient, with t significant at the .05 level or better. A (+) or (-) indicates that the coefficient was significant with probability in the interval (.2, .05). $\bar{R}^2$ is R^2 corrected for degrees of freedom; "Significance of Regression" is the probability that all coefficients except the intercept are zero. Coefficients are contained in Table B-10.

SOURCE: Based on data contained in Baltimore Travel Demand Data Set. Table compiled in August 1980.

tion may involve substantial travel substitution, or perhaps greater trip chaining and rationalization of tours

It should be noted that the comparisons made here are between employed and not-employed persons, holding sex and other variables constant Table 7 describes the *change* that employment status seems to make for men and women, not the total amount of time spent in the various activities

These differences relate to the overall amounts of time spent by persons of each sex and reflect, in part, existing sex roles For example, Table 8 shows that not-employed females average 0 18 hours in food shopping and employed females 0 09 hours, while not-employed males spend 0 07 and employed males 0 02 hours (Because Table 7 results control for all variables in the model, differences computed from Table 8, which control only for sex and employment status, will not necessarily equal those of Table 7) Though there is a reduction for both males and females, the difference for males is from a smaller initial amount to almost zero, while employed females spend about as much time in food shopping as not-employed males Likewise, for entertainment outside the home, there is a reduction between not employed and employed for both sexes However, not-

Table 5 Estimation results—not-employed persons (n = 321)

INDEPENDENT VARIABLE / DEPENDENT VARIABLE	INTERCEPT	PRESCHLF	YADULTG	ADULTMIX	ADLT3555	ADLT5655	SENIOR	ALONEF	MARSPW	HUSNTWKW	RACE	SEX	INC	INCSQ	AGE	AGESQ	EDUCY	EDUCYSQ	WORKWIFH	RACESEX	SENSEX	R^2	$\bar{R}^2$	Significance of Regression
THOME	+	+	+							(-)			+	-	+							.102	.042	.033
TPERSON	+			+						(+)					(+)		(+)					.085	.024	.121
TEAT	(+)	(-)			(+)	(+)			(-)	-	(+)	-									(+)	.058	0.0	.553
TPLEAS						+			(-)				+		(-)		(-)					.097	.037	.049
TFOOD	+			(-)	(-)																	.051	.013	.711
TSERVE					(-)	(-)					(+)		(-)	(+)								.064	.002	.424
TSHOP						(-)					(+)		-								(+)	.048	0.0	.774
TENTAIN	(+)			(+)							(-)	-		+	(-)						(+)	.130	.081	.0000
TVISIT	+	-	(-)	(-)									-		(-)							.084	.023	.129
TOUTDR				+						(+)		(+)			-				(+)			.092	.031	.075
TOTTRAV3	+							+			(-)				(-)					(+)		.174	.119	.0001

NOTE: A + or - indicates the sign of the coefficient, with t significant at the .05 level or better. A (+) or (-) indicates that the coefficient was significant with probability in the interval (.2, .05) $\bar{R}^2$ is R^2 corrected for degrees of freedom; "Significance of Regression" is the probability that all coefficients except the intercept are zero. Coefficients are contained in Table B-11.

SOURCE: Based on data contained in Baltimore Travel Demand Data Set. Table compiled in August 1980.

employed females are at a much higher level than males, while the employed of either sex averages the same amount In a reverse manner, both sexes increase time eating out, but not-employed males are almost zero, while employed males are roughly equal to employed females. For outdoor recreation, employment changes the time spent by males from a relatively large amount to a small amount, while females go from a small to a very small amount of time The general point here is that an overall understanding of the employment effect must encompass both level and change information and not simply focus on change

Life Cycle and Household Structure

One set of hypotheses that can be tested is whether the major break points in the life cycle signal major changes in time allocation These break points are taken to be (1) the time when a youth leaves home and either lives alone, with other young adults, or marries; (2) the appearance of preschool children, (3) when the youngest child reaches school age, (4) when all a couple's children have left home and the couple is not yet retired; and (5) when all members of a household have reached retirement age. It is illuminating to

Table 6 Estimation results—all persons (n = 1058)

INDEPENDENT VARIABLE / DEPENDENT VARIABLE	INTERCEPT	PRESCHLF	YADULTG	ADULTMIX	ADLT3555	ADLT5655	SENIOR	ALONEF	MARSPW	HUSNTWKW	EMPLOYED	EMPLSEX	RACE	SEX	INC	INCSQ	AGE	AGESQ	EDUCY	EDUCYSQ	WORKWIFH	RACESEX	SENSEX	R^2	$\bar{R}^2$	Significance of Regression
THOME	+	+	(+)						+	(-)	-	(-)			(-)		(+)	+			-			.416	.404	.0001
TWORK	+	(-)							-		+	+			+		+	-			+	(-)		.575	.566	.0001
TPERSON	+									+	-													.025	.004	.2377
TEAT					+	+				-		(+)		(-)				(+)	+	+				.080	.061	.0001
TPLEAS	(+)		+			+			(-)		-				+		-		(-)					.050	.030	.0002
TFOOD	+							(+)			-		(-)	-			+							.056	.036	.0001
TSERVE	(+)				(-)						(-)		(+)											.026	.006	.1799
TSHOP	+										-		(+)		(-)								(+)	.060	.040	.0001
TENTAIN	+	(-)	(-)								-	(+)	(-)	-			(-)	(+)		+	(+)		+	.045	.025	.0009
TVISIT	+	-	(-)							(+)	-	(-)			-	(+)	-							.063	.043	.0001
TOUTDR	(+)									(+)	(-)	-		+			-							.046	.026	.0007
TOTTRAV3	+							+			+		(-)				(-)			(+)	(+)			.067	.047	.0001

NOTE: A + or - indicates the sign of the coefficient, with t significant at the .05 level or better. A (+) or (-) indicates that the coefficient was significant with probability in the interval (.2, .05). $\bar{R}^2$ is R^2 corrected for degrees of freedom; "Significance of Regression" is the probability that all coefficients except the intercept are zero. Coefficients are contained in Table B-9.

SOURCE: Based on data contained in Baltimore Travel Demand Data Set. Table compiled in August 1980.

compare households at one stage of this stylized life cycle with households of the immediately preceding stage

The research team found that after holding employment status, age, marital status, and all other variables constant, men without children, men with preschool-age children, and men with school-age children show no statistically significant differences in time allocations Nor is there a difference between the time-use patterns of not-employed young women with children and similar women without children For employed women, however, the transition to having a young child does make a difference, with less time spent in pleasure riding and more time spent in general shopping than a person from a household of young adults For general travel, there is no reason to believe there is any impact, however

The change in time allocation associated with the youngest child reaching school age is somewhat stronger, revealing decreased demands of caring for young children For employed women, the transition results in less time at home, more time at work, and fewer hours spent in general shopping For not-employed women, the transition results in fewer hours at home and more time spent visiting friends.

Also revealed is the change that lessening demands for caring for children have as persons move through the later stages in the life cycle An employed member of a household of adults without children will tend to spend more time taking meals away from home until retirement age, and, with increasing age, will spend less time working than one in a household with children Not-employed members in similar households spend significantly less time serving passengers and, in older households, also spend less time in outdoor recreation and more time at home, in pleasure travel, and in eating out of home (these last two trends are reversed after reaching retirement age)

Sex, Race, Marital Status

Differences in time allocations between males and females are significant for unmarried blacks but not for white unmarried persons Employed unmarried black men tend to spend more time at work and traveling and less time at home and food shopping than unmarried black women A similar pattern is found for both black and white married men with working spouses, although blacks display a more pronounced pattern for such activities Among persons whose spouses do not work, the differences between men and women are much less sharp, but are similar in direction to those already noted

Age, Income, Education

For the employed, time at work tends to peak in terms of age in the early 40s, time spent at home reaches a minimum in the late 30s, and most other activities reach a minimum at some later age This is displayed in Figure 1. For employed persons, the household income variable tends not to be a significant predictor of time allocation, although there is some evidence that the person's wage would have a more significant effect For nonemployed persons, higher income implies more time spent at home, in pleasure traveling, and in entertainment and less time spent shopping, visiting friends, and serving other persons. Income tends not to affect travel time significantly for either the employed or unemployed

Education is not significant in any of the equations for the not employed, but it is an important variable in many of the activity equations for the employed. For the employed, increasing education implies decreased time at work, and increased time eating away from home, in entertainment, and in travel time. As age and income have been controlled for, it appears that the educated employed enjoy a distinctive lifestyle

Forecast Experiments

The model of individual weekday time allocation of travelers is then used to forecast time allocation in 1990. The exogenous variables are forecast using published data from the *Current Population Report* (9) and the *Monthly Labor Review* (*10*). The assumptions used in deriving these changes are discussed in Appendix C. Table 9 gives. (1) the sample average values for the independent variables in the models, (2) the change multipliers that were developed, and (3) the resulting values of the independent variables for 1990 The key demographic trends are an increased labor force participation rate of women, an older population, and a greater proportion of single-person households.

The result of these changes shows little difference in the amount of time spent at home and at work on average for the employed and not-employed groups considered separately because of the countervailing effects of age, income, etc However, because of the rising percentage of employed women and the fact that the employed spend a smaller proportion of their time at home, the effect of these changes in the pooled sample of employed and not employed is a decrease in the aggregate amount of time spent at home, an increase in the amount of time spent at work, and some

Table 7 The marginal impact of being employed on time allocation (in hours).

THE MARGINAL IMPACT OF BEING EMPLOYED
ON TIME ALLOCATION
(in hours)

Activity	Sex: Female	Sex: Male
Home	-4.29***	-5.21***
Work	5.61***	7.06***
Personal Business	-0.22**	-0.35***
Eat Out	0.04	0.12**
Pleasure Travel	-0.12**	-0.12*
Food Shopping	-0.10***	-0.05
Serve Passenger	-0.09	-0.20**
Other Shopping	-0.30***	-0.30**
Entertainment	-0.22***	-0.02
Visiting	-0.36**	-0 71***
Outdoor Recreation	-0.14*	-0.53***
Travel Time	0.22**	0.30**

NOTE The above table gives only the adjustment that men and women make to their activity pattern when they become employed. Since it does not make reference to the level at which they started when not employed, the table cannot be used to calculate total male/female differences See Table B-13 for this. The employment contrast for females is the coefficient EMPLOYED; for males it is the sum of the coefficients for EMPLOYED + EMPLSEX. Coefficients are contained in Table B-10

SOURCE Based on data contained in the Baltimore Travel Demand Data Set Table compiled in August 1980

LEGEND * - significant at the .10 level

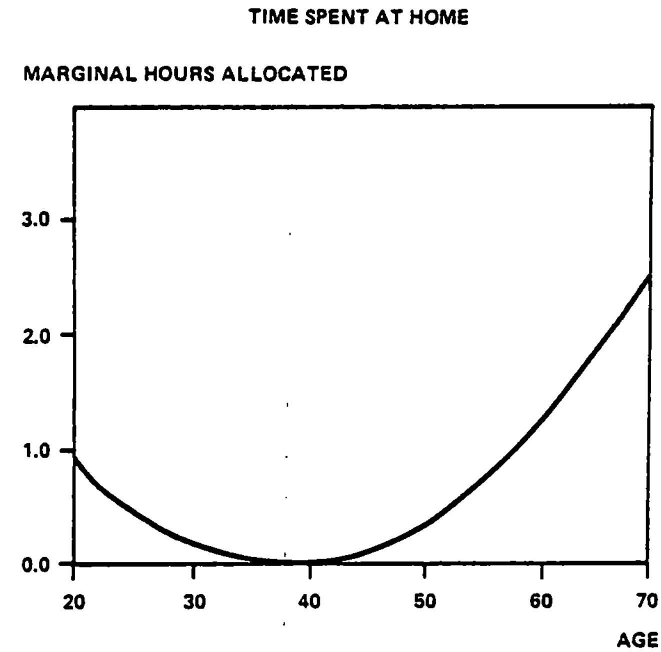
** - significant at the 05 level

*** - significant at the .01 level.

Table 8 Average time allocation by employment status and sex (in hours)

Activity	Employed: Males	Employed: Females	Not Employed: Males	Not Employed: Females
Home	13 73	15.35	19.81	20 19
Work	7.61	6 05	0	0
Personal Business	0 20	0 15	0.46	0 34
Eat Out	0.11	0.10	0 01	0 05
Pleasure Travel	0.07	0 04	0 15	0.15
Food Shopping	0.02	0.09	0.07	0 18
Serve Passenger	0 11	0.12	0 17	0 22
Other Shopping	0.11	0 18	0 51	0 54
Entertainment	0 14	0 13	0 21	0 32
Visiting	0 35	0 38	1 01	0 77
Outdoor Recreation	0 14	0 08	0 51	0 22
Travel Time	1.42	1 32	1 10	1 01
Number of Persons	439	298	96	225

SOURCE Based on data contained in Baltimore Travel Demand Data Set Table compiled in August 1979



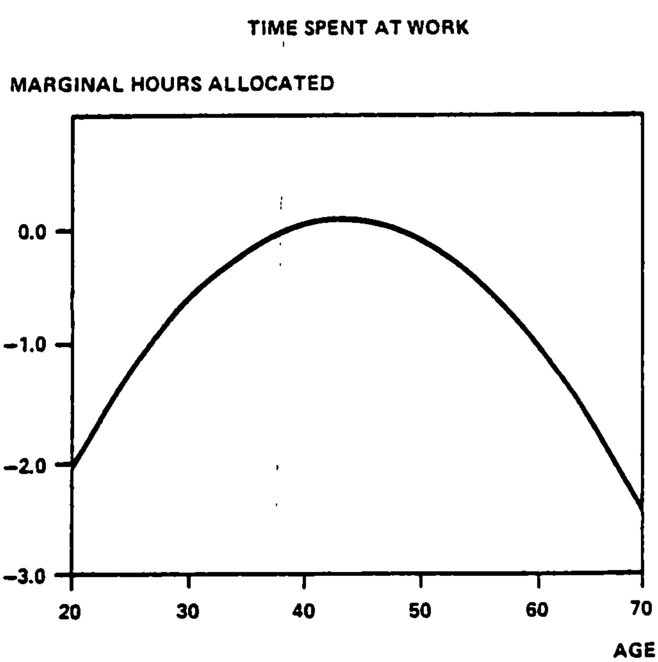


Figure 1 Marginal amounts of time allocated for employed persons (in hours)

Table 9 Exogenous variable forecast assumptions

Variable	Actual 1977	Change Multiplier 1977-1990	Estimate 1990
PRESCHLF	0.1153	0.9504	0.1096
YADULTG	0.0463	0.9687	0.0449
ADULTMIX	0.0813	0.9687	0.0787
ADLT3555	0.0794	1.1726	0.0931
ADLT5565	0.0624	0.8822	0.0550
SENIOR	0.0529	1.1827	0.0626
ALONEF	0.0246	1.2741	0.0313
MARSPW	0.3355	1.0414	0.3494
HUSNTWKW	0.0709	1.0000	0.0709
EMPLOYED	0.6966	1.0636	0.7409
EMPLSEX	0.4149	0.9837	0.4082
RACE	0.6380	0.9777	0.6238
SEX	0.5057	1.0006	0.5060
INC	0.0	(1 0144)*	264.5496
INCSQ	$143\ 7*10^6$	**	$147.9*10^6$
AGE	0.0	(1.0499)*	2.0175
AGESQ	263.1714	**	294.1613
EDUCY	0.0	(1.0107)*	0.1233
EDUCYSQ	11.9659	**	12.2385
WORKWIFH	0.1323	1.1705	0.1549
RACESEX	0.3336	0.9792	0.3267
SENSEX	0.0217	1.1651	0.0253
INTERCEP	1.0000	1.0000	1.0000

NOTE· See Table 2 for variable definitions

SOURCE Based on data contained in Baltimore Travel Demand Data Set Table compiled in August 1980

*Applied to variable before centering adjustment.

** Derived from calculation of linear variable -- not a direct scaling.

rearrangement of other out-of-home activities. These trends are displayed in Table 10 Time spent in personal business is forecast to decline for the employed but to increase for the not employed, this results in an overall decrease for the population as a whole. Conversely, for time spent eating out of home, the employed will spend more time and the not employed less, for the population as a whole, this results in more time eating out because of the increasing fraction of people employed Pleasure traveling, serving passengers, visiting, and out-of-door recreation are forecast to decline for both segments. Total travel time will increase somewhat to serve this rearranged activity schedule of the population. In summary, among nonwork, out-of-home activities, only travel and eating out are forecast to have higher time allocations among households, most nonwork, out-of-home activities will become more time constrained as a result of increased time spent at work. While overall changes are small, specific changes at the traffic zone level could be much larger

Table 10 Actual and forecast values of time allocation employed, not-employed, and all persons (in hours)

Activity Category*	Employed Persons Actual 1977	Forecast 1990	Percent Change**	Not Employed Persons Actual 1977	Forecast 1990	Percent Change**	All Persons - Weighted Average Actual 1977	Forecast 1990	Percent Change**
THOME	14.38	14.40	0.12	20.08	20.16	0.38	16.11	15.89	-1.37
TWORK	6.98	6.99	0.12	0.00	0.00	0.00	4.86	5.18	6.49
TPERSON	0.18	0.17	-3.80	0.38	0.39	3.48	0.24	0.23	-4.42
TEAT	0.10	0.11	3.39	0.04	0.03	-3.07	0.08	0.09	6.50
TPLEAS	0.05	0.05	-5.90	0.15	0.13	-14.41	0.08	0.07	-14.48
TFOOD	0.05	0.05	10.44	0.15	0.15	-0.18	0.08	0.08	-1.25
TSERVE	0.11	0.11	-0.53	0.20	0.18	-13.94	0.14	0.13	-8.43
TSHOP	0.14	0.13	-2.84	0.53	0.53	-0.92	0.26	0.24	-8.40
TENTAIN	0.14	0.14	2.38	0.28	0.30	4.80	0.18	0.18	-0.23
TVISIT	0.36	0.35	-4.66	0.84	0.81	-3.98	0.51	0.47	-8.32
TOUTDR	0.12	0.11	-8 19	0.31	0.28	-7.65	0.17	0.15	-12.45
TOTTRAV3	1.38	1.38	0.27	1.04	1.05	1.01	1.27	1.30	1.61
Proportion of Sample	.6966	.7409	--	.3034	.2591	--	1.00	1.00	--

*See Table 1 for definitions of activity categories

$$\text{**PERCENT CHANGE} = 100 \times \left(\frac{\text{Forecast 1990 - Actual 1977}}{\text{Actual 1977}}\right)$$

The percent change estimates were calculated before the time allocation estimates were rounded to two places.

SOURCE Based on data contained in Baltimore Travel Demand Data Set Table compiled in August 1980

HOUSEHOLD-LEVEL ANALYSES

The second level of analyses carried out with the Baltimore data was at the household level The primary purpose of the analysis is to analyze trip frequency by purpose, investigating the role of household structure and residential location in augmenting existing approaches. The major emphasis was on testing whether standard trip generation models could be improved by the addition of variables describing household structure (and other related concepts). Some of the variables employed are redefined in order to incorporate what was learned in the individual-level modeling and to accommodate a household level of analysis Preliminary analyses of travel-related variables are performed to obtain a greater understanding of the relationships in the data The preliminary analyses are described in Appendixes D and E. Finally, a series of modeling exercises of household-level trip frequency and related variables is performed. The models emphasize travel frequencies for particular purposes. Appendix F provides more details on these models as well as additional models of travel frequencies by modes.

Variable Definitions

The most important definitions involve the activity purposes, residential-zone descriptors, and a relationship-based typology of households. More details are provided in Appendix D. Table 11 displays these categories. Attributes of the zone—location variables—are also included in the models

Trip / Activity Purposes

Trip/activity purposes are redefined from 12 to 7 categories. In most cases this represented a collapsing of categories, although "pleasure travel" was split into "entertainment" and "service/accompany traveler."

Table 11 Household-level variable definitions

Activity/Trip Purpose	Household Typology
1. Home	1. Single Males
2. Work/School	2. Single Females
3. Shopping	3. Unrelated Individuals
4. Personal Business	4. Couples
5. Entertainment/Community	5. Single-Parent Household
6. Visit/Social	6. Nuclear Family
7. Service/Accompany Traveler	7. Adult Family with Children
	8. Adult Family without Children
Zonal Descriptors	
1. Population Residential Density	
2. Average Houshold Size	
3. Percent Developed in Residential Acreage	

It can be seen that the activity categories relate in a rough way to the role complex ideas proposed in Phase I of the project (*1*, p. 52), and further elaborated on early in Phase II (*11*, see App. A). These role complexes include work/career, household/family, interpersonal/social, and leisure/recreation There are problems in mapping our purposes to these. One cannot tell what persons are doing at home, and the activity could relate to any one of the four role complexes. Purpose 12 of the original Baltimore data set— entertainment, religious, civic, cultural—spans the interpersonal/social and leisure/recreation categories. Travel to terminal or accompanying another could be any of the four. However, a rough mapping would be the following: our home, shopping, personal business, and serve traveler categories are "home/family"; our work/school is "work/ career", our entertainment/community is largely "leisure/recreation", and our visit/social is "interpersonal/social."

Household Types

The individual-level modeling employed a definition of household type based on the age of the youngest and eldest members of the household. In this present typology, age of any member of the household is not treated explicitly, but is introduced in other ways in the modeling. The earlier typology is efficient in the sense that it represents one aspect of the age structure of the household, but it is difficult to forecast and does not relate easily to the more common ways in which households are described. In particular, it does not (nor was it intended to) represent whether the individuals were related or unrelated, a concept that has been noted as important by previous transportation analysts (*12*, *13*). Thus, a typology is developed that relates more closely to Census definitions, is implementable using household survey data, and represents the patterns detected in the Baltimore data.

The following four main criteria were employed: (1) relationship among individuals; (2) presence or absence of dependents, (3) age 20 as cut-off for childhood, and (4) number of type of adults present. The variables used for creating household types are age, sex, marital status, and last name of each nonvisitor in the household. The final decision logic is displayed in Figure D-1 of Appendix D. The categories include the following: males living alone; females living alone; groups of two or more unrelated individuals; couples; single-parent families, nuclear families (couple with minor children only); adult families (those with other adults besides a couple) with or without children.

Modeling

In the modeling it was necessary to distinguish between trip purpose defined by the activity at the destination (termed "activity-based") and home-based purposes. The activity-based analysis of trip frequency by purpose, for weekday and weekend, and by mode is discussed. A part of this analysis is replicated for home-based trips Finally, a system of structural equations developed to examine issues related to the trip frequency question is discussed. These topics are detailed in Appendix F.

Activity-Based Analysis Versus Home-Based Analysis

It is necessary to distinguish between "activity-based" travel—that for which the destination purpose defines the activity—and the more traditional home-based perspective—that which defines the purpose at the nonhome end of the trip, whether origin or destination. Considering travel as determined by activities leads to the use of the former definition (and includes nonhome-based travel), while the requirements of traditional practice lead to the use of the latter definition.

A concrete illustration of these two differing approaches involves using the trips actually utilized in modeling Of the 7,570 trips represented in the data, 2,958 originated at home and were destined for other purposes, while 2,962 returned to home from other purposes. These 5,920 trips are home-based trips, while the remaining 1,650 trips, which proceed from one nonhome origin to a nonhome destination, are nonhome-based trips. By contrast, the activity-based definition of a trip considers only its destination

The data reveal that the numbers of trips by purpose originating at home and those destined for home from the like purpose are very similar. Overall, roughly 80 percent of all trips are home-based trips. This symmetry of originations and destinations for home-based trips and the preponderance of home-based trips suggest that the fundamental determinants identified should be roughly the same regardless of whether an activity-based or a home-based approach is taken. Some distortion will occur, however. Activity-based trips by purpose are linked to home-based and nonhome-based trips by the following identities

$$AB_i = NHB_i + HB_i - P_{1i}, \quad \text{for } i > 1 \qquad (1)$$

$$AB_1 = \sum_{i=2}^{7} P_{1i} \qquad (2)$$

where.

i = trip purpose (here $i = 1, \ldots, 7$);
AB = activity-based trip frequency;
NHB = nonhome-based trip frequency;
HB = home-based trip frequency; and
P_{1i} = trip frequency from purpose i to home.

Equation 1 describes activity-based trips to nonhome destinations, and Eq. 2 describes trips to home. Because the numbers of home-originating and home-destined home-based trips seem to be fairly symmetrical, the distortion will arise principally from the determinants of nonhome-based trips differing from those of home-based trips at the household level

Activity-Based Analysis of Trip Frequency

In Appendix F a series of tests is performed to establish the best specification for household structure. The most efficient representation of household structure is to disaggregate total eligible persons by age and to add dummy variables for household relationship type.

The model is identical in functional form to that used in the individual-level modeling, although, of course, the dependent and independent variables are different and there are 7 rather than 12 purposes. The dependent variables are defined in Table 12; the independent variables are defined in Table 13.

Analysis of Variance. The importance of various determinants of trip generation behavior are tested in an incremental fashion First models of trip frequency analogous to the models in current use (standard models) are estimated using number of vehicles, income, and number of persons eligible to travel. Then, household structure variables and residential location variables are added (enhanced models); these contribute significant explanatory power to the basic model.

The basic model used in this case predicts frequency of weekday travel by purpose as a function of number of vehicles owned, household income, and number of persons eligible to travel (i.e., 12 and older) In the second set of models, vehicles and income are used and total eligible persons are subdivided into the five principal age categories utilized in the individual modeling. In addition, dummy variables are introduced for the presence of preschoolers and grade schoolers, the relationship-based household structure types, race, residence in a single family unit, and the presence of a "homemaker." As can be seen from Table 14, the addition of these variables produces a significant increase in the variance explained for each trip purpose. For each equation, the percent of variance explained rises from between 2 to 4 percentage points by disaggregating total eligible persons into age categories and introducing household structure variables. The improvement is statistically significant for total trip frequency, trips to home, work, and entertainment

When variables that describe the residential environment of the household (residential density, residence in Baltimore City, residence less than 6 months) are included, the increase in variance explained is less dramatic, being no more than 1 percent, but is nonetheless statistically significant for the entertainment and visiting categories.

The coefficients obtained from the final step of this procedure are given in Table 15. These coefficients indicate how trip frequency increases with a one-unit increase in the independent variables. Each class of variables is discussed in turn.

Table 12 Activity-based dependent variable definitions

Variable Names	Description
TRIPFREQ	Total Number of trips for all purposes
FREQPUR1	Trips to home
FREQPUR2	Trips to work
FREQPUR3	Trips to shopping
FREQPUR4	Trips for personal business purposes
FREQPUR5	Trips for entertainment/community purposes
FREQPUR6	Trips for visit/social purposes
FREQPUR7	Trips to service/accompany traveler

NOTE All variables are expressed in numbers of trips per household by eligible household members (age > 12). See Table D-1 for more extensive definitions.

Table 13 Independent variable definitions

Variable	Description
INTERCEP	Intercept (constant) term
Basic Model Variables	
VEHOWN	Numbers of vehicles owned by the household
INCOMEM	Household income (in $1,000)
TOTELIG	Total persons eligible for travel records (≥ 12 years of age), living at home[1]
Age Structure	
NTEEN	Numbers of persons age 12-19
N20TO34	Numbers of persons age 20-34
N35TO54	Numbers of persons age 35-54
N55TO64	Numbers of persons age 55-64
N65PLUS	Numbers of persons age 65 and over
Household Type[2,3]	
SMALE	Male living alone
SFMALE	Female living alone
UNRELI	Unrelated individuals (male, female, or mixed roommates)
COUPLE	Married couple or unmarried couple with ages within 10 years apart
SPHH	Single-parent household (male or female adult with children)
Household Type (Contirued)	
NUCLR	Nuclear family (married couple with children under 20)
AFWKID	Adult family with children (two or more adults with children present)
AFWOKID[4]	Adult family without children (adults with same last names, no children)
Other Household Characteristics	
SFDU[2]	Household living in single-family dwelling unit
PREDUM[2]	One or more preschool persons (< 5 years old) present
GRADEDUM[2]	One or more gradeschool persons (age 5-11) present
HMMAKEDM[2]	At least one member of the household has employment status of "homemaker"
HHRACE[2]	Family members are nonwhite
Residence Zone Descriptors[5]	
RDENP	Population per residential acre
CITY[2]	In Baltimore City Limits
HHRES6[2]	Longest residing member of household has resided at that address fewer than 6 months

NOTES:

[1]Households with visitors were excluded from analysis.

[2]Variable has value of one if the household has this characteristic, zero otherwise.

[3]See Appendix D for a discussion of household type.

[4]The omitted household category.

[5]Properties of traffic analysis zone of residence of household.

Table 14 Incremental explanatory power of household structure and residential location in activity-based trip generation model (for 629 households with weekday travel)

		Total	Home	Work	Shop	Personal Business	Entertainment	Visit	Serve Passenger
Basic Model	R^2	.51	.61	.36	.11	.02	.16	.13	.09
Household Structure Included	R^2	.55**	.65**	.40**	.13	.06	.20*	.16	.12
Residence Zone and Household Structure Included	R^2	.56	.66	.40	.13	.07	.21+	.17+	.12

*Difference between rows 1 and 2 significant at $p < .05$.

**Difference between rows 1 and 2 significant at $p < .01$.

+Differences between rows 2 and 3 significant at $p < .05$.

Vehicle Ownership and Income. In terms of total trip frequency for all purposes, number of vehicles owned makes a strong positive contribution, adding approximately one trip per vehicle per day (based on the coefficient 1.062) to the household's travel pattern, other things being equal. Number of vehicles owned is positively related to all categories of travel by purpose except for personal business and entertainment Income is not a significant determinant of total trip-making behavior, although it has marginal impact in the work and entertainment equations (entertainment is the type of activity one might expect to be associated with higher income), and a negative relationship to visiting frequency.

Age Structure. The age structure of the household shows declining total trip frequency with numbers of person by age group. The coefficients are used directly in estimating the age effects For total weekday trip frequency, each additional teenager in a household induces 3.3 trips per person, persons 20 to 34 contribute approximately 2 8 trips per person, persons 35 through 54 and those 55 to 64 contribute approximately 2.5 trips per person, and those over 65 contribute approximately 1 trip.

The presence of one or more preschoolers has a strong inhibiting effect on the frequency of total weekday travel, this reduced frequency comes principally from personal business and serve-passenger trips. The presence of grade schoolers has a slight positive effect on trip frequency, principally in the serve-passenger and entertainment areas.

Household Type. There are three distinct groupings of households from the point of view of trip frequency: groupings of individuals without children present (unrelated individuals, couples, and adult families without children); families with children present (nuclear families, single-parent families, and adult families with children); and single individuals.

The household type with the greatest impact on total trip frequency, other things equal, is that of unrelated individuals, who take approximately 3.2 more trips than their age, vehicle ownership, and location patterns would suggest Although the size of an unrelated-individual household is 2 2 persons, only slightly larger than that of couples, households of unrelated individuals take almost 1.2 more trips per day (3.221-2.039) than households of couples. This indicates that family relationships have an impact on trip frequency behavior. Individuals in households consisting of roommates tend to pursue their own schedules of activities and interests and are much less tied to the activities of other household members than are persons with a greater degree of commitment to a relationship, in addition, role relationships may introduce efficiencies into family trip making

Single-parent households' total trip rates are marginally higher than those of nuclear families when their vehicle ownership patterns, age structure, and residential location are accounted for. Adult families with children have the highest differential in total trip-making behavior of the families with children. This greater frequency seems to be related to the presence of extra adults, as it is the increased frequency of work / school, personal business, entertainment, and visiting trips—all adult-oriented activities—that contributes to the higher rate. Nonetheless, the three types are fairly similar in their rates Nuclear families and single-parent households are quite similar, but the similarity comes from countervailing effects—nuclear families are higher in serve-passenger trips, while single-parent households are generally higher in shopping trips and return-home trips

Of the single-person households, single males are more mobile than single females This is due principally to a higher frequency of entertainment trips and of return home trips.

Residential Location. Population density is negatively related to total trip making Although this has long been observed in trip generation models, the reasons for this point to potential lifestyle variations Frequency of work, shopping, and entertainment trips significantly increase with decreasing residential density Conversely, visiting trips are positively related to increasing net residential density, perhaps indicating a greater degree of socializing within the neighborhood in denser areas. Another location-related effect is the reduced frequency of entertainment and visiting trips for households with residences within the Baltimore City limit. Again, this would appear to be a lifestyle effect Short-term residence does not have a significant effect in any

Table 15 Trip frequency by purpose (for 629 households with weekday travel)

INDEPENDENT VARIABLES	TRIPFREQ PROB-T	FREQPUR1 PROB-T	FREQPUR2 PROB-T	FREQPUR3 PROB-T	FREQPUR4 PROB-T	FREQPUR5 PROB-T	FREQPUR6 PROB-T	FREQPUR7 PROB-T
	DEPENDENT VARIABLES							
INTERCEP	-1.625	-0.810	-0.535	-0.477	0.435	0.026	0.140	-0.403
	0.325	0.136	0.296	0.273	0.242	0.948	0.712	0.351
VEHOWN	1.062	0.329	0.266	0.147	0.033	-0.024	0.097	0.213
	0.000	0.000	0.002	0.047	0.596	0.729	0.130	0.004
INCOMEM	0.018	0.008	0.014	-0.003	-0.004	0.008 *	-0.009 *	0.003
	0.439	0.298	0.052	0.625	0.477	0.160	0.112	0.593
NTEEN	3.282	1.491	0.716	0.172	0.039	0.421	0.334	0.109
	0.000	0.000	0.000	0.009	0.494	0.000	0.000	0.099
N20TO34	2.836	1.305	0.539	0.316	0.029	0.358	0.181	0.107
	0.000	0.000	0.001	0.022	0.802	0.005	0.131	0.433
N35TO54	2.473	1.114	0.623	0.334	-0.044	0.271	0.132	0.043
	0.000	0.000	0.000	0.027	0.730	0.051	0.314	0.771
N55TO64	2.487	1.147	0.581	0.332	-0.094	0.308	0.031	0.182
	0.000	0.000	0.003	0.043	0.502	0.041	0.827	0.263
N65PLUS	1.003	0.629	0.184	0.327	-0.134	0.139	-0.140	-0.001
	0.115	0.003	0.352	0.051	0.349	0.369	0.336	0.993
SFDU	0.651	0.150	-0.082	0.104	0.207	-0.030	0.080	0.222
	0.261	0.431	0.647	0.497	0.113	0.830	0.545	0.143
PREDUM	-1.457	-0.491	-0.078	0.044	-0.417	-0.028	-0.115	-0.371
	0.032	0.028	0.711	0.807	0.007	0.867	0.460	0.037
GRADEDUM	0.158	0.056	-0.082	-0.198	-0.042	0.292	-0.070	0.202
	0.784	0.769	0.646	0.193	0.747	0.037	0.597	0.181
HHMAKEDM	0.404	0.034	-0.405	0.235	0.226	0.050	0.086	0.179
	0.378	0.819	0.004	0.053	0.029	0.656	0.416	0.136
HHRACE	-0.157	-0.194	-0.447	0.100	0.156	-0.006	0.069	0.165
	0.774	0.282	0.009	0.490	0.205	0.961	0.582	0.249
SMALE	2.585	1.119	0.483	0.456	-0.159	0.485	0.018	0.181
	0.071	0.017	0.276	0.226	0.622	0.162	0.955	0.629
SFMALE	1.892	0.788	0.622	0.473	-0.243	0.168	-0.112	0.195
	0.150	0.069	0.128	0.173	0.411	0.598	0.711	0.570
UNRELI	3.221	0.915	0.672	0.514	0.225	0.160	0.397	0.338
	0.016	0.038	0.106	0.145	0.454	0.622	0.196	0.335
COUPLE	2.039	0.560	0.318	0.371	0.224	0.188	0.246	0.133
	0.028	0.066	0.269	0.129	0.283	0.403	0.247	0.583
SFHH	2.333	0.870	0.611	0.919	-0.187	-0.034	-0.081	0.234
	0.096	0.059	0.160	0.013	0.554	0.921	0.801	0.524
NUCLR	2.127	0.689	0.459	0.668	0.157	-0.293	-0.058	0.505
	0.043	0.046	0.159	0.016	0.507	0.250	0.811	0.067
AFWKID	2.708	0.627	0.619	0.597	0.375	0.103	0.243	0.144
	0.007	0.057	0.047	0.024	0.097	0.671	0.291	0.584
RDENF	-0.018	-0.007	-0.005	-0.005	-0.003	-0.004	0.005	-0.001
	0.044	0.025	0.097	0.053	0.182	0.098	0.018	0.737
CITY	-0.185	0.034	0.346	0.111	0.025	-0.330	-0.309	-0.063
	0.752	0.860	0.057	0.472	0.849	0.020	0.022	0.680
HHRES6	0.448	-0.194	0.114	0.061	0.331	-0.070	0.060	0.146
	0.613	0.507	0.678	0.795	0.098	0.747	0.770	0.530
STD ERR	5.062	1.665	1.572	1.336	1.140	1.229	1.162	1.326
R-SQUARE	0.555	0.655	0.405	0.131	0.068	0.210	0.173	0.124

NOTES. 1. For variable definitions, see Tables 12 and 13.

2. For each variable, the coefficient is on the first line; the probability that this coefficient is different from zero is on the second line

3. "STD ERR" is the standard error of the estimated variable, "R-SQUARE" is the squared multiple correlation coefficient.

SOURCE. Based on data contained in the Baltimore Travel Demand Data Set. Table compiled in December 1980.

of the equations for weekday travel (except for a marginal positive relationship to personal business trips).

Weekend Travel

Although home and work equations are somewhat better predicted for the weekday, the variance explained for other trip purposes is higher for weekend travel (see Table 16). Total trips per vehicle owned are higher for weekend travel. The other patterns noted for weekday travel tend to hold as well, with the exception that short-term residence increases the frequency of weekend trip making, particularly shopping, personal business, and visiting. This may indicate a lesser degree of planning in trip-making behavior occasioned by the lesser familiarity with the area. That this effect occurs only for weekend travel suggests that weekday travel is much more constrained. Without knowing more about where the trips are destined, it is not possible to say whether such trips represent an increased frequency of, for example, visiting within the neighborhood in order to become acquainted or, conversely, an increased frequency of visiting outside of the neighborhood to longer standing friends and acquaintances.

Home-Based Trip Productions

A similar analysis is performed of home-based trips as of activity-based trips. The variance explained for total home-based trip making is considerably higher than for total trip frequency, although the increments from adding household structure and residential location are roughly the same between home-based and activity-based trips.

It can be seen in comparing the significant coefficients for activity-based trips versus home-based trip productions that the overall patterns of significance are fairly similar (Table 17 defines the variables and Table 18 presents the coefficients). The age structure of the household, however, tends to be more important in predicting home-based trips than in predicting activity-based trips.

There are differences for the household structure variables as well. Some coefficients that are marginal for the activity-based equations, such as adult families with children for the work equation and all the structure types for the shopping equation, lose significance in the home-based-trip production equations. Conversely, the determinants of serve-passenger trips seem to become more sharply defined for home-based trip productions, particularly with respect to the presence of grade schoolers, and for the homemaker, living in a single-family unit, and nuclear family variables. Likewise, the residential density and city variables gain significance in predicting home-based entertainment and visiting trip productions, but lose significance in predicting work-trip productions.

That variables describing the household and its residential environment gain in importance in predicting home-based versus activity-based trips is reasonable. The concept of "home-based" trips obviously brings the focus more sharply on the household and its residential setting than does that of "activity-based" trips which include trips that take place apart from home entirely. Thus, properties of the household and neighborhood should more effectively index home-based behavior.

The comparisons between weekday and weekend trip productions are also similar to those for the activity-based analysis (see Table 19). Weekend travel is better predicted for total trips, work, shopping, and visiting. The vehicle trip rate is higher for weekend travel. Short length of residence increases trip frequency. A comparison between activity and home-based weekend equations reveals a lessening importance of residence zone and an increasing importance of household type in predicting weekend home-based productions.

Numbers of employed persons, when added to these equations, indicate that numbers of entertainment trips are lowered and numbers of visiting trips are raised slightly with each employed member. The role of the homemaker variable is sharpened for total home-based trips, while the role of numbers of vehicles owned in predicting work trips is reduced to zero. The importance of age structure and household type is reduced slightly for total trips and work trips, but it is increased for predicting entertainment trips. The analysis of weekend trips reveals a slight reduction in personal business trips on the weekend attributable to the number employed, indicating that such trips may be performed in conjunction with work on the weekday.

