Title
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Publication Date
1981-10-01

UCI-ITS-AS-WP-81-4

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October 1981

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CHAINING BEHAVIOR IN URBAN TRIP MAKING: A CRITICAL REVIEW

1. Introduction

Although there exists a sizeable body of literature involving complex travel behavior most of this literature is of a highly fragmentary nature due to the lack of a comprehensive theoretical framework. Within the last decade transportation research has addressed such issues as activity time allocation (duration), destination choice, trip linkages, activity participation, activity scheduling, spatial/temporal constraints and the structure of multi-purpose travel but few studies have attempted to incorporate more than one or two of these concepts into a methodological framework. Similarly, a full range of models, from conceptual to empirical involving a wide range of techniques (e.g., Markov processes, Monte Carlo simulation, multiple regression analysis, utility maximization, etc.) have been employed with varying results. Although a descriptive review of all the existing literature would provide substantial background, a critical analysis of the most relevant sources serves as a better means to identify potential "building blocks" (i.e., variables, constraints, interactions, etc.) for use in the design and construction of a comprehensive theoretical framework. In general, three types of research were considered relevant to this study:

(1) studies that isolated critical variables and investigated their influence on individual's observed behavior

(2) studies that employed multivariate frameworks to examine the interactions between sets of variables, and

(3) studies that developed behavioral theories and empirically tested various theoretical constructs.

The hypotheses generated and the inferences drawn have been compared and contrasted so that both similarities and differences in the studies are revealed. To facilitate multiple comparisons between the various approaches, a literature taxonomy has also been constructed and is included in the appendix to this paper.[1]

2. Trip Linkage Analyses

Many of the early studies of complex travel behavior involved analyses of multiple-sojourn tours. Research into the intensity of linkages has focused on the frequency with which different land-use types, activity types and destinations (either zones or individual establishments) are combined into multiple-sojourn tours. Hanson and Marble (1971) tabulated activity type frequencies for both single- and multiple-sojourn tours to shed some light on the question of which activities are more likely to be included in multiple-, rather than single-sojourn tours. Wheeler (1972) explored the effect that spatial distribution of activities has on an individual's choice of multiple-sojourn travel linkages through the application of transaction flow analysis to an origin-destination flow matrix. The transaction flow model calculates the number of movements between locations i and j

[1] Components of the taxonomy include the following: (1) author, (2) date, (3) major theme, (4) underlying theory/hypotheses, (5) principal methodology, (6) major assumptions, (7) data sources, (8) sample size, (9) policy sensitivity and (10) primary results/conclusions.

that would be expected if each location j was an equally likely destination for movements originating at i and each location i was an equally likely origin for movements terminating at j. By comparing the actual number of observed movements to those generated by the model, Wheeler is not only able to identify the "dominant" flows (i.e., those flows that occur with greater frequency than expected) but also those locations that are most frequently linked to a specific destination, as origins and those locations that are most strongly linked to a given origin, as destinations. Results indicated that a large number of sojourns contained in multiple-sojourn tours were located in the principal business and commercial areas of the city but an even higher than expected proportion of sojourns were located in peripheral areas of the city. Wheeler suggests that it is here, at those locations farthest from the city center, that the advantages of trip linking are at their highest.

Another analytical tool often used in the early analyses of multiple-sojourn tours is factor analysis. This technique proved especially useful in outlining groups of origins with similar destination linkage patterns and groups of destinations with similar origin linkage patterns. Hanson and Marble (1971) identified land-use types with similar linkage configurations while Wheeler (1972) delineated zones with similar patterns of interaction. Although this technique is helpful in identifying sets of origins and destinations that are functionally interdependent, the model's emphasis on producing orthogonal factors (i.e., statistically independent groups) precludes it from identifying salient indirect linkages.

Markov models have been employed by many researchers in an attempt to identify both direct and indirect linkages. The essential feature of the Markov model is the transition probability matrix in which each element (p_{ij}) of the matrix represents the probability of moving from state i (e.g. location i, activity type i, etc.) to state j (e.g. location j, activity type j, etc.). It is through these transition probabilities that the relative strengths of the linkages are maintained. In addition to displaying the pattern of direct linkages, repeated powering of the matrix yields the pattern of indirect linkages. The mean first passage time (MFPT) is an index of the number of links an individual takes to move from state i to state j. The MFPT matrix, which incorporates both direct and indirect linkages, is a measure of the relative propensity of various states to link with one another. Hemmens (1966) used a Markov model in an investigation of household activity linkage and found that the likelihood of multiple-sojourn tours is directly related to household mobility (as measured by household income and automobile ownership) and residential location (as measured by distance from the CBD) and inversely related to household size. Hemmens also hypothesized that time of day exerts an influence on both choice of activity and duration; statistical tests (chi-square and analysis of variance) supported this hypothesis. Horton and Shuldiner (1967) determined the degree of "linkage" among various nonresidential land uses with the implicit assumption that this linkage strength was an index of the likelihood that multiple-sojourn tours will be made. Wheeler (1972) examined the linkages between activity types and found that (1) personal business activities were strongly linked with other personal business activities and shopping activities, (2) medical/dental activities were strongly linked with shopping activities and (3) work activities were strongly linked with social activities and shopping activities.

While the previous studies applied Markov models in the absence of any theoretical (behavioral) foundation, subsequent studies such as those performed by Gilbert et al. (1974) and Burnett (1978) sought to introduce behavioral concepts into the model. Gilbert et al. (1974) hypothesized that the amount of time an individual spends participating in an activity affects subsequent movements and they developed a semi-Markov model to account for this influence. Burnett (1978), in an attempt to shed some light on the confusion surrounding the relationships between cognition, choice and adaptation, investigated the potential of Markov models for yielding predictions about individuals' choice of successive destinations. Two types of behavioral hypotheses were tested. The first hypothesis assumed that, over time, individual decision makers adapt in such a way that they reach an equilibrium state characterized by habitual use of one destination for a specific activity (although different decision makers may use different destinations). The second hypothesis assumed that decision makers have a tendency to use their last destination for an activity but do fluctuate between alternative destinations over time. Statistical tests of the hypotheses resulted in the rejection of both models, thus indicating the inability of Markovian models to adequately represent individual travel behavior. Several explanations for this can be uncovered by a close examination of the model structure. First, the transition probabilities are empirically constructed from observed linkages by simply calculating the row percentages for each cell. This results in an aspatial/atemporal treatment of an inherently spatial/temporal phenomenon. Second, although the MFPT provides information about indirect linkages through the number of "time periods" it takes an individual to travel from one state i (location, activity type, etc.) to another state j, this measure of time is actually just the number of multiplications of the transition matrix. Third, and probably most important, is that the probability of transition from state i to state j is only dependent on location i--not on any locations visited prior to i. It is this lack of influence that travel history has on individual's current decisions that gives the model its "memoryless" nature. Although there are serious shortcomings associated with modeling multiple-sojourn tours via a Markovian framework, the use of such models have provided some insight into the relative strength of various linkages.

3. Simulation Models

Another group of early research efforts concentrated on the development and testing of various simulation models. Theories (or partial theories) were formulated as explanations of certain observable properties of multiple-sojourn tours (e.g., number of sojourns per tour, types of establishments visited, etc.) and simulation models based on the theoretical constructs were then developed to test the validity of the theory. Nystuen (1967) saw travel behavior as the complement of spatial location (i.e., travel behavior both determines and is determined by the spatial distribution of facilities) and attempted to develop a general theory that would incorporate this interdependency. Two assumptions were crucial to the development of the model:

(1) the location of a specific retail establishment relative to other establishments influences the individual's selection process, and

(2) home is a special location in the urban environment, the utility of which increases with time spent away from it.