Structural Equation Modeling—Activity-Based

The preceding sections of this chapter have examined separately both the time allocated and the trip frequencies for selected activities. The remainder of the chapter investigates the mutual interactions among time allocation, trip frequency, and other mobility measures. Investigations of this type are useful beginnings in the development of a common framework for dealing with dependent variables that are typically treated separately.

For this analysis, a set of structural models is developed with three objectives: (1) to investigate potential interrelationships among determinants of mobility such as number of driver licenses in the household and number of vehicles owned; (2) to determine the impact of such variables and sociodemographic, household structure, and residential location variables on household time allocation, and (3) to investigate the impact of activity time allocations on travel time, travel frequency, and person and vehicle-miles traveled.

Structural equation modeling typically results in a fairly complex set of interrelationships among variables. Particular attention is given to the relationships involving activity time, travel time, and travel distance in this discussion. The technical details and a more complete discussion of the results are presented in Appendix F.

Two-stage least squares is the estimation technique used (*14*); a block recursive structure is developed to examine various levels of interaction among the variables. Two-stage least squares is used in an attempt to remove the potential mutual dependency of one variable on another where each is used as a predictor of the other. Failure to use such a technique can result in biased coefficients estimates; by using this technique it is possible to test whether feedback relationships exist among variables or whether the presumed direction of causality runs in only one direction. Here the emphasis is on the allocation of time and the interrelationship of such measures with aggregate measures of travel by all modes.

Table 16 Trip frequency by purpose (for 221 households with weekend travel)

Independent Variables	DEPENDENT VARIABLES TRIPFREQ PROB-T	FREQPUR1 PROB-T	FREQPUR2 PROB-T	FREQPUR3 PROB-T	FREQPUR4 PROB-T	FREQPUR5 PROB-T	FREQPUR6 PROB-T	FREQPUR7 PROB-T
INTERCEP	3.405	1.339	-0.616	1.038	1.070	0.353	0.028	0.194
	0.120	0.072	0.359	0.094	0.039	0.507	0.959	0.716
VEHOWN	1.342	0.551	0.089	0.293	0.158	0.083	0.094	0.075
	0.003	0.000	0.525	0.024	0.142	0.455	0.412	0.499
INCOMEM	0.024	0.003	0.015	0.000	0.001	0.004	0.001	-0.001
	0.445	0.747	0.121	0.992	0.875	0.625	0.872	0.923
NTEEN	3.028	1.285	0.887	0.002	0.151	0.399	0.216	0.088
	0.000	0.000	0.000	0.990	0.173	0.001	0.068	0.443
N20TO34	1.443	0.620	0.613	-0.135	-0.244	0.327	0.148	0.113
	0.056	0.016	0.008	0.526	0.169	0.075	0.432	0.536
N35TO54	0.961	0.646	0.418	-0.122	-0.191	0.004	0.250	-0.044
	0.262	0.027	0.113	0.615	0.344	0.986	0.244	0.831
N55TO64	0.365	0.390	0.498	-0.228	-0.268	-0.013	-0.001	-0.013
	0.647	0.151	0.043	0.313	0.156	0.948	0.994	0.946
N65PLUS	0.433	0.311	0.104	-0.127	-0.237	0.101	0.137	0.145
	0.629	0.307	0.707	0.615	0.262	0.645	0.541	0.506
SFDU	-0.075	-0.195	-0.033	0.080	0.087	-0.027	-0.046	0.060
	0.935	0.534	0.906	0.760	0.690	0.903	0.842	0.790
PREDUM	-0.255	0.394	0.320	0.001	-0.180	-0.120	-0.248	-0.421
	0.819	0.299	0.351	0.998	0.493	0.658	0.375	0.122
GRADEDUM	1.398	0.477	0.392	0.327	0.336	-0.260	0.060	0.066
	0.158	0.156	0.197	0.243	0.150	0.279	0.808	0.782
HHMAKEDM	-0.728	-0.398	-0.346	-0.065	-0.079	0.290	-0.135	0.005
	0.325	0.114	0.129	0.758	0.652	0.108	0.466	0.978
HHRACE	0.805	0.098	0.140	0.532	-0.041	-0.054	-0.216	0.345
	0.339	0.733	0.587	0.026	0.836	0.794	0.307	0.093
SMALE	-0.616	0.026	0.630	-0.722	-0.879	0.049	0.274	0.006
	0.773	0.971	0.338	0.233	0.082	0.924	0.608	0.991
SFMALE	-1.121	-0.459	0.517	-0.473	-0.631	-0.104	-0.019	0.049
	0.510	0.428	0.323	0.326	0.117	0.801	0.964	0.905
UNRELI	3.277	0.423	0.463	0.129	0.509	1.269	0.070	0.415
	0.080	0.505	0.420	0.807	0.249	0.006	0.881	0.361
COUPLE	-0.174	-0.217	0.127	0.087	-0.280	0.014	0.052	0.043
	0.890	0.611	0.741	0.806	0.345	0.965	0.869	0.887
SPHH	-1.415	-1.012	-0.386	-0.591	-0.539	-0.106	0.504	0.716
	0.472	0.131	0.523	0.288	0.246	0.825	0.307	0.135
NUCLR	1.637	-0.056	0.350	-0.041	-0.265	0.261	0.498	0.890
	0.288	0.914	0.459	0.925	0.466	0.485	0.197	0.018
AFWKID	-1.691	-0.874	-1.013	-0.072	-0.367	0.039	0.371	0.223
	0.237	0.073	0.022	0.859	0.277	0.910	0.301	0.521
RDENP	-0.044	-0.009	-0.004	-0.007	-0.006	-0.006	-0.005	-0.006
	0.005	0.084	0.432	0.092	0.084	0.106	0.189	0.127
CITY	-0.213	-0.468	0.399	-0.046	0.126	-0.115	0.149	-0.259
	0.819	0.139	0.163	0.861	0.564	0.612	0.522	0.253
HHRES6	4.217	0.896	-0.224	1.364	0.702	0.235	0.821	0.423
	0.002	0.052	0.590	0.000	0.029	0.475	0.016	0.199
STD ERR	4.425	1.504	1.361	1.252	1.044	1.077	1.109	1.077
R-SQUARE	0.559	0.613	0.392	0.193	0.147	0.270	0.205	0.186

NOTES: 1. For variable definitions, see Tables 12 and 13.

2. For each variable, the coefficient is on the first line; the probability that this coefficient is different from zero is on the second line.

3. "STD ERR" is the standard error of the estimated variable; "R-SQUARE" is the squared multiple correlation coefficient.

SOURCE: Based on data contained in the Baltimore Travel Demand Data Set. Table compiled in December 1980.

Table 17 Home-based dependent variable definitions

Purpose	Definition
HTRIPFRQ	Total number of home-based trips for all purposes
HFRQPUR2	Home-based work trips
HFRQPUR3	Home-based shopping trips
HFRQPUR4	Home-based personal business trips
HFRQPUR5	Home-based entertainment/community trips
HFRQPUR6	Home-based visit/social trips
HFRQPUR7	Home-based service/accompany traveler trips

NOTES 1 All variables are expressed in numbers of trips per household by eligible household members (age > 12 years)

2. See Table D-1 for more extensive definitions

Clearly, the approach could be extended to a multimodal context, but the degree of complexity rises by a corresponding amount In order to simplify the analysis, the seven activities were combined into four These activities include activity time in home, time at work or school, time spent in entertainment or visiting, and time spent outside the home in home-serving activities such as shopping, personal business, and service/accompany traveler Travel by both motorized and nonmotorized modes is dealt with in the total trip time, frequency, and miles traveled variables

One striking finding is the extent to which vehicle ownership pervades the prediction of out-of-home time allocation even when other influences are controlled for Vehicle ownership is predicted by income, among other variables This structural relationship shows clearly why income is not an effective predictor of trip frequency when the number of vehicles owned is also in the equation, as demonstrated in earlier sections

For *activity time*, time at home and work substitute for each other, however, other out-of-home activities are complementary with time spent at home The negative relationship of age to out-of-home activity shows clearly in these results, as it has in all the prior modeling presented in this report As time at home and time at work are negatively related to the educational structure of the household, this would imply that households comprised of persons with a higher level of education tend to spend more time in out-of-home nonwork activities Other familiar relations such as the confining nature of having a preschooler in the family and the negative relationship of net residential density to measures of mobility are also found Increasing amounts of time spent in home-serving activities tend to increase total travel time and total frequency, but time spent outside of the home for other purposes does not

There is a positive and reciprocal relationship between *travel time* and trip frequency, both in the aggregate and for each purpose Total travel time tends to be related to total travel distance but tends not to be related to vehicle-miles traveled by purpose The positive relationship of trip time to density and the negative relationship to income indicate constraints of centrally located areas The negative relationship between activity time and trip time by purpose suggests a time budget for the activity as a whole, and consequent tradeoff of travel time against activity time.

In contrast to travel time, *travel frequency* is positively related to activity time for out-of-home purposes Travel distance is not traded off against frequency for out-of-home activity, and only for entertainment and visiting is travel time associated with frequency

With respect to *person-miles traveled* for out-of-home activities, the greater the amount of time spent in the activity, the farther the distance traveled to the activity Only in the case of entertainment is there a tradeoff between frequency and distance traveled The other relationships are consistent across purposes travel time and income are positively related, and density is negatively related

SUMMARY

This chapter has summarized the major findings from three areas of analysis: individual level time allocation models, household trip generation models, and household structural equation models of the interactions among mobility variables. The individual time allocation analysis has demonstrated the importance of individual and household characteristics in explaining daily activity patterns. The trip generation analysis suggests that standard trip generation models may be improved by including age structure, household structure, and residential zone characteristics The structural equation modeling is an example of a potentially useful approach for analyzing simultaneously aspects of travel behavior that are typically considered separately

Table 18 Home-based trip frequency by purpose (for 629 households with weekday travel)

INDEPENDENT VARIABLES	DEPENDENT VARIABLES HTRIPFRQ PROB-T	HFRQPUR2 PROB-T	HFRQPUR3 PROB-T	HFRQPUR4 PROB-T	HFRQPUR5 PROB-T	HFRQPUR6 PROB-T	HFRQPUR7 PROB-T
INTERCEP	-1.559	-0.826	-0.436	-0.187	0.263	0.255	-0.629
	0.154	0.178	0.416	0.620	0.626	0.558	0.159
VEHOWN	0.635	0.234	0.104	0.023	-0.091	0.122	0.243
	0.001	0.025	0.253	0.718	0.323	0.100	0.001
INCOMEM	0.016	0.021	-0.008	0.004	0.013	-0.012	-0.000
	0.301	0.019	0.280	0.450	0.101	0.048	0.939
NTEEN	2.989	1.425	0.312	0.116	0.606	0.440	0.090
	0.000	0.000	0.000	0.044	0.000	0.000	0.186
N20T034	2.604	1.024	0.501	0.261	0.417	0.288	0.113
	0.000	0.000	0.003	0.028	0.015	0.036	0.424
N35T054	2.227	1.004	0.493	0.164	0.290	0.182	0.095
	0.000	0.000	0.008	0.209	0.122	0.228	0.540
N55T064	2.281	0.840	0.600	0.170	0.393	0.134	0.144
	0.000	0.000	0.003	0.230	0.053	0.414	0.391
N65PLUS	1.273	0.364	0.505	0.205	0.182	-0.027	0.044
	0.003	0.123	0.015	0.159	0.384	0.874	0.799
SFDU	0.253	-0.380	0.067	0.186	-0.020	0.068	0.332
	0.508	0.077	0.722	0.159	0.917	0.656	0.035
PREDUM	-1.004	-0.202	0.027	-0.158	-0.099	-0.113	-0.460
	0.026	0.424	0.902	0.309	0.658	0.529	0.013
GRADEDUM	0.112	-0.278	-0.174	-0.129	0.458	-0.090	0.327
	0.769	0.194	0.353	0.327	0.016	0.554	0.036
HMMAKEDM	0.086	-0.390	0.197	0.120	-0.021	-0.091	0.272
	0.776	0.022	0.187	0.253	0.890	0.449	0.028
HHRACE	-0.360	-0.519	-0.024	-0.019	0.119	-0.056	0.140
	0.320	0.011	0.892	0.880	0.508	0.696	0.345
SMALE	2.149	0.679	0.567	0.224	0.443	-0.054	0.291
	0.023	0.200	0.222	0.493	0.345	0.885	0.452
SFMALE	1.521	0.790	0.429	0.121	0.119	-0.241	0.303
	0.081	0.106	0.315	0.688	0.783	0.488	0.394
UNRELI	1.791	0.964	0.486	0.107	0.012	-0.120	0.342
	0.043	0.052	0.263	0.726	0.979	0.734	0.345
COUPLE	1.100	0.371	0.073	0.197	0.111	0.181	0.167
	0.073	0.280	0.807	0.352	0.715	0.459	0.504
SPHH	1.702	0.845	0.720	0.147	-0.148	-0.195	0.333
	0.066	0.104	0.114	0.646	0.747	0.598	0.379
NUCLR	1.378	0.517	0.495	0.171	-0.381	-0.121	0.697
	0.048	0.185	0.147	0.476	0.269	0.661	0.014
AFWKID	1.226	0.249	0.563	0.063	-0.176	0.182	0.346
	0.065	0.504	0.084	0.783	0.592	0.492	0.202
RDENP	-0.013	-0.003	-0.006	-0.003	-0.005	0.006	-0.002
	0.026	0.319	0.050	0.143	0.074	0.014	0.467
CITY	0.034	0.299	0.272	0.161	-0.514	-0.303	0.120
	0.929	0.170	0.154	0.229	0.008	0.050	0.448
HHRES6	-0.366	-0.277	0.093	0.149	-0.370	-0.085	0.125
	0.533	0.400	0.747	0.462	0.204	0.715	0.603
STD ERR	3.350	1.879	1.645	1.157	1.661	1.336	1.370
R-SQUARE	0.652	0.545	0.136	0.064	0.196	0.192	0.155

NOTES: 1. For variable definitions, see Tables 13 and 17.

2. For each variable, the coefficient is on the first line; the probability that this coefficient is different from zero is on the second line.

3. "STD ERR" is the standard error of the estimated variables; "R-SQUARE" is the squared multiple correlation coefficient.

SOURCE: Based on data contained in the Baltimore Travel Demand Data Set. Table compiled in December 1980

Table 19 Home-based trip frequency by purpose (for 221 households with weekend travel)

INDEPENDENT VARIABLES	DEPENDENT VARIABLES HTRIPFREQ PROB-T	HFRQPUR2 PROB-T	HFRQPUR3 PROB-T	HFRQPUR4 PROB-T	HFRQPUR5 PROB-T	HFRQPUR6 PROB-T	HFRQPUR6 PROB-T
INTERCEP	2.474	-1.638	1.542	1.268	0.976	0.069	0.256
	0.100	0.069	0.033	0.043	0.196	0.916	0.635
VEHOWN	1.068	0.029	0.412	0.164	0.143	0.310	0.009
	0.001	0.876	0.006	0.206	0.364	0.025	0.934
INCOMEM	0.004	0.016	-0.009	-0.004	0.008	-0.007	-0.002
	0.862	0.201	0.396	0.691	0.443	0.464	0.810
NTEEN	2.566	1.769	-0.046	0.128	0.463	0.178	0.075
	0.000	0.000	0.765	0.340	0.005	0.210	0.520
N20TO34	1.318	1.325	-0.164	-0.322	0.085	0.275	0.118
	0.011	0.000	0.508	0.133	0.743	0.226	0.524
N35TO54	1.287	1.061	-0.021	-0.228	0.027	0.485	-0.036
	0.029	0.003	0.940	0.350	0.928	0.061	0.864
N55TO64	0.799	1.125	-0.170	-0.237	-0.023	0.029	0.075
	0.146	0.001	0.518	0.299	0.933	0.905	0.704
N65PLUS	0.624	0.506	-0.059	-0.294	0.113	0.231	0.127
	0.310	0.170	0.841	0.249	0.715	0.393	0.564
SFDU	-0.315	0.079	-0.188	0.342	-0.404	-0.385	0.242
	0.619	0.835	0.535	0.194	0.204	0.167	0.289
PREDUM	0.634	0.383	0.510	-0.075	0.465	-0.290	-0.358
	0.408	0.404	0.166	0.813	0.228	0.389	0.194
GRADEDUM	0.858	0.567	0.155	0.143	-0.338	0.374	-0.043
	0.206	0.163	0.632	0.610	0.320	0.210	0.861
HHMAKEDM	-0.743	-0.441	-0.181	-0.261	0.385	-0.324	0.079
	0.144	0.148	0.456	0.217	0.132	0.148	0.666
HHRACE	0.241	0.021	0.544	-0.177	-0.034	-0.410	0.297
	0.677	0.952	0.050	0.459	0.907	0.107	0.153
SMALE	0.128	1.400	-1.015	-1.129	0.079	0.792	0.001
	0.930	0.112	0.149	0.064	0.914	0.220	0.998
SFMALE	-0.818	1.159	-0.758	-0.867	-0.398	0.014	0.033
	0.484	0.099	0.176	0.074	0.497	0.978	0.938
UNRELI	1.026	0.165	-0.890	0.885	0.729	-0.157	0.294
	0.424	0.830	0.148	0.097	0.258	0.780	0.523
COUPLE	-0.350	0.119	-0.052	-0.353	-0.153	0.088	0.001
	0.684	0.818	0.899	0.324	0.723	0.816	0.996
SPHH	-1.842	-0.833	-0.966	-0.612	-0.220	0.291	0.498
	0.173	0.303	0.136	0.275	0.745	0.624	0.305
NUCLR	0.177	-0.355	-0.213	-0.306	-0.015	0.161	0.904
	0.867	0.575	0.674	0.485	0.978	0.729	0.018
AFWKID	-1.654	-1.784	-0.405	-0.203	-0.085	0.505	0.318
	0.093	0.003	0.388	0.618	0.863	0.242	0.367
RDENP	-0.018	0.004	-0.003	-0.002	-0.009	-0.002	-0.006
	0.092	0.551	0.529	0.654	0.110	0.605	0.141
CITY	-0.826	0.274	-0.382	0.027	-0.376	-0.095	-0.274
	0.196	0.473	0.211	0.920	0.241	0.735	0.233
HHRES6	1.875	-0.124	1.549	0.456	-0.375	0.162	0.206
	0.044	0.823	0.001	0.236	0.421	0.692	0.535
STD ERR	3.039	1.819	1.454	1.260	1.526	1.335	1.092
R-SQUARE	0.607	0.512	0.203	0.119	0.193	0.227	0.169

NOTES: 1. For variable definitions, see Tables 13 and 17.

2 For each variable, the coefficient is on the first line, the probability that this coefficient is different from zero is on the second line

3. "STD ERR" is the standard error of the estimated variables, "R-SQUARE" is the squared multiple correlation factor.

SOURCE. Based on data contained in the Baltimore Travel Demand Data set. Table compiled in December 1980.

CHAPTER THREE

APPLICATIONS

INTRODUCTION

This report has concentrated on the impact of externally observable characteristics of the individual and household in determining travel behavior measures—in particular, measures of the amount of time allocated to travel and the frequency of that travel by purpose. The examination of time allocation addressed a state-of-the-art issue in travel behavior research. The analysis of trip frequency has resulted in improved models of trip generation, which are the main practical focus of this chapter. The role of a variety of sociodemographic variables has been examined including, at the *individual level*, properties of the person as well as properties of the household situation within which persons find themselves. At the *household level*, the role of both family structure and age structure in determining trip generation rates has been examined, and the added value that such concepts, in conjunction with measures of residential location, can have in predicting household trip generation rates has been demonstrated.

At the household level, this analysis has been imbedded in a more traditional model framework that uses household size, vehicles owned, and income as predictors of trip generation rates. For the most part, income plays a negligible role in predicting trip generation when other factors, such as household composition, are included in the models This suggests that, in models such as these, household income is essentially a proxy for other variables that determine trip frequency. Although the number of vehicles owned by the household can be predicted as a function of household structure variables, it seems to contain additional information and probably captures preference for a certain type of lifestyle that cannot be measured with existing household interview data.

Consideration of basic demographic variables such as the age structure and relationship structure within the household, as well as characteristics of the residence location of the household, are important concepts to include in trip generation procedures. For example, the age, sex, and race composition of adults for the United States in the year 1990 is virtually known today, barring war, other massive catastrophes, or greatly altered patterns of immigration or emigration

Table 20 indicates that the number of children aged 0 through 19 will be rising relatively slowly in the next decade as will the number of young adults (20–34), while the fastest growing group is the baby boom cohort reaching middle age (35–54). Those nearing retirement age (55–64) will show a slight drop, while the ranks of senior citizens (65 and older) are expected to grow relatively rapidly. While the total population will show a moderate increase in that decade, the number of households is expected to rise at double that rate, and the population per household will fall As all of the results reported here (and elsewhere) show declining mobility with increasing age, one pssible implication for transportation is that the frequency of work trips may increase, or decrease at a lower rate, than all trips, and other types of travel may show decline. Effects of this sort can be quantified with the models presented in Appendix F.

Table 20 Population change, 1980–1990 by age group (in 1000s)

	Population Estimates		Percent
	1980	1990	Change
Child (0-19)	70,525	71,972	+ 2 1
Young Adult (20-34)	57,090	59,040	+ 3 4
Middle Age (35-54)	48,417	61,901	+ 27 8
Preretirement (55-64)	21,199	20,776	- 2 0
Senior Citizen (65+)	24,927	29,825	+ 19 6
Total Population	222,158	243,514	+ 9 6
Total Households	79,704	96,792	+ 21 4
Population per Household	2 8	2 5	- 9 7

SOURCE Charles River Associates Incorporated "Regional MARKETS Forecasts 1980 " Boston, Massachusetts, 1980

An open issue, however, is whether there are "cohort effects" with respect to mobility rates. For example, Wachs and Blanchard (*15*) argue that for those (more recent) elderly who have been more mobile in earlier life, established patterns of auto ownership and use, better health, and decentralized residential location will promote higher mobility rates in later life than that enjoyed by similar elderly cohorts from earlier epochs. Cross-sectional analysis will not answer this question, however.

For other variables that are considered here, such as employment patterns, rates of household formation, and (implicitly) fertility, the patterns are less predictable. However, changes are occurring in each which are not simply extrapolations of past trends. A recent report (*16*) foresees a decline in average household size, a rise in single-person households, a decline in husband / wife households, a rise in the proportion of female-headed households, a decline in the age at which children leave home, and a decline in the presence of "other" household members such as boarders, subfamilies, grandparents, other relatives, etc. Married couples with one worker only are a declining proportion of households, while married couples with two workers are an increasing proportion. Clearly such trends have implications for the use of time, out-of-home activities and travel, as well as residential location decisions. Each change, moreover, is related to variables that the research team found to be important in explaining activity and travel behavior; to ignore such changes in estimating such fundamental processes as trip generation rates, as conventional models do, would seem to be ill-advised, given the sorts of findings presented here

The forecasting of these quantities at the metropolitan area or traffic analysis zone level is, of course, fraught with greater uncertainty than it is at the national level. However, estimation at the small area level of variables such as are considered here is no more arbitrary than the forecasting of vehicle ownership or income levels—it simply means a reorientation of existing efforts (see NCHRP Project 8-24 (*5*) for procedures for predicting the independent variables in traditional models). Further, land-use models that deal with the sorts of variables considered in this report exist, and application of their output to trip generation questions is feasible The community analysis model (*17, 18, 19*) appears to be especially useful for generating the inputs for applying the trip generation models developed in this study This model produces estimates of 36 population types (4 classes of age, and 3 each of ethnicity and education) and 27 household-head types (omitting age 0–19) It also has housing, employment, and land-use variables. The neighborhoods are aggregations of Census tracts.

EXAMPLES

In Chapter Two, it was shown that the enhancement of standard trip generation models with variables describing the household and the residential zone improved the explanatory power of such models. In this section, a demonstration of how the predictions of the enhanced models compare to those of the standard models is presented The purpose of the demonstration is to test the importance of household and/or zonal descriptions in trip generation predictions

Example 1—The Effects of Life Cycle on Trip Generation

In this example, the relative sensitivities of the standard and enhanced trip generation models to changes in household life cycle are compared Five hypothetical households are considered· (1) a couple in their early 30's with a preschool child, (2) a couple with the older member over 35 and the younger under 35 with one gradeschool child, (3) a couple with both members over 35 with one teenage child; (4) a couple with both members over 55 with no children at home; and (5) a couple with both members over 65. The characteristics of these households in terms of the variables in the trip generation models are given in Table 21 These households can be viewed as either five different households or as a single household progressing through life-cycle stages

Because home-based trip generation models are commonly used in planning practice, the model in Table 18 is used as the enhanced model The corresponding standard model, which contains vehicle ownership, household size (total eligible), and income as explanatory variables, appears in Table 22

The estimated daily trip rates for the alternative models are presented in Table 23 The alternative models produce noticeably different results, both in absolute terms and in the predictions of how travel varies with life cycle The standard

Table 21 Characteristics of five hypothetical households used in applications of trip generation models

Variables*	Household 1	2	3	4	5
VEH	1	1	1	1	1
INCOMEM	20	20	20	20	15
TOTELIG	2	2	3	2	2
NTEEN	0	0	1	0	0
N20TO34	2	1	0	0	0
N35TO54	0	1	2	0	0
N55TO64	0	0	0	2	0
N65PLUS	0	0	0	0	2
SFDU	1	1	1	1	1
PREDUM	1	0	0	0	0
GRADEDUM	0	1	0	0	0
HMAKEDM	1	0	0	0	0
HHRACE	0	0	0	0	0
SMALE	0	0	0	0	0
SFMALE	0	0	0	0	0
UNRELI	0	0	0	0	0
COUPLE	0	0	0	1	1
SPHH	0	0	0	0	0
NUCLR	1	1	1	0	0
AFWKID	0	0	0	0	0
RDENP	41	41	41	41	41
CITY	1	1	1	1	1
HHRES6	0	0	0	0	0

*Variables are defined in Table 13.

Table 22 Standard home-based trip generation model (total daily trips)

Variable	Coefficient
INTERCEPT	2.046
VEHOWN	.807
INCOMEM	.018
TOTELIG	2.764

Note: Independent Variables are defined in Table 13.

SOURCE: Model estimated by CRA, 1981.

Table 23 Estimated trip frequencies for five hypothetical households

	Household* 1	2	3	4	5
Standard Model**	4.65	4.65	7 41	4 65	4 56
Enhanced Model+	4.82	5 47	7 97	4 81	2.72

*The characteristics of the five hypothetical households are defined in Table 21

**The coefficients of the standard home-based trip generation model are presented in Table 22.

+The coefficients of the enhanced home-based trip generation model are presented in Table 18 model changes substantially only for the third household, in which the teenage member counts for one additional eligible member

In contrast, the enhanced model shows substantial changes throughout the various life-cycle stages. As a family progresses from one with a preschool child to one with a school-age child (Household 2 vs Household 1), the restrictive effect of the preschooler is removed, thus increasing travel. When the child becomes a teenager (Household 3), his high trip generation rate substantially increases household travel The older couple (Household 4) has approximately the same expected travel frequency as the youngest household. The somewhat lower trip generation rates for older adults are offset by not having the restrictive effect of the preschool child. Finally, the oldest household has a very low expected travel frequency, reflecting the low trip generation rates of people over 65

In summary, this example shows that the enhanced trip generation model has noticeably more sensitivity to household characteristics when the model is applied at the household level. A similar conclusion is also likely for homogeneous zones For example, the enhanced model would likely produce lower trip generation rates for an area dominated by older households than it would for one with younger households The standard model, on the other hand, may not be sensitive to such differences.

Example 2—Aggregate Application

In this example, the standard and enhanced models are applied to areawide averages of the independent variables The approach parallels that used for the forecast experiments using the individual-level time-allocation models. That is, the sample avegarges for the Baltimore data set are adjusted to reflect key demographic changes between now and 1990. Table 24 presents this information

The specific values for 1990 are primarily illustrative. They were selected to reflect changes in household size and age composition likely to occur over the period. The values reflect the research team's judgment, informed by projections from census data and other sources.

Both models produce estimates that match the sample average trip generation (6.39 trips per day) for 1977 (This outcome results from the property of regression models that the estimated value of the dependent variables at the sample averages of the independent variables equals the sample average for the dependent variables.) For the forecast period, the projections are 5 65 trips and 5.87 trips for the standard and enhanced models, respectively.

It can be seen that although the enhanced model produces a forecast about 4 percent higher than that of the standard model, both models forecast a decline in trips per household. This outcome is primarily the result of the decline in household size Total travel, on the other hand, is likely to increase because of the increase in the number of households. For example, if the national rate of increase in the number of households of 21 4 percent (see Table 20) is applied with the trip generation models, the resulting increases in total trips are 7.3 percent and 11.5 percent for the standard and enhanced models, respectively.

Table 24 Current and projected values for independent variables of trip generation models (aggregate example)

Variables*	Current Values	Projected Values (1990)
VEH	1.21	1.21
INCOMEM	16.16	17.87
TOTELIG	2.59	2.32
NTEEN	.63	.53
N20TO34	.71	.60
N35TO54	.71	.75
NTTTO64	.28	.22
N65PLS	.30	.30
SFDU	.34	.34
PREDUM	.17	.15
GRADEDUM	.30	.30
HMMAKDM	.39	.39
HHRACE	.36	.36
SMALE	.05	.08
SFMALE	.08	.10
UNRELI	.03	.05
COUPLE	.18	.21
SPHH	.10	.12
NUCLR	.30	.21
AFWKID	.16	.13
RDENP	41.42	41.42
CITY	.64	.64
HHRES6	.06	.06
Daily Homebased Trips (Dependent Variable)	6.39	5.65 (Standard Model) 5.87 (Enhanced Model)

*Variables are defined in Table 13.

In this example, the difference in forecasts resulting from the alternative trip generation models is smaller than in the first example This outcome suggests that the sharp differences possible for single households (or homogeneous zones) cancel out to some extent in heterogeneous aggregates. Therefore, the enhanced models may provide the largest advantage over the standard models when applied to reasonably homogeneous areas Even in the case of heterogeneous areas, e g , urban areas, the smaller differences between these models may be of some importance

PRACTICAL APPLICATION OF NEW TRIP GENERATION MODELS

Using the trip generation models described in this report for practical planning applications would in many ways be similar to using standard Urban Transportation Planning System (UTPS) trip generation procedures. The major difference is in the number and types of independent variables included in the models.

In this section, a step-by-step description of model applications is provided. This discussion should be viewed as preliminary. As recommended in Chapter Four, a practical demonstration of the trip generation models for particular metropolitan transportation planning problems would result in comprehensive guidelines for future applications.

The following steps would be followed in developing and applying new trip generation models: (1) preparing data, (2) estimating the model; (3) forecasting values of independent variables, and (4) applying models to forecast trip frequency.

Step 1—Preparing Data

The trip generation models developed in this study have been designed to be compatible with standard transportation data bases. Therefore the first step is to prepare a data file containing the dependent and independent variables of the models from origin-destination survey data.

Dependent Variables

Trip frequency, defined as either activity-based or home-based, is classified into several trip purpose categories. Home-based trip generation models are more likely to be of immediate practical usefulness because they directly replace currently used trip generation models.

Preparation of the home-based trip frequencies is very similar to the procedure necessary to apply current UTPS home-based trip generation models. Trip purpose classification, defined by the purpose at the nonhome trip end, would follow the trip purpose classification scheme described in Appendix D, Table D-1. (Some judgment by the analyst may be necessary if trip purpose categories do not perfectly match the categories used in the Baltimore Data Set.)

Activity-based trip frequencies are defined by the trip purpose at the destination. With the exception of purpose definition, data preparation follows the same procedures as does the preparation of home-based trip frequency variables

Independent Variables

As discussed in Chapter Two, the independent variables in the trip generation models are of five types. (1) variables used in current trip generation models, (2) age structure variables, (3) household type; (4) other household characteristics; and (5) residence zone descriptors Table 13 provides definitions of the variables.

With the exception of the third type of variable, data preparation is straightforward and quite similar to preparing the independent variables for standard home-based trip generation models. Of course, particular variables might differ somewhat from the definitions in the Baltimore Data Set, e.g., different break points might be used in defining age categories. The practical demonstration recommended in the next chapter would be useful in identifying such differences and in providing guidelines for dealing with them.

The household typology developed for this study resulted in eight types of households. The procedures followed in assigning households to each class are described in detail in Appendix D. Again, there may be differences between the Baltimore survey instrument and an origin-destination survey instrument that might require modifications in the household typology definitions and procedure. The practical demonstration would illuminate the consequences of any such differences in data bases.

Step 2—Estimating the Model

Following the data preparation steps, the analyst would have a data file in which each record would represent a household. The variables would include the dependent and independent variables of the trip generation models This data file would be the input to a standard regression analysis program, which is typically well known and readily available to metropolitan transportation planners.

For each trip purpose category, as well as for combined (total) trip frequency, the regression model would contain the measure of trip frequency as the dependent variable. (As noted earlier, home-based trip frequencies are more directly compatible with standard UTPS procedures.) The same set of independent variables, prepared in the previous step, would be used for each trip purpose category.

The total number of independent variables listed in Table 13 is quite large. Further, not all of the variables contributed substantially to the trip generation models in this report. Therefore, in order to facilitate forecasting with the models it may be desirable to use a smaller number of independent variables

A practical demonstration of the new trip generation procedures would result in guidelines for selection of the subset of independent variables. In general, variables that have only a small impact on estimated trip frequencies over a wide range of forecasts can be excluded from the model. This criterion is not necessarily the same as dropping variables that are statistically insignificant at the standard 0 05 level.

Step 3—Forecasting Future Values of Independent Variables

The first two steps produce trip generation models ready for applications to practical planning problems These applications require forecasts of the independent variables of the models at the level of aggregation for which the model is applied. In many cases, this will be the traffic analysis zone

Earlier in this chapter the issue of forecasting the independent variables of the new trip generation models was discussed. It was concluded that there are promising procedures for such forecasts, which should be a major focus of the practical demonstration of the new trip generation models.

Step 4—Applying Model to Forecast Trip Frequency

This last step is the straightforward application of the trip generation models with the independent variables forecast in Step 3 as inputs The examples in the previous subsection illustrate how the models can be applied Because the models would be applied to each unit of analysis, e.g., traffic analysis zone, the trip generation equation would be incorporated into the UTPS software. This modification to the standard four-step sequence should require minimal effort.

This four-step procedure for applying the new trip generation models assumes that a metropolitan area would develop its own trip generation equations as typical in applications of UTPS. If future research produces guidelines for transferring models from other areas, the first two steps would be bypassed and the analyst would proceed directly to Step 3 with the transferred models.

TRANSFERABILITY AND IMPLEMENTATION ISSUES

Transferability

The transferability issue has been discussed by numerous researchers. One review (*20*, Ch. 3) has concluded that logit travel demand models cannot be transferred from city to city without modification but that there are situations under which such models may be successfully transferred They note that bias may be introduced because of different "utilities" between the calibration and prediction samples, because of variation in the utility of subgroups of the calibration sample (termed "aggregate misspecification"), and because of aggregation bias. This latter form of bias affects models that are nonlinear either in variables or parameters; it will not concern us here because the household-level models formulated in this study are linear in both variables and parameters. Thus, it will not matter whether predictions are made at the individual or market segment level and averaged, or whether average values of the independent variables are used in the prediction equations directly.

However, other factors may affect the transferability of a model. Differing parameter values between applications is one possibility. This may arise because of variations among subgroups of the calibration sample for which the model does not control (inadequate segmentation), variations for like subgroups between cities (interregional variation), variations over time, or model specification error.

Segmentation is one issue which, given limited degrees of freedom and limited theoretical rationale for segmenting, may always be a problem However, an attempt has been made to introduce a number of main effects into the models to capture important relationships, although certain interaction effects may be lost.

Interregional variation may well occur because of different cultures in different cities, different scales of the city, different level of service of transit or auto, a different structure of opportunities, etc Presumably, all but the first of these would affect trip generation less than the others, although recent evidence indicates problems even here (*21*).

Because household interview surveys are conducted at different times in different cities, temporal changes in the parameters might also occur, even if the model were correctly specified. This is essentially another kind of difference between the calibration and prediction samples, although it will not always occur in attempts at transferability This factor can be important if there are secular trends in patterns of behavior, or if there are sudden shocks, such as oil embargoes, which disrupt existing behavior patterns.

Finally, there is the problem of other specification error. This might arise from omitting variables that may vary differently in different times, regions or segments, or from incorrect choice of functional form If data are not available in a new area and a reduced specification is employed, a known specification error is introduced.

Implementation Problems

There are also possible biases in estimating values for both the dependent and independent variables in any validation or application task. Typically, the dependent variables would be generated from a home interview survey, using the sampling weights developed from the sampling procedure. Except in the case of a "complete enumeration," as for certain items of the U S. Decennial Census (even here, underenumeration is a problem), the values of the dependent variables will only be as good as the sampling procedure allows. In the case of small samples, or estimates of travel behavior for small market segments or small areas, where only a few observations may represent the entire population, estimates of the dependent variables may be subject to considerable variance. This may be termed "factoring bias "

There is also the issue of estimating the values of the exogenous variables. This may arise in two contexts One, a planner may have estimates from the Census or elsewhere of aggregate measures such as counts of households by numbers of vehicles owned and counts of households by income class when what is desired is estimates of the joint frequency of numbers of households by vehicle and income class. A method of synthesizing such information using disaggregate data from household interview surveys, the Census Public Use Sample information, or the National Personal Transportation Survey data, in conjunction with known distributions by area, can be used to estimate such joint distributions. This technique is discussed more fully by CRA (*20*), Birch (*22*), and McFadden (*23*).

Finally, one may estimate the values of exogenous variables required either by extrapolation from a base year or by the development of a "land-use" model that attempts a more behaviorally oriented explanation of the change that occurs. The former method is a naive one and applicable only if the variables' rates of change are quite stable (and in that case perhaps not particularly interesting). The development of a more behavioral land-use model is, of course, a very large undertaking

One might note that these transferability issues exist in principle for all proposed travel models. The approach developed here has the advantage that it explicitly incorporates a number of important determinants of travel behavior, potentially reducing errors of specification, which are one source of bias.

CHAPTER FOUR

CONCLUSIONS AND RECOMMENDATIONS

This report has presented models of individual and household time allocation, has examined the impact that such allocations have on travel behavior, and has examined the effect of household structure and other demographic variables on behavior The trip frequency models have been formulated in a manner that allows them to be interfaced with UTPS

The principal conclusion of the research is that household structure and life-cycle concepts have an important role to play in travel demand forecasting This importance stems from two sources (1) the inclusion of such variables significantly increases the explanatory power of the estimating equations, and (2) broad societal trends are changing the age structure of the population and the nature of family relationships These trends can be expected to have a direct impact on overall travel behavior in urban areas, to have potentially greater impacts in specific subareas undergoing change, and to affect residential location patterns, which will also affect travel patterns

The examples presented in Chapter Three demonstrate that the inclusion of household structure and life-cycle variables can have a substantial impact on trip generation forecasts, especially at the household and homogeneous zone level. The examination of structural relationships among the variables suggests that a knowledge of these relationships can aid in assessing the impacts of changing time allocations on travel behavior Although all forecasting methods are subject to bias, the approach developed here has the advantage that it explicitly incorporates a number of important determinants of travel behavior, potentially reducing errors of specification that are one source of bias

The principal recommendations for further work in this area include both practical and theoretical investigations A thorough demonstration of the trip generation models developed in this study would be highly useful. Rochester, New York, is a possible site for a demonstration There is a fairly recent origin-destination data set available and, as described in Chapter Three, there also is a land-use model for projecting the household and zonal level input variables Of course, other sites may also have the necessary information

A demonstration would serve two major purposes First, a replication of this basic approach to trip generation would be a test of its usefulness beyond the Baltimore case An important issue would be the extent to which the trip generation model structures are transferable across urban areas Second, a successful demonstration would provide a basis for the development of practical guidelines for the development and application of the enhanced trip generation models in urban transportation policy analysis

The practical guidelines would likely cover a number of issues. First, recommendations on how to develop new enhanced trip generation models or transfer them from other areas would be discussed. Second, procedures for forecasting the input variables at regional and subregional levels would be described In this regard, the applicability of land-use models and the procedures developed in NCHRP Project 8-24 would be particularly important Third, a discussion of the situations in which the enhanced models are especially powerful would be provided The hypothetical examples in Chapter Three suggest that the enhanced models differ from the standard models most in applications to homogeneous groups of households. A demonstration would provide much more definitive conclusions of this nature In addition to the issue of the level of aggregation, the guidelines would also discuss the types of policy application, e g , long-range facilities planning, special areas studies, etc , for which the enhanced models are most useful

Although this study emphasized improvements in trip generation models, the fundamental concepts identified and examined here are applicable to other components of the traditional four-step UTPS sequence For example, Salomon and Ben-Akiva (*24*) found that a life-style categorization, based on household characteristics, was very effective in nonwork trip distribution and modal choice models More research on all components of the traditional sequence may identify promising areas for enhancing the entire sequence and, ultimately, guidelines on how and where to apply the improved models

In addition to improving practical transportation planning tools, this study also examined theoretical concepts such as lifestyle, life-cycle, and activity-based approaches to understanding travel behavior The principal concepts of the activity approach are the following. activity patterns of individuals and households, the scheduling of activities in space and time, corresponding spatial and temporal constraints on activity, interactions of decisions over the day and within the household, a stress on household characteristics such as life cycle, and adaptation and change

The theoretical parts of this project complement the considerable amount of recent research on activity-based approaches. Damm (*25*) provides a very useful integrative summary of this work, including this project While Damm's paper clearly identifies the key concepts and findings, there is still a need to study interrelationships among the major concepts Almost all of the previous work has addressed only one or two of the concepts

The structural equation approach illustrated in Chapter Two appears to be a promising method for a comprehensive and integrative examination of the various facets of activity and travel behavior. Only by identifying these structural relationships among such variables can one understand the nature of the adjustments made in persons' and households' activity and travel as a reaction to changed circumstances Additional research into life-cycle changes and their effect on travel behavior, explanation of the overall trends producing these changes, and further research on the prediction of life-cycle changes at the traffic analysis zone level would prove fruitful.