A spatial association index of retail establishments was constructed along with a temporal probability function for tour continuance and these two components combined to form the simulation model. Given the first activity of the tour, the simulation model predicted whether the tour would terminate because of time and if not, where the next trip would go. The model resulted in an overestimation of total trips due to an overestimation of multiple-sojourn tours (at the expense of single-sojourn tours) but these results could probably be improved with the addition of activity duration into the model structure. Another stochastic model of multiple-sojourn tours was developed by Ginn (1969) with the aid of dynamic programming techniques. He assumed that the probability of making a link between two locations i and j, given that an arrival at location i took place on the previous link, was a function of (1) the utility of location j, (2) the transportation "cost" (both temporal and monetary) of travel between locations i and j and (3) the expected cumulative utility and cost for all the other links on the tour beginning at location j. Due to the complexity of the phenomenon being modeled, Ginn did not seek true optimization in his model. Instead, probabilistic tour paths and expected frequencies of multiple-sojourn tours were estimated together with the expected cumulative utility and cost of the multiple-sojourn tours. Despite only limited empirical testing on hypothetical spatial arrangements, Ginn's recognition of the interdependent nature of individual's travel decisions and his operationalization of this concept (through a dynamic "look-ahead" mechanism) is significant.

Another investigation into the relationship between retail location and consumer movement was conducted by Mackay (1971). He viewed individuals as "discriminating" between various establishments when making their decisions and modeled this "discrimination" as a sequential three-stage process involving the decisions (1) whether or not a shopping tour should be made at a particular time period, (2) how many establishments should be visited during the tour, and (3) which establishment type should be visited on each stop in the tour. Information concerning the household's composition, accessibility to retail establishments, attitudes about the "attractiveness" of retail establishments and general shopping habits (e.g., frequency, size of purchases, etc.) was used in the construction of discriminant (choice) functions and the individual choices were simulated by sampling the posterior probabilities of the discriminant functions with the aid of a Monte Carlo sampling procedure. Several consumer movement heuristics (e.g. total tour distance minimization, sequential trip distance minimization, etc.) were used to model the individual's final decision regarding the specific establishment to visit on each trip. Although discrepancies between simulated and observed multiple-sojourn shopping tours existed at the individual level, the simulated distributions of shopping tours by number of sojourns, day of the week, distance traveled and establishment types are significantly close to the actual distributions.

Vidakovic (1974), in an attempt to model the relationship between the frequency of multiple-sojourn tours and tour length (i.e., number of sojourns), developed a harmonic series model. Statistical tests on the distribution of tours by number of sojourns failed to indicate any significant difference between the expected and observed distributions at the .05 level. In addition, Vidakovic (1977) also developed models of the relationships between tour length and the number of different activities combined on a given tour, the mixture of travel modes on a given tour and the distance traveled between activities. More important than the actual results are Vidakovic's recognition of the interrelationships that exist between individual's time-space decisions and his initial attempts to develop a methodological framework capable of analyzing all decisions as an integrated whole.

Westelius (1973) distinguished between activities that are fixed in time and space (e.g., work, school) and activities that are substitutable (i.e., activities that can occur at various times and locations) and with this dichotomy placed individual travel behavior into a "needs accumulation" context. The fundamental tenet of this approach is that individuals accumulate a desire (or need) to travel over time and travel does not take place until the need surpasses some minimum "threshold." Within this framework, multiple-sojourn tours occur as a result of one of two situations:

(1) multiple travel needs exceeding the corresponding need thresholds at exactly the same time, or

(2) one travel need exceeding the need threshold, causing a trip to be made and then other thresholds being lowered below the current levels of need as a result of the original trip.

The individual need variables (although quite possibly related to the socioeconomic characteristics of the individual and/or household) were estimated heuristically with the aid of an iterative procedure. An initial set of values was specified for the need variables and input to the simulation model. Upon completion of the simulation, a comparison was made between the simulated and observed multiple-sojourn tours and the parameters were then adjusted prior to the next simulation. Results of the simulation showed that as the distance between the individual's home and the nearest retail center increases so does the mean number of sojourns per tour and the proportion of sojourns at substitutable activity locations made in connection with fixed activities. The substitutable activity locations visited in tours involving fixed activities are in close proximity to the fixed activity locations, indicating the effect that relative location has on destination choice.