This report has pursued the investigation of activity patterns and household characteristics most intensively. While the models incorporating these concepts implicitly deal with the question of constraints, more work needs to be done in this area, as in the area of scheduling. The models developed here might serve to predict the constraint set for a mathematical programming model of scheduling or interaction, for example Such an investigation would also lead into the area of adaptation and change, an area more amenable to research with time-series data bases.

Finally, it is noted that the fundamental concepts emphasized in this study were selected, in part, on the basis of short-term improvements to existing travel demand models Thus, approaches amenable to quantitative analysis were emphasized. As described in Appendix A, a wide range of fundamental social science concepts were considered before narrowing the focus of this study. These concepts included psychological approaches such as attitudinal analysis and applying general personality and motivational measures to explain behavior. Qualitative and quantitative applications of these psychological approaches have the potential of improving the understanding of travel behavior Potential areas of application include aspects of trip making, such as the reasons for particular types of trips, as well as issues related to automobiles, such as fuel conservation and safety.

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APPENDIX A

BACKGROUND

This appendix presents brief reviews of several key concepts of relevance to the research reported below. First, we describe a general review of behavioral science concepts of potential use to travel behavior. Next, we review specific concepts that have been used to analyze transit behavior, including: activity approaches, changing household composition, trip generation, the Baltimore area, and the Baltimore Travel Demand Data Set. Activity approaches are an important cornerstone of the approach developed here. The issue of household composition naturally flows from this, but also relates to the broader societal changes which will affect transportation planning. The topics of trip generation, the Baltimore area, and the data set are provided as brief introductions to topics that relate to the development of the approach. Finally, we describe further research that is consistent with the general concepts developed in this study.

LITERATURE REVIEW

As part of this project, an extensive review of behavioral science concepts potentially useful for travel forecasting was conducted. The results of this review, which built upon the findings from Phase I of this project (see reference A1 and Appendix G for the summary), are described in detail in a project interim report (A2). Here, the major results are summarized.

The review of behavioral science concepts to be incorporated in travel forecasting practice concentrated on elements from sociology and psychology.

However, literature from other fields, particularly market research and geography, often incorporates these concepts and, consequently, was closely read in coordination with the review of Phase I research results.

It is useful tc classify concepts into the following overlapping categories:

- Attitudes
- Other intrapersonal characteristics
- Environmental perceptions
- Roles
- Lifestyles
- Life cycles
- Market segmentation
- Family dynamics and decisionmaking

The categories of roles, lifestyles, andlife cycles were selected as the major focus of this project.

Roles

The concept of roles generally means expectations for appropriate behavior of a person and can thus shed light on how individuals' social position can structure behavior. Others' opinions and expectations have great power in influencing judgment, attitudes and behavior. People in similar status positions tend to have similar demands placed upon them and this is one reason that "sociodemographic" variables can be effectively used in predicting behavior and devising market segmentation schemes.

Perhaps the most important use of roles is in the definition of role complexes. In Phase I, four categories were suggested. 1) household/family, 2) work/career, 3) interpersonal/social, 4) leisure/recreation. A link may be made between role complexes and activity categories. In Chapter 2, the trip purposes used for the household models were motivated by the role complex concept. How a person allocates time among these categories is an effective way of defining "lifestyle" and, as we shall see shortly, has important implications for transportation behavior and activities analyses. Defining roles in terms of activities allows the use of the concept with standard datasets.

The concept of role expectation has other applications for transportation analysis. Social expectations related to power, control, and independence may lie behind the choice of automobile as a mode of transportation, for example. Sex differences in modal choice may also be related to social expectations in some, as yet undetermined, way. Culturally induced expectations which influence a person's tolerance for physical contact or close proximity in public can have relevance for vehicle design.

Lifestyle

The concept of lifestyle, which may be thought of in activity terms as the way a person allocates time among role complexes, has important implications for travel behavior. This is so because activity patterns are an important component of lifestyle and vary with different lifestyles. Lifestyle may have a direct influence on travel frequency, mode, and

destination choice and an indirect influence on travel behavior through its effect on the choice of residential location. The important idea here is the linkage which exists between lifestyle, roles, and activities, activities clearly can give rise to transportation demands. Some lifestyles prompt a person to leave the home and thus require some form of travel, if only walking. A more home-centered lifestyle or one which revolves about localized kinship ties generates much less travel than a lifestyle devoted to participation in formal organizations or recreational pursuits. If regularities of lifestyle can be identified, this can be a powerful aid to transportation demand analysis.

Life Cycle

Lifestyles are not static throughout a person's life. Demands of one's career and family obligations change over time as well as one's interests and abilities to participate in various social and recreational activities. Thus the patterns of lifestyles which exist at certain ages and life circumstances can be valuable indices of travel demands. Variables such as age, marital status, and the age distribution of children have been found important in analyzing a person's activities and should be incorporated into transportation demand analyses in a systematic and comprehensive way. Pronounced differences in the amount of free time available exist between the pre-child rearing and the initial child rearing stages, as well as between the pre-retirement and post-retirement stages of life. Child rearing implies greater residential dispersion, increased non-volitional travel, and greater travel as children grow older. Leisure and recreation activities predominate in both the early and late stages of life cycles, while career and home maintenance activities predominate in the middle stage. The frequency of travel declines with age. There is less substitutability of activities and less flexibility in the mid-life stage. There are systematic differences in voluntary participation in organizations by age and child-rearing status. Impacts such as these on activity patterns have less clear but researchable implications for travel demand analyses.

ACTIVITY APPROACHES

The research reported herein takes an activity orientation to predicting travel behavior. Although the "activity approach" is not a single and easily-definable set of concepts and methods that can be neatly labeled, several principal themes and methods of research fall under this rubric. These principal concepts include the following: activity patterns of individuals and households; the scheduling of activities in space and time; corresponding spatial and temporal constraints on activity, interactions of decisions over the day and within the household; the importance of household characteristics such as life cycle; and adaptation and change. This is not to say that more traditional modeling approaches do not include some of the above features or that each application of the "activity approach" includes all of them, but only that the above are recurrent themes in this body of literature. (Jones (A3) and Damm (A4) utilize similar categories.)

Activity Patterns

Although it is almost an article of faith that travel is a "derived demand," many approaches ignore explicit consideration of activities and proceed directly to the analysis of travel behavior per se. While this may be defended on pragmatic grounds, such an approach cannot deal with travel demand changes resulting from changes in activity patterns in general. Early works, such as those of Sorokin and Berger (A5) began to deal with "time budgets"; this analysis continued in the work of Szalai (A6), Robinson (A7), and others. Chapin (A8) was perhaps the first to give close scrutiny to the links between activity and travel behavior, but much work has been in recent years (see TRR (A9)). Zahavi (A10) has promoted the idea of time and money travel budgets and has developed a modeling system that attempts to account for such constraints. Wigan and Morris (A11) have also examined this question. Kelly (A12) contrasts the time budget approach with the more established "psychographic" approach to defining lifestyle and activity patterns.

Scheduling

A consideration of activity patterns naturally leads into the question of the scheduling of these activities and the related travel behavior. Goodwin (in Jones (A3)) makes the point that the order and timing of activities may be as important for transportation analysis as are the origin and destinations of the trips. Holzapfel (A13) deals with the question of the dominance or hierarchy of activities implied by such analysis. Questions of scheduling naturally lead into the spatial patterning of activities, making the link between activity patterns and their spatial distribution. Finally, the notion of scheduling encompasses that of chained trips and complex travel (see Burnett and Hanson (A14)). Although chained trips are typically only about one fifth of all trips, the issue of trip chaining is of particular policy relevance, as this type of rescheduling has been found to be one principal mechanism for conserving energy in times of shortage while achieving the goals of a personal activity budget.

Spatial and Temporal Constraints

Spatial and temporal constraints are another important emphasis of the activity approach. Lenntorp (A15) has developed Hagerstrand's concept of "space-time prisms" to illustrate the constraints on people's movement as they pass through the daily activity schedule. Authors such as Burnett and Hanson (A14), Broeg and Erl (A16), Jones et al. (A3), Zahavi (A10), and a host of others emphasize the role of constraints on movement and transportation choices (such as mode). This is in contrast to Chapin and more traditional disaggregate demand modeling which emphasize choice rather than constraint. Damm notes, however, that this may be a false distinction. Constraints may come in many forms. social roles may prescribe what certain persons do (Holzapfel), income and vehicle ownership may impose constraints (Broeg), and the spatial distribution of opportunity may impose constraints, many other physical and temporal constraints, such as the opening and closing times of shops, may also limit choice. Recker et al. (A17) has proposed the use of transform analysis to model such constraints and scheduling.

Interactions

The notion of activities, scheduling, and constraints naturally focuses attention on various forms of interaction. The most important of these are perhaps the interaction of decisions over the day (the scheduling of activities over the day has been dealt with by Damm). Interactions may also occur within the household and affect household and individual tripmaking, this has been dealt with by Jacobson (A18), Jones et al. (A3), and in the Appendix B modeling presented here, among others. The critical point here is that behavior does not exist in isolation but must be considered within other contexts to be explained.

Household Characteristics

The stress on household decision making leads to a focus on the importance of household characteristics in explaining travel behavior. While not ignored by other approaches, its importance is stressed by those utilizing the activity approach. Of particular importance has been the "life-cycle" concept which attempts to examine the variation of activity and travel behavior as persons and households move through definable stages of life (young couples without children, families with preschool children, families with older children, unrelated individuals, individuals living alone, etc.). As there are broad societal trends occurring in rates of family formation, child rearing, and employment patterns, to name only a few areas, such considerations should not be ignored in the analysis of travel behavior. (In Appendix C we experiment with forecasting changes in travel resulting from such demographic shifts.)

Adaptation and Change

There are other important aspects of the activity approach which have not been developed as fully as some of the above. The question of adaptation relates both to a person's resistance to change in the face of changing circumstances as well as to changes that may occur with changed circumstances. These issues have been dealt with by Fried, Havens, and Thall (A1) and Jones et al. (A3). The question of change naturally raises the issue of time series analysis of activity and travel behavior of both individuals and households. At this point, little has been done due to the lack of data, although a framework for analysis has been provided by Tardiff (A19).

HOUSEHOLD COMPOSITION, LIFESTYLE, AND LIFE CYCLE

The question of life cycle was reviewed in greater detail in our First Interim Report (A2). Several of the references noted above treat the relation to travel behavior in some detail, as does the modeling reported below. While these are all cross-sectional studies, a recent paper by Downes (A20) reports that trip rates change over time in a manner consistent with cross-sectional results.

Salomon and Ben-Akiva (A21) define lifestyle in terms of the types of longer-term activity patterns (work, leisure, and family structure) available to the household and they operationalize the concept by using several sociodemographic variables, e.g., income, education, and age, to assign households to lifestyle groups. By using cluster analysis, the authors

derive five groups, for which separate shopping destination and mode choice models are estimated. There are differences among the groups in the resulting models. For example, the groups differ in their sensitivity to travel time. Further, the lifecycle segmentation performs better than do segmentations based upon income and a somewhat simple lifecycle delineation.

There are numerous findings of relevance for travel behavior which are related to life cycle. Chapin, who defined life cycle in terms of age of the household head and the age distribution of children, found the most pronounced differences between the prechildrearing and the initial childrearing stages, and between the preretirement and postretirement stages, in terms of amount of free time available (A8, p. 181). Fried, Havens, and Thall (A1, pp. 85-86) postulate that childrearing implies greater residential dispersion, increased nonvolitional travel, and greater travel as children grow older, that leisure and recreation activities predominate in both the early and late stages of the life cycle, while career and home maintenance activities dominate the middle stage; that the frequency of travel declines with age; that there is less substitutability of activities and less flexibility in midlife cycle; that expectations become more precise with increasing age, and that attitude structures become more stable with time. Zimmerman (A22) examines trip frequencies and distance for 11 lifecyle stages based upon ages of adults and children. Houdeholds with older children have the highest travel demand, which is consistent with the trip generation models of Chapter 2.

Emerging trends in household composition also have a relevance for travel behavior. As pointed out in a recent study, nearly two-thirds of the households in the United States are expected to be childless by 1990 (A23). These expectations are based on declining fertility, increased female labor force participation, increased solitary living, and delayed age of marriage. The authors also foresee a decline in average household size, a rise in single-person households, a decline in the proportion of husband/wife households, a rise in the proportion of female-headed households, a decline in the age at which children leave home, and a decline in the presence of "other" household members such as boarders, subfamilies, grandparents, other relatives, etc. Married couples with one worker only are a declining proportion of households, while married couples with two workers are an increasing proportion. Clearly such trends have implications for the use of time, out-of-home activities and travel, as well as residential location decisions.

Table 20 in Chapter 2 indicates that the number of children aged 0 through 29 will be rising relatively slowly in the next decade as will the number of young adults (20-34), while the fastest growing group is the baby boom cohort reaching middle age (35-54). Those nearing retirement age (55-64) will show a slight drop, while the ranks of senior citizens (65 and older) are expected to grow relatively rapidly. While the total population will show moderate increase in that decade, the number of households is expected to rise at double that rate and the population per household will fall.

TRIP FREQUENCY

Trip frequency has been approached from a variety of methodological perspectives. Cross-classification tables are commonly used. FHWA (A24) has developed an extensive methodology based primarily on auto ownership and income, but modified by other variables, such as city size. For another NCHRP project, John Hamburg and Associates (A25) have looked at the effects of household size, auto ownership, and income on trip frequency and have described methods for forecasting these variables. Dobson and McGarvey (A26) have shown that cross-classification methods are a special case of the general linear model. Tardiff (A27), CRA (A28) and others have employed logit estimation. Jacobson (A18) employed the "tobit" estimator to shopping trip participation and duration, in recognition of the truncated form of the dependent variable.

Papers by both Lerman and Gonzalez (A29) and Ruijgrok and van Essen (A30) have dealt with estimating trip generation as a Poisson process by maximum likelihood methods. Charles River Associates (A31) has utilized structural equations employing two-stage least squares to estimate trip frequencies. Although there are certain conceptual problems in utilizing least squares for this purpose, the benefits outweigh the limitations. This is the approach taken in this report.

THE CITY OF BALTIMORE

The City of Baltimore was specifically chosen as a site representative of other large cities in its urban travel environment for the collection of a major disaggregate data set. This is now referred to as the Baltimore Travel Demand Data Set. Despite its representativeness, Baltimore is atypical in at least one major respect: a large percentage of its households live in row houses in old, very high-density neighborhoods. With this in mind, a general description of the city is warranted so that the study results can be interpreted in a particular context and extrapolated to other cities with some knowledge of similarities and differences.

In order to be selected as the data collection site, the City of Baltimore had to meet a general test of representativeness as well as several specific criteria as follows: 1) the city had to be representative of the urban travel environment, 2) transit had to compete with auto in at least one major transportation corridor, 3) no major travel disruptions were to be scheduled around the time of the survey, and 4) a base of related data had to be available to assist in generating systems performance data.

The Baltimore urbanized area, which is comparable to the area represented by the data set, had a 1970 population of about 1.75 million people, a land area of about 825 square miles, and median family income of about $10,400 (see A32, p. 2). According to the 1970 Census there were approximately 1.05 autos available per household (this is lower than the data set average of 1.2 autos per household). About 18 percent of work trips were made by bus and work-trip auto occupancy was about 1.25 persons per car. These figures compare with Census averages for cities of this size of 1.2 autos per household, 22 percent of work trips made by bus, and work-trip auto occupancy of 1.2 persons per car (A32, p. 3).

Other factors which were felt to affect travel behavior and which led to the choice of Baltimore as a representative city included growth rate, population density, age and income distribution, and a balanced employment profile between different occupational groups. These and other factors evaluated in city selection are described in more detail in Ref. A33.

As mentioned earlier, however, Baltimore is less typical in some of its housing and perhaps ethnic characteristics. In the initial choice of a city, Baltimore was also found to have more poverty and government employment than other cities it was compared with. For further information on Baltimore, Olson (A34) gives a closer look at some of the specific features of Baltimore's housing, city structure, and migration characteristics in a 1976 study.

THE BALTIMORE TRAVEL DEMAND DATA SET

In the spring of 1977, the Baltimore Travel Demand Data Set was collected under the sponsorship of the Federal Highway Administration, Office of Planning. Its purpose was to fill an absence of such data to support the development of disaggregate behavioral travel demand models. The project collected 967 usable household interviews and obtained summary records of all trips taken over a 24-hour period by all household members 12 years old and over. Besides the trip summaries, socioeconomic data were collected on each household member as well as on the household as a whole. A detailed record was obtained on one randomly selected tour made by a randomly selected primary respondent from each household. These data included extensive information on alternative modes or destinations for the trip taken. Data were also collected on each vehicle available for the household's use.

A two-stage sampling plan was carried out. The first stage was an area probability sample. The second stage used disproportionate sampling in Census tracts with high transit use. The sample was also stratified on transit access, race, and income.

ADDITIONAL KEY MODELING ISSUES CONSISTENT WITH THE BASIC CONCEPTS

Additional model development can be undertaken with alternative, not necessarily extant, data bases. Some issues not addressed in the above discussion of modeling include:

1) Technical improvements in probability choice estimation methods;
2) Application of depth interview or interactive game techniques,
3) Application of longitudinal or quasi-experimental data,
4) Interaction of internal, external, and objective variables in determining behavior.

Subjects 1) and 2) have been under intensive study by a number of other research projects being funded by NCHRP, NSF and DOT University Grants, thus it would have been redundant for us to pursue these topics. The use of longitudinal or quasi-experimental data, the third item above, was beyond the scope of this project though we feel it is a very important topic. Although there has been a limited amount of research using panel data and other

longitudinal data bases, extensive research in this area may be valuable for a fuller undersanding of the dynamics of travel behavior.

The interaction of family dynamics, social pressures, personal attitudes, and objective variables is also an important area of further research. We feel that some breakthroughs in travel behavior forecasting could potentially be achieved if appropriate survey data existed which had enough information on each of these concepts.

The following research strategy could have a high payoff in this area 1) check whether existing data sources allow forecasting of activity patterns as a function of external, internal and objective variables, 2) acquire data sets which appear promising; and 3) employ design and data collection methodology which would be specific to the modeling task at hand if existing data sets are inadequate.

In general, the weaknesses of existing data sets are clear. System measures abound, such as levels of service, time and monetary costs, as do externally-observable characteristics of the person such as income or demographic descriptors. Measures of attitudes are less common, but gaining in popularity. Measures of people's perceptions of roles and societal expectations are scarce, measures of susceptibility to such influences are nonexistent in existing data. Measures of family interaction are not collected, although, from an analysis of time budget data for a whole families, inferences about the results of the decision making and role assignment process can be made.

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APPENDIX B

INDIVIDUAL-LEVEL MODELING

Recent work investigating travel behavior has been increasingly broadening in scope as it has turned to view travel behavior as part of the larger allocation of time (and money) to activities across separate locations. Part of this effort has involved attempting to capture the social and physical determinants of behavior outside of immediate economic forces, which have been shown to be important in mode choice. This part of the study attempts to contribute to this literature by modeling individual time allocation in its entirety. By examining time spent in the home and time spent outside the home by purpose and travel time, we attempt to locate the important social determinants that affect behavior. Special emphasis is placed on household structure and the activity pattern of other household members. Only activity time is treated here. We see this as the proper place to start, subscribing to the view that travel behavior, including trip frequency and travel time, is for the most part a "derived demand" which serves the activity schedule of the individual. We defer the question of trip frequency to a later appendix dealing with household-level behavior.

The work reported here is at the level of the individual. We begin at this level for several reasons. First, it is at this level that tradeoffs among individuals may be observed, such tradeoffs are crucial to understanding household role structure. Second, some of the basic demographic characteristics, either known or thought to influence travel behavior, are characteristics of individuals. Such characteristics include employment and marital status, age, sex, race, and education. The concept of income is both an individual- and household-level concept -- income is ascribed to particular members of a household, but other members utilize these resources in differing degrees depending on their roles. (There are also problems with the concept of income as used here which we discuss in the concluding section.)

The general orientation with which we approached the research was that the social circumstances in which an individual lives should have a considerable bearing on the opportunities and the constraints that he or she faces in making activity choices. Whether one lives alone or with others will affect the opportunities for coordination and tradeoff and economies of scale regarding necessary household activities as well as travel instrumental to other pursuits. A married couple with a young preschool child (or children) will generally find itself less mobile than a similar couple without children or with older children who do not require as much care. Elderly and retired persons who live with younger adults are likely to be more active outside the home than elderly persons living with persons roughly their own age or living alone. A single parent will face both the reduced opportunities for tradeoff of the adult living alone and the added constraints on mobility of the presence of children. The number of children and the number of adults living together in a household may also have a bearing on the broad pattern of time use of the individual members.

One way of introducing such notions into a modeling framework is to develop a set of household types that captures these distinctions and to add

this measure to the equations predicting individual behavior. Our goal in designing a household typology has been to test these hypotheses and to determine whether the importance of these structures differs by the sex of the member. We discuss this typology in greater detail below. An alternative approach would be to model household interactions as a set of simultaneous equations for each household member, or class of household members. This, however, would result in a much more complex model. As will be seen, a fair level of complexity is introduced even in our current formulation, and we felt that this was the appropriate place to start.

THE MODEL

A complete framework for analyzing household activity patterns should include household structure and the joint determinants of each member's behavior, so that interdependencies can be uncovered. The determinants include wage opportunities, wealth constraints, presence of children and childcare facilities, auto availability and transit facilities, the opportunities for coordination between household members, and economies of scale in performing activities. Even in the absence of a well-developed theory of household decision making, it seems that opportunities and constraints should be entered into a model for exploratory analysis

Because it is difficult to model members' interactions explicitly, we have tested the adequacy of a simple household typology as a proxy for a large number of these opportunities and constraints. Household relationships also enter the model in the definition of marital status and the employment status of spouse. More traditional socioeconomic variables describing the person, such as sex, race, age, income, education, and employment status of self, index other constraints and opportunities.

Model Structure

The basic form of the system is as depicted in Equation 1 below:

(1) Activity time i = f_i (household type, marital status, employment status [self and spouse], sex, race, age, income, education), where i = 1...12, the set of purposes.

Because the sum of all 12 activity times for each person in the sample is a constant (in this case 24), because the models are linear in the parameters, and because we employ the same set of independent variables in each equation, the following properties hold: 1) the sum of the constant terms across equations is 24; 2) the sum across equations of the coefficients of each other exogenous variable is zero, and 3) the sum across equations of the residuals for each individual is zero. These properties are discussed in greater detail below. It should be noted that ordinary least squares applied to each equation is the appropriate estimator here. This is so because we employ the same set of exogenous variables for each equation and the generalized least squares estimator for the system reduces to ordinary least squares applied to each equation separately (see (B1, pp. 309-311)).

The above properties are useful in forecasting, since the sum of activity times will always add up to the time budget regardless of the values of the independent variables. Only the reallocation among activities is affected by changes in the independent variables. The time budget (in this

case, 24 hours) will always equal the sum of the constant terms. (In forecasting it will rarely be the case that constant terms will be changed, but if they are, the analyst should be aware that their sum should always equal a predetermined time period that is equivalent to the aggregate time budget.) In Appendix C we report on forecasting experiments that utilize these properties.

These properties of the equations do not ensure that individual forecast time allocations will lie between zero and the time budget, only their sum is constrained to equal the time budget. Predictions of mean tendencies, however, are unlikely to be affected by this problem, because the means of the exogenous variables employed will typically lie well inside the range of observations in the estimation data.

Mathematical Properties

This section demonstrates the mathematical properties of the time allocation model. Readers notinterested in these details can go directly to the next section without loss of continuity.

This model has several important characteristics which can be exploited in forecasting. To highlight these attributes, we rewrite the equations using a more formal notation

$$(1) \quad Y_{it} = \sum_{k=0}^{K} \beta_{ik} X_{kt} + V_{it} \qquad i = 1, \ldots, 12 \quad t = 1, \ldots, T$$

where:

Y_{it} = time spent in activity i by individual t;

X_{kt} = value of the k-th exogenous variable for individual t,

β_{ik} = estimated regression coefficient for activity time equation i and exogenous variable k;

V_{it} = residual error term for activity time equation i and individual t.

Also, by convention we will denote the constant term as β_{i0} for the ith equation and, consequently, X_{0t} will be identically equal to one for all individuals.

To demonstrate some of the important properties of the model, we use the following matrix notation conventions:

$$\beta_i = \begin{pmatrix} \beta_{i0} \\ \beta_{i1} \\ \vdots \\ \beta_{iK} \end{pmatrix}.$$

$$Y_i = \begin{pmatrix} Y_{i1} \\ Y_{i2} \\ \vdots \\ Y_{iT} \end{pmatrix}$$

$$X = \begin{pmatrix} X_{01} & X_{11} & \cdot & X_{K1} \\ X_{02} & & & \cdot \\ & & & \\ X_{0T} & \cdot & \cdots & X_{KT} \end{pmatrix}$$

where $X_{0t} = 1$ for t = 1, 2,...T.

$$\beta = \sum_{i=1}^{12} \beta_i$$

$$Y = \sum_{i=1}^{12} Y_i$$

Note that the budget constraint of 24 hours on every individual implies:

$$Y = \begin{pmatrix} 24 \\ 24 \\ \cdot \\ \cdot \\ \cdot \\ 24 \end{pmatrix}$$

The transpose of the ordinary least squares estimator for the model coefficients is as follows:

$$(2) \quad \beta_i' = Y_i' X (X'X)^{-1}$$

Now we note the following equality:

$$(3) \quad \beta' = \sum_{i=1}^{12} Y_i' X (X'X)^{-1} = Y' X (X'X)^{-1}$$

That is, the sum of the coefficients across activity equations is itself an ordinary least squares estimate derived by regressing the sum of activity time allocations on the independent variables. However, the sum of activity time allocations is constant across observations and, consequently, the properties of this regression are such that:

$$(4) \quad \beta = \begin{pmatrix} 24 \\ 0 \\ \cdot \\ \cdot \\ \cdot \\ 0 \end{pmatrix}$$

That is, the constant term in this regression would be equal to the constant, 24, and the slope coefficients would all equal zero. This in turn means that:

$$(5) \quad \sum_{i=1}^{12} \beta_i \quad \begin{pmatrix} 24 \\ 0 \\ \cdot \\ \cdot \\ \cdot \\ 0 \end{pmatrix}$$

Returning to our notation in Equation 1, we can now state the properties of the model implied by Equation 5.

1. The sum of the constant terms across activities is equal to the time budget:

$$(6) \quad \sum_{i=1}^{12} \beta_{i0} = 24$$

2. The forecast sum of activities will equal 24 hours for every individual for all values of the independent variables:

$$(7) \quad \sum_{i=1}^{12} \sum_{k=0}^{K} \beta_{ik} X_{kt} = 24 \quad \text{for all values of } X_{kt},\ k=1,2,\ \ldots,\ K$$

This result follows from noting that:

$$\sum_{i=1}^{12} \sum_{k=0}^{K} \beta_{ik} X_{kt} = \sum_{k=0}^{K} \left(\sum_{i=1}^{12} \beta_{ik} \right) X_{kt} = X_\beta \qquad \text{all } t=1,\ \ldots,\ T$$

3. The sum of the residuals across activities is always zero for each individual regardless of the value of the independent variables:

$$(8) \quad \sum_{i=1}^{12} V_{it} = 0$$

This follows from substituting

$$\sum_{i=1}^{12} Y_{it} = 24$$

and Equation (7) into the following

$$\sum_{i=1}^{12} Y_{it} = \sum_{i=1}^{12} \sum_{k=0}^{K} \beta_{ik} X_{kt} + \sum_{i=1}^{12} V_{it}$$

This latter equation is simply the sum of activity time regressions depicted by Equation 1.

An immediate consequence of these results is that forecasts such as those performed in Appendix C will always satisfy the total time constraint even though this was not built directly into the estimating equations. This does not mean, however, that any forecast of time allocation to a specific activity will of necessity be between zero and the total time budget. In practice, forecasts will tend to fall in this boundary as demonstrated by the forecast experiments in Appendix C.

Dependent Variables

The dependent variables are the total time devoted to an activity by an individual in the 24 hours prior to the survey day (see Table B-1). In each case, the total time is an aggregate of all spells of an activity in the day; no distinction is made between times of day, nor between interrupted and continuous use of time. An hour spent shopping between 5 p.m. and 6 p.m. is treated as identical to an hour composed of 30 minutes from 9 a.m. to 9:30 a.m. and two spells of 15 minutes each sometime in the evening.

In the Baltimore trip file each trip is described as having a single purpose, a time of departure and a time of arrival at the destination. The purpose of a trip was defined by the trip maker in the interview and was selected from a list of 19 alternatives. We aggregated those alternatives that were very close in type or for which there were few observations. The following purposes were combined: work with work-related business; serving a child passenger with serving an adult passenger; pleasure riding, driving, walking with riding to accompany a driver; and personal business, doctor or dentist with auto-related business. Activity time was calculated as the elapsed time between consecutive trips. Travel time to an activity was distinguished from activity time except in the case of serving passengers (TSERV) and pleasure riding (TPLEAS) where travel time is logically part of

Table B-1

THE DEPENDENT VARIABLES

THOME	Time spent at home in the 24-hour period, obtained as a residual, the difference between time available and total time spent outside of the home.
TWORK	Time spent at work, or work-related business.
TPERSON	Time spent in visiting the doctor or dentist. auto-related purpose, or personal business not otherwise specified.
TEAT	Time spent to eat a meal away from home.
TPLEAS	Time spent in pleasure walking, riding or driving or accompanying someone else on a trip (includes both travel time and time at destination).
TFOOD	Time spent grocery shopping.
TSERVE	Time spent in serving a child or an adult (includes both travel time and time spent at the destination).
TSHOP	Time spent in shopping other than food shopping.
TENTAIN	Time spent in entertainment, civic, cultural, or religious activities.
TVISIT	Time spent visiting friends or relatives.
TOUTDR	Time spent in outdoor recreation.
TOTTRAV3	Time spent in all travel except that part of TSERVE and TPLEAS which is also travel.

NOTE: All variables are expressed in hours.

activity time. An additional category (TOTTRAV3) comprised total time spent in all other traveling.

Independent Variables

The major explanatory variables are household type, marital status, employment status of self and of spouse (if married), age, sex, race, and household income.

Employment Status. Because employment status has such a large effect on the overall pattern of weekday time use we have introduced it into the models in two ways. One is by estimating a model on the pooled sample of both employed and not employed, utilizing the variables EMPLOYED (1 = employed, 0= not employed) and EMPLSEX (1 = employed male, 0 = other). The second way, which allows the coefficients for all other variables to vary freely, is to estimate models for the employed and not employed separately. Both sets of results are discussed below.

Household Type. In order to test the importance of household structure in the choice of activity pattern, we developed a typology to reflect the typical opportunities and constraints that would impinge on time use. Household types are defined by the age category of the youngest and oldest members, and one-person households are split off from all others. This is an extension of the typology developed by Ian Heggie (B2), who uses only age of the youngest member. The age categories correspond roughly to expected transition points in dependency (or independence), opportunity, and life

style. Tables B-2 and B-3 provide counts of the number of individuals and households by type, and Table B-4 presents the age distribution of individuals living alone.

The set of household types used in the model (Table B-5) is somewhat smaller than that found in Table B-2. We aggregated the smaller cells and aggregated further when no behavioral difference between household types could be detected. For example, we found no difference between households with a preschool child and the oldest adult over 35 and similar households with a preschool child and the oldest adult under 35. We also examined sex interactions with household type. In the two cases where this interaction was important the type was redefined to include the sex of the respondent.

Marital Status and Spouse Employment Status. The interdependencies between adults modeled are marital status and whether a respondent's spouse was employed. The marital status variable was defined together with the spouse employment status variable so that one would be either not married, married with a working spouse, or married with a not-working spouse (see Table B-6). As we were particularly interested in measuring the impact on husbands of having working wives, and as it might make a difference whether one is a woman with a nonemployed husband rather than a man with a nonemployed wife, the spouse employment categories were interacted with sex.

Other Demographics. Our definitions of other demographic descriptors are contained in Table B-7.

Table B-2

THE DISTRIBUTION OF HOUSEHOLDS BY TYPE

Age Category of Youngest Member
by Age Category of Oldest Member
(Counts of Individuals)

Age of Youngest Member	Age of Oldest Member					Total
	12 to 19	20 to 34	35 to 54	55 to 64	Over 65	
Less than 6	0	121	91	7	20	239
6 to 11	0	25	118	19	12	174
12 to 19	1	10	173	39	30	253
20 to 34	0	72	26	48	12	158
35 to 54	0	0	39	33	26	98
55 to 64	0	0	0	50	31	81
Over 65	0	0	0	0	57	57
Total	1	228	447	196	188	1060

NOTE: The household types defined above include households with only one member. To obtain the household distributions for household types used in later regression analysis, one can subtract individuals who live alone (see Table B-4) from the cell totals.

SOURCE Based on data contained in the Baltimore Travel Demand Data Set Table compiled in July 1979

Table B-3

THE DISTRIBUTION OF HOUSEHOLDS BY TYPE

Age Category of Youngest Member
by Age Category of Oldest Member
(Counts of Households)

Age of Youngest Member	Age of Oldest Member					Total
	12 to 19	20 to 34	35 to 54	55 to 64	Over 65	
Less than 6	0	76	46	3	11	136
6 to 11	0	18	66	7	5	96
12 to 19	1	8	75	17	14	115
20 to 34	0	50	14	20	5	89
35 to 54	0	0	27	18	17	62
55 to 64	0	0	0	37	22	59
Over 65	0	0	0	0	52	52
Total	1	152	228	102	126	609

NOTE: The household types defined above include households with only one member. To obtain the household distributions for household types used in later regression analysis, one can subtract individuals who live alone (see Table B-4) from the cell totals.

SOURCE Based on data contained in the Baltimore Travel Demand Data Set Table compiled in July 1979

Table B-4

DISTRIBUTION OF INDIVIDUALS WHO LIVE ALONE BY AGE AND SEX

	Age Category				Total
	20 to 34	35 to 54	55 to 64	65 to over	
Males	14	6	6	8	34
Females	9	8	9	21	47
Total	23	14	15	29	81

SOURCE Based on data contained in the Baltimore Travel Demand Data Set
Table compiled in July 1979

Table B-5

TABLE OF HOUSEHOLD TYPES DEFINED BY AGES
OF YOUNGEST AND OLDEST MEMBERS AND SEX OF RESPONDENT

PRESCHLF	- presence of a preschool child and respondent is female, adults of any age
PRESCHLM	- presence of a preschool child and respondent is male, adults of any age
YOUTH	- presence of children between age 6 and 19, adults of any age and sex
YADULTG	- household composed entirely of adults between the ages of 20 and 34
ADULTMIX	- youngest member between 20 and 34, and oldest 35 or over
ADLT3555	- youngest member between ages 35 and 54
ADLT5565	- youngest member between ages 55 and 64
SENIOR	- all members age 65 or over, including seniors living alone
ALONEF	- woman under age 65 living alone
ALONEM	- man under age 65 living alone

NOTE: Variable has value of one if the individual is in a household type, zero otherwise.

In the regressions YOUTH is the left-out category and hence does not appear in the regressions. In test regressions, men living alone under age 65, and men with a preschool child in the household were not found to behave differently from men from YOUTH household type. Accordingly, ALONEM and PRESCHLM were also left out of the equations. The left-out category is properly the union of YOUTH, ALONEM, and PRESCHLM groups.

We did not create a single-parent category for this data set as there were only 44 such families with weekday travel. The effect can be picked up by a total adult variable, but this variable was found not to be significant in prior tests.

Table B-6

MARITAL STATUS AND SPOUSE EMPLOYMENT STATUS VARIABLES

MARSPW	- married, spouse works, respondent male or female
MARNSPWH	- married man, spouse does not work
HUSNTWKW	- married man, spouse works, the interaction of MARSPW and SEX
NMAR	- not married

NOTE Variable has value of one if the individual is in a marital status type, zero otherwise.

The underlying logical division is tripartite: not married, married and spouse works, married and spouse does not work. These can then be interacted with the sex variable to give a total of six dummy variables, four of which could appear in the equations. We chose to have unmarried the left-out category; however we also found that men whose spouses do not work do not differ from unmarried men, and so this group was also added to the left-out category. The left-out categories were thus NMAR and MARNSPWH.

Table B-7

OTHER DEMOGRAPHICS

SEX	- takes the value 1 for males, 0 for females
RACE	- takes the value 1 for whites, 0 for blacks
RACESEX	- white male, the interaction of RACE and SEX
SENSEX	- male age 65 or over, the interaction of SENIOR and SEX
INCZ	- household income midpoint* centered**
INCZSQ	- square of INCZ
AGEZ	- age centered**
AGEZSQ	- square of AGEZ
EDUCYZ	- years of education midpoint+ centered**
EDUCYZSQ	- square of EDUCYZ

*Household income estimated as the midpoint of 19 categories.

**Variables were centered at the means of their respective sample (total sample, employed persons, not employed persons) for the appropriate set of equations. INCHH, AGEP, and EDUCY, used in the pooled regressions, differ from INCZ, AGEZ, and EDUCYZ only in that a different centering adjustment was used.

+Education estimated as the midpoint of 9 categories.

Sex -- SEX was coded as one for males and zero for females. To allow a comparison of sex differences among the elderly, we interacted the senior-citizen household type with sex (SENSEX).

Race -- RACE was coded as one for whites and zero for all others. The nonwhite group is almost entirely black, but includes several Asians and native Americans. To facilitate our race/sex comparisons, we also interacted race with sex (RACESEX).

Age, Education, and Income -- Age is the only one of these three variables reported precisely. Education was coded by group grade school, some high school, high school graduate, some college, college graduate, and postgraduate. We replaced each category with the midpoint years of school. A similar transformation was performed on the household income category variable. Each of these three variables was coded as a deviation from the sample mean for the appropriate subsample, the squares of these three variables were also added to the equations. We experimented with categorical variables for the age, income, and education variables, but the pattern of coefficients in almost all cases was either linear or quadratic. We have lost nothing in terms of fit by imposing this functional form on the equations estimated, have gained several degrees of freedom, and have a somewhat more succinct and easily grasped relationship. We discuss these results in greater detail below. Our major loss is that the forecasting properties of the equations are somewhat impaired, in that only a change in mean, but not distribution, of these variables is usable directly.

Person Types -- The demographic, marital, and spouse employment status variables define 12 person types, as displayed in Table B-8. For example, white unmarried females are defined by Person Type 7, RACE+NMAR (since NMAR is an omitted category, this reduces to RACE). White unmarried males are defined by Person Type 10, RACE+RACESEX+SEX+NMAR. The test of the difference between white unmarried males and females is then:

Type 7 - Type 10 = (RACE + RACESEX + SEX + NMAR) - (RACE + NMAR)

= RACE + RACESEX

Tests of this sort are employed extensively below. Theil (B1, pp. 143-144) discusses the testing procedure.