Almost all of the previous simulation models have been constructed under the general assumption of non-optimal behavior on the part of the individual. One notable exception to this is the optimization model developed by Kobayashi (1976). Created as a mathematical extension of the theoretical framework advanced by Chapin,[2] this model helped to relate the "latent mechanism" of travel patterns to the travel environment (as characterized by the transportation and activity systems). More specifically, serial queues were used to represent the transportation and activity systems and the maximum number of trips attainable by an individual in a given time period was estimated as a function of the amount of time required for travel and activity participation. A cost-effectiveness function was also developed based on both the maximum number of attainable trips and simple benefit-cost ratios for each individual trip.[3] The optimal travel pattern was then determined by maximizing the cost-effectiveness function subject to the constraint of total available time. Although the model was not tested on any real data, several hypothetical case studies were used to conduct a preliminary investigation of the model validity and, in general, the model produced realistic results.

Bentley, et al. (1977) acknowledged the multitude of factors that influence individual travel behavior and, as a result of the complexity

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[2] Chapin's activity framework viewed trip motivation as arising from two sets of needs--fundamental and supplemental. An urban activity was defined as an interaction between human behavior and the environment and was seen as an evolutionary process of motivation-choice-activity in which both fundamental and supplemental needs are optimized (Chapin, 1968).

[3] The benefit per unit time of an activity was not defined but instead it was assumed to be linearly proportional to the activity duration.

at the disaggregate level, chose to model the distribution of return trips to home by stage in the tour. The two parameters of the distribution were estimated by comparing the observed distribution with the expected distribution and minimizing the chi-squared statistic. Although the authors offer possible behavioral interpretations of the parameters,[4] in actuality, they represent nothing more than the "best fitting" aggregate distribution of the observed number of multiple-sojourn tours. The authors do, however, present some supportive evidence that an analysis of tour continuation is a more appropriate analysis framework for urban travel behavior than an analysis of individual trips. Another attempt at modeling aggregate behavior was made by Burnett (1977). Using the widely acknowledged concept of distance decay (both with respect to information and destination usage) as a basis, Burnett hypothesized that the spatial distribution of the origins of all users of a specific destination could be described by a circular normal probability density function. Despite individuals' increasing levels of information over time, it was also hypothesized that the total amount of information obtained by individuals during a given time period would always decline with distance from the destination (i.e., circular normal probability density functions can be "fit" to data obtained over successive time periods, however, the parameters of the

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[4] The first parameter was seen as a measure of the proportion of initial trips that have the "potential to continue forward" (i.e., the potential to be linked with at least one additional trip in the same tour) while the second was interpreted as the proportion of the trips with the potential to continue that are actually continued forward to the next stage.

distributions will vary with time). Goodness-of-fit tests showed that there were no statistically significant differences between the observed and estimated distributions, thus lending support not only to the original hypothesis but also to the further development of dynamic models of destination choice.

4. Spatial-Temporal Constraints

While all of the works cited previously recognize the complex nature of individual movement, it was the pioneering work of Hagerstrand and his University of Lund colleages that first provided a comprehensive and unified paradigm for the analysis of complex travel behavior. In his approach to understanding human behavior, an individual's choice of a specific activity "pattern" is viewed as being the solution to an allocation problem in which the individual is simultaneously allocating limited resources of time and space to achieve some higher "quality of life." Hagerstrand approaches the problem of understanding individual behavior by analyzing the constraints imposed on an individual to determine how they limit possible behavior alternatives. This view from "outside" represents a break from the more traditional "inside" viewpoint, in which individual behavior is described via observed actions. The constraints defined by Hagerstrand can be classified into one of three categories: capability, coupling or authority. Capability constraints are present due to the physical and physiological needs of the individual. Authority constraints manifest themselves whenever an individual is required to fulfill some obligation before participating in a particular action. Coupling constraints refer to items such as transportation technology, locational pattern of facilities and operating policies, which interact to determine where, when and how long an individual undertakes an activity.