Data Source

The data source that we employed in fitting this model is the Baltimore Travel Demand Data Set, described in Appendix A. We utilized selected person and household information from this data set and constructed our activity summaries as described above. We did not utilize the detailed link information nor do we treat mode, frequency, or distance of travel in this phase of the work, although we do in the household-level modeling described in Appendix F.

Because the data set contains a complete 24-hour recalled travel diary for each member over 11 years old for each household, it provides a complete record of household time allocation patterns. As such, it presents an excellent data base for studying the joint behavior patterns that reflect the

Table B-8

PERSON TYPES CONSTRUCTED FROM DUMMY VARIABLES

				Dummy Variables*	
Type	Race	Sex	Marital Status	Included Categories	Excluded Categories
1	Black	Female	Unmarried		(+NMAR)
2	Black	Female	Married, Spouse Not Working	HUSNTWKW	
3	Black	Female	Married, Spouse Working	MARSPW	
4	Black	Male	Unmarried	SEX	(+NMAR)
5	Black	Male	Married, Spouse Not Working	SEX	(+MARNSPW)
6	Black	Male	Married, Spouse Working	SEX+MARSPW+WORKWIFH	
7	White	Female	Unmarried	RACE	(+NMAR)
8	White	Female	Married, Spouse Not Working	RACE+HUSNTWKW	
9	White	Female	Married, Spouse Working	RACE+MARSPW	
10	White	Male	Unmarried	RACE+RACESEX+SEX	(+NMAR)
11	White	Male	Married, Spouse Not Working	RACE+RACESEX+SEX	(+MARNSPWH)
12	White	Male	Married, Spouse Working	RACE+RACESEX+SEX +MARSPW+WORKWIFH	

*See Tables B-6 and B-7 for definitions of these variables.

interdependencies influencing travel behavior. Because the data set was collected to study movement in space, no detail was gathered on individual behavior in the home, however.

The version of the data set utilized in the work reported in this appendix was a preliminary release which FHWA provided to us in the spring of 1979. At that time FHWA was engaged in the process of editing and verification, and certain anomalous cases were dropped pending a resolution of the discrepancies. We have excluded from the data set used for fitting the following major classes of persons 1) those with anomalous data; 2) nontravelers, 3) not-employed students; and 4) weekend trip records. We have thus estimated models of weekday travelers.

RESULTS

The major results were described in Chapter 2. Technical details are provided in the remainder of this appendix. The coefficients of the models form a major part of the following analyses. Tables B-9 through B-11 present these coefficients for the combined, employed, and not employed samples, respectively. Much of the discussion in Chapter 2 was based upon the coefficients for the combined sample (Table B-9). For example, the effects of employment status on time allocation that were reported in Table 7 are based on the coefficient EMPLOYED, which measures the effect of employment status on women, and the sum EMPLOYED + EMPLSEX, which measures the same effect for men. Specific findings are in Chapter 2.

Table B-9

ESTIMATED ACTIVITY EQUATIONS FOR 1058 EMPLOYED AND NOT-EMPLOYED PERSONS WITH WEEKDAY TRAVEL

	DEPENDENT VARIABLE					
INDEPENDENT VARIABLE	THOME T-STAT	TWORK T-STAT	TPERSON T-STAT	TEAT T-STAT	TPLEAS T-STAT	TFOOD T-STAT
INTERCEP	19.0689 43.3658	1.284288 3.3735	0.32348 2.43	-0.014562 -0.2854	0.116364 1.7482	0.229474 5.6703
PRESCHLD	0.935154 2.4599	-0.487936 -1.4825	-0.102737 -0.8927	-0.00451606 -0.1024	0.070988 1.2336	-0.026049 -0.7445
YADULTG	0.750204 1.44[illegible]1	-0.067027 -0.1493	-0.014961 -0.0953	0.03278 0.5449	0.192156 2.4486	0.023417 0.4908
ADULTMIX	0.205268 0.5151	-0.094845 -0.2749	0.128097 1.0618	-0.053135 -1.149	-0.034216 -0.5672	-0.034846 -0.9501
ADLT3555	0.127029 -0.3079	0.093974 0.259	0.039472 0.3112	0.150259 3.0899	-0.024193 -0.3814	-0.048411 -1.2553
ADLT5565	0.249265 0.4836	-0.447307 -1.0025	-0.131152 -0.8406	0.30821 5.1531	0.22031 2.8238	-0.05037 -1.0619
SENIOR	-0.232956 -0.2883	0.374013 0.5346	0.067124 0.2744	-0.00838785 -0.0895	0.002053143 0.0168	0.040121 0.5395
ALONE	-0.064015 -0.0874	-0.118574 -0.1869	0.11509 0.5189	-0.05688 -0.669	0.049515 0.4465	0.087979 1.3048
MARSFW	0.881015 2.3113	-0.991517 -3.0046	0.061848 0.536	0.005104264 0.1154	-0.091276 -1.5819	0.02912 0.8301
HUSNTWKW	-0.615293 -1.3229	-0.167619 -0.4163	0.282392 2.0056	-0.112118 -2.0772	0.076422 1.0854	-0.045744 -1.0686
RACE	-0.18431 -0.5621	0.276348 0.9735	0.016256 0.1638	0.030587 0.8039	0.039152 0.7888	-0.041083 -1.3614
SEX	-0.363775 -0.6622	-0.013316 -0.028	0.180443 1.085	-0.124274 -1.9493	-0.01661 -0.1997	-0.126925 -2.5104
INCHH	.0000222999 -1.8968	.00003439565 3.3792	2.51002E-07 0.0705	1.11349E-07 0.0816	.00000433479 2.4357	1.87698E-07 0.1735
INCHHSQ	-1.69074E-10 -0.3531	-5.00666E-10 -1.2079	-1.85074E-10 -1.2769	3.16765E-11 0.5701	-2.00236E-11 -0.2763	-2.70107E-11 -0.613
AGEF	0.015734 1.7737	0.02044 2.6615	0.0006226861 0.2319	-0.0010463 -1.0164	-0.00323861 -2.4118	0.002141715 2.6233
AGEFSQ	0.001583186 3.1642	-0.00193542 -4.4679	.00004147229 0.2738	.00009323421 1.6057	.00002190549 0.2892	-.0000364823 -0.7923
EDUCY	-0.00654024 -0.1714	-0.031404 -0.9505	0.013854 1.1992	0.016795 3.7925	-0.010347 -1.7911	-0.00175141 -0.4987
EDUCYSQ	-0.000409109 -0.0842	-0.0036787 -0.8741	-0.00100385 -0.6821	0.001389778 2.4635	0.000231919 0.3152	-0.000303129 -0.6775
WORKWIFH	-1.38951 -2.8361	0.876814 2.0672	0.110589 -0.7456	0.035453 0.6236	0.087952 1.1859	-0.055035 -1.2206
RACESEX	0.352578 0.7779	-0.530719 -1.3525	0.086797 0.6326	0.037178 0.7068	0.040684 0.593	0.042928 1.0291
SENSEX	-0.357958 -0.3545	0.131056 0.1499	-0.223794 -0.7321	0.03469 0.2961	-0.027572 -0.1804	-0.063327 -0.6815
EMPLOYED	-4.2903 -13.2524	5.60546 19.9996	-0.222001 -2.2652	0.03526 0.9385	-0.123757 -2.5253	-0.100097 -3.3596
EMPLSEX	-0.921682 -1.7271	1.457395 3.1544	-0.128931 -0.7981	0.080712 1.3033	0.008449994 0.1046	0.052028 1.0593
STD ERR	3.345444	2.896359	1.012774	0.3862345	0.5064208	0.3078928
R-SQUARE	0.4161	0.5754	0.025	0.0799	0.0497	0.0556

Table continued on following page.

Table B-9 (Continued)

ESTIMATED ACTIVITY EQUATIONS FOR 1058 EMPLOYED AND NOT-EMPLOYED PERSONS WITH WEEKDAY TRAVEL

	DEPENDENT VARIABLE					
INDEPENDENT VARIABLE	TSERVE T-STAT	TSHOP T-STAT	TENTAIN T-STAT	TVISIT T-STAT	TOUTDR T-STAT	TOTTRAV3 T-STAT
INTERCEP	0.159119 1.7139	0.429077 3.7262	0.418384 3.8118	0.719206 3.6961	0.177194 1.5483	1.089079 8.7045
PRESCHLF	0.095041 1.1841	0.127369 1.2794	-0.162437 -1.7118	-0.332283 -1.9752	-0.014407 -0.1456	-0.098189 -0.9078
YADULTG	-0.073708 -0.6734	-0.097652 -0.7193	-0.206241 -1.5938	-0.441275 -1.9235	-0.118708 -0.8798	0.021015 0.1425
ADULTMIX	-0.07577 -0.9006	-0.116418 -1.1156	0.104662 1.0522	-0.14367 0.8147	0.113323 1.0927	0.001550947 0.0137
ADLT3555	-0.126792 -1.4331	-0.076604 -0.6981	-0.09196 -0.8792	0.223757 1.2067	-0.020136 -0.1846	0.00966103 0.081
ADLT5565	-0.09163 -0.8421	-0.081606 -0.6046	-0.113793 -0.8845	0.080008 0.3508	-0.066211 -0.4936	0.124277 0.8475
SENIOR	-0.065717 -0.3852	-0.042927 -0.2029	-0.253573 -1.2572	-0.00386078 -0.0108	0.016797 0.0799	0.107313 0.4668
ALONEF	-0.070517 -0.4559	-0.115863 -0.6039	-0.211704 -1.1577	-0.348865 -1.0761	-0.045582 -0.2391	0.779417 3.7391
MARSPW	0.060336 0.7497	0.044717 0.448	-0.087951 -0.9244	0.101884 0.604	0.002628171 0.0265	-0.015908 -0.1467
HUSNTWKW	-0.00695077 -0.0708	-0.130524 -1.0716	0.021073 0.1815	0.374193 1.8181	0.212059 1.7518	0.11211 0.8471
RACE	0.108567 1.5683	0.133668 1.5567	-0.109716 -1.3406	-0.120915 -0.8334	0.030414 0.3564	-0.17897 -1.9183
SEX	0.102715 0.8855	0.018959 0.1318	-0.403246 -2.9406	0.246752 1.015	0.406476 2.8429	0.092803 0.5937
INCHH	.0000020009 -0.8061	-0.000005219 -1.6951	.00000340245 1.1594	-.0000134013 -2.5759	-.0000010255 -0.3351	.00000126359 0.3777
INCHHSQ	9.43094E-11 0.933	9.01852E-11 0.7193	1.13487E-10 0.9496	3.96134E-10 1.8697	5.65060E-11 0.4535	1.19550E-10 0.8776
AGEF	-0.00131329 -0.7012	0.001187083 0.511	-0.00348702 -1.5748	-0.018466 -4.704	-0.0084598 -3.6642	-0.00411519 -1.6304
AGEFSQ	-0.000132455 -1.2538	-.0000652263 -0.4978	0.0002160919 1.7302	0.0002486922 1.1232	-.0000172093 -0.1322	-.0000177919 -0.125
EDUCY	0.004489694 0.5572	0.002751764 0.2754	0.007004038 0.7353	0.00330273 0.1956	-0.00660585 -0.6651	0.008450731 0.7783
EDUCYSQ	-0.00045861 -0.4468	.00008839212 0.0694	0.002985485 2.4604	-0.0013653 -0.6347	-0.000190197 -0.1503	0.00271333 1.9616
WORKWIFH	0.010228 0.0989	-0.068301 -0.5324	0.173724 1.4206	0.105362 0.486	0.138585 1.0869	0.195316 1.4011
RACESEX	-0.015901 -0.1662	-0.13952 -1.1755	0.143633 1.2696	0.054279 0.2706	0.008390853 0.0711	-0.080328 -0.6229
SENSEX	-0.066195 -0.3105	0.489888 1.8527	0.522385 2.0727	-0.136413 -0.3053	-0.199161 -0.7579	-0.103601 -0.3606
EMPLOYED	-0.091415 -1.3374	-0.302786 -3.5715	-0.224457 -2.7777	-0.362195 -2.5282	-0.143496 -1.7031	0.21978 2.386
EMPLSEX	-0.106237 -0.9429	0.004377251 0.0313	0.205722 1.5444	-0.347872 -1.4731	-0.381992 -2.7503	0.07803 0.5139
STD ERR	0.7063406	0.8760862	0.8350593	1.480427	0.8706928	0.9518955
R-SQUARE	0.0263	0.0598	0.0453	0.0629	0.046	0.0666

SOURCE: Based on data contained in the Baltimore Travel Demand Data Set. Table compiled in August 1980.

Table B-10

ESTIMATED ACTIVITY EQUATIONS FOR 737 EMPLOYED PERSONS WITH WEEKDAY TRAVEL

	DEPENDENT VARIABLE					
INDEPENDENT VARIABLE	THOME T-STAT	TWORK T-STAT	TPERSON T-STAT	TEAT T-STAT	TPLEAS T-STAT	TFOOD T-STAT
INTERCEP	14.3634	7.437253	-0.00633373	-0.023254	0.026664	0.151302
	32.0062	16.1773	-0.0495	-0.395	0.4558	4.6195
FRESCHLF	0.868597	-1.11398	0.064849	0.034763	0.029734	-0.023158
	1.5458	-1.9359	0.4051	0.4717	0.4061	-0.5649
YADULTG	0.389979	-0.082793	-0.034363	0.05627	0.263539	0.037191
	0.6864	-0.1423	-0.2123	0.7551	3.5596	0.8972
ADULTMIX	0.198808	0.116667	-0.071788	-0.074106	-0.009737	0.004452158
	0.4356	0.2496	-0.5522	-1.2381	-0.1637	0.1337
ADLT3555	-0.234089	0.336279	-0.014012	0.162077	-0.029549	-0.029111
	-0.4735	0.6642	-0.0995	2.4999	-0.4587	-0.8071
ADLT5565	-0.288971	-0.428942	0.048754	0.42561	0.050061	-0.085433
	-0.4394	-0.6369	0.2603	4.9347	0.5842	-1.7806
SENIOR	-1.18206	1.593741	0.04271	-0.025116	-0.00351266	-0.160999
	-0.722	0.9506	0.0916	-0.117	-0.0165	-1.3478
ALONEF	0.004645342	-0.093694	0.165513	-0.035275	0.021216	0.136244
	0.0059	-0.1156	0.7344	-0.34	0.2058	2.3604
MARSFW	1.057745	-1.23073	0.129877	0.048658	-0.05626	0.006517612
	2.2389	-2.5438	0.9651	0.7853	-0.9139	0.1891
HUSNTWKW	-0.312094	-0.172528	0.18877	-0.117205	0.021915	-0.068958
	-0.502	-0.271	1.0658	-1.4373	0.2705	-1.5201
RACE	-0.337966	0.372173	0.095225	0.045548	0.003573248	-0.094118
	-0.7974	0.8574	0.7887	0.8194	0.0647	-3.0435
SEX	-1.52862	1.500241	0.120085	-0.033486	-0.041272	-0.115807
	-3.0029	2.8778	0.8281	-0.5016	-0.6222	-3.1181
INCZ	-.0000439576	.00004136876	4.78291E-07	4.16511E-07	.00000150816	6.80485E-07
	-3.3557	3.0838	0.1282	0.2424	0.8836	0.712
INCZSQ	7.73615E-10	-6.46398E-10	-1.52943E-10	2.58528E-11	2.35084E-11	-3.61978E-11
	1.3802	-1.1261	-0.9579	0.3517	0.3219	-0.8851
AGEZ	-0.000155486	0.037281	-0.00403187	-0.00142654	-0.00181612	0.002133124
	-0.0139	3.2545	-1.2653	-0.9724	-1.246	2.6138
AGEZSQ	0.002572598	-0.00384895	0.000185866	0.0001761964	.00004695759	0.0000053882
	3.4584	-5.0526	0.8771	1.806	0.4845	0.0993
EDUCYZ	-0.014793	-0.047837	0.006738836	0.022284	-0.00437806	-0.00264687
	-0.3209	-1.0132	0.5131	3.6856	-0.7288	-0.7869
EDUCYZSQ	0.008023398	-0.011288	-0.00106755	0.001404131	-0.000593692	0.0003851161
	1.2671	-1.7407	-0.5919	1.6908	-0.7195	0.8336
WORKWIFH	-1.34803	0.975554	-0.147722	0.0002160618	0.066177	-0.028595
	-2.3626	1.6696	-0.9089	0.0029	0.8901	-0.6869
RACESEX	0.718227	-0.804448	0.038041	0.057142	0.079363	0.087711
	1.2982	-1.4199	0.2414	0.7875	1.1009	2.173
SENSEX	1.584134	-0.596041	-0.242767	-0.168309	-0.039885	0.173746
	0.6912	-0.254	-0.3719	-0.56	-0.1336	1.0391
STD ERR	3.342631	3.423115	0.952188	0.4383902	0.4355606	0.243875
R-SQUARE	0.1079	0.1209	0.013	0.1011	0.0344	0.0574

Table continued on following page.

Table B-10 (Continued)

ESTIMATED ACTIVITY EQUATIONS
FOR 737 EMPLOYED PERSONS WITH WEEKDAY TRAVEL

INDEPENDENT VARIABLE	DEPENDENT VARIABLE					
	TSERVE T-STAT	TSHOP T-STAT	TENTAIN T-STAT	TVISIT T-STAT	TOUTDR T-STAT	TOTTRAV3 T-STAT
INTERCEP	0.108508 1.4838	0.223961 4.247	0.092915 0.9917	0.332031 2.0562	-0.00855502 -0.1028	1.297113 10.198
PRESCHLF	0.052117 0.5694	0.121321 1.8381	0.013448 0.1147	-0.068665 -0.3397	0.037415 0.3594	-0.016446 -0.1033
YADULTG	-0.047554 -0.5138	-0.037516 -0.5621	-0.226138 -1.907	-0.235672 -1.1531	-0.135698 -1.2889	0.052756 0.3277
ADULTMIX	-0.048783 -0.6562	-0.083052 -1.5492	0.055051 0.578	0.046252 0.2818	-0.064784 -0.7661	-0.06898 -0.5335
ADLT3555	-0.057191 -0.7102	-0.033228 -0.5722	-0.145243 -1.4077	0.155182 0.8727	-0.045667 -0.4986	-0.06545 -0.4673
ADLT5565	-0.070327 -0.6565	0.104254 1.3496	-0.123065 -0.8966	0.115716 0.4892	0.022715 0.1864	0.229629 1.2324
SENIOR	-0.048335 -0.1812	-0.150088 -0.7804	-0.318941 -0.9334	-0.20587 -0.3496	-0.00640033 -0.0211	0.464867 1.0021
ALONEF	-0.036384 -0.2823	-0.057691 -0.6208	-0.210718 -1.2762	-0.169679 -0.5963	-0.046674 -0.3184	0.322496 1.4388
MARSPW	0.013219 0.1718	-0.016189 -0.2917	-0.034878 -0.3537	0.108882 0.6407	0.066086 0.7549	-0.09293 -0.6943
HUSNTWKW	-0.01901 -0.1877	-0.048048 -0.6579	0.183421 1.4135	0.175433 0.7844	-0.015876 -0.1378	0.184181 1.0455
RACE	0.041418 0.5999	-0.046772 -0.9394	0.048912 0.5529	-0.153231 -1.0051	0.105992 1.3496	-0.080754 -0.6724
SEX	-0.00845197 -0.1019	-0.055454 -0.9274	-0.047995 -0.4517	-0.110883 -0.6056	0.079633 0.8443	0.242012 1.678
INCZ	.00000156202 0.732	4.70800E-07 0.306	8.36273E-07 0.3059	-.0000038588 -0.819	-1.60794E-07 -0.0662	6.55884E-07 0.1767
INCZSQ	-4.54707E-11 -0.498	-4.99242E-11 -0.7582	-1.02433E-10 -0.8756	1.51071E-10 0.7493	-2.70131E-11 -0.2601	8.63324E-11 0.5436
AGEZ	-0.000969546 -0.5321	-0.000296798 -0.2259	-0.00129649 -0.5553	-0.01846 -4.5881	-0.00491733 -2.3725	-0.00604309 -1.9068
AGEZSQ	.00002502883 0.2066	-.0000157094 -0.1798	0.0002064058 1.3295	0.0005098986 1.9057	0.0001205722 0.8748	.00001574319 0.0747
EDUCYZ	0.008744885 1.1645	0.002420207 0.4469	0.016732 1.739	0.0002712661 0.0164	-0.00893938 -1.0465	0.021402 1.6385
EDUCYZSQ	-.0000608292 -0.059	0.0002480062 0.3334	0.002372344 1.7951	-0.00248076 -1.0892	-0.000213696 -0.1821	0.003271277 1.8234
WORKWIFH	0.012751 0.1372	-0.054239 -0.8092	0.113885 0.9563	0.147678 0.7196	-0.00508869 -0.0481	0.267415 1.6542
RACESEX	-0.017922 -0.1989	0.01183 0.182	0.023912 0.2071	0.08219 0.413	-0.038364 -0.3742	-0.237681 -1.5163
SENSEX	-0.060258 -0.1614	0.045501 0.169	0.033173 0.0694	0.123731 0.1501	-0.089341 -0.2104	-0.763685 -1.1761
STD ERR	0.5445053	0.3926525	0.6976446	1.202333	0.6193602	0.9470628
R-SQUARE	0.0107	0.0332	0.0242	0.0436	0.0217	0.0455

SOURCE: Based on data contained in the Baltimore Travel Demand Data Set. Table compiled in August 1980.

Table B-11

ESTIMATED ACTIVITY EQUATIONS
FOR 321 NOT-EMPLOYED PERSONS WITH WEEKDAY TRAVEL

INDEPENDENT VARIABLE	DEPENDENT VARIABLE THOME T-STAT	TWORK T-STAT	TPERSON T-STAT	TEAT T-STAT	TPLEAS T-STAT	TFOOD T-STAT
INTERCEP	20.43161	0	0.496084	0.075651	0.087922	0.243179
	31.9211	.	2.2505	1.7709	0.7052	2.9637
PRESCHLD	1.058706	0	-0.14518	-0.048463	0.08797	-0.062074
	1.9761	.	-0.7868	-1.3553	0.843	-0.9038
YADULTG	2.755662	0	-0.050137	-0.062793	-0.063012	-0.030075
	2.137	.	-0.1129	-0.7296	-0.2509	-0.1819
ADULTMIX	-0.38949	0	0.624573	-0.018295	-0.053205	-0.195941
	-0.4615	.	2.1489	-0.3248	-0.3237	-1.8111
ADLT3555	-0.442763	0	0.261954	0.08334	-0.00616044	-0.1356
	-0.5378	.	0.9239	1.5168	-0.0384	-1.2849
ADLT5565	1.100207	0	-0.368324	0.091467	0.515935	-0.05393
	1.248	.	-1.2131	1.5545	3.0046	-0.4772
SENIOR	0.290205	0	-0.017051	-0.058057	0.139368	0.017987
	0.2748	.	-0.0469	-0.8237	0.6776	0.1329
ALONEF	-2.01735	0	-0.00815156	-0.110096	0.055043	-0.257511
	-0.9977	.	-0.0117	-0.8159	0.1398	-0.9935
MARSPW	0.011167	0	-0.11158	-0.074901	-0.168203	0.046674
	0.0167	.	-0.4844	-1.6778	-1.2911	0.5443
HUSNTWKW	-1.04854	0	0.376438	-0.115272	0.108565	-0.029954
	-1.4607	.	1.5226	-2.406	0.7765	-0.3255
RACE	-0.242569	0	-0.089684	0.053546	0.103976	0.022532
	-0.4277	.	-0.4591	1.4146	0.9412	0.3099
SEX	-0.193396	0	0.084184	-0.101745	-0.01739	-0.082751
	-0.2876	.	0.3635	-2.2669	-0.1328	-0.9599
INCZ	.00006741977	0	.00000193141	-1.15496E-09	.00001198202	-3.98557E-07
	2.5929	.	0.2157	-0.0007	2.3659	-0.1196
INCZSQ	-2.67492E-09	0	-3.46251E-10	-3.74301E-11	-1.13325E-10	-3.76717E-11
	-2.7009	.	-1.0152	-0.5663	-0.5875	-0.2967
AGEZ	0.041641	0	0.006965238	-0.000409226	-0.00583621	0.002075737
	2.6819	.	1.3025	-0.3949	-1.9298	1.0428
AGEZSQ	0.0003295957	0	-0.000207318	.00002630291	-.0000454149	-.0000602065
	0.444	.	-0.8109	0.5309	-0.3141	-0.6327
EDUCYZ	-0.00790704	0	0.034	0.0005650194	-0.022209	-0.0029817
	-0.11	.	1.3733	0.1178	-1.5861	-0.3235
EDUCYZSQ	-0.00660864	0	0.002900851	.00005219847	-.0000227297	-0.00113483
	-0.6622	.	0.8441	0.0784	-0.0117	-0.8871
WORKWIFH	-0.881684	0	-0.199866	0.042601	0.051659	-0.068322
	-0.7025	.	-0.4624	0.5086	0.2113	-0.4247
RACESEX	-0.53645	0	0.136264	-0.065	0.001847155	0.0009294752
	-0.5943	.	0.4384	-1.079	0.0105	0.008
SENSEX	-0.487305	0	-0.17109	0.113048	-0.00416744	-0.095816
	-0.4135	.	-0.4216	1.4375	-0.0182	-0.6343
STD ERR	3.2935	0	1.134271	0.219809	0.641492	0.422212
R-SQUARE	0.1018	0	0.0853	0.0582	0.097	0.0508

Table continued on following page.

Table B-11 (Continued)

ESTIMATED ACTIVITY EQUATIONS
FOR 321 NOT-EMPLOYED PERSONS WITH WEEKDAY TRAVEL

[illegible]	DEPENDENT VARIABLE					
	TSERVE T-STAT	TSHOP T-STAT	TENTAIN T-STAT	TVISIT T-STAT	TOUTDR T-STAT	TOTTRAV3 T-STAT
INTERCEP	0.130417 0.6782	0.32273 1.1169	0.316695 1.5315	0.824468 2.14	0.092531 0.3747	0.978714 5.4841
PRESCHLF	0.074469 0.4627	0.059476 0.2459	-0.206949 -1.1956	-0.653318 -2.0259	-0.074655 -0.3611	-0.089984 -0.6024
YADULTC	-0.260384 -0.6771	-0.494725 -0.8499	0.011378 0.0273	-1.40491 -1.81	-0.01185 -0.0238	-0.389154 -1.0824
ADULTMIX	-0.227478 0.8972	-0.239496 -0.6286	0.439015 1.6101	-0.881119 -1.7345	0.690175 2.1194	0.25126 1.0678
ADLT3555	-0.419121 -1.6947	-0.206951 -0.5569	0.214494 0.8065	0.387379 0.7818	-0.019815 -0.0624	0.283243 1.234
ADLT5565	-0.381739 -1.4413	-0.520348 -1.3074	0.097622 0.3427	-0.251538 -0.474	-0.227885 -0.6699	-0.00146685 -0.006
SENIOR	-0.160916 -0.5072	-0.379743 -0.7965	0.01365 0.04	-0.321289 -0.5054	0.20147 0.4944	0.274375 0.9318
ALONEF	-0.278249 -0.4581	-0.180055 -0.1973	-0.215365 -0.3297	-0.98572 -0.8101	0.129839 0.1664	3.867813 6.8609
MARSLW	0.148672 0.7399	0.099791 0.3305	-0.156254 -0.7231	0.082683 0.2054	-0.073196 -0.2836	0.195148 1.0464
HUSNTWKW	-0.012795 -0.0593	-0.316096 -0.9754	-0.144874 -0.6247	0.550468 1.274	0.490939 1.7724	0.141122 0.7051
RACE	0.241372 1.4166	0.479526 1.8729	-0.255519 -1.3945	0.020971 0.0614	-0.03506 -0.1602	-0.299092 -1.8913
SEX	0.092031 0.4555	0.091119 0.3001	-0.542294 -2.496	0.336779 0.832	0.347268 1.3383	-0.013806 -0.0736
INCZ	-.0000131191 -1.6795	-.0000246399 -2.0992	.00000155031 0.1846	-.0000398361 -2.5453	-0.000003722 -0.371	-.0000011666 -0.1609
INCZSQ	3.88762E-10 1.3066	4.05443E-10 0.9069	1.09050E-09 3.4082	7.11990E-10 1.1944	2.95191E-10 0.7725	3.17713E-10 1.1506
AGEZ	-0.00255045 -0.5468	0.00258073 0.3682	-0.00728617 -1.4525	-0.015627 -1.6721	-0.015945 -2.6614	-0.00560907 -1.2956
AGEZSQ	-0.000258997 -1.1614	-.0000664066 -0.1982	0.0002753364 1.1481	.00002849905 0.0638	.00003205909 0.1119	-.0000534498 -0.2582
EDUCYZ	-0.011764 -0.5447	-0.0058405 -0.18	0.008638992 0.372	0.022636 0.5231	0.003503355 0.1263	-0.018641 -0.93
EDUCYZSQ	-0.00150872 -0.5033	0.0004310663 0.0957	0.00246784 0.7655	0.002484212 0.4136	-0.000196814 -0.0511	0.001135575 0.4081
WORKWIFH	0.331491 0.8792	0.224206 0.3957	0.200715 0.495	-0.627403 -0.8306	0.854404 1.7644	0.0722 0.2063
RACESEX	0.181341 0.6688	-0.326906 -0.8023	0.153772 0.5273	0.061753 0.1137	0.041221 0.1184	0.351228 1.3956
SENSEX	-0.174972 -0.4943	0.695631 1.3077	0.681684 1.7906	-0.177771 -0.2506	-0.204219 -0.4492	-0.175023 -0.5327
STD ERR	0.9894286	1.486794	1.064037	1.982393	1.270812	0.9182973
R-SQUARE	0.0644	0.0475	0.1383	0.0843	0.0917	0.1743

SOURCE: Based on data contained in the Baltimore Travel Demand Data Set. Table compiled in August 1980.

Table B-12

LIFECYCLE CONTRASTS IN TIME ALLOCATION
(In Hours)

Transition To:	Activity Category[1]											
Employed Persons	THOME	TWORK	TPERSON	TEAT	TPLEAS	TFOOD	TSERVE	TSHOP	TENTAIN	TVISIT	TOUTDR	TOTTRAV3
Preschool Children (PRESCHLF-YADULTG)[2]	.07	.04	.02	-.07	-.26***	-.03	.08	.16*	.19	-.14	.09	-.15
School-Aged Children (-PRESCHLF)[3]	-.87	1.11*	-.06	-.03	-.03	.02	-.05	-.12*	-.01	.07	-.04	.02
No Children, Younger (ADLT3555)[3]	-.23	.34	-.01	.16**	-.03	-.03	-.06	-.03	-.15	.16	-.05	-.07
No Children, Older (ADLT5565)[3,4]	.74	-1.22**	.04	.47***	.03	-.04	-.08	.09	-.07	-.05	-.03	.12
Preretirement (ADLT5565-ADLT3555)[4]	.97	-1.56**	.06	.31***	.06	-.01	-.02	.13	.08	-.20	.02	.18
Senior Status (SENIOR-ADLT5565)[4,5]	.39	.47	.05	-.38*	-.05	-.05	.02	-.27	-.11	-.25	-.02	.18
Not-Employed Persons												
Preschool Children (PRESCHLF-YADULTG)[2]	-1.23	0	.02	.01	.09	0.0	.34	.60	-.35	.55	-.27	.24
School-Aged Children (-PRESCHLF)[3]	-1.06**	0	.15	.05	-.09	.06	-.07	-.06	.21	.65**	.07	.09
No Children, Younger (ADLT3555)[3]	-.44	0	.26	.08	-.01	-.14	-.42*	-.21	.21	.39	.02	.28
No Children, Older (ADLT5565)[4]	2.06**	0	-.31	.09*	.38**	-.04	-.54**	-.50	.06	-.55	-.53*	-.14
Preretirement (ADLT5565-ADLT3555)[4]	2.51**	0	-.57*	.01	.39**	.10	-.12	-.29	-.15	-.94	-.51	-.42
Senior Status (SENIOR-ADLT5565)[4,5]	-.23	0	.32	-.14**	-.46**	.06	.07	.13	-.02	-.21	.29	.19

**SOURCE: Based on data contained in Baltimore Travel Demand Data Set.
Table compiled in August 1980.**

[1]See Table B-1 for definitions of activity categories.

[2]YADULTG is age-corrected with Z1 = -12.5*AGEZ + 156.25*AGEZSQ as the correction factor in the text.

[3]YOUTH is the omitted variable.

[4]ADLT5565 is age-corrected with Z2 = 20*AGEZ + 400*AGEZSQ as the correction factor in the text.

[5]SENIOR is age-corrected with Z3 = 30*AGEZ + 900*AGEZSQ as the correction factor in the text

LEGEND: * - significant at the .10 level.

** - significant at the .05 level.

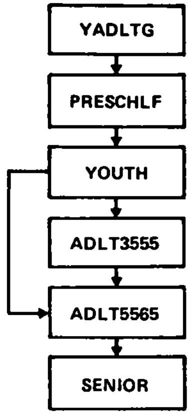
*** - significant at the .01 level.

Lifecycle and Household Structure

One set of hypotheses that we wished to test was whether the major break points in the life cycle signaled major changes in time allocation that would show up in the type of data set we have examined. We take these break points to be: a) the time when a youth leaves home and either lives alone, with other young adults, or marries; b) the appearance of preschool children; c) when the youngest child reaches school age; d) when all a couple's children have left home and the couple is not yet retired; e) when all members of a household have reached retirement-age. We can test the last four of these break points for statistical significance in the model we have estimated by computing the difference between various coefficients of the variables in Table B-5. It is illuminating to compare households at one stage of this stylized life cycle with households of the immediately-preceding stage. These comparisons are depicted in Figure B-1. In all cases the comparison is done by subtracting the coefficient of the earlier stage from that of the subsequent stage, as in the person type comparison outlined above.

We begin by comparing households with preschool children with households of young adults (PRESCHLF-YADULTG), some of whom are no doubt single and others are probably recently married couples. We then compare persons in PRESCHLF households with those having older children (YOUTH, the omitted category), and households with youths with the following: all adults 35-54

Figure B-1
TYPICAL LIFE-CYCLE TRANSITIONS
NOTE Household types are defined in Table B-5



(ADLT3555), and those with all adults 55-64 (ADLT5565). We also contrast persons in households with only adults 35-54 with those only 55-64 (ADLT5565-ADLT3555), and these with senior citizen households (SENIOR-ADLT5565).

Table B-12 presents the contrasts computed from the coefficients in Tables B-10 and B-11. Those that are statistically significant are marked, and our discussion is based on them. Each row sums to zero (the time budget remaining constant at 24 hours). Not every entry in each row is significant; this implies that some combination of differences for the remainder of activities is significant, but we cannot detect it with this model and data.

The family types that we have defined are not independent of the age of the travelers, and in the comparison of some family types it is useful to take implied age differences into account before performing statistical tests. For example, the mean age of the employed is 40 years, yet a 40-year-old could not come from a young adult, a preretirement group of adults, or a senior citizen type family. Hence, in evaluating the time allocation of families of these types, we corrected for the mean ages of these groups. This is done by adding or subtracting a factor times the age and age squared coefficients as noted in Tables B-12 and B-13. Because the mean age of the sample was approximately 40 years, we subtract 12.5 to arrive at the midpoint of the 20 to 34 group (YADULTG), add 20 to reach the midpoint of the ADLT5565 group, and add 30 to correct for those over 65. For example,

Table B-13

OTHER HOUSEHOLD CONTRASTS
(In Hours)

Contrast	Activity Category[1]											
Employed Persons	THOME	TWORK	TPERSON	TEAT	TPLEAS	TFOOD	TSERVE	TSHOP	TENTAIN	TVISIT	TOUTDR	TOTTRAV3
Young Adults vs. Households with Children (YADULTG)[2,3]	.79	-1.5**	.05	.10	.29***	.01	-.03	-.04	-.18	-.07	-.06	.13
Older Adults vs. Young Adults (ADULTMIX-YADULTG)[3]	-.60	1.27*	-.12	-.18*	-.30***	-.01	-.02	-.05	.23	-.03	-.01	-.20
Not-Employed Persons												
Young Adults vs. Households with Children (YADULTG)[2,3]	2.29*	0	-.17	-.05	0.0	-.07	-.27	-.54	.15	-1.21	.19	-.33
Older Adults vs. Young Adults (ADULTMIX-YADULTG)[3]	-2.68*	0	.79	.04	-.06	-.13	.04	.30	.29	.32	.50	.58

SOURCE: Based on data contained in Baltimore Travel Demand Data Set. Table compiled in August 1980.

[1]See Table B-1 for definitions of activity categories.

[2]YOUTH is the omitted variable.

[3]YADLTG is age-corrected with ZI = -12.5*AGEZ + 156.25*AGEZSQ as the correction factor in the text.

LEGEND:

* - significant at the .10 level.

** - significant at the .05 level.

*** - significant at the .01 level.

for the employed subsample, the correction to a test involving YADULTG in the THOME equation would be computed from Table B-10 as follows:

$$Z1 = (-12.5) * (-1.5549 * 10^{-4}) + 156.25 * .25725 * 10^{-2} = .4039.$$

The test of the difference between employed persons in households with preschoolers versus households of young adults for time at home as computed from Table B-10 is thus

$$PRESCHLF - (YADULTG + Z1) = .8686 - (.3900 + .4039) = .0747$$

as reported in Table B-12. In this case the correction makes it less likely that a difference will be found and results in a more conservative test.

First, we found in test regressions (not reported here) that preschool children have no effect on the behavior of men. Holding employment status, age, marital status, and all other variables constant, men without children, men with preschool-age children, and men with school-age children are behaviorally indistinguishable in their broad pattern of time use. For this reason, we omitted preschool children/male adult category (PRESCHLM), and only examined preschool children/female adult (PRESCHLF). However, we could not detect a statistically significant difference between the time use patterns of not-employed young women with children and similar women without children, as can be seen in Table B-12.

For employed women, however, the transition to having a young child does make a difference Table B-12 shows that a woman with a preschool-age child is predicted to spend 0.26 hours less in pleasure riding, and 0.16 hours more in general shopping than a person from a household of young adults. For general travel, there is no reason to believe there is any impact whatever. There are no significant differences for the not-employed women with preschoolers, as noted above.

The change in time allocation associated with the youngest child reaching school age is somewhat stronger, revealing a lessening of the demands of caring for young children. For employed women, the transition results in 0.87 hours less at home, 1.11 additional hours at work, and 0.12 fewer hours spent in general shopping. For not-employed women, the transition results in 1.06 fewer hours at home and an additional 0.65 hours visiting friends.

There are three household structures defined that have older adults as their youngest member ADLT3555, ADLT5565, and SENIOR. The first two are candidates for the next stage in the life cycle (even though we cannot be sure that these individuals have ever had children). An employed member of a household of adults aged 35 through 54 without children present will spend 0.16 hours more eating out than a member of a household with children. A similar member of a household of 55-through-64-year-olds will spend 1.22 hours less working and .47 hours more eating out.

The not-employed member of the households aged 35 through 54 will spend

0.42 hours less in serving passengers. These tendencies are even more pronounced for households of adults aged 55 through 64, with less time being spent in serving passengers and outdoor recreation, and more time spent at home, eating out, and in pleasure traveling.

There is also a noticeable difference between household members of the ADLT3555 and the ADLT5565 groups, although it is not easy to assign this transition to any obvious life-cycle change apart from aging. For the employed, the ADLT5565 group spends even more time eating meals away from home and less time working. For the not employed, the ADLT5565 household members spend 2.5 more hours at home, 0.57 fewer hours in personal business, and 0.39 additional hours in pleasure traveling.

In measuring the impact of the transition from preretirement to retirement, the largest effect would come from the change in work status, which we would expect to swamp any family structure variables. If we hold employment status constant, we find the SENIOR group spending less time taking meals away from home than the ADLT5565 group, whether employed or not employed. The not employed also spend less time in pleasure riding.

It is not necessary to restrict ourselves to comparing "adjacent" household structures along a conventional life-cycle profile, and several interesting contrasts emerge when we compare separated household types and types not obviously fitting into a life-cycle scenario. For example, in comparing the employed young adult group (YADULTG) with the school-age child group (YOUTH) in Table B-13, we find that the employed young adults spend

less time in entertainment (including cultural, religious, and civic affairs) than their counterparts having school-age children. They also spend less time at work (a significant contrast). The young adults seem to spend their time in pleasure traveling instead. While we might suspect that the traveling is a form of visiting friends, we do not find this borne out among the not employed. In this subsample, we find the YADULTG group visiting friends less than those with school-age children, and the extra time is absorbed at home, rather than in pleasure riding.