The means of illustration utilized by Hagerstrand was that of the three-dimensional space-time model, in which geographical space is represented by a two-dimensional plane and time is defined on the remaining, vertical, axis. The use of this representation allows definition of an individual's activity pattern in terms of a "path" through time and space. The location of activity sites, or "stations," together with the maximum speed an individual can travel in a given direction establishes the individuals's space-time "prism." The area (or volume) inside this prism represents the full range of possible locations at which an individual can participate (i.e. his/her physical "reach") or conversely, the outside depicts the entire set of locations that are inaccessible at any time. Once an individual travels to a specific location inside his/her "prism," the potential action space that remains for any subsequent activities will be reduced in size depending on the activity duration; hence, at no time is the individual able to visit the entire set of locations contained in the prism. In addition, the delineation of the reachable activity area is highly dependent on the mode of travel used because of the variation in travel speed across the different modes. Although this emphasis on potential rather than actual alternatives does not reveal explicitly the intrinsic character of the individual's choice mechanism, it does promote an understanding of the manner in which various types of constraints operate to restrict choice. Using these theoretical constructs, traditional atemporal home-based measures of accessibility can be replaced with measures that reflect the individual's accessibility with respect to current location in both time and space. Consequently, an individual's accessibility to opportunities may, for example, be different if he/she is at work at 4:00 p.m. instead of at home at 12:00 p.m.

A host of other researchers have attempted to expand and refine the original theoretical foundation built by Hagerstrand. Cullen and Godson (1975) viewed individual's lives as "containing highly organized episodes which give structure and pattern to the whole stream of behavior" and outlined a set of propositions which served as the basic framework for the analysis of the individual's activity/time /space decision process. The propositions focused on relationships between individual priorities, levels of activity commitment, flexibility of activities, number of participants and activity sequencing; it was felt that these "subjective" dimensions give rise to the highly organized episodes that act as "pegs" in the individual's scheduling process. A variety of statistical techniques (e.g. discriminant analysis, factor analysis, time series analysis, etc.) were used to investigate the validity of the proposed relationships and the following general conclusions were reached:

(1) Despite the lack of any direct constraints on sleeping, waking and eating, individuals tend to adhere to fairly rigid daily cycles for these activities.

(2) Work activities, routine non-work activities and activities arranged with other people are the most rigidly constrained in

time and space and are also assigned the highest priorities by individuals. Consequently, these activities are the most important "structuring" episodes in the individual's day.

(3) Activities constrained in space are more common than those constrained in time, but the temporal constraint is a much stronger "structuring" influence than the spatial constraint.

Stephens (1975) also postulated that the "level of activity commitment" is a crucial determinant of the individual's activity sequence in time-space and defined "level of commitment" in terms of an individual's perception regarding the degree to which an activity could be carried out at different locations and times. Using this definition, he constructed an activity flexibility measure which ranged from unexpected and unplanned to prearranged and routine. These subjective measures were combined with objective constraints imposed by the individual's environment and hypotheses concerning individual's space-time behavior were tested via simulation. Probability distributions (frequency of activity occurrence and duration by constraint, location, linkage and distance) were constructed as approximations of activity pattern structure and using the "level of commitment" to determine the most fixed activity (or "peg"), a Monte Carlo procedure was employed to select activities, locations and durations which could be "fit" into a sequence centered around the peg. The simulation predicted the activity sequences in the neighborhood of fixed activities reasonably well, but was unable to reproduce those sequences involving activities of low commitment (i.e., high flexibility).

Tomlinson et al. (1973) utilized an aggregate approach in their simulation of complex travel behavior. Instead of focusing on the individual, they chose to model the distribution of individuals (students) in different activities and locations throughout the day. Prior to the construction of the model, two basic assumptions were made regarding the aggregate behavior of the individuals. First, it was assumed that the amount of time spent in various activities (i.e. the time budget) remains constant for a particular socioeconomic group although it was allowed to vary across different groups. Second, it was assumed that the behavior of individuals is subject to a number of spatial and temporal constraints that determine the times and/or locations of activities. With these two assumptions, the problem of modeling complex travel behavior was seen as a problem of determining the most probable distribution of individuals over activities in time and space subject to the constraints that: (1) the proportion of time spent in different activities by the population groups must equal the observed time budgets and (2) activity availability restrictions cannot be violated. This distribution was obtained with the aid of a simulation model that incorporated both the theory of entropy maximation (used to generate the number of individuals engaged in a particular activity at a particular time) and the theory of distance decay (used to allocate the individuals to various activity locations). Although no attempt was made within the framework of the model to identify the sequence of activity and locational choices made by an individual, it was possible to examine the sensitivity of flows of people to various spatial and temporal distributions of activities and different levels of activity fixity. In general, the simulated distributions were reasonably close to those actually observed; however, additional improvements could be made by: (1) removing the assumption that the distribution of individuals to activities at each time period is independent of preceeding distributions, (2) including additional factors in the submodel that distributes individuals to locations and (3) incorporating group time preferences with respect to activity participation.