This apparent "twist" in the time-use profile of the young adult toward pleasure riding and away from entertainment also results in significant differences between the YADULTG group and the ADULTMIX group (YADULTG-ADULTMIX), again with the employed YADULTG group showing more pleasure riding, and less entertainment and work than the ADULTMIX group. In addition, there is more eating out among the young adult household members. Among the not employed, there is a significant shifting of time toward out-of-home activities.

Sex

Since employment status is so important to time allocation, we discuss the employed and the not employed separately.

Employed Persons. The difference in behavior between men and women varies considerably among demographic subgroups. Among the employed it is most marked in the group of unmarried blacks, least marked in unmarried whites, and varies by behavior affected depending on the employment status of the spouse.

The difference between unmarried male and female blacks is picked up in the SEX coefficient (person type 4 minus type 1). For employed persons (see Table B-14), it is clearly significant in the home, work, and food shopping equations, with the black men spending more time at work than their female counterparts and less time at home and food shopping. Black males travel somewhat greater amounts.

For white unmarrieds, the difference is picked up by the sum of the SEX and RACESEX coefficients (person type 10 minus type 7) and is quite sharply moderated. In each case of significance for the SEX coefficient above, the RACESEX coefficient is opposite in sign, and in the travel time equation the point estimate of the net sex difference is almost exactly zero. In all but one of the 12 equations the estimated white sex difference is not statistically different from zero at the .10 level. Females spend 0.81 hours more at home than males, however.

We do find white sex differences among married persons, however. The most natural case to examine is the difference in time allocation between men and women when their spouses work. For whites the men are expected to work about 1.7 more hours, travel about 0.3 additional hours, and spend about 2.2 fewer hours at home. Women spend somewhat less time in pleasure traveling, and somewhat more in food and other shopping. Other activities receive a positive but statistically insignificant amount of time. Blacks display a more extreme pattern for home, work, travel, and food shopping, but do not

have significant differences for pleasure traveling and other shopping. Among persons whose spouses do not work, the difference between men and women also vanishes, with the exception that black women work less and spend more time at home, in entertainment, and in visiting. White married women whose spouses do not work spend less time eating out than men.

Not-Employed Persons. Among the not employed, the differences between the sexes are not as widespread. Unmarried men of both races appear to spend less time eating away from home than do women. Men appear to spend less time in formally defined entertainment than women, but these differences are not significant. For both races, not-employed men with working spouses spend more time in outdoor recreation, and white males spend more time serving passengers. Sex differences are not significant for the not employed with non-working sponses. This may imply a pattern of increased common activities.

Race

The effects by race are given in the RACE coefficient for females and the RACE + RACESEX combination for males (see Table B-15). For the employed, black females spend somewhat more time in food shopping than white females. Employed black males spend somewhat less time in eating out and pleasure traveling, and 0.32 hours more in other travel than white males. For the not employed, black males spend 0.42 hours less serving passengers, while black females spend more time traveling and less time shopping.

Table B-14

SEX CONTRASTS IN TIME ALLOCATION BY MARITAL STATUS, RACE, AND EMPLOYMENT STATUS (In Hours)

	Activity Category[1]											
Employed Persons	THOME	TWORK	TPERSON	TEAT	TPLEAS	TFOOD	TSERVE	TSHOP	TENTAIN	TVISIT	TOUTDR	TOTTRAV3
Unmarried - Black[2]	-1.53**	1.50***	.12	-.03	-.04	-.12***	-.01	-.06	-.05	-.11	.08	.24*
White[3]	- .81*	.70	.16	.02	.04	-.03	-.03	-.04	-.02	-.03	.04	0.0
Married, Spouse Working												
- Black[4]	-2.88***	2.48***	-.03	-.03	.02	-.14***	0.0	-.11	.07	.04	.07	.51***
White[5]	-2.16***	1.67***	.01	.02	.10*	-.06*	-.01	-.10*	.09	.12	.04	.27**
Married, Spouse Not Working												
- Black[6]	-1.22*	1.67**	-.07	.08	-.06	-.05	.01	-.01	-.23*	-.29	.10	.06
White[7]	- .05	.87	-.03	.14*	.02	.04	-.01	0.0	-.21	-.20	.06	-.18
Not-Employed Persons												
Unmarried - Black[2]	- .19	0	.08	-.10**	-.02	-.08	.09	.09	-.54	.34	.35	-.01
White[3]	- .73	0	.22	-.17***	-.02	-.08	.27	-.24	-.39	.40	.39	.34
Married, Spouse Working												
- Black[4]	-1.08	0	-.12	-.06	.03	-.15	.42	.32	-.34	-.29	1.20**	.06
White[5]	-1.61	0	.02	-.12	.04	-.15	.60*	-.01	-.19	-.23	1.24***	.41
Married, Spouse Not Working												
- Black[6]	.86	0	-.29	.01	-.13	-.05	.10	.41	-.40	-.21	- .14	-.15
- White[7]	.32	0	-.16	-.05	-.12	-.05	.29	.08	-.24	-.15	- .10	.20

SOURCE: Based on data contained in Baltimore Travel Demand Data Set. Table compiled in August 1980.

[1]See Table B-1 for definitions of activity categories.
[2]SEX, person type 4-1.
[3]SEX + RACESEX, person type 10-7.
[4]SEX + WORKWHFH, person type 6-3.
[5]SEX + RACESEX + WORKWFH, person type 12-9.
[6]SEX - HUSNTWKW, person type 5-2.
[7]SEX + RACESEX-HUSNTWKW, person type 11-8.

LEGEND:
* - significant at the .10 level.
** - significant at the .05 level.
*** - significant at the .01 level.

Table B-15

RACE AND MARITAL STATUS CONTRASTS IN TIME ALLOCATION BY EMPLOYMENT STATUS, SEX, AND EMPLOYMENT STATUS OF SPOUSE (In Hours)

RACE (WHITE - BLACK)	Activity Category[1]											
	THOME	TWORK	TPERSON	TEAT	TPLEAS	TFOOD	TSERVE	TSHOP	TENTAIN	TVISIT	TOUTDR	TOTTRAV3
Employed Persons												
Females[2]	-.34	.37	.10	.05	.00	-.09**	.04	-.05	.05	-.15	.11	-.08
Males[3]	.38	-.43	.13	.10**	.08*	-.01	.02	-.03	.07	-.07	.07	-.32***
Not Employed Persons												
Females[2]	-.24	0	-.09	.05	.10	.02	.24	.48*	-.26	.02	-.04	-.30*
Males[3]	-.78	0	.05	-.01	.11	.02	.42*	.15	-.10	.08	.01	.05
MARITAL STATUS												
Employed Persons												
Males[4] Females·	-.29	-.26	-.02	.05	.01	-.02	.03	-.07	.08	.26*	.06	.17*
Married, spouse working-unmarried[5]	1.06**	-1.23**	.13	.05	.06	.01	.01	-.02	-.03	.11	.07	-.09
Married, spouse not working-unmarried[6]	-.31	-.17	.19	-.12	.02	-.07	-.02	-.05	.18	.18	-.02	.18
Married, spouse working-spouse not working[7]	1.37**	-1.06	-.06	.17**	-.08	-.08	.03	.03	-.22*	-.07	.08	-.28
Not Employed Persons												
Males[4] Females:	-.87	0	-.31	-.03	-.12	-.02	.48	.32	.04	-.54	.78*	.27
Married, spouse working-unmarried[5]	.01	0	-.11	-.07*	-.17	.05	.15	-.10	-.16	.08	-.07	.20
Married, spouse not working-unmarried[6]	-1.05	0	.38	-.12**	.11	-.03	-.01	-.32	-.14	.55	.49*	.14
Married, spouse working-spouse not working[7]	1.06	0	-.49*	.04	-.28*	.08	.16	.42	-.01	-.47	-.56**	.05

SOURCE: Based on data contained in Baltimore Travel Demand Data Set. Table compiled in August 1980.

[1]See Table B-1 for definitions of activity categories.
[2]RACE, types 7-1, 8-2, or 9-3.
[3]RACE + RACESEX, types 10-4, 11-5, or 12-6.
[4]MARSPW + WORKWIFH: married spouse working vs. unmarried or married, spouse not working. (Married spouse not working vs. unmarried is a null contrast.)
[5]MARSPW, types 3-1 or 9-7.
[6]HUSNTWKW, types 2-1 or 8-7.
[7]MARSPW - HUSNTWK, types 3-2 or 9-8.

LEGEND.
* - significant at the .10 level.
** - significant at the .05 level.
*** - significant at the .01 level.

Marital Status

Employed Persons. For marital status, exclusive of race, several contrasts are significant for the employed (see Table B-15). Married males whose wives also work spend more time traveling and visiting than other males. Females whose husbands work spend 1.06 hours more at home and 1.23 hours less at work than unmarried females. There are no significant differences between married employed females whose husbands do not work and unmarried females. Married working women whose spouses are also working spend more time at home and eating out, and less time in entertainment, than those whose spouses do not work.

Not-Employed Persons. Not-employed males whose spouses work spend more time in outdoor recreation than other men. Married, not-employed women whose spouses work spend less time eating out than unmarried women, while those whose spouses do not work also spend less time eating out but more time in outdoor recreation than unmarried women. Married women whose spouses work spend less time in personal business, pleasure traveling, and outdoor recreation than do those whose spouses are not working.

Age

Our equations were originally fit with dummy variables for age categories 20 through 34, 35 through 54, 55 through 64, and over 65, in order to capture any significant departures from linearity. Most of our results fit a linear or quadratic pattern. We respecified this as a quadratic in age, giving up very little in R^2 for the reduction in number parameters estimated, as well as a reduction of mean square error in some equations.

When the quadratic term is significantly different from zero, it implies that there is a maximum or minimum age at which the activity is engaged in, other things equal. Figure 1 in Chapter 2 illustrates the profile of time spent at home for employed persons, controlling for household composition, education, income, sex, race, etc., as estimated from these data. As can be seen, the age at which the minimum time is spent at home for employed persons occurs at about 39 years, while the maximum time at work is spent by those 44 years old. The differential is, of course, spent on other out-of-home activities.

In Table B-16 we present these calculated maxima and minima for employed persons. In 8 of the 12 activities we find that individuals initially devote less time to the activity as they grow older, but at a certain age the process is reversed and they begin to spend more time in the activity with further increases in age. The table provides the estimated age at which the "turnaround" occurs. When it comes to time at work, activity increases with age until 43.6 years of age, and then declines. Where the coefficient of the squared term is very close to zero, the effect is linear in age and the computation is not meaningful; these cases are marked with dashes.

Income

Employed Persons. The income variables are generally not significant in any of the time allocation equations for employed persons, with the exception of THOME and TWORK. Indeed, the coefficients on income and income squared are virtually identical but opposite in sign across these two equations,

Table B-16

AGE OF PREDICTED MINIMUM (MAXIMUM) ACTIVITY LEVEL
(Holding All Other Variables Constant)
(Employed Persons)

Activity	Age in Years*
THOME	38.79
TWORK	(43.60) **
TPERS	49.60
TEAT	42.80
TPLEAS	58.09
TFOOD	-----
TSERVE	58.12
TSHOP	-----
TENTAIN	41.90
TVISIT	56.86
TOUTDR	59.15
TOTTRAV3	-----

NOTE: See Table B-1 for definitions of activity variables.

*Obtained by solving $B_1 + 2B_2X = 0$, where B_1 is the coefficient of AGEZ, B_2 is the coefficient of AGEZSQ and X is the inflection point. This point is thus $-\frac{B_1}{2B_2} + \overline{AGE}$, since AGEZ = AGE - $\overline{AGE}$.

**This is a maximum; all other entries are minima.

SOURCE Based on data contained in Baltimore Travel Demand Data Set. Table compiled in August 1980.

indicating that the substitution is taking place strictly between the two uses of time (see Table B-10).

The results are partly due to misspecification of the equations; we ought to enter personal earnings and other income as separate variables. Personal earnings would provide a measure of the shadow value of a person's time (taking hours of work into account) and other income would provide the family financial environment in which the respondent makes decisions. From a theoretical point of view, the market wage a person can earn and other family income may well have opposite effects on behavior, and we should disentangle them.

When we reestimated the model with household income separated into personal income and all other income, where personal income is "estimated personal gross income in 1976" as reported by the respondent, we found some slight evidence that the categories should be separated. (The coefficients for this set of equations are not presented here.) For the work and home equations, own income and other income have very similar coefficients, and hence aggregation appears in order in these cases. The separate income variables perform somewhat better in the TPERSON (almost significant negative linear effect of own income), TSERVE (significant positive linear effect of own income), TENTAIN (significant other income variables), and TVISIT equations (almost significant other income variables) for the employed. However, a genuine difference between the two types of income is only showing up in the TENTAIN equation, where the positive effect is coming strictly from other income. For the remaining six equations, neither type of income shows any effect. These results do suggest that a measure of personal earnings as distinct from personal income could improve the equations.

Not-Employed Persons. Income plays a slightly larger role in the equations for the not employed (see Table B-11). Here, household income is largely other income and the variable is less a confusion of different elements. Higher income here implies more time spent at home, in pleasure driving, and entertainment, less time spent shopping, visiting friends, and serving others. Again the income terms are not significant in the travel equations.

From the model as specified, it appears that while income may influence mode of travel and destination, it does not have any noticeable effect on the travel time budget. In the equations in which income has the strongest significant effect for the not employed, one standard deviation of income can result in a noticeable behavioral difference. For example, an $11,000 change in income will reduce time spent shopping by 0.22 hours, increase pleasure riding by 0.12 hours, decrease time serving passengers by 0.10 hours, decrease time visiting by 0.35 hours, and increase time at home by 0.42 hours.

Education

While education is not significant in any of the equations for the not employed, it is an important variable in many of the activity equations for the employed (see Tables B-10 and B-11). This is particularly noteworthy

since the education variable is measured by midpoints for categories rather than an exact number of years, and so the coefficients are estimated with less precision. The coefficients are significant in the work, eat, entertainment and travel equations. Evaluated at the mean of 12.09 years of education for the employed, a one standard deviation increase in education of 3.2 years has the following effects on time reallocation. time at work decreases by 0.27 hours, eating away from home increases by 0.09 hours, entertainment increases by 0.08 hours, and travel time increases by 0.10 hours. This result is not an artifact of the data set containing working students. Of the 277 persons with at least some college, 28 were also students at the time of the survey. When the entire model was restructured excluding these individuals, the education coefficients did not change, if anything, the standard errors declined and the estimates gained in precision. (These results are not presented.)

As age and income have been controlled for, it appears that the educated employed enjoy a rather distinctive lifestyle. However, if income is largely composed of earnings, the work reduction results may in part be reflecting the fact that more educated persons earn more per hour. Hence, holding income constant implies reduced work effort.

PROBLEMS AND QUALIFICATIONS

Problems in this area of study divide into data-related matters and issues of modeling and analysis.

Data Problems

1. Some of the difficulties we encountered in the current study stem from the fact that the Baltimore data set was not designed to study time per se, but travel behavior. We were able to extract the outside-the-home activity pattern of each respondent from the chronological record of all trips made during the day. Since each trip was assigned a single purpose, we were forced to assign all destination time to a single category. Future travel data collection efforts would do well to add several questions concerning other activities at the destination to their questionnaires.

2. Although household income was separated into the personal incomes of each respondent in the household, we do not have information on earnings or wages. Hence, we could not measure the importance of the price of time for its use.

3. Several demographic variables were defined in ways not in agreement with the usual Census definitions. Marital status was coded as either married or not married, and employment status was decided by the respondent.

4. The trip purpose categories were very aggregate in some areas and very disaggregate in others. We would have preferred to separate religious, cultural, civic affairs, and entertainment into individual components.

These problems increase the likelihood that we find that particular subgroups of individuals do not differ in time use, and that certain determinants of behavior (such as income) have little effect on the allocation of time. We think that improved data would sharpen our results, but would not overturn our positive findings.

Statistical Issues

The statistical problems that we have not dealt with all revolve around the nature of the dependent variables individuals cannot spend negative amounts of time in any activity, and a large number of potential observations will record zero time in an activity. These conditions violate the assumptions of the standard responsive model. Indeed, our ordinary least squares estimates do predict negative durations in certain activities for certain population subgroups.

In light of these considerations, we found it best not to include nontravelers in the data set, as their activity time in all categories outside the home would have been zero. A proper correction for this "selectivity bias" would have been to estimate the probability of being in the traveling sample and using this information to correct the estimates. There is extensive econometric literature on such biases, growing out of Heckman's seminal paper (B3). (For a summary of the issues and bibliography of related work, see Heckman (B4).) We have not performed this correction, but this would be a natural extension of the approach.

SUMMARY

In this appendix we present a model of individual time allocation to 12 activity categories, including travel time. The major explanatory variables employed are household type, marital status, employment status of self and spouse, and other demographic descriptors such as age, sex, race, and household income. Household type is defined by the age of the youngest and oldest members.

Three sets of equations were estimated. One set of equations was estimated for employed persons for 12 activity types; another set was estimated for not-employed persons for 11 activity types (excluding time at work), and a final set of 12 equations was estimated for the pooled sample utilizing a dummy variable for employed/not employed and one for employed males.

One set of hypotheses that we wished to test was whether the major break points in the life cycle signaled major changes in time allocation that would show up in the type of data set we have examined.

While presence of preschool children had no impact on the behavior of men or not-employed women, they did impact the time allocation of employed women. Having the youngest child reach school age has an impact on both employed and not-employed women. Progression through the life cycle prompts less time working and food shopping and more time eating out. Time eating out declines again in post-retirement years, however.

Employment status has an enormous impact on weekday activity, causing a considerable shifting of time from most activities to the workplace. Both men and women draw most of their working time from time that would otherwise be spent at home, but the substitution is not complete. However, the pattern is not at all the same between men and women. These differences relate to the initial amounts of time spent by persons of each sex and reflect, in part, existing sex roles.

The difference in behavior between men and women varies considerably among demographic subgroups. Among the employed it is most marked in the group of unmarried blacks, least marked in unmarried whites, and varies by behavior affected depending on the employment status of the spouse. Among the not employed, the differences between the sexes are not as widespread.

We find that a quadratic specification for age fits the data well in most cases, with definable maxima or minima existing for most activity classes. Income tended not to be a significant predictor in most equations for the employed; in part this is due to earnings not being separated from other sources of income. Household income was more important for the not employed, however. Education is a significant predictor of activity for the employed, but not for the not employed.

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APPENDIX C

IMPACTS OF DEMOGRAPHIC TRENDS ON INDIVIDUAL TIME ALLOCATION

Given the set of models describing the time allocation of individuals as presented in Appendix B, it is natural to use them for simulation experiments to see what changes might be expected given changes in the independent variables. Because the models are developed in terms of sociodemographic variables, these simulations look at the impact of shifting age structure, employment status, etc., on time allocation in general, and travel time in particular.

The motivation for this appendix is thus to use the model to investigate aggregate household activity impacts caused by the major social changes that have been occurring over the past several decades. The magnitude of trends such as decreased family size and increased female labor force participation has been well-established as have some of the root causes which go back almost two centuries (C1). It is also widely believed that these trends will have major impacts on aggregate consumer behavior and, consequently, on consumer products and marketing (C2) as well as planning at all levels of government (C3). However, most of the presumed impacts are speculative and little, if anything, is available in the way of quantified estimates of long-run lifestyle changes.

In order to determine the magnitude of impact of these trends on broad categories of household activities, we have used the model described in Appendix B with published 1990 projections of changes in age and household structure and changes in labor force participation, to predict the effect of such changes on time allocation to the activities. This assumes, of course,

that the underlying parameters and constraints remain the same as they were in 1977, the year in which the data used for fitting the model were collected. This appendix is a description of the forecasts, including the assumptions employed in forecasting the exogenous variables and a discussion of the resulting forecasts of time allocations.

FORECASTS OF EXOGENOUS VARIABLES

Forecasts had to be prepared for each exogenous variable of the model. We typically did this by examining the ratio of growth from 1977 to 1990 for each published series utilized and then multiplying this ratio times the relevant 1977 number derived from the Baltimore data set to arrive at the forecast value for the sample in 1990. We proceeded in this manner since the fractions in the various categories from the sample did not correspond exactly to the U.S. total figures given in our source of forecasts.

We had at our disposal forecasts of the number of persons in various types of households from the Current Population Report (CPR) of the Census (C4). Labor force forecasts were available from an article in the *Monthly Labor Review* (MLR) by Flaim and Fullerton (C5). These were the principal sources utilized in constructing our forecast scenarios.

Various assumptions were used in these two publications. The Current Population Report used the Census Series 2 Population Projections for all of its scenarios, varying primarily the trends in marital status and householder proportions. (The term "householder proportions" is now used in place of "headship rates" by the Census.) We have employed Series C from this report, which assumed that the short-term trend in marital status and householder proportions from 1974 to 1978 would hold until 1980; a longer-term trend (1966 to 1980) was assumed to hold between 1980 and 1990. The result of these trends is essentially a very large growth in the number of nonfamily households relative to family households and a large growth in female householders with no husband present. The forecast that we used from the Monthly Labor Review was an intermediate growth forecast which projected a slight decline in male labor force participation and a fairly substantial increase in female labor force participation.

Household Structure

For the family structure variables (PRESCHLF, YADULTG, ADULTMIX, ADLT3555, ADLT5565, SENIOR) we assumed that the fractions in each category would change at the same rate that the fractions for the corresponding age categories of persons in the United States changed. The CPR provided a breakdown of the population by age groups for 1978 and 1990 for persons 14 years and over (C4, Table 4), this roughly corresponds to the sample universe of the Baltimore data set. We computed the fraction of the population 14 years and over that each relevant age grouping was in during the two time periods, and then we calculated the ratio of the 1990 fraction over the 1978 fraction for each age group. We then extrapolated this back to 1977 using the same compound rate of change as from 1978 to 1990. We applied these particular age-specific trends to the fraction in each category derived from the Baltimore data to arrive at 1990 forecasts. These multipliers are detailed in Table 9.

For the alone-female variable (ALONEF) we took the number of females not in families from the CPR and expressed this as a ratio of the total population for each year (C4, Table A). Since 90 percent of all nonfamily households are one-person households, this ratio was deflated by 0.9. The growth rate of this ratio was calculated, and the change was extrapolated back to 1977. This ratio was applied to the Baltimore data as well.

Race and Sex

Proportions by race and sex were derived using the figures from Flaim and Fullerton (C5, Table 2), which presented 1977 data and 1990 estimates on the civilian institutional population by age, sex, and race. The fraction male (SEX), the fraction white (RACE), and the fraction white male (RACESEX) were established from this source. The fraction of senior males (SENSEX) was established from the U.S. Department of Commerce (C4, Table 4). The trends in these ratios were established and applied to the Baltimore data set proportions.

Employment Status

Labor force variables were also derived using the figures from the MLR. Since we assume a constant unemployment rate (HUSNTWKW), the EMPLOYED variable was assumed to be proportional to the labor force participation rate. We thus calculated the trend in the labor force participation rate from 1977 to 1990 from Flaim and Fullerton (C5, Table 3). A similar trend could also be established for the employment by sex interaction variable (EMPLSEX), employed males as a fraction of the total population. These figures were also taken from Flaim and Fullerton (C5, Table 3).

The variables dealing with household interaction in employment status were derived using a combination of the CPR and MLR data. The calculation of the multiplier for the married with spouse working variable (MARSPW) was done as follows. The number of married persons with spouse present for males and females from the U.S. Department of Commerce (C4, Table 4) was multiplied by the labor force participation rate by sex from Flaim and Fullerton (C5, Table 3). This gave, for each sex, the number of persons in the labor force who were married with spouse present. The sum of the male and female values was the total number of persons married with spouse present and working. This was expressed as a ratio to the total number of persons 14 years and over, and the trend in this ratio over time was likewise extrapolated to 1977 and applied to the Baltimore figures as was done for the household structure variables. The working wife variable (WORKWIF) was derived by expressing the number of working women with spouse present, derived from the above procedure, over the total number of persons 14 years and older. The trend in this ratio was likewise extrapolated to 1977 and applied to the Baltimore data.

Age, Education, and Income

The change in mean age was calculated as follows. From the data given in the CPR we established the midpoint of each age group, multiplied this times the population in that age group to get "aggregate age" for each class, summed these numbers, and divided the total number of persons 14 years and older to arrive at an estimate of average age for 1978 and 1990; the trend was extrapolated back to 1977. The change in average age derived in this way from the CPR was then applied to mean age from the Baltimore data before the centering adjustments described above in Appendix B were performed.

For the growth of income, we did not utilize published forecasts but rather extrapolated changes in real family income from the past. This was an average of short- and long-term change as follows. Mean family income for 1970 and 1977 (C6, Table 748) was converted to constant 1967 dollars by using the Consumer Price Index for the relevant years (C7, Table B-49). The compound growth rate for this series in constant dollars was found to be approximately 0.45 percent. We also examined the long-term trend in real median family income for all families between 1950 and 1977 (C7, Table 729). The compound growth rate over this 27-year period was found to be approximately 2.44 percent per year. The average of these two growth rates was 1.44 percent and is what we used to extrapolate household income for the Baltimore data set.

We also calculated the average growth rate in median school years completed between 1950 and 1977 and used this growth rate of approximately 1 percent per year to extrapolate our education variable from the Baltimore data (C6, Table 225).

Discussion

The ratios that we derived in this manner as well as their effect on sample Baltimore data are shown in Table 9. As can be seen, the changes that resulted are small in most cases.

These assumptions generally show trends toward the following: older age groups, more women living alone; more working wives and married persons with spouses working; a greater fraction of the population employed, but a smaller fraction of the employed being male; a slight decline in the proportion of whites; a slight rise in the proportion of males, and a substantial increase in the proportion of older males. Income and education undergo substantial change. Unemployment is unchanged. Strictly speaking, household income should be functionally related to the percentage of married persons with working spouses, etc., but we have not developed that complete an accounting system here.

FORECASTS TO 1990

Two sets of forecasts were performed. In one, we simulated the equations for the pooled sample of employed and not-employed persons. These showed the overall impact one might expect from changing demographic forces. In the other, we computed forecasts for the employed and not employed separately and then computed the weighted average to arrive at the overall impact. This produced some interesting insights into the components behind the overall change.

Pooled Sample Forecasts

When we utilize the equation fit on all persons (Table B-9) there are several forces at work to determine the result. One is the increased labor force participation of women, which tends to increase the value of the EMPLOYED variable and hence to raise the average number of hours worked per day for the entire sample. The concomitant increase in husbands with working wives (WORKWIFH) also tends to increase average time at work, but the increase in the fraction married with spouse working (MARSPW) tends to depress average time at work, as does the slight decline in the fraction of employed males. The effect of increasing income and age on time at work is

concave downward because of the negative coefficient for the square term in each; since we are centering these variables at their means to begin with, any increase past this point will begin to subtract from time at work. The basic tension here seems to be the effect of the increasing labor force participation rate of women versus the increasing age and real income level of the population.

It can be seen from Table C-1 that the increasing percentage of women in the labor force is having a larger impact on time allocation than is the increasing age and income of the population. Time at home is decreasing while time at work is rising. Except for a slight rise in the amount of travel required and in the amount of time eating out, this change adversely affects all other categories of time allocation to greater or lesser degrees.

These results are not unreasonable, but there are several qualifications. First of all, the average effects of these shifts are fairly small. Time spent at home goes down by about 9 minutes, time spent at work goes up by about 14 minutes, time spent in traveling goes up by about 1 minute, and time spent at other activities goes down by approximately 6.5 minutes. These are, of course, averages over the entire population, and the effect on individual persons would in many cases be greater in magnitude. However, the aggregate effects will be small.

Next, there is a slight problem of aggregation bias in that the squared terms for age, income, and education will not aggregate in a linear fashion.

Table C-1

COMPARISON OF 1977 ACTUAL AND 1990 FORECAST OF TIME ALLOCATIONS
POOLED SAMPLE FORECAST
(In Hours)

Activity Category*	Actual 1977	Forecast 1990	Change 1977 to 1990		
			Hours	Minutes	Percent
THOME	16.11	15.97	-0.14	-8.65	-0.89
TWORK	4.86	5.10	0.24	14.32	4.90
TPERSON	0.24	0.23	-0.01	-0.34	-2.39
TEAT	0.08	0.09	0.00	0.25	4.93
TPLEAS	0.08	0.07	-0.01	-0.84	-16.88
TFOOD	0.08	0.08	-0.00	-0.11	-2.40
TSERVE	0.14	0.13	-0.01	-0.77	-9.09
TSHOP	0.26	0.24	-0.02	-0.94	-6.12
TENTAIN	0.18	0.18	-0.01	-0.42	-3.78
TVISIT	0.51	0.47	-0.04	-2.24	-7.33
TOUTDR	0.17	0.15	-0.02	-1.21	-11.60
TOTTRAV3	1.27	1.29	0.02	0.96	1.25

SOURCE Based on data contained in Baltimore Travel Demand Data Set. Table compiled in August 1980.

*See Table B-1 for definitions of activity categories.

Since we are only changing age by a small amount, this may not be a serious problem. However, a better procedure would be to make predictions within specified age classes and then compute a weighted sum to arrive at the aggregate time allocation profiles. We have not taken this step here.

The other problem is the use of the equation that includes both employed and not-employed persons. As we saw in Appendix B, the effects of many of the variables differ between the two segments. Again, a superior procedure would be to make predictions for the employed and not employed separately and then perform a weighted average before making comparisons, or simply make the comparisons within the segments themselves. It is to this that we now turn.

Separate Forecasts for Employed vs. Not Employed

It is instructive to look beneath these aggregate numbers derived from the equation that was fit on both employed and not-employed persons collectively. In Table C-2 we present forecasts to 1990 of time allocation for the employed and the not employed separately, utilizing the separate equations that were discussed above. Since the effects of the exogenous variables were different in some cases between employed and not-employed subsamples, and this difference was not necessarily perfectly captured in the EMPLOYED and EMPLSEX variables of the pooled equation, we would expect the results to be somewhat different. We have also weighted these separate forecasts by the proportion of the employed and not employed that are expected to be in the sample in 1990, and we have presented these results for

Table C-2

ACTUAL AND FORECAST VALUES OF TIME ALLOCATION
EMPLOYED, NOT EMPLOYED AND ALL PERSONS
(In Hours)

Activity Category*	Employed Persons Actual 1977	Employed Persons Forecast 1990	Employed Persons Percent Change	Not Employed Persons Actual 1977	Not Employed Persons Forecast 1990	Not Employed Persons Percent Change	All Persons - Weighted Average Actual 1977	All Persons - Weighted Average Forecast 1990	All Persons - Weighted Average Percent Change
THOME	14 38	14 40	0 12	20 08	20 16	0 38	16 11	15 89	-1 37
TWORK	6.98	6 99	0 12	0 00	0 00	0 00	4 86	5 18	6 49
TPERSON	0 18	0 17	-3 80	0 38	0 39	3 48	0 24	0 23	-4 42
TEAT	0 10	0 11	3 39	0 04	0 03	-3 07	0 08	0 09	6 50
TPLEAS	0.05	0 05	-5 90	0 15	0 13	-14 41	0 08	0 07	-14 48
TFOOD	0 05	0 05	10 44	0 15	0 15	-0 18	0 08	0 08	-1 25
TSERVE	0 11	0 11	-0 53	0 20	0 18	-13 94	0 14	0 13	-8 43
TSHOP	0 14	0 13	-2 84	0 53	0 53	-0 92	0 26	0 24	-8 40
TENTAIN	0.14	0 14	2 38	0 28	0 30	4 88	0 18	0 18	-0 23
TVISIT	0 36	0 35	-4 66	0 84	0 81	-3 98	0 51	0 47	-8 32
TOUTDR	0 12	0 11	-8 19	0 31	0 28	-7 65	0 17	0 15	-12 45
TOTTRAV3	1 38	1 38	0 27	1 04	1 05	1 01	1 27	1 30	1 61
Proportion of Sample	6966	7409	--	3034	2591	--	1 00	1 00	--

SOURCE Based on data contained in Baltimore Travel Demand Data Set Table compiled in August 1980

*See Table B-1 for definitions of activity categories.

comparison. Some nonintuitive results produced by the weighting procedure are discussed below.

To forecast the exogenous variables we proceeded in roughly the same manner as described above, but we prepared separate sets of exogenous variables for the employed and not employed. That is, we calculated the means in 1977 for each subsample separately, applied the growth multipliers presented in Table 9 to each set, and utilized these values in the separate equations. A table analogous to Table 9 is not presented here, but it would reveal the not employed to be concentrated in households with preschoolers or with exclusively older members and to be underrepresented in households of alone-females, those with a working wife, and among white males.

Table C-2 contains the results of our forecasts by employed and not-employed subsamples, as well as the weighted average obtained by weighting the vectors for employed and not-employed by their expected proportion of the total population (the EMPLOYED variable of Table C-1). A comparison of these series reveals how changes by subsample are reflected in the total sample.

As can be seen from Table C-2, time at home rises slightly for both the employed and not-employed subsamples; indeed, the percent change is almost zero for both the employed and the not-employed subsamples. If income and education are not assumed to grow in real terms, however, time at home rises to a greater degree for both groups. Interestingly enough, the pooled results show a slight decline in time spent at home. This is a result of the changing proportion of persons employed, which rises from 70 to 74 percent in the 13-year period. Since employed persons spend approximately 5.5 fewer hours at home, their increasing predominance in the population will tend to reduce the average amount of time spent at home, even though both employed and not-employed persons are spending slightly more time at home in 1990 than they did in 1977.

This weighting effect also holds true for the time at work category. Time at work is forecast to increase only slightly over the time period for employed persons (and remains at zero for not employed, of course). However, the average amount of time spent at work for the entire sample rises since, again, a greater proportion of the total sample is employed.

This effect shows up again in the personal business category. Time spent in this category declines slightly for the employed and rises for the not employed. The aggregate effect for the entire sample, however, is a slight reduction in average time spent in personal business because the employed spend approximately half as much time at personal business as the not employed and the former fraction of the population is expected to climb.

Time spent eating out is forecast to increase for the employed and decrease for the not employed. This is reflected in a moderately large percentage increase for the pooled sample.

Time spent in traveling for pleasure is forecast to decline for both the employed ard the not employed. The effect in the pooled sample in this case is for a reduction in this category.

Time spent in grocery shopping is forecast to increase for the employed, but not to change for the not employed. Again, since the employed spend only one-third the time in grocery shopping compared to the not employed, the effect in the pooled sample is for a reduction in the average amount of food shopping for the entire sample.

Time spent in serving another person is forecast to decline for both the employed and the not employed subsamples as well as in the pooled samples. The decline is greatest in percentage terms for the not employed.

Time spent in other than food shopping is forecast to decline for the employed and not to change for the not employed. The effect in the pooled sample is for an even greater decline on average as the effect in the employed subsample is magnified by the increasing importance of this group.

Time spent in entertainment, civic, cultural, or religious activities is forecast to increase for both the employed and for the not-employed subsamples. The overall effect is to show a very slight decline for the average amount of time spent in the pooled sample, again due to the mix effect.

Time spent visiting friends or relatives, in contrast, is forecast to decline for both the employed and the not employed. In this case, however, there is a substantial decline in percentage terms for the pooled sample.

Time spent in outdoor recreation follows a similar pattern. There is a substantial decrease for both the employed and the not employed. The overall result is for a decrease for the pooled sample.

Finally, there is a slight increase in the amount spent in travel time for the employed, and a more substantial increase, in percentage terms, for travel time for the not employed. This results in an even greater increase in travel time for the pooled sample, when measured in percentage terms.

SUMMARY

This section is concerned with using our model of time allocation in hours of individual travelers to in-home activities, 10 classes of travel-generating activities, and total travel time to perform forecast experiments utilizing published forecasts of employment and demographic characteristics of the population in 1990. Several interesting results emerged concerning the impacts of demographic trends on time allocation.

First of all, in order to produce the forecasts at all, it is necessary to forecast the exogenous variables, and to do this it was necessary to pull together data from various sources. The overall trends are for an aging of the population and an increase in labor force participation, primarily due to a greatly increased labor force participation among females. Household composition is shifting toward households with older members and toward single-person households. Income and education levels are rising.

The predicted impacts of these changes are believable but vary by category of time use as well as employment status. Perhaps the most significant finding is that the increasing percentage of women in the labor force is having a larger impact on time allocation than is the increasing age and income of the population. Time at home and work changes very little for both employed and not-employed groups. There are a variety of other effects in the other categories. Due to the rising percentage of the employed in the total population, however, and the differing patterns of time use that the employed have as compared with the not employed, the effect in the overall

sample is for a slight decrease in the amount of time spent at home and an increase in the amount of time spent at work on average. Average travel time rises, but pleasure traveling and time spent in serve-traveler trips declines for both groups. Time spent in food shopping and eating out rises for the employed and falls for the not employed. Time spent in personal business falls for the employed and rises for the not employed. The changes, when averaged over the entire population, are of fairly small magnitude, however, with only about one-quarter of an hour being reallocated among activities overall. Consequently, among admittedly broad categories of measures of consumer behavior, we perceive relatively small impacts on weekday activities from the major and persistent social and demographic transitions now taking place.

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APPENDIX D

HOUSEHOLD-LEVEL VARIABLE CLASSIFICATION AND DEFINITION

After examining individual-level behavior and associated household-level constraints, the principal focus of the project turned to the explanation of trip generation at the household level. This has benefited from our experience with the individual-level modeling, comments from the NCHRP Advisory Panel, and the final release of the fully-cleaned Baltimore Travel Demand Data Set. Although focusing on the trip frequency question, we have maintained the orientation that travel is generated in response to the desire for a particular allocation of time to different activities on the part of individuals and, taken collectively, households.

We have attempted to extend the range of analysis as well. Travel time and frequency by mode are included, although this is not a central focus. Miles traveled by mode and purpose are considered, as is the question of fuel consumed by household-owned cars. Our trip and activity purpose categories, as well as our household type categories, have been redefined to reflect what we learned in the individual analysis.

In the sections that follow, we discuss the classifications we have made of purpose, mode, household structure, and neighborhood type. A brief description of the data processing that was performed follows. In a subsequent appendix we present two descriptive analyses: one of socioeconomic and travel behavior differences by household type, the other an examination of the trip linkage question. The final appendix describes the equations that were estimated and tests that were performed. Here we deal with two competing approaches. One is the activity-based approach, which we

feel is most useful for basic investigations into the relationships between individuals' and households' lifestyle and their travel behavior. Practical planning methods, utilized in the Urban Transportation Planning System (UTPS), on the other hand, concentrate on home-based trip productions, i.e., trips that either start or end at home. This eliminates the "home" trip purpose of the activity-based approach. Instead of resolving the question analytically, additional models are developed, similar in structure to the activity-based models, for predicting home-based trip productions and interfacing with UTPS.

VARIABLE CLASSIFICATION

As noted above, four sets of classifications were developed. The first is for activity and trip purpose, while the second is mode. These are straightforward. The third deals with a revised household structure classification in which we attempt to capture some notion of the relationships among household members. Finally is the question of neighborhood definition.

Activity and Trip Purpose

We have defined seven activity trip purpose categories from the trip file as shown in Table D-1. These are home, work or school, shopping, personal business, entertainment or community activities, visiting and social activities, and servicing or accompanying a traveler. We decided it was necessary to reduce the number of trip purposes that we were using, in part because of the consideration of mode used (which increases the dimensionality of the problem) and in part because some of our earlier categories represented only a small number of trips. It can be seen that the

Table D-1

TRIP PURPOSE CATEGORIES

Recoded		Baltimore Data Set	
Category	**Definition**	**Category**	**Definition**
1	Home	1	Home
2	Work/School	2	Work
		3	Work Related Business
		4	School
3	Shopping	5	Food Shopping
		6	Convenience Shopping
		7	Other Shopping
4	Personal Business	8	Personal Business (NEC)
		9	Medical Appointment
		11	Auto-Related
		19	Travel to Terminal
5	Entertainment/Community	10	Eat Meal
		12	Entertainment, Religious, Civic, Cultural
		14	Outdoor Recreation
		15	Pleasure Travel
6	Visit/Social	13	Visit Friends or Relatives

Table continued on following page.

Table D-1 (Continued)

TRIP PURPOSE CATEGORIES

Recoded		Baltimore Data Set	
Category	**Definition**	**Category**	**Definition**
7	Service/Accompany Traveler	16	Serve Children < 16
		17	Serve Adult
		18	Accompany Driver
		20	Accompany Child-No Auto
		21	Accompany Adult-No Auto

categories relate in a rough way to the role complex ideas proposed in Phase I of the project (D1, p. 52), and further elaborated on in Task 1 of CRA's work on Phase II (D2, Appendix B).

These role complexes include work/career, household/family, interpersonal/social, and leisure/recreation. There are problems in mapping our purposes to these. We cannot tell what persons are doing at home, and the activity could relate to any one of the four role complexes. Purpose 12 of the original data set -- entertainment, religious, civic, cultural -- spans the interpersonal/social and leisure/recreation categories. Travel to terminal or accompanying another could be any of the four. However, a rough mapping would be the following our home, shopping, personal business and serve traveler categories are "home/family"; our work/school is "work/ career"; our entertainment/community is largely "leisure/recreation"; and our visit/social is " interpersonal/social." Other schemes are, of course, possible.

Table D-2 shows the average number of trips per household in each category, the average amount of time spent in each activity, and the average amount of travel time associated with each activity. This table treats each household as a unit of observation and deals with the trip and activity patterns of all members of the household over 11 years of age, excluding those who were away on the travel day and guests with residences elsewhere. These averages are not scaled to account for differing household size. The sum of travel and activity times implies an average of 2.6 persons age 12 or greater, and hence eligible for travel records.

Table D-2

AGGREGATE TRIP FREQUENCIES AND TIME ALLOCATIONS
BY TRIP PURPOSE FOR TRAVEL DAY
(Averaged Across 961 Households)

Trip Purpose	Trip Frequency	Trip Duration (In Minutes)	Activity Duration (In Minutes)
1. Return Home	3.06	67.9	2,730.0
2. Work/School	1.52	38.4	525.9
3. Shopping	.93	13.7	35.0
4. Personal Business	.51	10.9	29.9
5. Entertainment/Community	.69	15.8	86.8
6. Visit/Social	.62	12.4	86.5
7. Service/Accompany Traveler	.49	7.6	10.4
TOTAL	7.83	166.8	3,504.4

SOURCE: Based on data contained in Baltimore Travel Demand Data Set. Table compiled in June 1980.

Travel Mode

The travel modes that we have defined are presented in Table D-3. These modes distinguish between the driver and the passenger of a household vehicle, a passenger on a bus, walking, other nonmotorized modes, and other motorized modes. The first four categories are of primary interest. Category 5, Other Nonmotorized Modes, is extremely heterogeneous, as is Category 6, Other Motorized Modes. These latter two categories were isolated to preserve the integrity of the preceding four. The average amount of time spent traveling by mode by household is presented in Table D-4. Again, these times are not scaled to account for household size.

Household Types

In the individual-level modeling we employed a definition of household type based on the age of the youngest and eldest members of the household. In this present typology we do not treat age of any member of the household explicitly, but introduce it in other ways in the modeling. The earlier typology was efficient in the sense that it represented one aspect of the age structure of the household, but it is difficult to forecast and does not relate easily to the more common ways in which households are described. In particular, it does not (nor was it intended to) represent whether the individuals were related or unrelated, a concept that has been noted as important by previous transportation analysts (D3, D4). We thus developed a typology that relates more closely to Census definitions, is implementable using household survey data, and represents the patterns that we detected in the Baltimore data.

Table D-3

TRAVEL MODE CATEGORIES

Recoded		Baltimore Data Set	
Category	Definition	Category	Definition
1	Auto Driver, Household Vehicle	1	Auto Driver (Household Vehicle)
2	Auto Passenger, Household Vehicle	2	Auto Passenger (Household Vehicle)
3	Bus	9	Bus
4	Walk	12	Walking
5	Other Nonmotorized Modes	11	Bicycle
		13	Hitchhiking
		14	Boat
		15	Horse
6	Other Motorized Modes	1	Auto Driver (Non-household Vehicle)
		2	Auto Passenger (Non-household Vehicle)
		3	Van Pool
		4	Commercial Driving
		5	Motorcycle Driver
		6	Motorcycle Passenger
		7	Tax
		8	Railroad
		10	School Bus

Table D-4

AGGREGATE TIME SPENT BY MODE FOR TRAVEL DAY
(Averaged Across 961 Households)

Mode	Travel Time (in minutes)
1. Auto Driver, Household Vehicle	73.6
2. Auto Passenger, Household Vehicle	17.0
3. Bus	27.8
4. Walk	19.3
5. Other Nonmotorized Mode	2.0
6. Other Motorized Mode	27.0
TOTAL	166.8

SOURCE: Based on data contained in Baltimore Travel Demand Data Set. Table compiled in June 1980.

Classification Criteria. The four main criteria employed were as follows

- Relationship among individuals,
- Presence or absence of dependents,
- Age 20 as cut-off for childhood; and
- Number and type of adults present.

The variables used for creating household types were age, sex, marital status, and last name of each nonvisitor in the household. The decision logic used is displayed in Figure D-1.

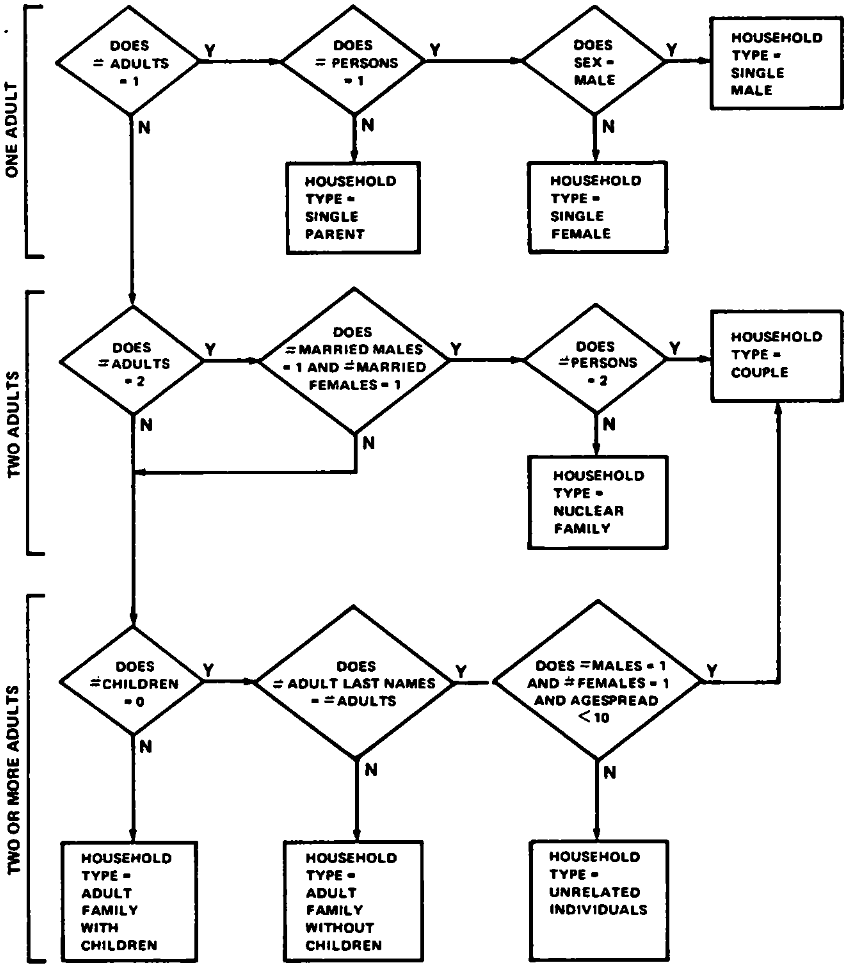
One major criterion for classification was whether households were made up of related or unrelated individuals as best as we could infer it. The time allocation and travel behavior of unrelated individuals, it was felt, would be relatively autonomous, whereas related individuals would be more likely to chain trips, accompany others, or have complementary travel patterns by purpose, which would be reflected in differing trip generation rates.

The presence or absence of dependents was also a major criterion in typology development, since it was felt that the presence of children would have a direct bearing on the travel behavior of adults in the household. In looking at the data it was also clear that the division between generations in a specific household would often have been quite arbitrary, so we did not attempt to classify three-generation households, etc., explicitly.

Ages 19 and 20 were used as the cut-off between children and adults. This age was chosen as a likely division between dependence on adult family members and adult independence itself. The data appear to support this

Figure D–1

FLOWCHART OF HOUSEHOLD TYPOLOGY



choice, there are very few 18 or 19 year olds living outside of a family structure or heading families themselves.

Related to the two previous criteria, a final major criterion for household classification was the number and type of adults present. The main distinctions were among households with a single adult, those headed by a couple, and those with other combinations of two or more adults. Marital status was also considered.

The Household Types. Twelve household types were first developed, leaving no unclassified households, and were later combined into eight final categories as presented in Table D-5 and discussed below.

Single males and single females make up about 5 percent and 10 percent of the households, respectively. They are adults living alone; marital status is not meant to be implied.

Unrelated male, female, and mixed sex households together make up only 4 percent of the households. Individuals in a household were judged unrelated if all were adults and if all last names were unique. As mentioned earlier, these individuals were expected to have relatively autonomous life styles and hence travel behavior.

An exception among unrelated people, we thought, were households of unmarried couples. Defined as one male and one female adult within 10 years of age, they were grouped with married couples, whose travel behavior they were expected to more closely resemble. (Only 12 such households were identified.) Married couples were defined as one married male and one

Table D-5

HOUSEHOLD CLASSIFICATION

Household Type	Number of Households	Percent of Households	Number of Individuals	Percent of Individuals	Values of Variable CHHTYPE	Values of Variable HHTYPE
SINGLE MALES	49	5 1	49	1.5	1	1
SINGLE FEMALES	95	9 8	95	3 0	2	2
UNRELATED INDIVIDUALS	38	3 9	89	2 8	3	
Male Roommates	9	0 9	22	0 7		4
Female Roommates	22	2 3	47	1 5		5
Mixed Roommates	7	0 7	20	0 6		6
COUPLES	173	17 9	346	10 9	4	
Married	161	16 6	322	10 1		3
Unmarried	12	1 2	24	0 8		11
SINGLE PARENT HOUSEHOLD	93	9 6	333	10 5	5	
Male Headed	7	0 7	17	0 5		8
Female Headed	86	8 9	316	10 0		9
NUCLEAR FAMILY	256	26 5	1102	34 7	6	7
ADULT FAMILY WITH CHILDREN	164	17 0	874	27 5	7	12
ADULT FAMILY WITHOUT CHILDREN	99	10 2	285	9 0	8	13
TOTAL HOUSEHOLDS	967	100.0	3173	100 0		

SOURCE Based on data contained in Baltimore Travel Demand Data Set Table compiled in August 1980

*Figures include households with guests that were later deleted. The final number of households is 929. The percent of households in the major categories in column 3 vary at most 1 percent from the final data.

married female; last name was not considered. Together married and unmarried couples without children make up about 18 percent of the households.

Less than 10 percent of the households are single parent households, and 92 percent of these are headed by females. They were classified by checking for the presence of one adult and any number of individuals under 20. Last name and marital status were not considered.

Over 26 percent of the households are "traditional" nuclear families by our definition. They were identified by one male and one female married adult and children under 20 years of age only. As with married couples, marital status rather than a common last name was the identifying criterion. Also, in each household type that includes children, the children's last names were not considered.

Equally numerous, but more difficult to classify, were other family groups that failed to fit into any of the previous household types. The presence of dependents and additional adults or, if adults only, a family relationship between adults distinguished these households. They ranged from households of siblings, to mother/son households, to three-generation households, to nuclear families with children 20 years and older. In many cases the combination of several last names and nearly continuous age spreads made it impossible to decipher how household members were related. In the end a simple criterion, the presence of dependents, was used to divide the households into adult families with children, and adult families without children.

The former household type, 17 percent of the households, was distinguished from nuclear families and single parent households by the presence of additional adults. That is, there was more than one person over 20 and some combination of adults other than or in addition to one married couple. These extra adults may have been older siblings of the dependent children, grandparents, a second apparently unrelated parent, or other adults.

The final family type, grown families without children, make up just over 10 percent of the households. They were households with at least two related adults based on a common last name. These were often families with grown children, couples with an older parent present, or households with one parent and a grown child. Adults with other last names were often present as well. Although we do not know whether they were related or not, it is probable that an adult household with any related individuals is likely to operate more as a unit rather than as autonomous individuals.

Although the latter two categories are clearly diverse, it was not felt that any other sizeable household types were indicated by the data or could be easily and logically separated from the others. Further, these latter two household types, as well as the previous six, were distinguished by the major criteria, mentioned above, which we thought important to understanding households in general as well as their travel behavior in particular.

As a postscript it should be noted that (only) 12 households were classified "by hand." Eight of them failed the age test. These were as follows. a single 19-year-old male, a group of four 19-year-old female roommates, two married couples with one member under 20 years old, and four nuclear families with one or both parents under 20. In each of these cases the 18- or 19-year-old was in an adult role and, although the algorithm considered them children, they were recoded into the adult category they resembled. Finally, there were also four apparently married couples with a missing value for the marital status of one member of the pair. They were placed initially with unmarried couples and ended up in the couples category.

In many of the household types there were a few missing values, possible coding errors, or borderline cases subject to different interpretation. However, this classification scheme has the benefit of being straightforward, relatively easy to implement (in retrospect), and requiring a minimum of second guessing the data. Most of all we think that it does justice both to the diversity of the households and to the factors most relevant to travel behavior.

Comparison with Prior Household Types. In Table D-6 we present a cross tabulation of the household types used in the individual analysis with these present household types, to indicate how they differ. It should be noted that Table D-6 includes all of the households for which this information was available, while Tables B-3 and B-4, which are also tabulations at the household level, only present information for the reduced set of households used in that analysis. (Tables B-3 and B-4 thus exclude 320 households that traveled on the weekends, contained anomalous data -- the data set used there

Table D-6

RELATIONSHIP-BASED VS AGE-BASED HOUSEHOLD TYPOLOGIES
(Number of Households)

Relationship-Based Categories**	Age-Based Categories*								
	ALONE+	PRESCHOOL++	YOUTH	YADULTG	ADULTMIX	ADLT3555	ADLT5565	SENIOR	TOTAL
Single Male	36							13	49
Single Female	47							48	95
Unrelated Individuals			1	6	3	11	5	7	33
Couple			2	28	3	42	56	41	172
Single Parent		29	63						92
Nuclear Family		103	146						249
Adult Family, with Children		46	102						148
Adult Family, no Children				3	56	21	7	4	91
Total	83	178	314	37	62	74	68	113	929

SOURCE Based on data contained in Baltimore Travel Demand Data Set Table compiled in August 1980

*See Table B-5 and accompanying text for definitions.

**See Table D-5 and accompanying text for definitions

+Includes ALONEM and ALONEF

++Includes PRESCHLM and PRESCHLF

was an earlier version of the Travel Demand Data Set -- and households that were discarded for other reasons.) Large areas of Table D-6 are logically excluded from having nonzero entries. The single male and female categories consist of ALONEF and ALONEM and part of the SENIOR category utilized at the individual level. Unrelated individuals and couples are spread across the entire spectrum of adult household categories utilized at the individual level (the three entries in the youth category are, as mentioned above, filled by households of persons under 20 who were performing adult roles). The single parent, nuclear family, and adult family with children categories used here are only represented in the PRESCHL and YOUTH categories at the individual level, which denoted families with the youngest member being preschool or of school age, respectively. Finally, the adult family with no children category maps into all of the YADULTG and above categories at the individual level. This table shows that, for those categories that are defined in common, the two categorization schemes break households down in quite different ways. We report in a later section on a comparison to test the relative efficiency of the two different schemes in predicting trip frequency.

Neighborhood Type

The final typology that we needed to develop was that for neighborhoods. There are two reasons to introduce neighborhood-level information into equations that predict at the level of the household. On the one hand, this need represents a deficiency in the amount of information that we have about each household. In particular, typical travel survey type information only reveals information about externally-observable characteristics of the household and person, but no information about their preferences. Although we attempt to infer preferences from this observable information, such inferences may be biased. For example, people reveal a preference for a certain lifestyle by their choice of residential location. They then reveal their preferences by acting in various ways. This choice of location also seems to affect their subsequent behavior, relationships within the family, etc. These questions were dealt with at length in our first interim report (D2, Appendices B and C).

In the case of mode choice, it has been argued that the failure to account for residential choice may lead to an overprediction of the elasticity of use of transit with respect to level of service (D5, pp. 1-23 to 1-32). This argument essentially is that households with little interest in using transit will not locate in transit-accessible areas, such as the city. By pooling both groups in an analysis and not accounting for this factor, one notes a relationship between transit level of service and use of the service which may overpredict the responsiveness of households to change in level of service in suburban areas. Thus, variables that describe the location of the residents of the household proxy other variables that we are not measuring (but which need to be measured).

The other reason for introducing neighborhood type variables is that they index, in a crude way, the opportunities available to a household in a particular area. One may hypothesize, for example, that households living in "opportunity rich" areas will make shorter, more frequent trips and engage in

less trip chaining than those in less dense areas, for whom trips involve greater planning and consolidation. Ideally, one would use measures that relate the area of residence to other proximate areas with similar or greater opportunity to derive a general measure of accessibility. There are several reasons we did not do this. First, these techniques involve a great deal of computation and do not lend themselves readily to the types of applications that we foresaw for the measures. Second, one must choose a way of "discounting for space," and this is often an arbitrary procedure. Log-sum terms from the denominator of a logit function are sometimes used (D6, D7), but unless these terms arise from the model calibrated to the region of analysis, another source of bias is introduced. The results of accessibility measures have been mixed in these and other studies (D8). Third, in our "activity-based" analysis we are not concerned with the origin or destination of the activity in space, rather we are interested in indexing by the destination activity. In the case of nonhome-based trips, the attributes of the residential zone or its surrounding zones are irrelevant, except as such properties index the choice of lifestyle, as discussed above.

In order to isolate relatively independent factors for inclusion in the models, we used factor analysis on several properties of the traffic analysis zone. We followed a standard procedure.

Variables that the previous literature review suggested as indexing lifestyle included population residential density (persons per residential acre), household residential density (households per residential acre), average household size, percentage of the family households, average income, average number of autos, "other density" (nonretail employment density per acre), and percent of the land area developed residentially. These variables by no means exhausted the variables available to us at the zonal level, but were selected as indices of mobility and lifestyle.

Three factors emerged. The first clearly represented both population and household residential density. The second was positively correlated with household size and negatively correlated with other density; income also had a positive correlation with this factor, although not quite as high as the other two. The third factor had positive correlations with average number of autos in the zone and percent developed in residential acreage. We selected population residential density, average household size, and percent developed in residential acreage as variables representative of these factors, rather than using the factor scores themselves. We did this because 1) the loadings were high, 2) transferability to another area was facilitated, and 3) computational complexity was again reduced.

VARIABLE DEFINITIONS

A data base at the household level was constructed utilizing various files from the Baltimore Travel Demand Data Set discussed more fully in Appendix A. Because we utilized in some parts of the analysis a block recursive structure, where dependent variables at one level were used as independent variables at a lower level of modeling, it is not possible to separate strictly dependent and independent variables. However, we adopt that convention here.

Dependent Variables

The variables created from the trip file include activity time by purpose, and travel time, frequency, and miles traveled by mode and purpose. The records, which exist trip by trip, were aggregated to the household level and eventually merged into the household data set, to be used as dependent variables.

It was necessary to aggregate the individual activity times derived from the trip file to the household level by trip purpose. Because of the way the trip file was structured, it was necessary to impute the time allocated to the first activity in the morning from 4:00 a.m. to the first trip using its associated "purpose at origin." While most people began the travel day at home, there were a few individuals who were engaged in out-of-home activities between 4:00 a.m. and their first trip of the day. The time allocation for nontraveling members of households (for which there were no trip records in the trip file) was added to in-home time for the entire day. We did not allocate any time to the household for children 11 years and under, adults outside of the area on the study day, or visitors to the home on that travel day. Our accounting is thus for "eligible household members" as defined in the Baltimore data set.

Individual travel times were also determined from the trip file and were aggregated to the household level by trip mode, trip purpose, and 42 categories of mode-by-purpose.

Combining activity and travel times resulted in variables for total time by purpose, and a sum of total time for every eligible household member for the entire day. The latter variable was a check that the full day was accounted for for all eligible members.

Trip frequency and person-miles traveled were treated much the same way. They were broken down by purpose, mode, and mode-by-purpose, then aggregated by the household level. Trip frequency was aggregated by purpose in two different ways, however. One was based on the activity at the destination, and utilized the seven purposes in Table E-1. The other tabulated the frequency of home-based trips, and was accumulated for all nonhome purposes. These two definitions -- the one that we term "activity-based," the other home-based -- are discussed in greater detail in Appendix F.

Miles traveled was computed differently, depending on mode, however. Highway distance was used for auto driver and auto passenger trips as well as other motorized and nonmotorized trips. Transit distance was used for bus trips, and trip time divided by 19 minutes per mile, an estimated walking speed, was used for walking trips.

Vehicle miles traveled by purpose was retained for all auto driver trips. At the same time, variables for gallons of gas used by purpose were created by dividing vehicle-miles traveled by city miles per gallon for all auto driver trips.

The activity-based dependent variables created from the trip file are shown in Table D-7.

Independent Variables

The independent variables vary somewhat with the particular models being developed. Specific variables are defined in Table 13 of Chapter 2 and Table F-11 of Appendix F.

Table D-7

DEPENDENT VARIABLES
(Activity-Based)

	Totals	Purpose[1]	Mode[2]	Mode and Purpose
Activity Times	TOTACT	APURj		
Activity Times at First Purpose		FPURk[3]		
Travel Times	TTRAVTM	TTPURj	TTMODEi	TMOiPURj
Total Time[4]	TOTDAY	TAAPURj		
Frequency	TRIPFREQ	FREQPURj	FREQMOi	FMOiPURj
Person-Miles Traveled	PERSMILE	MILEPURj[5]	MILEMOj	MMOiPURJ
Vehicle-Miles Traveled[6]	TOTVMT	VMTPURj		
Gallons of Gas Used[6]	TOTGAS	GASPURj		

[1] j = 1 ... 7

[2] i = 1 ... 6

[3] k = 1, 2, 4, 5, 6

[4] Total Time = Activity Time + Travel Time

[5] Transit distance used for bus. Trip time/19 used for walk. Highway distance used for other modes.

[6] Calculated for auto driver, household vehicle only

VMTPURj = MMO1PURj

TOTVMT = MILEMO1

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APPENDIX E

PRELIMINARY ANALYSES

Before discussing the modeling which we performed, we will present certain descriptive findings about the data to put the modeling into perspective. First, we apply analysis of variance procedures to various basic statistics and assess the implications for modeling. Second, we look at the trip linkage question in some detail. This discussion treats home-based travel and travel linkages among activities as well as the differences that occur when one introduces residential location. A subsequent appendix deals with our modeling in greater detail.

DIFFERENCES BY HOUSEHOLD TYPE

As a first look at the data by household type, the means of selected variables are compared and discussed below.

Table E-1 presents means of number of persons by age and by family type. The household size for single male, single female, and couples households is established by definition; this is also true for the number of children for these categories, as well as unrelated individuals and adult families without children (although a few roommates with members under 20 were exceptions). Single parent households, nuclear families, and adult families with children rank in ascending order of family size (these differences are statistically significant at the .001 level). Roommates, although averaging slightly larger than two persons per household, do not have significantly larger households than couples.

Table E-1

AGE COMPOSITION BY HOUSEHOLD TYPE
(Average Numbers of Persons)

Household Type	Family Size	Children (Age < 20)	Preschoolers (Age < 6)	Elementary (Age 6-11)	Eligible Children (Age 12-19)	Age of Eldest Member
Single Male	1.0	0.0	0.0	0.0	0.0	46.6
Single Female	1.0	0.0	0.0	0.0	0.0	58.3
Unrelated Individuals	2.3	0.1	0.0	0.0	0.1	58.5
Couples	2.0	0.0	0.0	0.0	0.0	57.3
Single Parent	3.5	2.6	0.3	1.2	1.1	38.3
Nuclear Family	4.2	2.3	0.4	0.9	1.0	39.1
Adult Family with Children	5.2	2.2	0.3	0.6	1.3	52.6
Adult Family without Children	2.8	0.0	0.0	0.0	0.0	61.8
All Types	3.2	1.2	0.2	0.4	0.6	49.8

SOURCE Based on data contained in the Baltimore Travel Demand Data Set. Table compiled in October 1980.

It is interesting to note that the number of children per household is highest for single-parent households, who have an average of 2.6 children. Nuclear families, with 2.3 children on average, are not significantly different from adult families with 2.2 children under 20. Numbers of children by age follow the following patterns: nuclear families have a larger number of preschoolers; the number of elementary school children is highest for single-parent households and lowest for adult families with children; and more teenagers (who are eligible for travel records) appear in adult families with children. (These differences are statistically significant.) The average ages of the eldest members of single parent and nuclear parent households do not differ from each other, but are significantly lower than for the other household types.

Mean household income, displayed in Table E-2, shows a systematic pattern. (Grouped median income was recorded and averages across households for these figures.) Averaging approximately $20,000 annually are nuclear families and adult families with or without children. Couples stand apart at $17,000. Unrelated individuals' household income averages $12,000 which is not significantly different from single males at $9,000, which in turn is not statistically different from single parent households at under $8,000, and single females at $7,000. The overall mean household income was $16,000.

Not surprisingly, households rank the same on vehicles owned as they do on income. It is notable that single parent households' low rate of auto ownership, considerably less than one auto per adult, resembles that of

Table E-2

OTHER CHARACTERISTICS BY HOUSEHOLD TYPE

	Household Income (in dollars)	Vehicles Owned	Population per Residential Area
Household Type			
Single Male	9,049	0.6	51.1
Single Female	7,079	0.4	41.2
Unrelated Individuals	12,125	0.6	52.4
Couples	17,067	1.2	35.5
Single Parent	7,729	0.4	62.5
Nuclear Family	19,781	1.6	33.8
Adult Family with Children	19,736	1.7	44.5
Adult Family without Children	20,343	1.5	41.1
All Types	16,094	1.2	41.6
R^2	0.18	0.23	0.09

SOURCE. Based on data contained in the Baltimore Travel Demand Data Set. Table compiled in October 1980.

single and unrelated households more than it does other family groups, since with children present there is more pressure for serve-passenger trips. The financial pressure of larger numbers of children and lower household income is no doubt reflected in these auto ownership figures. In addition, there is the lower propensity of women (who head most of the single parent households) to own cars, as witnessed by the similarity of vehicle ownership rates of single parent households and single women households. Couples fall in the middle with significantly more autos than single women and single parent households, but fewer autos than the other household groups. Nuclear families and adult families are statistically indistinguishable in their rates of auto ownership.

Yet another difference between single parent families and nuclear families is the residential density in the zones where they live. The average population per residential acre in the traffic zone is significantly higher for single parent households than for all other household types. In contrast, the residential density where nuclear families live is lower than for all other households except for couples. Adult families, singles, and roommates all tend to live in areas having residential densities that are intermediate, and statistically indistinguishable from each other.

Across all household types, the mean number of trips taken on the date the data were collected was 7.8 (see Table E-3). Because household types are in part defined by household size, a comparison of trip frequency by household reflects the number of eligible travelers. (This is dealt with

Table E-3

TRAVEL STATISTICS BY HOUSEHOLD TYPE

	Total Trips	Trips per Eligible Person	Total Travel Time (in minutes)	Vehicle Miles Traveled
Household Type				
Single Male	3.1	3.1	74.3	6.9
Single Female	2.2	2.2	56.9	4.3
Unrelated Individuals	6.5	2.8	133.6	10.5
Couples	5.4	2.8	118.0	20.3
Single Parent	6.2	3.0	130.8	7.6
Nuclear Family	10.7	3.7	202.8	28.6
Adult Family with Children	13.0	3.0	300.4	27.1
Adult Family without Children	6.5	2.3	159.7	22.1
All Types	7.8	3.0	167.1	19.7
R^2	0.25	0.05	0.22	0.12

SOURCE Based on data contained in the Baltimore Travel Demand Data Set. Table compiled in October 1980.

more systematically in Appendix F.) Related adults with children took an average of 13 trips, while nuclear families took 10.7 trips. Related adults without children, single parent households, and unrelated individuals all took 6.5 to 6.2 trips, while couples took 5.4 trips; these means are not statistically different from one another. Single males and females took 2 to 3 trips on average, again, these means are not distinguishable. One-quarter of the variance in trip frequency is explained by household type.

Looking at trip frequency for the seven different trip purposes (defined on an activity basis) reveals that this pattern generally holds for each purpose. Although we do not present these means, there are minor shifts of position and statistical significance. Adult families with children and nuclear families always took the most trips, while single people always took the fewest trips. The rearrangements that occur suggest that the number of eligible travelers does not fully describe travel frequency. Other factors influencing trip frequency cannot be sufficiently controlled for or explored by looking solely at means. Though means are useful statistics, they can be improved upon by methods such as regression analysis which allow one to control for many variables at once.

An illustration of a probable factor disguised by the means procedure is the effect of children on trip generation. While nuclear families average only one additional member eligible to travel over couples, nuclear families take twice as many total trips. This can be seen more clearly by looking at total trip means scaled by the number of eligible travelers. In Table E-3, nuclear families make significantly more trips than the other household types (except single males) on a per capita basis.

Total travel time averages by household types, as with total trip averages, closely follow the number of household members eligible for travel. Hence, grown families with children and nuclear families spend the most time traveling and at between-trip activities, while single persons spend the least.

Not surprisingly, average total vehicle miles traveled appears to vary with the average number of vehicles owned by the household, rather than with total members eligible to travel. Nuclear families, both types of adult families, and couples averaged over 20 miles in household-owned vehicles, while unrelated, single parent, and single person households averaged 10.5 or fewer miles. As will be recalled from Table E-2, nuclear families and both types of adult families average 1.5 household-owned vehicles or more, couples average 1.2, the other household types averaged .6 vehicles or fewer.

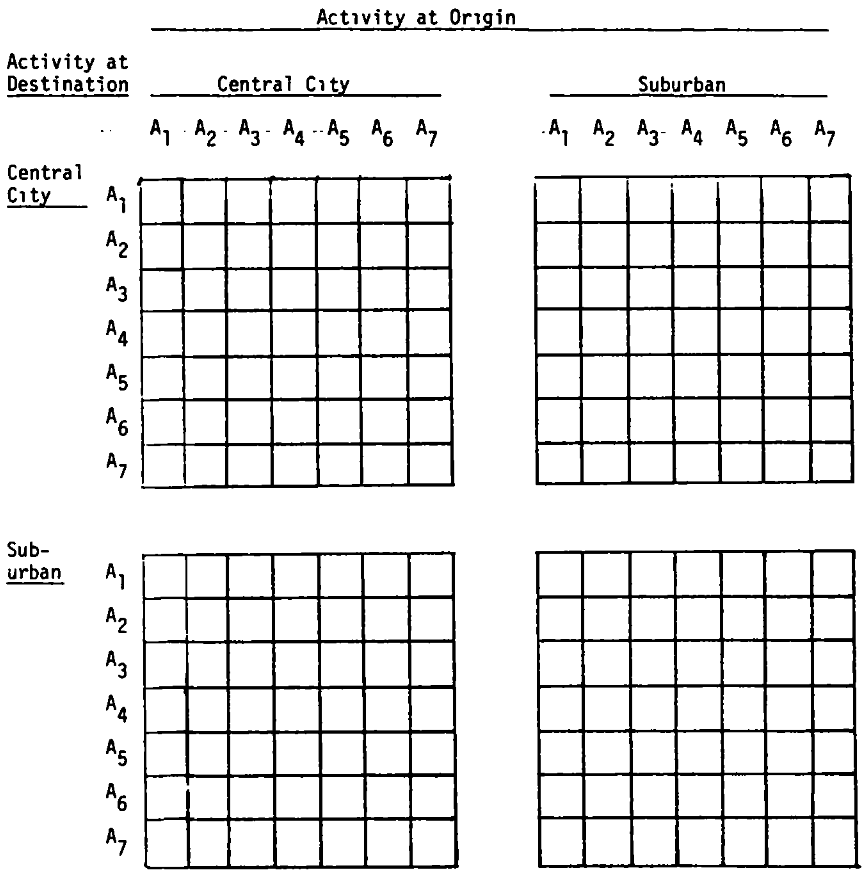
SPATIAL AND TRIP PURPOSE LINKAGES

The linkages of activities (and the spatial locations of the activities) can be examined with flow matrices. This technique was described in our First Interim Report (E1). This section reports on the development of flow matrices from the Baltimore data set. The basic unit of analysis is the individual trip record, which describes trip origin and destination locations and purposes.

The full amount of information is contained in the flow matrix represented by Figure E-1. This matrix presents the number of trips, with particular combinations of trip origin purpose and location and destination purpose and location. For example, the number of trips originating in a

Figure E-1

FLOW MATRIX



central city home going to a suburban work location is reported in the matrix.

Trip purposes were classified into the seven categories discussed above. Origins and destinations were classified into two location categories: Baltimore central city and suburban.

The complete flow matrix was prepared, but even with our aggregate destination types, this results in a matrix of 196 cells, and most linkages between trip purposes and destinations are quite small. In order to simplify the interpretation of the tables and to emphasize the more important linkages, it is useful to observe the linkages between trip purposes and trip destinations alone. We also look at the linkages between destinations for particular purposes. Highlights of the analysis are described

- The three most prominent activity purposes are home, work/school, and shopping. About 70 percent of all trip origins and destinations involve these purposes.
- A large majority (78 percent) of trips are home-based, i.e., one trip end is home. The 22 percent of the trips that are not home-based give some indication of the amount of trip chaining represented in the data set.
- About 36 percent of trips are work- or school-based. This proportion is similar to the proportions typically found in transportation surveys.
- About three-quarters of all residents live and work within the same location. There are no statistically significant differences between central city and suburban residents in this regard.

- The total number of home to work trips is larger than the number of return trips. This fact suggests that more trip chaining occurs on the way home from work. This finding is consistent with Damm's (E2) finding from 1970 Twin Cities data.
- Suburban residents are significantly more likely to shop within their own areas, i.e., suburban shopping opportunities appear to attract central city residents to a greater degree than central city shopping attracts suburbanites (20.6 percent of the shopping trips of central city residents are in the suburbs; only 9.6 percent of the shopping trips of suburban residents are in the central city).
- For shopping, there are more return trips. This finding, which is oppposite to the work-trip finding, suggests that more trip chaining occurs on the way to a shopping location.
- Central city residents are somewhat more likely to shop within the central city than they are to confine their work trips to the central city (79.4 percent of their shopping trips are in the central city versus 76 percent of their work trips). Suburban residents are substantially more likely to confine their shopping trips within the suburbs than they are to confine their work travel (90.4 percent of their shopping trips are in the suburbs versus 73.7 percent of their work trips). The contribution of these two tendencies results in about 85 percent of all shopping travel ending within the location of origin (compared with about 75 percent for work trips).
- Considering all home-based trips, central city residents are less likely to travel within their area than are suburban residents (78.4 percent of all trips for central city residents vs. 76 percent for suburban residents).

- The total number of trips from home is almost identical to the number of return trips. This suggests that, in general, trip chaining is equally likely on either trip link. However, as noted in the discussion of work and shopping travel, trip chaining may be more likely on one or the other trip ends for specific activity purposes.

BIBLIOGRAPHY TO APPENDIX E

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APPENDIX F

HOUSEHOLD-LEVEL MODELING

This appendix presents the modeling performed at the household level. Modeling at this level is useful both in interfacing with existing transportation planning methods and in understanding household decision processes which affect travel behavior. We begin with a discussion of "activity-based" versus "home-based" approaches to trip generation. Then we present an activity-based analysis of, principally, trip frequency by purpose for weekday travel. However, weekend travel and mode are also dealt with. This analysis is then replicated from a home-based perspective in order to be able to relate to traditional practice. The appendix concludes with the discussion of a system of equations developed to examine interrelationships in travel behavior. This system first looks at variables such as vehicles owned, drivers' licenses, number of persons not traveling, and gas consumption per mile. Models of activity time are also constructed. Based partly on activity time and partly on the demographic variables, models of frequency, travel time, and miles traveled are also introduced. Certain interactions are considered utilizing a structural equation methodology.

TECHNICAL ISSUES

Several statistical and algebraic issues which come up in the analysis are worth treating briefly. The first is the analysis of variance procedure, or "Chow test," which is utilized to evaluate the importance of particular groups of variables. Then we note a particular use of this procedure to test hypotheses about differing slope and intercept terms for differing stratifications or segmentations of the sample. Next, the ideas on constrained equations, treated in Appendix B, are informally generalized to the case analyzed here. Readers not interested in this technical discussion may proceed to the next section without loss of continuity.

Analysis of Variance Procedure

An analysis of variance procedure, commonly known in the econometric literature as a "Chow test," is used to test the significance of sets of variables in regression equations (see Chow (FA1) or Fisher (FA2) for a formal discussion). The "t-test" of coefficient values is commonly used to test whether the deletion of that variable would significantly reduce the variance explained, the Chow test performs a similar test for sets of variables. Indeed, the Chow test and t-test of a coefficient give identical results for testing the deletion of a single variable (the value of t^2 equals F in this case). When a revised equation is fit omitting certain variables, this is equivalent to specifying a priori that the coefficients of the omitted variables equal zero.

The Chow test proceeds by computing the difference between the sum of squared errors (SSE) of the equation with the reduced set of variables minus the SSE of the equation with the full set of variables; this is divided by the number of variables deleted; and this in turn is divided by the mean square error of the equation with the larger number of variables (coefficients unconstrained in value). This ratio is then distributed as the

F-distribution and can be compared with standard tables. Essentially, this tests that the reduction in variance explained is larger than would be expected by chance.

Although the formula is given in numerous places, it is repeated below for convenience. The test statistic is

$$(1) \qquad \frac{(SSE2 - SSE1)/(K1 - K2)}{SSE1/(T - K1)}, \quad K1 > K2$$

where

SSE1 = sum of squared residuals of unconstrained equation,

SSE2 = sum of squared residuals of equation with K1 - K2 coefficients constrained to be zero,

K_i = number of variables (including constant term) in each respective equation, and

T = number of observations.

This statistic is distributed as F, with (K1 - K2) and (T - K1) degrees of freedom.

Slope and Intercept Adjustments

There are numerous ways of testing for the importance of categorical variables such as household type. Dobson and McGarvey (FA3) utilized an approach based on the general linear model to perform an analysis of variance of trip generation rates utilizing categorical variables for income and auto ownership. Dobson (FA4) suggests the use of covariance analysis for tests of market segmentation. The procedure followed here is an analysis of covariance of household type in which we test for the difference in slopes as well as for the difference in intercept terms. Typically the use of "dummy variables" in regression equations simply tests whether an intercept adjustment is significantly different from zero and does not test whether the slope of the fitted line is different depending upon the category employed.

This distinction may be made clearer with an example. Suppose we are investigating differences in trip frequency between two types of households -- those of high and low income -- as a function of number of vehicles owned. One way is to estimate two equations of the form

(2) $F_i = \alpha_i + \beta_i X + \varepsilon$

where

i = 1 (low income), 2 (high income),

F = trip frequency, and

X = number of vehicles owned.

If $\beta_1 \neq \beta_2$, it implies that the rate of trip making per vehicle is different depending on whether the family is of high or low income (a "slope difference"). If $\alpha_1 \neq \alpha_2$, it implies that households of different income classes differ in trip frequency when no vehicles are owned.

There are four possible cases.

(a) $\beta_1 = \beta_2$ and $\alpha_1 = \alpha_2$ -- the behavior does not vary by income class (the lines are the same);

(b) $\beta_1 = \beta_2$ and $\alpha_1 \neq \alpha_2$ -- higher-income families take some fixed, different number of trips, no matter how many vehicles are owned (the lines are parallel) --this is the assumption behind including "dummy variables" only;

(c) $\beta_1 \neq \beta_2$ and $\alpha_1 = \alpha_2$ --trip frequency increases differentially with number of vehicles if the household is of high or low income, but frequency is the same for households with no vehicles;

(d $\beta_1 \neq \beta_2$ and $\alpha_1 \neq \alpha_2$ -- the same as (3) except household income has a differential effect even with no vehicles.

Typically, one first tests the slope (β) and, if different, tests the intercept (α).

Rather than estimating two equations, equivalent parameter estimates may be obtained with a single equation of the form:

(3) $F = b_0 + b_1 * X + b_2 * Z + b_3 * Z * X + \Sigma$

where

F and X are defined as above, and

Z = 1, if the income group is 1, or

Z = 0, if the income group is 2.