Lenntorp (1976) also extended Hagerstrand's approach by developing a model that calculated the total number of space-time paths an individual could follow given a specific activity program (i.e., a set of desired activities and durations) and the urban "environment" (as defined by the transportation network and the spatial/temporal distribution of activities). Lenntorp's PESASP (Program Evaluating the Set of Alternative Sample Paths) model is especially noteworthy since it represented the first attempt to operationalize the theoretical framework advanced by Hagerstrand in a manner that would allow meaningful policy evaluation. One policy-oriented application of the model involved a sample of individuals from the city of Karlstad, Sweden (Lenntorp, 1976b). A set of feasible space-time paths was generated for each member of the sample under existing conditions and then compared to alternative sets of paths obtained by changing various public transit service characteristics (e.g., service frequency, travel speed, route configuration, etc.), repeating the simulation. Although Lenntorp's model yielded information about the effect of service changes on an individual's range of potential actions, it was unable to provide any information on the individual's most probable responses to the changes. This inability to predict individual reaction to change illustrates the major disadvantage of the model--a lack of any behavioral foundation. Despite this emphasis on potential rather than actual alternatives, Lenntorp's approach does offer an understanding of how spatial and temporal constraints interact to restrict individual choice.

Constraints on individual behavior were also investigated by Burns (1978) through a methodological study of accessibility. In this study, Burns viewed accessibility as the freedom of individuals to participate in different activities and, with the aid of the space-time "prism" (which served as a diagrammatic representation of accessibility), investigated the dependence of accessibility on its transportation, temporal and spatial components. In addition, accessibility benefit measures were constructed based on different assumptions about how individuals value the opportunities available to them. These were used to analyze and compare the accessibility implications of a variety of transportation, temporal and spatial strategies. Two important results were obtained from this study:

(1) To produce equivalent marginal accessibility benefits, the percentage change in the individual's travel speed must be greater than that associated with the amount of time between fixed activities, and

(2) the less constrained an individual's freedom in space and time, the greater the attractiveness of a strategy that relaxes the

time constraints confronted to a strategy that increases the speed of travel.

Based on these results, Burns concluded that temporal strategies (i.e., those strategies that relax the time constraints of individuals) have the potential to provide substantially greater increases in accessibility than velocity strategies.

The concept of space-time constraints and their effect on an individual's freedom of choice was also considered by Landau et al. (1980) in their study of shopping destination choice modeling. Recognizing that shopping activities are not performed in isolation from other activities, they developed a model to calculate the maximum amount of time an individual could spend at a retail establishment based on the following set of constraints: (1) the obligatory activities (i.e., work or school) contained in the individual's activity program, (2) the spatial distribution of retail establishments, (3) the temporal distribution of retail establishments and (4) the transportation system. Any stores that could not be reached by an individual were eliminated from the choice set. A demonstration of the model showed that the inclusion of spatial/temporal constraints in the destination choice set specification process yields improvements in destination choice prediction accuracy and facilitates the evaluation of temporal strategies (i.e., those strategies aimed at increasing the amount of time available to individuals for shopping). More important was the incorporation of activity program constraints into measures of individual accessibility. Results indicated that the accessibility of certain population sub-groups (i.e., workers, students) to shopping destinations is much lower than the accessibility of other groups as a result of the additional constraints imposed on them by obligatory activities (e.g. work or school). Finally, although the current model deals only with shopping activities, the methodological framework is flexible enough to permit extensions to other activities.[5]

In acknowledgement that spatial/temporal constraints exert influence across many dimensions (not just destination choice), Landau et al (1981) also developed a trip generation model system that was sensitive to these constraints. Based on the assumption that household generation results from a two-stage, sequential decision process, the following models were developed:

(1) a household trip purpose (HTP) model that estimated the probability of a household making a trip for a particular purpose, and

(2) a household travel time period (HTTP) model that estimated the conditional probability that a trip for a particular purpose would be executed at a particular time period.