This yields equivalent parameter estimates to Equation 2 as follows:

(4) $\beta_1 = b_1 + b_3$

(5) $\beta_2 = b_1$

(6) $\alpha_1 = b_0 + b_2$

(7) $\alpha_2 \mp b_0$.

A test of $\beta_1 - \beta_2 = 0$ is equivalent to testing if $b_3 = 0$. Likewise, a test of $\alpha_1 - \alpha_2 = 0$ is equivalent to testing for $b_2 = 0$. It will be noted that this is similar to the tests by person type performed in Appendix B.

Constraint Equations

A final concept utilized in this appendix is a generalization of the "constraint equation" idea utilized in Appendix B. It will be recalled that there we noted that, because the same set of independent variables was used in each equation, the sum of the intercept terms across all equations that were estimated would equal the total time budget for the person, or 24 hours. It was also noted that the sum of the coefficients of all other variables would be zero across equations. This is so because the sum of all the dependent variables, the allocation of time to activities by purpose, is 24 hours for each individual. If we were to estimate an equation for the total time lived in the day by each individual, the dependent variable for all observations would be 24. In such a situation, computing a regression equation with an intercept term and any number of independent variables will have a result that the coefficient for the intercept term is 24, and the coefficients for all of the other variables are zero. When the same set of independent variables is used to predict every component of the 24-hour day, the coefficients of any particular independent variable, when summed across the component equations, will equal the coefficient of the equation predicting the number of hours in the day.

In the activity time equations considered in this Appendix, the dependent variable is not a constant. However, it is a function of the number of persons in the household. In this case, the amount of time available to a household in the day is equal to 1,440 minutes times the number of total eligible persons. Fitting a regression with total time lived by the household as a dependent variable, and, as dependent variables, a constant term, number of total eligible persons, and other variables will result in a coefficient of 1,400 for total eligible persons and zeros for all the other coefficients, including the constant term. If activity and travel time equations by purpose are fit using an identical set of independent variables, the sum of the coefficients across the equations will equal 1,440 for total eligible and zero for all other independent variables, including the constant term. In this case the "constraint equation" is

(13) $1440 * TE_t = b_{o0} + b_{o1} * TE_t + \sum_{j=2}^{K} b_{oj} * X_{tj}$,

where TE_t = total eligible persons in household t;

$b_{o0} = 0$;

$b_{o1} = 1,440$, and

$b_{oj} = 0$ for $j>1$.

Then activity and travel time equations of the form

(14) $Y_{ti} = b_{i0} + b_{i1} * TE + \sum_{j=2}^{K} b_{ij} * X_{tj}$,

for each purpose i, will have identities similar to equations 10-12 above

(15) $\sum_{i=1}^{P} Y_{ti} = 1,440 * TE_t$, for all t;

(16) $\sum_{i=1}^{P} b_{i1} = 1,440$; and

$$(17) \quad \sum_{i=1}^{p} b_{ij} = b_{ij} = 0, \text{ for } j = 0, 2 \ldots K.$$

In the case of trip frequency, there is no exact relationship between household size and total number of trips taken. The coefficients of any variable in that model will be determined by the data and will be free to take any value. However, if one maintains the same set of independent variables and fits a full set of trip frequency equations by purpose, the coefficients for each independent variable, including the constant term, will sum to the values of the coefficients for the total trip frequency equation. In this case, the total trip frequency equation is the "constraint equation," and will be of the form

$$(18) \quad TF_t = b_{00} + \sum_{j=1}^{K} b_{0j} X_{tj},$$

where TF_t = total trip frequency for household t; and

b_{0j} = any value, $j = 1 \ldots K$.

Then trip frequency equations by purpose i,

$$(19) \quad Y_{ti} = b_{i0} + \sum_{j=1}^{K} b_{ij} X_{tj},$$

will have identities

$$(20) \quad \sum_{i=1}^{p} Y_{ti} = TF_t; \text{ and}$$

$$(21) \quad \sum_{i=1}^{p} b_{ij} = b_{0j}, \text{ for each } j.$$

Again, it should be emphasized that these restrictions may not guarantee that individual predictions will be accurate, as was discussed in Appendix B. It merely constrains the equations (and predictions) to sum to their respective marginal distributions.

ACTIVITY-BASED VERSUS HOME-BASED DEFINITIONS

As discussed in Appendix D, the principal dependent variables that were constructed consist of trip frequency by purpose. (Frequencies by mode, and by mode and purpose are also considered.) Frequency was constructed in two different ways; each corresponding to a different type of analysis: these may be best described as "activity-based" and "home-based." Approaching the trip-frequency question by way of activity analysis, behavior is defined with respect to the activity at the end of the trip. This approach views the "lifestyle" of the household as comprising differing time allocations to activities; an important component of this is time spent at home. The choice of an activity schedule then gives rise to demands for travel, including trip frequency, trip time, and miles traveled. For this style of analysis, then, it is necessary to be able to relate trip frequency, time, and distance by purpose to the associated activity purpose at the destination, one of which is "home."

The conventional urban transportation planning process views trip generation in a fundamentally different way, and it is necessary to accommodate this concept in modeling. Trip generation in the urban transportation planning process is well described in a reference such as Stopher and Meyburg (F1, pp. 62-65, 109-123). Fundamental trip categories include "home-based trips," or those for which either the origin or the destination is home; and "nonhome-based trips," where neither origin nor destination is home. Trip generation is further subdivided into "productions" and "attractions." The zone of production for a home-based trip is always the residential zone and the attraction zone is always the nonhome zone; this is true whether or not the trip proceeds from home to a nonhome destination or the reverse. For nonhome-based trips the zone of production is always the zone of origin, and the zone of attraction is always the zone of destination.

These two concepts are, in a sense, competing paradigms. Home-based productions are defined in this way because, in general, only the characteristics of the residence zone are known with certainty for households and can be predicted on a behavioral basis. Nonhome-based trips, by contrast, can start and end at arbitrary places and are much less amenable to prediction by disaggregate or aggregate methods. Typically, home-based attractions and nonhome-based tripmaking are based on the employment characteristics of the zone. Other parts of the transportation planning process make the link between productions and attractions.

Table F-1 presents a concrete illustration of these two differing approaches using the trips actually utilized in modeling. Of the 7,570 trips in the file, 2,958 originated at home and were destined for other purposes, while 2,962 returned to home from other purposes. These 5,920 trips are home-based trips, while the remaining 1,650 trips, which proceed from one nonhome origin to a nonhome destination, are nonhome-based trips. By

Table F-1

STRATIFICATION OF TRIPS BY ORIGIN AND DESTINATION PURPOSES

Destination	Origin: HOME	WORK/SCHOOL	SHOPPING	PERSONAL BUSINES	ENTERTAINMENT	VISIT/SOCIAL	SERVICE/ACCOMPANI	TOTAL
HOME	2 0.03 0.07 0.07	1045 13.80 35.28 71.04	585 7.73 19.75 65.29	256 3.38 8.64 51.82	419 5.54 14.15 62.82	392 5.18 13.23 64.58	263 3.47 8.88 55.14	2962 39.13
WORK/SCHOOL	1142 15.09 77.37 38.61	186 2.46 12.60 12.64	27 0.36 1.83 3.01	35 0.46 2.37 7.09	37 0.49 2.51 5.55	11 0.15 0.75 1.81	38 0.50 2.57 7.97	1476 19.50
SHOPPING	514 6.79 57.37 17.38	64 0.85 7.14 4.35	136 1.80 15.18 15.18	70 0.92 7.81 14.17	43 0.57 4.80 6.45	42 0.55 4.69 6.92	27 0.36 3.01 5.66	896 11.84
PERSONAL BUSINES	272 3.59 54.95 9.20	50 0.66 10.10 3.40	30 0.40 6.06 3.35	60 0.79 12.12 12.15	26 0.34 5.25 3.90	31 0.41 6.26 5.11	26 0.34 5.25 5.45	49- 6.54
ENTERTAINMENT	414 5.47 62.54 14.00	59 0.78 8.91 4.01	32 0.42 4.83 3.57	15 0.20 2.27 3.04	65 0.86 9.82 9.75	56 0.74 8.46 9.23	21 0.28 3.17 4.40	662 8.75
VISIT/SOCIAL	354 4.68 58.80 11.97	28 0.37 4.65 1.90	54 0.71 8.97 6.03	39 0.52 6.48 7.89	51 0.67 8.47 7.65	59 0.78 9.80 9.72	17 0.22 2.82 3.56	602 7.95
SERVICE/ACCOMPAN	260 3.43 54.51 8.79	39 0.52 8.18 2.65	32 0.42 6.71 3.57	19 0.25 3.98 3.85	26 0.34 5.45 3.90	16 0.21 3.35 2.64	85 1.12 17.82 17.82	477 6.30
TOTAL	2958 39.08	1471 19.43	896 11.84	494 6.53	667 8.81	607 8.02	477 6.30	7570 100.00

Note: Numbers in each cell are frequency count, percent of total, percent of row, and percent of column, from top to bottom respectively.

SOURCE: Based on data contained in Baltimore Travel Demand Data Set. Table compiled in June 1980.

contrast, the activity-based definition of a trip considers only its destination and is thus represented by the "total" column at the right margin of Table F-1.

Table F-1 reveals that the numbers of trips by purpose originating at home and those destined for home from the like purpose are very similar. Trips from home to work or school, for example, are approximately 9 percent higher than those returning directly to home from work or school. Likewise, 6 percent more trips leave home destined directly for a personal business stop than return home from personal business. In contrast, 12 percent fewer trips leave home directly for shopping than return home from shopping. Approximately 10 percent fewer trips leave home to visit than return home from visiting. The frequency of leaving home directly for entertainment or a serve-passenger destination is only 1 percent less in each case than that returning from the same purpose. Overall, roughly 80 percent of all trips in the file are home-based trips.

This symmetry of originations and destinations for home-based trips and the preponderance of home-based trips in the file suggest that the fundamental determinants identified should be roughly the same regardless of whether an activity-based or a home-based approach is taken. Some distortion will occur, however. Activity-based trips by purpose are linked to home-based and nonhome-based trips by the following identities:

(1) $AB_i = NHB_i + HB_i - P_{1i}$, for $i > 1$, and

(2) $AB_1 = \sum_{i=2}^{7} P_{1i}$,

where:

i = trip purpose (here $i = 1, \ldots, 7$);

AB = activity-based trip frequency;

NHB = nonhome-based trip frequency;

HB = home-based trip frequency; and

P_{1i} = trip frequency from purpose i to home.

Because the numbers of home-originating and home-destined home-based trips seem to be fairly symmetrical, coefficient differences between activity and home-based frequency equations will arise principally from two sources. First, the determinants of nonhome-based trips may differ from those of home-based trips at the household level. Since nonhomebound trips are included in activity-based trip frequency, this would affect the coefficients. Second, the numbers of trips by purpose will differ for home- versus activity-based definitions because of the exclusion of nonhome-based trips and the reallocation of trips home to other purposes for the home-based frequencies. The trip generation models developed for this study include numbers of persons in the household by various categories; to the extent that home-based and activity-based frequencies differ, the difference in scale will be reflected in the coefficients.

ACTIVITY-BASED ANALYSIS OF TRIP FREQUENCY

As noted above, it is important to distinguish between "activity-based" purposes and the more conventional urban transportation "home-based" trip purposes. Much of the basic analysis was performed from an activity-based perspective; this is what is reported on in this section. A subsequent section replicates a part of that analysis in a form suitable for interfacing with a conventional system such as UTPS.

This section discusses issues related to modeling household structure. Next incremental improvements to a basic model of trip generation for weekday travel are treated and compared with similar models of weekend travel. Frequency by mode is also examined.

Specification of Household Structure

Several steps were required to establish the specification for household structure that is utilized. The steps involve use of analysis of variance (ANOVA) procedures to compare the efficacy of one specification with another; these procedures are discussed at the beginning of this appendix.

Relationship-Based Typology. Appendix D presents a relationship-based household typology. The categories are single male, single female, unrelated individuals, couples, single-parent families, nuclear families, adult families with children, and adult families without children. A model utilizing only these household types accounts for 25 percent of the variance in total trip frequency. Of course, the types represent different household sizes, and it may be questioned whether knowledge of household type furnishes information over and above knowing total (persons) eligible for travel (12 years or older).

This hypothesis is examined utilizing analysis of variance procedures. The least restrictive model allows different slopes and different intercept

adjustments for five of the eight household types. Single males, single females, and couples are deleted from the analysis. This is done because all three categories are determined in part on the basis of size, and there is an exact linear relationship between their defining dummy variables and that dummy times total eligible persons.

The analysis is performed as follows. For each trip purpose, a regression equation is fit which contains as independent variables an intercept, total eligible members in the household, five of the eight variables for household type, and five corresponding interaction terms of the dummy variables times total eligible persons. Table F-2 defines the dependent variables, while Table F-3 defines the independent variables.

The procedure may be represented as

$$(3)\quad FREGPUR_j = \alpha_0 + \sum_{i=1}^{5} \alpha_i * d_i + \beta_0 * TOTELIG + \sum_{i=1}^{5} \beta_i + d_i * TOTELIG$$

where:

$FREQPUR_j$ = trip frequency by purpose j;

d = 1 if the household is of type i, 0 otherwise, and

TOTELIG = total eligible persons in the household.

Reestimating the same equation deleting the slope adjustments ($\beta_1 \ldots \beta_5$) tests for the significance of the contribution of differing rate of trip production per total eligible members of the household. If this is not significant, a comparison of this model to a model deleting both intercept

Table F-2

ACTIVITY-BASED DEPENDENT VARIABLE DEFINITIONS

Variable	Description
Purpose	
TRIPFREQ	Total Number of trips for all purposes
FREQPUR1	Trips to home
FREQPUR2	Trips to work
FREQPUR3	Trips to shopping
FREQPUR4	Trips for personal business purposes
FREQPUR5	Trips for entertainment/community purposes
FREQPUR6	Trips for visit/social purposes
FREQPUR7	Trips to service/accompany traveler
Mode	
FREQMO1	Auto driver trips, household vehicle
FREQMO2	Auto passenger trips, household vehicle
FREQMO3	Bus trips
FREQMO4	Walk trips
FREQMO5	Other nonmotorized mode trips
FREQMO6	Other motorized mode trips

NOTE: All variables are expressed in numbers of trips per household by eligible household members (age ≥ 12 years). See Tables D-1 and D-3 for more extensive purpose and mode definitions.

Table F-3

INDEPENDENT VARIABLE DEFINITIONS

Variable	Description
INTERCEP	Intercept (constant) term
Basic Model Variables	
VEHOWN	Numbers of vehicles owned by the household
INCOMEM	Household income (in $1,000)
TOTELIG	Total persons eligible for travel records (≥ 12 years of age), living at home[1]
Age Structure	
NTEEN	Numbers of persons age 12-19
N20TO34	Numbers of persons age 20-34
N35TO54	Numbers of persons age 35-54
N55TO64	Numbers of persons age 55-64
N65PLUS	Numbers of persons age 65 and over
Household Type[2,3]	
SMALE	Male living alone
SFMALE	Female living alone
UNRELI	Unrelated individuals (male, female, or mixed roommates)
COUPLE	Married couple or unmarried couple with ages within 10 years apart
SPHH	Single-parent household (male or female adult with children)

Table continued on following page.

Table F-3 (Continued)

INDEPENDENT VARIABLE DEFINITIONS

Variable	Description
Household Type (Continued)	
NUCLR	Nuclear family (married couple with children under 20)
AFWKID	Adult family with children (two or more adults with children present)
AFWOKID[4]	Adult family without children (adults with same last names, no children)
Other Household Characteristics	
SFDU[2]	Household living in single-family dwelling unit
PREDUM[2]	One or more preschool persons (< 5 years old) present
GRADEDUM[2]	One or more gradeschool persons (age 5-11) present
HMMAKEDM[2]	At least one member of the household has employment status of "homemaker"
HHRACE[2]	Family members are nonwhite
Residence Zone Descriptors[5]	
RDENP	Population per residential acre
CITY[2]	In Baltimore City Limits
HHRES6[2]	Longest residing member of household has resided at that address fewer than 6 months

Notes on following page.

Table F-3 (Continued)

INDEPENDENT VARIABLE DEFINITIONS

NOTES:

[1]Households with visitors were excluded from analysis.

[2]Variable has value of one if the household has this characteristic; zero otherwise.

[3]See Appendix D for a discussion of household type.

[4]The omitted household category.

[5]Properties of traffic analysis zone of residence of household.

and slope (or rate) adjustments is made by deleting the intercept adjustments as well ($\alpha_1 \ldots \alpha_5$).

The variance explained by each of the three models, as well as the F-tests for comparing the two cases, is given in Table F-4. As can be seen, total eligible persons alone explains 42 percent of the variance in total trip frequency, more for trips home, and considerably less for trips with other purposes. Adding household structure information raises this explained variance explained by between 1 to 4 percent. When the models utilizing both slope and intercept adjustments are compared with those utilizing only intercept adjustments, it can be seen that only the prediction of frequency of work trips benefits, and this at the .05 level of significance. This implies that allowing the rate of trip generation per person to vary by household type does not add significant explanatory power. Although certain specific β coefficients were significant, considering all as a set does not help significantly.

The intercept adjustments alone add significant explanatory power over utilizing only total eligible persons for total trips, returning home, going to work, shopping, and to serve passengers. This suggests that, while the lines relating trip frequency to total eligible persons may be parallel, they are separated by a constant amount for certain household types and purposes. In other words, although the contribution of each household member to trip frequency does not appear to vary with household type, the household types have different "base" levels of trip frequency. Thus, the inclusion of "dummy variables" for household type is warranted.

Table F-4

RELATIONSHIP-BASED HOUSEHOLD-TYPE ANOVA
FOR TRIP FREQUENCY BY PURPOSE

SLOPE AND INTERCEPT ADJUSTMENTS[1]

	TRIPFREQ	FREQPUR1	FREQPUR2	FREQPUR3	FREQPUR4	FREQPUR5	FREQPUR6	FREQPUR7
SSE	25649.85	2863.69	2496.70	1574.13	1124.12	1318.49	1187.07	1483.84
DFE	917.00	917.00	917.00	917.00	917.00	917.00	917.00	917.00
MSE	27.97	3.12	2.72	1.72	1.23	1.44	1.29	1.62
RSQUARE	0.45	0.56	0.30	0.08	0.03	0.15	0.14	0.08

INTERCEPT ADJUSTMENT[1]

	TRIPFREQ	FREQPUR1	FREQPUR2	FREQPUR3	FREQPUR4	FREQPUR5	FREQPUR6	FREQPUR7
SSE	25768.75	2890.66	2534.98	1584.38	1132.76	1325.06	1188.31	1489.55
DFE	922.00	922.00	922.00	922.00	922.00	922.00	922.00	922.00
MSE	27.95	3.14	2.75	1.72	1.23	1.44	1.29	1.62
RSQUARE	0.45	0.55	0.29	0.07	0.03	0.14	0.13	0.08

NO ADJUSTMENT[1]

	TRIPFREQ	FREQPUR1	FREQPUR2	FREQPUR3	FREQPUR4	FREQPUR5	FREQPUR6	FREQPUR7
SSE	26904.61	3013.84	2586.71	1604.34	1140.55	1328.79	1199.46	1547.09
DFE	927.00	927.00	927.00	927.00	927.00	927.00	927.00	927.00
MSE	29.02	3.25	2.79	1.73	1.23	1.43	1.29	1.67
RSQUARE	0.42	0.53	0.27	0.06	0.02	0.14	0.13	0.04

Table continued on following page

Table F-4 (Continued)

RELATIONSHIP-BASED HOUSEHOLD-TYPE ANOVA
FOR TRIP FREQUENCY BY PURPOSE

ANOVA FOR DELETING SLOPE ADJUSTMENT

	TRIPFREQ	FREQPUR1	FREQPUR2	FREQPUR3	FREQPUR4	FREQPUR5	FREQPUR6	FREQPUR7
F-RATIO [illegible]	0.85	1.73	2.81*	1.19	1.41	0.91	0.19	0.71

ANOVA FOR DELETING SLOPE AND INTERCEPT ADJUSTMENT

	TRIPFREQ	FREQPUR1	FREQPUR2	FREQPUR3	FREQPUR4	FREQPUR5	FREQPUR6	FREQPUR7
F-RATIO [illegible]	4.49**	4.81**	3.31**	1.76	1.34	0.72	0.96	3.91**

NOTES: [1]See text for explanation of model. For variable definitions see Table F-2.

[2]SSE = sum of squared errors.

[3]DFE = degrees of freedom.

[4]MSE = mean squared error (MSE = SSE/DFE).

[5]RSQUARE = coefficient of determination.

[6]F-RATIO = "Chow test" for coefficient restriction. Numbers in parentheses are degrees of freedom for F-ratio.

Notes continued on following page.

Table F-4 (Continued)

RELATIONSHIP-BASED HOUSEHOLD-TYPE ANOVA
FOR TRIP FREQUENCY BY PURPOSE

LEGEND: *Significant at .05 level.

**Significant at .01 level.

SOURCE Based on data contained in Baltimore Travel Demand Data Set. Table compiled in December 1980.

Comparison with Age-Based Typology. As a check to compare the efficacy of household types based on relationship versus household types based on the age of youngest and eldest (as used in the individual modeling in Appendix B), we fit models employing total eligible persons and intercept adjustments for the age-based household categories (see Table F-5). In terms of variance explained, when only these dummy variables were used, the relationship-based typology performed better for serve-passenger trips, the two were similar for total frequency, return-home, shopping, and personal business trips; while the age-based typology was better for shopping, entertainment, and visiting trips. When dummy variables for the presence or absence of persons of various ages were introduced into the relationship-based typology, the variance explained for return-home and visiting trips was raised. These results indicate that roughly the same amount of information is contained in each household typology, but that the relationship-based typology, when supplemented with age structure information, may be a superior modeling approach at the household level.

Representation of Age Structure. As a final step, the efficacy of disaggregating total eligible persons by age rather than utilizing only total eligible persons and household type is tested. As can be seen from Table F-5, the variance explained for this latter method is greater than or equal to that obtained by using only total eligible persons and household type. This indicates that introducing the age structure of the household explicitly into the modeling is a desirable specification. Thus, while household type is an important concept, explicitly modeling the age structure

Table F-5

VARIANCE EXPLAINED BY DIFFERENT HOUSEHOLD TYPOLOGIES

	TRIPFREQ	FREQPUR1	FREQPUR2	FREQPUR3	FREQPUR4	FREQPUR5	FREQPUR6	FREQPUR7
AGE-BASE[1]	0.45	0.55	0.30	0.07	0.03	0.15	0.14	0.07
REL-BASE[2]	0.45	0.55	0.29	0.07	0.03	0.14	0.13	0.08
REL-BASD[3]	0.45	0.56	0.29	0.07	0.03	0.14	0.14	0.08
REL-BASN[4]	0.46	0.57	0.31	0.07	0.04	0.15	0.15	0.09

NOTES: [1]Types used in individual-level analysis of dummy variables and total eligible persons.

[2]Relationship-based dummy variables and total eligible persons

[3]Relationship-based dummy variables with age dummies and total eligible persons.

[4]Relationship-based dummy variables with total eligible persons by age class.

For variable definitions see Table F-2.

SOURCE: Based on data contained in Baltimore Travel Demand Data Set. Table compiled in December 1980

of the household produces somewhat superior results in dealing with trip frequency. In addition, in a practical forecasting sense, the age distribution is more easily forecast than is household type per se. To the extent that one is interested in analyzing the impact of changing household relationships on household behavior, such household-type variables do add explanatory power. As shown in Chapter 2, there is a clear pattern involving the coefficients for age groups; i.e., trip generation rates decline with age.

Incremental Improvements to Basic Model

As concluded above, the most efficient representation of household structure seems to be disaggregating total eligible persons by age and adding dummy variables for household relationship type. In Chapter 2, incremental improvements to an analog to the typical zonal trip generation model are tested. The analysis proceeds from this basic model to one that adds properties of the household, and then to a model that introduces properties of the residence zone of the household. As described in Chapter 2, the enhancement of the basic model resulted in a clear improvement in many cases. Further, the examples in Chapter 3 indicated that the enhanced models can produce markedly different forecasts than the standard models.

Frequency by Mode

The question of frequency by mode has also been investigated utilizing a diagnostic methodology similar to that used above, successively entering household and residence zone variables. Since the analysis is intended to test the explanatory power of household and residential variables in modal frequency models, but not to produce models for planning practice, numerical results are not presented. Important findings are described.

As in the case of frequency by purpose, introducing household structure and residential-type variables to the model by mode increases the explanatory power of the equations. Again, the increase attributable to adding household structure variables is greater than that brought about by adding residential-type variables. Household type significantly enhances the explanation of the four principal modes (auto driver, auto passenger, bus, walk), while residence zone information enhances prediction of auto and driver frequency.

It should be noted that level-of-service variables are not included in these equations, because the basic intent is to examine the impact of demographic and residential location factors on frequency by mode. It may also be argued that a household chooses level of service with its choice of location, so that, for a household, "level of service" is a function of the households' attributes and not an exogenous determinant of choice.

The equation for auto drivers explains approximately 48 percent of the variance in trip frequency. Not surprisingly, most of the explanatory power comes from number of vehicles owned and net residential density; numbers of persons aged 35 to 54 and nuclear family type are also marginally significant. Income is not important for the auto passenger or bus mode and is somewhat negatively related to frequency of walk trips. Not surprisingly, number of vehicles owned was positively related to number of auto passenger

trips and negatively related to bus and walk trips. Auto passenger trips are positively related to number of teenagers, the presence of a homemaker, and adult families with children, implying a chauffeuring role. The coefficient for number of teenagers for the walk mode is also considerably higher than that for other modes. Senior citizens have lower coefficients than other groups for auto passenger trips and walk trips. The frequency of walk trips declines by age group. The presence of a preschooler tends to depress the number of auto passenger trips, while the presence of a grade schooler in the household tends to increase the number of walk trips marginally. The presence of a homemaker in the household increases the number of auto passenger trips and decreases the number of bus trips, perhaps indicating the greater amount of chauffeuring that is done by persons occupying such a role. Single male households take significantly more bus trips than other types, although the difference between single males, single females, and single-parent households is small. The greater the residential density, the less either auto mode is used, while, not surprisingly, the bus mode is more frequently used within the City of Baltimore. Short-term residence slightly depresses the frequency of walk trips.

The results for weekend travel, although plagued by an inability to distinguish significant effects because of reduced sample sizes, are for the most part, however, similar to the weekday results. The approach explains more of the variance in frequency for the main three motorized modes for weekend than for weekday travel. On the weekend, the unrelated individual household type has the largest increment in auto driver trips.

HOME-BASED ANALYSIS

Trip Productions by Purpose

Weekday Travel. A similar procedure is followed in the analysis of home-based trips as in the analysis of activity-based trip-making behavior. Total home-based trips are, as noted above, approximately four-fifths of all trips. Due to the essential symmetry of home-based originations versus destinations, the purposes "work" through "serve-passenger" will account for approximately 1.6 times the number of trips, while, of course, there will be no "home" activity purpose. Table F-6 defines these dependent variables. As can be seen from Table F-7, there is a similar progression from the variance explained by the "basic model" utilizing income, vehicles owned and total eligible travelers, versus those models that include household structure and residential location. Here, the improvement is on the order of two to six percent, with household structure accounting for most of the increment. The improvement due to household structure is statistically significant for total trip frequency, work, entertainment, and serve-passenger trips. Residential zone information improves the entertainment and visiting equations.

The variance explained for total home-based trip making is considerably higher than for total trip frequency, although the increments from adding household structure and residential location are roughly the same between home-based and activity-based trips. Likewise, the work-purpose equations are much higher in terms of variance explained and, indeed, the addition of household and residence variables increases the explanatory power to a

Table F-6

HOME-BASED DEPENDENT VARIABLE DEFINITIONS

Purpose	Definition
HTRIPFRQ	Total number of home-based trips for all purposes
HFRQPUR2	Home-based work trips
HFRQPUR3	Home-based shopping trips
HFRQPUR4	Home-based personal business trips
HFRQPUR5	Home-based entertainment/community trips
HFRQPUR6	Home-based visit/social trips
HFRQPUR7	Home-based service/accompany traveler trips
Mode	
HFRQMO1	Auto Driver Trips, Household Vehicle
HFRQMO2	Auto Passenger Trips, Household Vehicle
HFRQMO3	Bus Trips
HFRQMO4	Walk Trips
HFRQMO5	Other Non-motorized Mode Trips
HFRQMO6	Other Motorized Mode Trips

Notes: 1. All variables are expressed in numbers of trips per household by eligible household members (age $\geq$ 12 years).

2. See Tables D-1 and D-3 for more extensive mode and purpose definitions.

Table F-7

ANALYSIS OF VARIANCE FOR HOME-BASED TRIP FREQUENCY BY PURPOSE
(For 629 Weekday Travelers)

BASIC MODEL[1]

	HTRIPFRQ	HFRQPUR2	HFRQPUR3	HFRQPUR4	HFRQPUR5	HFRQPUR6	HFRQPUR7
SSE	7675.11	2391.63	1671.13	829.09	1785.50	1134.01	1219.40
DFE	625.00	625.00	625.00	625.00	625.00	625.00	625.00
MSE	12.28	3.83	2.67	1.33	2.86	1.81	1.95
RSQUARE	0.61	0.49	0.12	0.04	0.14	0.15	0.09

HOUSEHOLD STRUCTURE INCLUDED[1]

	HTRIPFRQ	HFRQPUR2	HFRQPUR3	HFRQPUR4	HFRQPUR5	HFRQPUR6	HFRQPUR7
SSE	6862.32	2150.48	1654.36	816.25	1709.91	1096.80	1139.25
DFE	609.00	609.00	609.00	609.00	609.00	609.00	609.00
MSE	11.27	3.53	2.72	1.34	2.81	1.80	1.87
RSQUARE	0.65	0.54	0.13	0.06	0.18	0.18	0.15

RESIDENCE ZONE AND HOUSEHOLD STRUCTURE INCLUDED[1]

	HTRIPFRQ	HFRQPUR2	HFRQPUR3	HFRQPUR4	HFRQPUR5	HFRQPUR6	HFRQPUR7
SSE	6801.49	2139.18	1640.51	811.45	1671.50	1081.58	1137.01
DFE	606.00	606.00	606.00	606.00	606.00	606.00	606.00
MSE	11.22	3.53	2.71	1.34	2.76	1.78	1.88
RSQUARE	0.65	0.55	0.14	0.06	0.20	0.19	0.15

Table continued on following page.

Table F-7 (Continued)

ANALYSIS OF VARIANCE FOR HOME-BASED TRIP FREQUENCY BY PURPOSE
(For 629 Weekday Travelers)

ANOVA FOR DELETING RESIDENCE ZONE INFORMATION

	HTRIPFRQ	HFRQPUR2	HFRQPUR3	HFRQPUR4	HFRQPUR5	HFRQPUR6	HFRQPUR7
F-RATIO (3,606)	1.81	1.07	1.71	1.19	4.64**	2.84**	0.40

ANOVA FOR DELETING HOUSEHOLD STRUCTURE INFORMATION

	HTRIPFRQ	HFRQPUR2	HFRQPUR3	HFRQPUR4	HFRQPUR5	HFRQPUR6	HFRQPUR7
F-RATIO (16,609)	4.51**	4.27**	0.39	0.60	1.68**	1.29	2.68**

ANOVA FOR DELETING HOUSEHOLD STRUCTURE AND RESIDENCE ZONE INFORMATION

	HTRIPFRQ	HFRQPUR2	HFRQPUR3	HFRQPUR4	HFRQPUR5	HFRQPUR6	HFRQPUR7
F-RATIO (19,606)	4.10**	3.76**	0.60	0.69	2.18**	1.55	2.31**

NOTES: 1. See text for explanation of model. For variable definitions see Table F-6

2. SSE = sum of squared errors.

3. DFE = degrees of freedom.

4. MSE = mean squared error (MSE = SSE/DFE).

Notes continued on following page.

Table F-7 (Continued)

ANALYSIS OF VARIANCE FOR HOME-BASED TRIP FREQUENCY BY PURPOSE
(For 629 Weekday Travelers)

5. RSQUARE = coefficient of determination.

6. F-RATIO = "Chow Test" for coefficient restriction (see Attachment FA) Numbers in parentheses are degrees of freedom for F-ratio.

LEGEND: *Significant at .05 level.

**Significant at .01 level.

SOURCE: Based on data contained in Baltimore Travel Demand Data Set. Table compiled in December 1980.

greater extent than it does for activity-based purposes. On the other hand, shopping trips are identical in terms of variance explained. Home-based personal business trips are better explained by the basic model than are activity-based trips, but the reverse is true when household structure and residential location are included. Home-based entertainment trips are slightly less well explained by the full model than are activity-based trips, while home-based visiting and serve-passenger trips are better explained.

As described in Chapter 2 for weekday activity-based trips versus home-based trip productions, the overall patterns of significance are fairly similar.

Employment Status

Because employment status is important in predicting activity allocation to other purposes, as shown in Appendix B,the number of persons in the household employed part or full time (NEMPLOY) is added to the equation. Clearly, its use will be important in predicting work trips, and an endogeneity is introduced, but the intent here is to see if other purposes are affected. The results for weekday travel are displayed in Table F-8.

The probability of the employment coefficient being different from zero is significant for the total home-based, work, and entertainment equations and marginal for visiting. Employed persons reduce the number of entertainment trips and raise slightly the number of visiting trips. The role of the homemaker variable is sharpened for total home-based trips, while the role of number of vehicles owned in predicting work-trip frequency is reduced to zero. By knowing number employed, the importance of the age

Table F-8

HOME-BASED TRIP FREQUENCY BY PURPOSE INCLUDING NUMBER EMPLOYED
(For 629 Households with Weekday Travel)

	DEPENDENT VARIABLES						
INDEPENDENT VARIABLES	HTRIPFRQ PROB-T	HFRQPUR2 PROB-T	HFRQPUR3 PROB-T	HFRQPUR4 PROB-T	HFRQPUR5 PROB-T	HFRQPUR6 PROB-T	HFRQPUR7 PROB-T
INTERCEP	-1.419 0.186	-0.679 0.236	-0.434 0.419	-0.191 0.612	0.229 0.672	0.272 0.531	-0.616 0.165
VEHOWN	0.420 0.026	0.008 0.937	0.101 0.283	0.030 0.648	-0.037 0.695	0.094 0.214	0.224 0.004
INCOMEM	0.002 0.875	0.006 0.463	-0.009 0.276	0.005 0.410	0.016 0.040	-0.014 0.026	-0.002 0.789
NTEEN	2.809 0.000	1.236 0.000	0.309 0.000	0.122 0.039	0.651 0.000	0.418 0.000	0.073 0.292
N20T034	1.976 0.000	0.365 0.060	0.491 0.007	0.282 0.028	0.574 0.002	0.208 0.158	0.056 0.713
N35T054	1.636 0.000	0.383 0.067	0.484 0.014	0.183 0.184	0.438 0.026	0.107 0.502	0.041 0.801
N55T064	1.644 0.000	0.172 0.449	0.590 0.006	0.191 0.201	0.553 0.010	0.053 0.759	0.086 0.627
N65PLUS	1.137 0.006	0.222 0.315	0.503 0.015	0.209 0.152	0.215 0.301	-0.044 0.795	0.031 0.855
SFDU	0.415 0.272	-0.210 0.298	0.069 0.714	0.181 0.173	-0.060 0.751	0.089 0.563	0.346 0.029
FREDUM	-0.965 0.029	-0.161 0.495	0.028 0.900	-0.159 0.306	-0.108 0.626	-0.108 0.547	-0.456 0.013
GRADEDUM	0.256 0.497	-0.128 0.525	-0.172 0.361	-0.134 0.311	0.422 0.026	-0.072 0.637	0.340 0.030

Table F-8 (Continued)

HOME-BASED TRIP FREQUENCY BY TRIP PURPOSE INCLUDING NUMBER EMPLOYED
(For 629 Households with Weekday Travel)

DEPENDENT VARIABLES

INDEPENDENT VARIABLES	HTRIPFRQ PROB-T	HFRQPUR2 PROB-T	HFRQPUR3 PROB-T	HFRQPUR4 PROB-T	HFRQPUR5 PROB-T	HFRQPUR6 PROB-T	HFRQPUR7 PROB-T
HMMAKEDM	0.709 0.030	0.265 0.128	0.206 0.205	0.099 0.387	-0.177 0.279	-0.[illegible] 0.924	0.329 0.01[illegible]
HHRACE	-0.145 0.686	-0.293 0.126	-0.021 0.908	-0.026 0.837	0.065 0.719	-0.029 0.841	0.159 0.286
SMALE	2.037 0.029	0.562 0.258	0.565 0.224	0.227 0.487	0.471 0.314	-0.068 0.856	0.281 0.463
SFMALE	1.287 0.133	0.544 0.235	0.425 0.321	0.128 0.670	0.178 0.680	-0.270 0.436	0.282 0.429
UNRELI	1.598 0.067	0.761 0.102	0.483 0.267	0.113 0.711	0.060 0.890	-0.144 0.6[illegible]	0.324 0.[illegible]70
COUPLE	1.101 0.067	0.372 0.247	0.073 0.807	0.197 0.352	0.110 0.715	0.181 0.459	0.167 0.50[illegible]
SPHH	1.449 0.112	0.579 0.235	0.716 0.117	0.155 0.628	-0.084 0.854	-0.227 0 540	0.310 0.414
NUCLR	1.163 0.090	0.291 0.426	0.492 0.151	0.178 0.459	-0.327 0.342	-0.149 0.592	0.677 0.019
AFWKID	0.990 0.130	0.000 1.000	0.559 0.088	0.071 0.758	-0.117 0.723	0.152 0.567	0.325 0.[illegible]33
RDENP	-0.012 0.037	-0.002 0.478	-0.006 0.051	-0.003 0.139	-0.006 0.060	0.006 0.012	-0.002 0.4[illegible]
CITY	0.006 0 98[illegible]	0.269 0.186	0.271 0.155	0.142 0.[illegible]	-0.507 0.008	-0.307 0.04[illegible]	0.118 0 4[illegible]
HHRES6	-0.309 0.593	-0.217 0.481	0.094 0.745	0.147 0.468	-0.384 0.185	-[illegible].278 [illegible]38	0.130 [illegible].598

Table F-9 (Continued)

HOME-BASED TRIP FREQUENCY BY PURPOSE INCLUDING NUMBER EMPLOYED
(For 629 Households with Weekday Travel)

DEPENDENT VARIABLES

INDEPENDENT VARIABLES	HTRIPFRQ PROB-T	HFRQPUR2 PROB-T	HFRQPUR3 PROB-T	HFRQPUR4 PROB-T	HFRQPUR5 PROB-T	HFRQPUR6 PROB-T	HFRQPUR7 PROB-T
NEMPLOY	1.019 0.000	1.070 0.000	0.016 0 892	-0.033 0.659	-0 256 0.018	0.129 0 139	0.093 0.301
STD ERR	3.292	1.758	1.647	1.158	1.655	1.335	1.370
R-SQUARE	0.664	0.602	0.136	0.065	0.204	0.195	0.156

NOTES:

1. For variable definitions, see Tables F-3 and F-6.
2. For each variable, the coefficient is on the first line; the probability that this coefficient is different from zero is on the second line.
3. "STD ERR" is the standard error of the estimated variables; "R-SQUARE" is the squared multiple correlation coefficient.

SOURCE: Based on data contained in the Baltimore Travel Demand Data Set. Table compiled in December 1980.

structure (for those over 19) is reduced for predicting work trips and increased for predicting entertainment trips. The importance of the household-type variables is reduced slightly for total trips, but this change is not readily related to specific trip purposes.

The results for weekend travel by purpose (not shown) reveal a much smaller overall effect, attributable mostly to work trips. However, there is a slight reduction in the frequency of personal business trips on the weekend attributable to number employed, indicating that such trips may be performed in conjunction with the work trip during the weekday.

Trip Productions by Mode

The pattern by mode between activity and home-based definitions is similar to that by purpose. Four of the six home-based weekday equations are better fit. Age variables are more important for home-based auto driver frequency, while selected household-type variables gain in significance, especially for bus and walk modes. Otherwise, the pattern of results is very similar.

The home-based models for weekend travel are similar to those for activity-based trips. The three main motorized modes are better predicted. Unrelated individuals make the largest incremental number of auto driver trips. The household age structure is somewhat more important for home-based trips, particularly bus trips.

Trip Productions by Mode and Purpose

Extending this methodology further, it is possible to construct models that sum one way to frequency by mode and the other way to frequency by purpose, giving, in each cell, the frequency by a particular mode and purpose. As noted in the discussion of statistical issues, if all independent variables used in all the models are the same, the coefficients of the mode-by-purpose equations, when summed across modes, will equal the corresponding coefficient of the equation for the particular mode for all purposes.