Since the latter model estimated only the probability of <u>any household member</u> executing a trip for a specific purpose at a particular

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[5] One possible extension discussed by the authors involved a sequential procedure. It was assumed that activities could be classified according to priority (primary, secondary, tertiary, etc.) and the choice set for the primary activity would be constructed as previously. The specific choice of the primary activity would then impose additional constraints on the set of potential locations for the secondary activity. The location of the secondary activity would then be predicted, taking these new constraints into account.

time, an alternate model that estimated the probability of a specific household member executing a trip (HMTTP model) was also developed. The activities executed by households (i.e., the reasons for travel) were classified into three groups (subsistence, maintenance and leisure) based on their degree of temporal flexibility and separate models were estimated for maintenance and leisure activities.[6] Results of the estimations showed that:

(1) the explanatory power of temporal constraints was more significant in the HMTTP model than in the HTTP model,

(2) temporal constraints were only significant in the models of leisure trips, and

(3) there was a significant influence on the HMTTP model due to the interaction variables (i.e., those variables which represented the activities of other household memebers).

Based on these results, the following behavioral implications were advanced by the authors:

(1) The individual, not the household, is the appropriate behavioral unit,

(2) maintenance trips, due to their essential nature, are usually performed at regular intervals and, once this interval is decided, the household will perform these trips regardless of any temporal constraints imposed on it, and

(3) an individual's decision to travel during a specific time period is influenced by both the amount of time available in different

[6] No models were estimated for subsistence activities since they were assumed to occur on a daily basis at fixed locations and times.

periods throughout the day and the activities performed by other household members.

Another study involving spatio-temporal constraints focused on the feasibility of various ridesharing strategies. Davis, et al. (1981), hypothesized the existence of a high potential for ridesharing (as a result of the inherent flexibility contained in individuals' activity patterns) and developed a methodology to investigate this potential. Various scenarios were constructed based on different assumptions about auto availability, fuel availability, the number of individuals per vehicle and the hours of operation of the ridesharing program. These assumptions were input to a simulation model to obtain estimates of the number of individuals who could utilize a ridesharing program. Although a simple maximum route deviation constraint was the only criterion used in the determination of whether or not an individual could utilize a ridesharing program, the examination of ridesharing for both work and non-work travel is significant.

5. Utility Maximization

Another sizeable collection of complex travel behavior research efforts can be categorized as multivariate in scope. Borrowing heavily from the fields of operations research and econometrics, researchers have employed various methodologies, such as utility maximization, to develop models that explain how a set of "causal factors" affect individual behavior. A major emphasis of these models is the mathematical representation of the actual decision making process undertaken by the individual when evaluating alternative courses of action. Upon completion of the estimation of these models, many authors investigated the impacts of changes in the transportation system, the activity system and the household.

In his thesis, Bain (1976) focused on activity duration (plus associated travel time) as the dependent variable and used the theoretical econometric approach of Tobin[7] to model the individual's two-fold choice of whether or not to participate and for how long. Although Bain included a variable "in-home activity supply" to account for the individual's trade-off between staying at home and traveling to non-home activities, he failed to account for the interdependence between activity durations and therefore was unable to explain particular activity sequences. Despite this shortcoming, Bain's work provided a foundation for subsequent research efforts. Jacobson (1978) extended the work of Bain with his investigation of the "simultaneity in intrahousehold task sharing." A simultaneous equation model was estimated and compared to single equation models for both the household head and spouse to test explicitly the hypothesis concerning joint allocation of activity time. Empirical results illustrated the need for additional research in the development of a behavioral theory that "recognizes the substitutability and complementarity of the household heads' activity time."

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[7] Tobin, James (1958). "Estimation for Relationships for Limited Dependent Variables," Econometrica, Vol. 26, pp. 24-36.