Likewise, when the coefficients for each variable are summed across modes within a particular purpose, the sum of each such set of coefficients will equal the corresponding coefficient in that purpose equation for all modes. When the equations for total trips by mode are summed across mode, the sum of these coefficients will equal the coefficient for total trip frequency for that variable; the same is true when the summation is carried across the total mode equation by purpose.

This means that, given any specific set of exogenous variables, the prediction of total trip frequency for all modes and purposes will be the same whether these exogenous variables are: 1) substituted into the total trip frequency equation; 2) substituted into the total mode and purpose equations and summed to total trips; or 3) individually substituted into the 36 mode-by-purpose equations and then summed across mode and purpose. As we noted in Appendix B, however, while the overall totals are constrained, the values of the components may fluctuate in order to achieve this overall constraint. This means that the standard errors for the mode-by-purpose equation may be very large for an individual mode-by-purpose equation.

While a complete system of such equations has been estimated, because of its complexity we present only the coefficients of determination (R^2) which result from this fitting process. As can be seen from Table F-9, while the variance explained for purposes by all modes or modes by all purposes is fairly high in some cases, as one works down into the mode by purpose equations, the variance explained becomes fairly low in some cases.

STRUCTURAL EQUATION MODELING: ACTIVITY BASED

In the previous sections of this report, as is usually the case, the various facets of travel behavior such as trip frequency and activity time have been addressed independently. In this final section of the report, potential interactions among variables such as activity time allocations, trip frequencies, and travel times and distances are explored. Our approach is comprehensive, in that a wide range of potential interactions are explored; however the work should be viewed as primarily illustrative, in that it represents only one possible structure.

A set of structural models is developed for this purpose with three objectives: 1) to investigate potential interrelationships among determinants of mobility such number of driver's licenses in the household and number of vehicles owned, 2) to determine the impact of such variables in addition to the standard set of sociodemographic, household structure, and residential location variables on household time allocation; and 3) to investigate the impact of such activity time allocations on travel time, travel frequency, person and vehicle miles traveled.

Table F-9

VARIANCE EXPLAINED BY MODE AND PURPOSE·
WEEKDAY HOME-BASED TRIPS

	Mode[a]						
Purpose[a]	All Modes	Auto Driver	Auto Passenger	Bus	Walk	Other Nonmotor	Other Motorized
All Purposes	65	54	17	.30	41	04	23
Work/School	55	43	08	26	33	06	22
Shopping	14	17	07	09	09	03	05
Personal Business	06	07	05	06	05	04	03
Entertainment/ Recreation	20	15	09	06	15	04	08
Visiting	19	10	07	11	20	04	11
Serve/Accompany Traveler	16	16	05	0 0[b]	07	0 0[b]	03

NOTES [a]See Table F-G for mode and purpose definitions

[b]No Observations for these mode/purpose combinations

SOURCE Based on data contained in Baltimore Travel Demand Data Set
Table compiled in January 1981

When considering the interactions among the measures of mobility such as distance, frequency, and travel time, hypotheses and results from previous work are of interest. For example, the travel time budget notion may imply that total travel distance increases with travel time, but the reverse relationship of travel distance determining travel time would not hold.

Two-stage least squares is the estimation technique utilized, a block recursive structure is developed to examine various levels of interaction among the variables. Two-stage least squares is utilized in an attempt to remove the potential mutual dependency of one variable on another where each is used as a predictor of the other. Failure to use such a technique can result in biased coefficient estimates, by utilizing this technique it is possible to test whether feedback relationships exist among variables or whether the presumed direction of causality runs in only one direction. The use of this technique is described in numerous texts such as that by Theil (F2). Structural equation methods have been used elsewhere to estimate cross-elasticities among modes (F3), but here the emphasis is on the allocation of time and the interrelationship of such measures with aggregate measures of travel by all modes. Clearly, the approach could be extended to a multimodal context, but the degree of complexity rises by a corresponding amount.

In order to simplify the analysis, the seven activities were combined into four. These activities, defined in Table F-10, include activity time in home, activity time at work or school, time spent in entertainment or

Table F-10

ENDOGENOUS VARIABLES UTILIZED IN THE STRUCTURAL ESTIMATION

Variable	Definition
Mobility Precursors	
NDRIVLIC	Number of drivers licenses in household
STAYHOME	Number of eligible persons not traveling
VEHOWN	Number of household vehicles owned
Fuel Efficiency	
GASPVMT	Gallons of gas used per vehicle miles traveled weighted average[1]
Household Time Allocations[2]	
ATINHOM	In-home time
ATWORK	Time at work or school
ATEXHOM	Time outside home in home-serving activities (shop, personal business, serve/accompany traveler)
ATENTVI	Time in entertainment or visiting outside home
Aggregate Mobility Measures	
TRIPFREQ	Total number of trips[3]
TTRAVTM	Total Travel time[2,3]
PERSMILE	Person miles traveled[3]
TOTVMT	Total vehicle miles traveled by household-owned vehicles
Mobility Measures by Purpose	
TTINHOM[2,3]	Travel time to home
TTWORK[2,3]	Travel time to work or school
TTEXHOM[2,3]	Travel time to home-serving activities
TTENTVI[2,3]	Travel time to entertainment or visiting

Table continued on following page.

Table F-10 (Continued)

ENDOGENOUS VARIABLES UTILIZED IN THE STRUCTURAL ESTIMATION

Variable	Definition
FQINHOM, FQWORK, FQEXHOM, FQENTVI	Trip frequency by purpose[3]
TDINHOM, TDWORK, TDEXHOM, TDENTVI	Person miles traveled by purpose[3]
VMTINHOM, VMTWORK, VMTEXHOM, VMTENTVI	Vehicle miles traveled by purpose in household-owned vehicles

NOTES: [1]See Appendix D for definitions.

[2]Time in minutes.

[3]By motorized and nonmotorized modes.

visiting, and time spent outside the home in home-serving activities such as shopping, personal business, and service/accompany traveler. Travel by both motorized and nonmotorized modes is dealt with in the total trip time, frequency, and miles traveled variables. Additional exogenous variables are defined in Table F-11.

The basic orientation is as follows and is depicted in Figure F-1 (which also summarizes the empirical results). The number of vehicles in the household is determined by the household's choice of lifestyle as revealed by location as well as the number of driver's licenses and material constraints such as income. The number of driver's licenses is affected by the age and education structure of the household. Numbers of persons staying at home is affected by age, opportunity for mobility as revealed by numbers of vehicles owned, and other locational factors. Numbers of vehicles, in conjunction with the age and education structure of the household and location variables then determine the time devoted to in-home and out-of-home activities. These time allocations are instrumental in predicting travel time and travel frequency. Frequency and travel time are modeled as potentially feeding back on each other. Person and vehicle miles traveled are modeled as a function of frequency and travel time. The analysis of travel time, frequency, and distance is also carried out by the four trip purposes.

Mobility Precursors

As was seen in previous sections, the number of household vehicles owned was a strong determinant of trip frequency. Table F-12 presents results for

Table F-11

ADDITIONAL EXOGENOUS VARIABLE DEFINITIONS

Variable	Definition
NEDCOLL	Number of persons with some college
NEDHS	Number of persons with high school
NEDGS	Number of persons with grade school education or less
NEMPLOY	Number of persons employed full- or part-time
NEMPFT	Number of persons employed full-time
NMADULT	Number of male adults
NFADULT	Number of female adults
RDEVELOP	Proportion of Land Developed Residentially

NOTE. See Table F-3 for other variable definitions.

Table F-12

MOBILITY PRECURSORS
(For 605 households with weekday travel)

Jointly and Predetermined Variables*	Second Stage Equations		
	NDRIVLIC	VEHOWN	STAYHOME
B1. NDRIVLIC** +		.461###	.113
B1. VEHOWN** +	.987###		-.458###
B1. STAYHOME** +		.165	
B1. ATINHOM** +		-.7x10-4#	
INTERCEPT	-.015	.568##	.022
NTEEN	-.043		.086##
N20TO34	-.298###		.305###
N35TO54	-.283###		.398###
N55TO64	-.204##		.387###
N65PLUS	-.308###		.663###
NEDCOLL	-.481###		
NEDHS	.423		
NEDGS	.332###		
INCOMEM	-.005	.018###	
CITY	.070	-.187##	-.055
HHRES6			.037
RDENP	.0002	-.004###	.0002
RDEVELOP		-.256##	

Table continued on following page.

Table F-12 (Continued)

MOBILITY PRECURSORS
(For 605 households with weekday travel)

Jointly and Predetermined Variables*	Second Stage Equations		
	NDRIVLIC	VEHOWM	STAYHOME
NEMPLOY		.149###	
SMALE		.033	
SFMALE		-.096	
UNRELI		-.158	
COUPLE		.023	
SPHH		-.004	
NUCLR		.018	
AFWKID		.042	
PREDUM			.132#
GRADEDUM			.019
SFDU	-.021		
R-SQUARE	.664	.632	.201

*Variables are defined in Tables F-3, F-10, and F-11.

**Jointly determined variables for Block 1 include: NDRIVLIC, VEHOWN, STAYHOME, ATHOME, ATWORK, ATEXHOM, ATENTVI, TTRAUTM, TRIPFREQ, PERSMILE, TOTUMT.

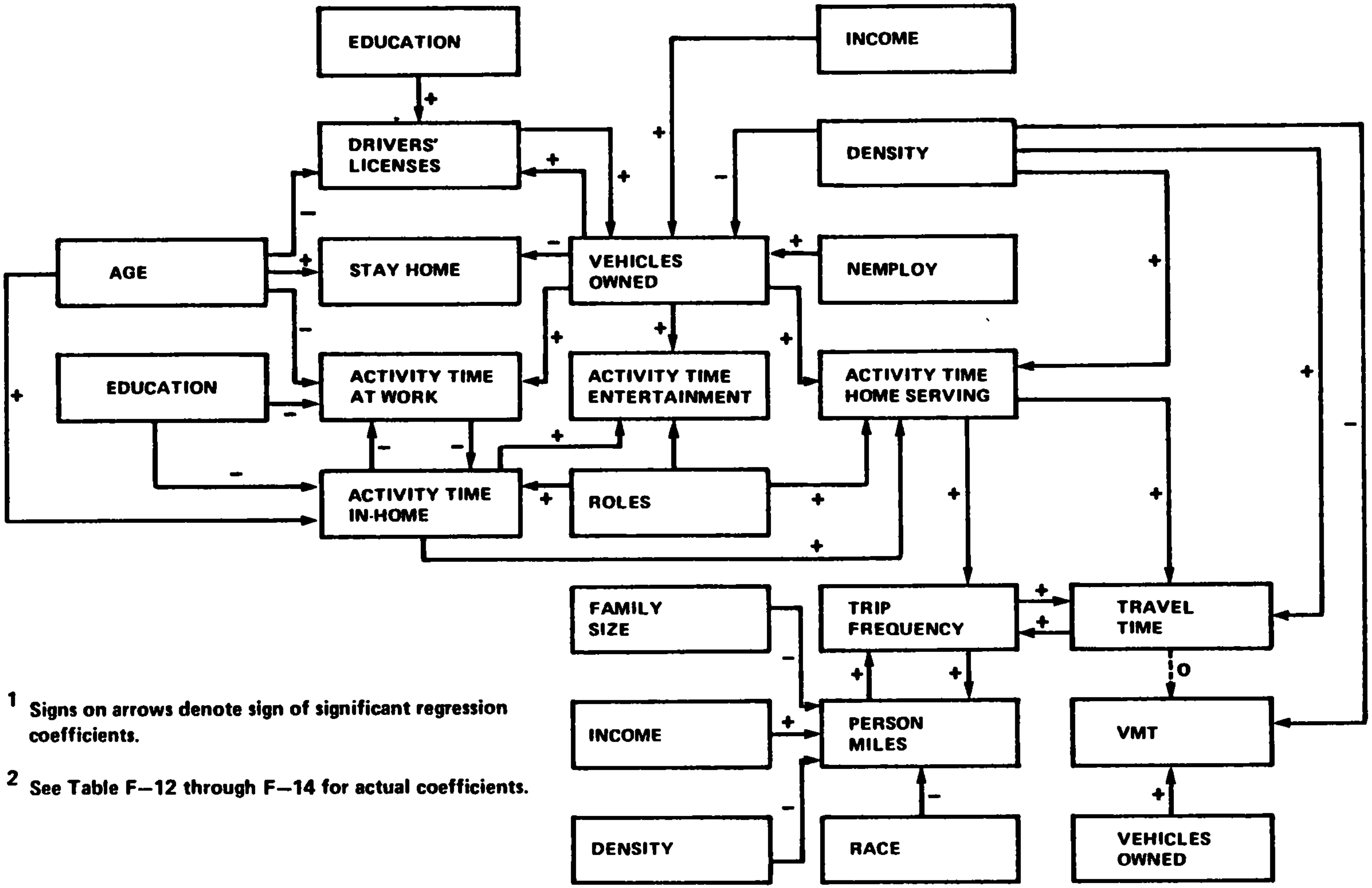
+Identifying restrictions apply across Tables F-12 to F-14.

Legend: significance levels for coefficients

\# Prob (t) < .20
\## Prob (t) < .05
\### Prob (t) < .01

Figure F–1

STRUCTURAL RELATIONS AMONG VARIABLES[1,2]
(WEEKDAY TRAVELERS)



1 Signs on arrows denote sign of significant regression coefficients.

2 See Table F–12 through F–14 for actual coefficients.

models of number of driver's licenses, number of vehicles owned, and number of persons not traveling on the travel day. These measures, along with household time allocations and aggregate mobility measures, are fit as one endogenous system.

Vehicles Owned. As can be seen from Table F-12, number of vehicles owned has a strong positive relationship to number of driver's licenses and a weak negative relationship to total time spent in the home. Number of vehicles owned is also positively related to number of persons employed full or part time and to median income, while it is negatively related to three measures of residential density. presence in Baltimore, percent of land area in the zone developed residentially, and the population per residential acres in the zone. Household type does not make a significant contribution to predicting number of vehicles owned when these relationships are accounted for.

Driver's Licenses. Likewise, the number of vehicles owned makes a positive contribution to the prediction of the number of driver's licenses in the household. Numbers of driver's licenses are related in a negative manner to the age structure of the household, and in a positive manner to the education structure of the household.

Stay-at-Homes. Number of persons staying in the home is not related to the number of driver's licenses in the home but is negatively related to the number of vehicles owned, indicating the constraining nature of lack of vehicle ownership. Number of persons staying at home is positively related

to the age structure of the household and marginally related to the presence of a preschooler.

Household Time Allocation

The time allocation of households is modeled for the four activity purposes described above. These results are presented in Table F-13. Various interrelationships among time allocations are explored as well as the relationship to the mobility precursors discussed above.

In-Home. Time spent at home is negatively related to time spent at work, as one would expect. It is also positively related to the presence of a preschooler, positively related to the age structure of the household, and negatively related to the education structure, as was found for a number of stay-at-homes. The only family structure-type variable that was significant was adult families with children, which bore a strong negative relationship to time spent at home.

At Work. Likewise, time spent at work is negatively related to time spent at home and the number of vehicles owned. It is negatively related to the age structure of the household and positively related to the education structure.

Home-Serving. Time spent in home-serving activities outside the home is positively related to time spent inside the home as well as the number of vehicles owned, but is not constrained by time spent at work. It is also positively related to the homemaker variable and to the percent of land developed for residential purposes, perhaps indicating a suburban lifestyle.

Table F-13

HOUSEHOLD TIME ALLOCATION
(For 605 households with weekday travel)

Jointly and Predetermined Variables*	Second Stage Equations			
	ATINHOM	ATWORK	ATEXHOM	ATENTVI
B1. ATINHOM** +		-.197###	0.015#	0.068###
B1. ATWORK** +	-0.726###		-0.021	-0.027
B1. ATEXHOM** +				
B1. ATENTVI** +				
B1. VEHOWN** +	-67.089	268.527###	59.174###	81.276#
B1. STAYHOME** +	-2.890			
INTERCEPT	-39.972	-38.931	-63.086#	-151.369#
NTEEN	1052.303###	338.980###		
N20T034	993.468###	103.930###		
N35T054	1032.212###	102.985###		
N55T064	1037.129###	93.591##		
N65PLUS	1167.900###			
NEDCOLL	204.695###	141.526###		
NEDHS	241.222###	187.246###		
NEDGS	275.069###	226.915###		
PREDUM	170.222###		-24.939#	
HMMAKEDM	45.629		29.177##	
SMALE	-43.737		8.714	158.912##
SFMALE	43.574		1.321	55.456

Table continued on following page.

Table F-13 (Continued)

HOUSEHOLD TIME ALLOCATION
(For 605 households with weekday travel)

Jointly and Predetermined Variables*	Second Stage Equations			
	ATINHOM	ATWORK	ATEXHOM	ATENTVI
UNRELI	-103.219		37.335	31.829
COUPLE	-47.363		-11.940	62.984
SPHH	-11.563		23.296	139.895##
NUCLR	-12.873		-4.212	42.330
AFWKID	-200.441##		1.128	100.908#
HHRACE		63.177#	16.580	-13.833
RDEVELOP			70.699###	
HHRES6			3.033	
INCOMEM			-0.965	-1.367
RDENP				0.238
R-SQUARE	.902	.548	.087	.117

*Variables are defined in Tables F-3, F-10, and F-11.

**Jointly determined variables for Block 1 include: NDRIVLIC, VEHOWN, STAYHOME, ATHOME, ATWORK, ATEXHOM, ATENTVI, TTRAUTM, TRIPFREQ, PERSMILE, TOTUMT.

+Identifying restrictions apply across Tables F-12 to F-14.

Legend significance levels for coefficients:

Prob (t) < .20
Prob (t) < .05
Prob (t) < .01

Visiting/Entertainment. Likewise, time spent in visiting and entertainment is significantly related to time spent at home, but only marginally related to a number of vehicles owned. Household types that allocate greater amounts of time to such activities than the norm include single-male households, single-parent households, and adult families with children.

Aggregate Mobility Measures

Total travel time is modeled as a function of the three out-of-home time allocations, total trip frequency, and total person miles traveled by all modes, as well as residential density and median income. Total travel time is simultaneously determined with time spent in home serving out-of-home activities, as well as the total trip frequency. These results are presented in Table F-14.

Likewise, total trip frequency is determined by time spent in home-serving activities, total travel time, and person miles traveled. In addition, it is also positively related to the number of teenagers in the household when these other influences are accounted for.

Total vehicle miles traveled for household-owned vehicles is not related to trip frequency or travel time but is most strongly related to the number of vehicles owned and net residential density. Person miles traveled, on the other hand, is marginally related to total travel time and positively related to total trip frequency. The fact that travel time was a determinant of distance, but not vice versa, appears to be consistent with the notion of a household travel time budget (which varies by household). Person miles

Table F-14

AGGREGATE MOBILITY MEASURES
(For 605 households with weekday travel)

Jointly and Predetermined Variables*	Second Stage Equations: TTRAVTM	TRIPFREQ	PERSMILE	TOTVMT
B1. TTRAVTM** +		0.015#	0.067#	0.020
B1. TRIPFREQ** +	13.661###		2.783###	-0.326
B1. PERSMILE** +	-0.015	0.069###		
B1. TOTVMT** +				
B1. ATWORK** +	0.039	0.001		
B1. ATEXHOM** +	0.301#	0.012#		
B1. ATENTVI** +	0.081	-0.001		
B1. NDRIVLIC** +				2.023
B1. VEHOWN** +				15.164###
INTERCEPT	-6.204	0.544	7.651###	1.035
RDENP	0.330#	0.002	-0.118###	-0.076**
HHRES6		-0.707		
INCOMEM	-0.211		0.533###	0.050
NTEEN		1.378###		
N20TO34		0.153		
N35TO54		0.061		
N55TO64		-0.286		
TOTELIG			-3.092#	
HHRACE			-5.426##	
R-SQUARE	0.502	0.658	0.543	0.406

Notes on following page.

Table F-14 (Continued)

AGGREGATE MOBILITY MEASURES
(For 605 households with weekday travel)

NOTES:

*Variables are defined in Tables F-3, F-10, and F-11.

**Jointly determined variables for Block 1 include: NDRIVLIC, VEHOWN, STAYHOME, ATHOME, ATWORK, ATEXHOM, ATENTVI, TTRAVTM, TRIPFREQ, PERSMILE, TOTVMT.

+Identifying restrictions apply across Tables F-12 to F-14.

Legend: significance levels for coefficients.

Prob (t) < .20
Prob (t) < .05
Prob (t) < .01

traveled is positively related to income, perhaps reflecting the choice of slower modes by those of lesser incomes. Person miles traveled is negatively related to family size, net residential density, and household race, perhaps indicating a central city location with constrained mobility.

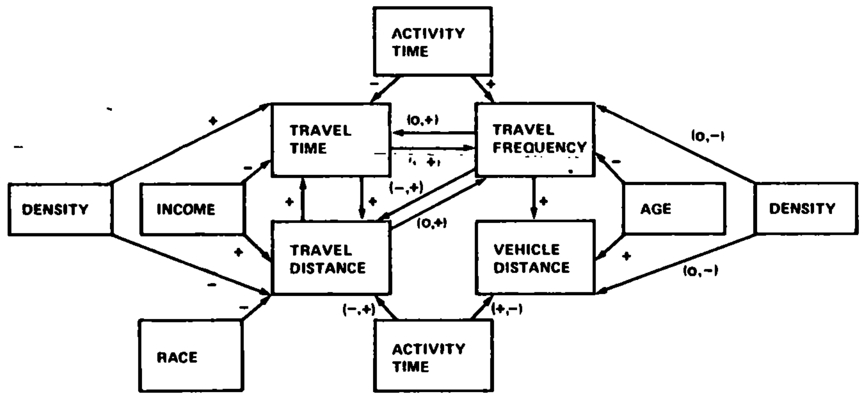
Mobility Measures by Purpose

The interrelationships among activity time, travel time, frequency, and distance by purpose traveled are also explored with a similar methodology. These results are presented in Figure F-2 and Tables F-15 through F-18. In this case, travel time frequency and distance by purpose are simultaneously estimated, while vehicle miles traveled is modeled as a function of activity and trip time and frequency by purpose.

Travel Time. Travel time by purpose is modeled in a manner analogous to that used for total travel time. For each purpose, the determinants are the activity time at the destination, frequency and travel distance by purpose, as well as residential density and income. The pattern is, for the most part, the same: frequency and distance both are positively related to travel time, and activity time bears a weak negative relation to travel time. Residential density (and residence in Baltimore) is positively related, and income is negatively related to travel time. The latter two relationships may again reveal the choice of transit by poorer persons in denser areas. The negative relationship between travel time and activity time may indicate a fixed budget for the activity/trip bundle, with a tradeoff of travel time for activity time.

Figure F-2

MOBILITY RELATIONS FOR TRAVEL BY PURPOSE[1,2,3]



1 Purposes are In-Home, Work/School, Shop/Personal Business/Serve-Passenger, Entertainment/Visiting

2 Signs on arrows denote sign of significant regression coefficients

3 See Tables F-15 through F-18 for actual coefficients

Table F-15

MOBILITY MEASURES BY PURPOSE: IN-HOME
(For 605 households with weekday travel)

Jointly and Predetermined Variables*	Second Stage Equations			
	TTINHOM	FQINHOM	TDINHOM	TVINHOM
B2. TTINHOM** +		0.013#	0.144###	-0.101##
B2. FQINHOM** +	10.876###		-3.100##	4.095###
B2. TDINHOM** +	3.347###	0.060##		
B2. TVINHOM** +				
INTERCEPT	-17.898##	0.270	3.383###	3.520##
ATINHOM++	-0.001	-0.0002	-0.009+	-0.004#
RDENP	0.181###	-0.004###	-0.071+	-0.052###
HHRES6		-0.165		0.620
CITY	22.497###			
SFDU	0.679			
HHRACE			-3.116###	
TOTELIG			13.629###	
INCOMEM	-0.733###		0.189###	
NTEEN		1.139##		0.969
N20T034		0.718#		4.772#
N35T054		0.583#		5.857#
N55T064		0.600#		5.564#
N65PLUS		0.569#		3.993
R-SQUARE	0.574	0.692	0.493	0.235

Footnotes on following page.

Table F-15 (Continued)

MOBILITY MEASURES BY PURPOSE: IN-HOME
(For 605 households with weekday travel)

NOTES:

*Variables are defined in Tables F-3, F-10, and F-11.

**Jointly determined variables for Block 2 include the travel time, frequency, distance, and vehicle distance variables by purpose.

+Identifying restrictions apply across Tables F-15 to F-18.

++Activity times are assumed exogenous.

Legend. significance levels for coefficients:

Prob (t) < .20
Prob (t) < .05
Prob (t) < .01

Table F-16

MOBILITY MEASURES BY PURPOSE: WORK/SCHOOL
(For 605 households with weekday travel)

Jointly and Predetermined Variables*	Second Stage Equations			
	TTWORK	FQWORK	TDWORK	TVWORK
B2. TTWORK** +		0.010#	0.147#	-0.057
B2. FQWORK** +	29.189###		-5.140	4.121#
B2. TDWORK** +	2.385###	0.016		
B2. TVWORK** +				
INTERCEPT	-10.230#	0.206#	2.990##	2.094#
ATWORK++	-0.044#	0.002###	0.017##	0.002
RDENP	0.135#	-0.003#	-0.052##	-0.042##
HHRES6		0.074		1.873
CITY	9.287#			
SFDU	-2.972			
HHRACE			-1.936#	
TOTELIG			-0.027	
INCOMEM	-0.214		0.108##	
NTEEN		0.114#		-2.339###
N20TO34		-0.010		0.575
N35TO54		-0.012		1.186#
N55TO64		-0.034		0.970
N65PLUS		0.015		-0.457
R-SQUARE	0.508	0.746	0.352	0.301

Footnotes on following page.

Table F-16 (Continued)

MOBILITY MEASURES BY PURPOSE: WORK/SCHOOL
(For 605 households with weekday travel)

NOTES:

*Variables are defined in Tables F-3, F-10, and F-11.

**Jointly determined variables for Block 2 include the travel time, frequency, distance, and vehicle distance variables by purpose.

+Identifying restrictions apply across Tables F-15 to F-18.

++Activity times are assumed exogenous.

Legend significance levels for coefficients:

Prob (t) < .20
Prob (t) < .05
Prob (t) < .01

Table F-17

MOBILITY MEASURES BY PURPOSE: SHOP, PERSONAL, BUSINESS, SERVE PASSENGER
(For 605 households with weekday travel)

Jointly and Predetermined Variables*	Second Stage Equations			
	TTEXHOM	FQEXHOM	TDEXHOM	TVEXHOM
B2. TTEXHOM** +		0.010	0.070###	-0.061
B2. FQEXHOM** +	0.165		1.845#	5.776###
B2. TDEXHOM** +	7.461###	0.079##		
B2. TVEXHOM** +				
INTERCEPT	-25.283###	0.456#	1.258#	-0.434
ATEXHOM++	-0.083#	0.004###	0.005	-0.021#
RDENP	0.084	-0.001	-0.028##	-0.020
HHRES6		-0.291		1.143
CITY	28.902###			
SFDU	2.219			
HHRACE			-1.239#	
TOTELIG			-0.074	
INCOMEM	-0.588##		0.072##	
NTEEN		0.234###		-1.854##
N20TO34		0.073		-0.466
N35TO54		0.134		-0.203
N55TO64		-0.010		0.161
N65PLUS		-0.025		-0.154
R-SQUARE	0.237	0.471	0.455	0.128

Footnotes on following page.

Table F-17 (Continued)

MOBILITY MEASURES BY PURPOSE: SHOP, PERSONAL, BUSINESS, SERVE PASSENGER
(For 605 households with weekday travel)

NOTES:

*Variables are defined in Tables F-3, F-10, and F-11.

**Jointly determined variables for Block 2 include the travel time, frequency, distance, and vehicle distance variables by purpose.

+Identifying restrictions apply across Tables F-15 to F-18.

++Activity times are assumed exogenous.

Legend: significance levels for coefficients·

Prob (t) < .20
Prob (t) < .05
Prob (t) < .01

-

Table F-18

MOBILITY MEASURES BY PURPOSE: VISITING/ENTERTAINMENT
(For 605 households with weekday travel)

Jointly and Predetermined Variables*	Second Stage Equations			
	TTENTVI	FQENTVI	TDENTVI	TVENTVI
B2. TTENTVI** +		0.028###	0.221##	-0.009
B2. FQENTVI** +	19.165###		-3.509#	1.503
B2. TDENTVI** +	2.282##	-0.022		
B2. TVENTVI** +				
INTERCEPT	-9.784#	0.053	1.795#	2.958###
ATENTVI++	-0.028	0.001#	0.014###	0.004
RDENP	0.053	-0.001	-0.026#	-0.039###
HHRES6		0.116		-0.005
CITY	8.613##			
SFDU	2.820			
HHRACE			-1.687#	
TOTELIG			-0.091	
INCOMEM	-0.208#		0.094##	
NTEEN		0.243###		-1.342##
N20TO34		0.044		-0.396
N35TO54		0.038		0.033
N55TO64		-0.004		0.742#
N65PLUS		0.035		-0.577
R-SQUARE	0.520	0.576	0.371	0.210

Tables continued on following page

Table F-18 (Continued)

MOBILITY MEASURES BY PURPOSE: VISITING/ENTERTAINMENT
(For 605 households with weekday travel)

NOTES:

*Variables are defined in Tables F-3, F-10, and F-11.

**Jointly determined variables for Block 2 include the travel time, frequency, distance, and vehicle distance variables by purpose.

+Identifying restrictions apply across Tables F-15 to F-18.

++Activity times are assumed exogenous.

Legend significance levels for coefficients:

Prob (t) < .20
Prob (t) < .05
Prob (t) < .01

Travel Frequency. In contrast to travel time, travel frequency is positively related to activity time for out-of-home purposes. Travel distance is not traded off against frequency for out-of-home activity, and only for entertainment and visiting is travel time associated with frequency. Numbers of teens are positively related to out-of-home frequency. For in-home activity, travel time and distance are marginally but positively related to frequency, as are numbers of teens; residential density is negatively related.

Person Miles Traveled. For out-of-home activities, the greater the amount of time spent in the activity, the farther the distance traveled to the activity. Only in the case of entertainment is there a tradeoff between frequency and distance traveled. The other relationships are consistent across purposes: travel time and income are positively related, while race and density are negatively related.

Vehicle Miles Traveled. For VMT, the patterns are less regular across purposes. Net residential density is negatively related for trips home and for visiting/entertainment. Frequency is positively related for all but entertainment/visiting. Travel time tends not to be related. (Frequency and time are for all modes, so the lack of a strong relationship is primarily indicative of no tradeoffs to the vehicular mode.) Numbers of teenagers are associated with shorter vehicle travel for out-of-home purposes.

Fuel Efficiency

Gas consumed by household vehicles is modeled as an identity of vehicle miles traveled times gallons consumed per vehicle miles traveled. In order to estimate fuel consumption, it is recessary to model fuel efficiency. Table F-19 displays this (it should be noted that gas per vehicle miles traveled is the inverse of miles per gallon, and the signs will thus be reversed in interpretation). The fuel efficiency variable used here is a weighted average of each auto owned by the household, utilizing both the number of miles driven using that auto and its respective mileage rating. As can be seen, the more vehicles the household owns, the greater the average fuel economy of the household fleet; a larger number of young adults with residence within the Baltimore city limits also promotes fuel efficiency. White households tend to have more fuel efficient vehicles, but households with greater numbers of male adults tend to have less efficient vehicles.

As total VMT for a household was used in calculating fuel efficiency, two-stage least squares was used to estimate the two simultaneously. The model for VMT is the same as used in Table F-18, although estimated on all households with fuel efficiency information, no matter what day of the week on which travel occurred. VMT makes no contribution to predicting fuel efficiency in this case. The coefficients for predicting the harmonic mean of household fuel efficiency are similar to that for weighted fuel efficiency.

Summary

This section delineates the structure of certain household activity and trip-making behaviors. Given the results presented in earlier sections as well as the work of others, these results are not necessarily surprising,

Table F-19

ESTIMATED FUEL CONSUMPTION EQUATIONS
(For 429 households with information)

Joint and Predetermined Variables*	Second Stage Estimates	
	GASPVMT**	HHGPMHM**
INTERCEPT	0.092###	0.1010###
VEHOWN	-0.0068###	-0.0039##
NTEEN	-0.0011	-0.0011
N20T034	-0.0068###	-0.0068###
HHRACE	0.0060##	0.0070###
CITY	-0.0062##	-0.0056##
RDENP	0.0001	¶
NMADULT	0.0083##	0.0063#
NFADULT	0.0029	0.0020
NEMPFT	0.0009	¶
SMALE	-0.0012	-0.0019
SFMALE	0.0005	-0.0020
UNRELI	-0.0048	-0.0036
COUPLE	-0.0028	-0.0024
SPHH	0.0031	0.0020
NUCLR	0.0059#	0.0065#
AFWKID	0.0018	0.0030
NEDCOLL	-0.0034#	-0.0031#
NEDHS	-0.0006	¶

Table continued on following page.

Table F-19 (Continued)

ESTIMATED FUEL CONSUMPTION EQUATIONS
(For 429 households with information)

Joint and Predetermined Variables*	Second Stage Estimates	
	GASPVMT**	HHGPMHM**
NEDGS	-0.0023	-0.0020
INCOMEM	¶	¶
NDRIVLIC	0.0026#	0.0016
TOTVMT+	0.0001	¶
R-SQUARE	0.174	0.186

*Variables defined in Tables and F-3, F-10, AND F-11.

**Fuel consumption variables are discussed in Appendix D.

+TOTVMT is jointly estimated with GASPVMT and HHGDMHM, using a structural model (for different observations) similar to Table F-14.

Legend: significance levels for coefficients:

- # Prob (t) < .20
- ## Prob (t) < .05
- ### Prob (t) < .01
- ¶ Number is less than 0.00005

however, it is necessary to proceed in this fashion if the interrelationships among household lifestyle variables and travel variables are to be uncovered. The trip frequency models presented in prior sections may be viewed as reduced-form equations (although not necessarily the structural equations presented here).

One striking finding is the extent to which vehicle ownership pervades the prediction of out-of-home time allocation even when other influences are controlled for. Vehicle ownership is predicted by income, among other variables. This structural relation shows clearly why income is not an effective predictor of trip frequency when the number of vehicles owned is also in the equation, as demonstrated in earlier sections.

For activity time, time at home and work substitute for each other, however other out-of-home activities are complementary with time spent at home. The negative relationship of age to out-of-home activity shows clearly in these results, as it has in all the prior modeling presented in this report. As time at home and time at work are negatively related to the educational structure of the household, this would imply that higher educated households tend to spend more time in out-of-home nonwork activities. Other familiar relations such as the confining nature of having a preschooler in the family and the negative relationship of net residential density to measures of mobility are also found. Increasing amounts of time spent in home-serving activities tend to increase total travel time and total frequency, but time spent outside of the home for other purposes does not.

There is a positive and reciprocal relationship between travel time and trip frequency, both in the aggregate and for each purpose. Travel time tends to be related to trip distance but tends not to be related to vehicle miles traveled by purpose. The positive relationship of trip time to density and the negative relationship to income indicate constraints of centrally located areas. The negative relationship between activity time and trip time by purpose indicates a time budget for the activity as a whole, and consequent tradeoff of travel time against activity time.

In contrast to travel time, travel frequency is positively related to activity time for out-of-home purposes. Travel distance is not traded off against frequency for out-of-home activity, and only for entertainment and visiting is travel time associated with frequency.

With respect to person miles traveled for out-of-home activities, the greater the amount of time spent in the activity, the farther the distance traveled to the activity. Only in the case of entertainment is there a tradeoff between frequency and distance traveled. The other relationships are consistent across purposes: travel time and income are positively related, and density is negatively related.

Fuel efficiency, measured as gallons per mile, averaged over each household's fleet of autos, is also estimated. The more vehicles the household owns the greater the average fuel economy, a larger number of young adults and residence within the Baltimore city limits also are associated with greater fuel efficiency. Average vehicle fuel efficiency tends to be lower for nonwhite households, households with large numbers of male adults and when the total miles traveled for household-owned vehicles is greater.

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F2. Theil, H. Principles of Econometrics. John Wiley & Sons, Inc. (1971).

F3. Charles River Associates. "Estimating the Impacts of Urban Travel Policies." Cambridge, Mass., April 1976.

APPENDIX G

SUMMARY OF FINDINGS FROM PHASE I

This Appendix reproduces the summary from the final report from Phase I, conducted by Fried, et al. (G1) of Boston College.

The main purpose of this project is to develop an approach to understanding travel behavior. The project was conceived on the assumption that a behaviorally valid travel theory was necessary for useful research and for current and future planning objectives. The travel theory developed is based on individual attributes (demographic, psychological, social) that interact with physical and social features of the environment to produce activity-travel behavior or changes in these behavior patterns.

Since the purpose and orientation of this study are different from most travel studies, its findings are understandably different. Three major types of product present these findings.

a. Extensive reviews of the literature and state of the art summaries were developed for several social science and travel behavior research areas (these papers are not part of this report but an overall summary is given in Appendix A and a list of papers is contained in Appendix B).

b. A dynamic, process-oriented theory was formulated which explains travel behavior as socially, psychologically, and economically constrained adaptations to discrepancies in person-environment fit. This theory synthesizes many elements of social science and travel theory but involves a modification and development of these elements (Chapter 2).

c. To place this "microtheory" of travel behavior in context, we developed a synthesis of the elements of theories of urban structure and change. This formulation integrates features of several social sciences and recent evidence to modify the traditional theory, mainly based on urban economics and geography, and points it toward an understanding of the impact on activity/travel adaptations.

In basic theoretical research, it is difficult to outline major findings but several assumptions and hypotheses from which the more detailed theory derives can be succinctly presented:

1. Travel behavior is viewed as integrally tied to the location of activities so that the two issues of travel and the activities it subserves are inseparable in theoretical development.

2. Individuals, alone and as members of households, are the decision-making units of activity/travel decisions and the determinants of their behavior must be considered before these can be meaningfully aggregated.

3. Traditional economic frameworks, even when extended to include factors other than purely economic interests and even when broadened beyond purely rational decision-making or learning approaches, are insufficient to account for (a) the diversity of influences operating on activity/travel behavior, and (b) the changes and adjustments in human behavior to cope with both changing environmental conditions and changing human needs.

4. A process of adaptation, involving changes in activity and travel patterns and adjustments over time, provides a useful theoretical

framework for understanding the travel behavior of individuals and populations; the motivating force behind these behaviors and changes is the effort to reduce imbalances that exist or develop between personal needs and environmental structures.

5. The stable points of reference in human social behavior affecting travel (and associated activities) are the role structures of individuals, particularly those involving work and occupation, household and family, extrafamilial interpersonal interaction, and leisure and recreation. The major influences on variations in role patterns are physical structure of the environment (including especially the distribution of transportation and activity options), sociocultural expectations, individual socioeconomic status, life cycle stages, and residential location.

6. Once individual and environmental factors are encapsulated within role patterns, there is less latitude for attitudes, orientations, and perceptions, or for small-scale or short-term changes in activity and travel options to influence the adaptational process. To the extent that they do, however, it is the entire travel-activity sequence that is evaluated and the totality is subject to change.

7. Discrepancies in person-environment fit invoke the adaptational process consisting of informed trial-and-error sequences of adjustment that continue until the discrepancies are resolved. The adaptation may be small in scale (changing attitudes, travel, or activity frequencies or location) or of a major type (changing total travel-activity patterns, residential relocation). Aggregated as population movements these may affect environmental structures but environmental structures readily assimilate these influences with only a modicum of change.

The single most important finding on this project is, thus, the development of a microtheory of adaptational change affecting the travel behavior of individuals. It serves several immediate functions:

a. It provides a theoretical framework for modeling travel behavior;

b. It establishes basic hypotheses for systematic, empirical research;

c. It provides a basis for behaviorally-informed policy development;

d. It formulates behavioral criteria relevant for policy assessment, and

e. It presents the framework within which further and more detailed analysis of travel issues may be developed.

BIBLIOGRAPHY TO APPENDIX G

G1. Fried, M.; Havens, J.; and Thall, M. "Travel Behavior: A Synthesized Theory: Final Report." Laboratory of Psychological Studies, Boston College, NCHRP 8-14 Final Report (1977). Chestnut Hill, Mass.

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