Horowitz (1976) utilized an ordinary least squares regression model to examine hypotheses about the effects of auto travel time and operating costs on the frequency of non-work travel and the demand for multi-destination tours. Statistical tests revealed that only travel time had a significant effect on non-work auto travel frequency. In addition, reductions in travel frequency resulting from travel time increases were not compensated by increases in the average number of destinations visited per tour. Unfortunately, the hypothesis that increases in travel time cause reductions in trip length was not examined. In a second study, Horowitz (1978) developed a utility maximizing model for non-work travel demand that related tour frequency, sojourn frequency and destination choice to household characteristics, destination characteristics and transportation level of service. Horowitz hypothesized that households consider both post travel decisions and future travel plans when making current travel decisions due to limited travel resources (e.g., time, money, automobiles) and his incorporation of this concept into the model structure is significant. Model estimations showed that increases in household size and automobile ownership lead to increases in sojourn frequency. The average number of sojourns per tour was not, however, dependent on transportation level of service variables and this was due to the failure to include travel times and costs between non-work destinations in the model structure. In another study, Horowitz (1980) utilized a system of disaggregate travel demand models to estimate urban traveler responses to various gasoline allocation procedures. The allocation procedures considered were:

(1) allocation by traditional rationing, (2) allocation by white-market coupons and (3) allocation by price increase (i.e., allowing the price to rise to a market clearing level). A wide range of potential responses was examined, including changes in mode, destinations, travel frequency, multi-destination tours and the price of gasoline. The results showed that reductions in non-work trip frequencies and trip lengths were the main sources of gasoline savings, irrespective of allocation procedure. Reductions in travel were considerably larger for low-income households than for high-income households when price-based allocation methods were used, while the distribution of effects is reversed in the case of non-price-based methods of allocation. Multi-destination travel increased only in the case of traditional rationing but this may have been due, in part, to the independent estimation of the work and non-work travel demand models which precluded any estimations of the potential for combining work and non-work travel. Sensitivity tests were also performed due to the age of the data set (1968 Washington, D.C. Household Interview Survey) and the indications were that the qualitative characteristics of travelers' responses to gasoline shortages were not highly sensitive to moderate changes in the travel environment.

Oster (1978a, 1978b) hypothesized that a principal incentive for visiting a non-work destination during a workplace-related trip (i.e., either a trip from home to work, a trip from work to home, or a tour that originates and terminates at the workplace) is to obtain a savings in the time and cost of travel, thereby lowering the total cost of the goods and services acquired via travel. Two alternate methods were used to obtain estimates of these savings. The first method (the fixed destination assumption) assumed that the household would have made a separate single destination trip to to the same destination for the same purpose. This alternative represents the situation where the destination offers a highly specialized service (or product) of high value to the household and serves as an upper bound for the travel savings. The second method (the average destination assumption) assumed that a different destination would be visited for the same purpose via a single destination trip. This corresponds to the case where substitute services (or goods) are available at many locations in an urban area. Since the substitutability of activities varies across individuals and no information on this was available, the single destination trip used to visit this alternate destination was assumed to be equal to the average travel time and distance for all single destination trips made for the same purpose by households living in the same census tract. Results indicated that savings in travel resources on the order of 15% and 22% are obtained under the fixed and average destination assumptions. Oster also utilized ordinary least squares regression in an analysis of the relationships between the characteristics of household members and their use of workplace-related travel and found that the presence of a second worker in the household decreases the total number of non-work destinations visited but increases the number of non-work destinations visited via workplace-related travel.

Lerman (1979) synthesized two different analysis methodologies, utility maximization and semi-Markov processes, to develop an operational, stochastic simulation model of non-work travel behavior. In this approach, probability distributions of dwell time at home and non-home locations were used to determine the departure times of the trips and multinomial logit models were estimated to predict the individual's joint choice of mode and destination.[8] (The actual simulation process consisted of alternating applications of the two methodologies throughout the day.) A lack of available data resulted in only limited testing of the model system. However, several theoretical shortcomings can be identified. First, the individual's choice of departure time was assumed to be independent of any spatial effects (e.g., transportation level of service) or travel history (e.g., number of activity locations previously visited). Second, it was assumed that individuals choose their next mode/destination combination only after completion of their current activity. This rather myopic type of behavior precludes factors such as relative location from exerting an influence on individuals' choices. Finally, no consideration was given to the determinants of activity sequencing and therefore it was unclear how individuals decide the order in which they perform activities.

Most of the prior research, although recognizing the complicated nature of individual's travel behavior, chose to simplify the problem by

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7 Lerman estimated two distributions of departure time from home (one for the first departure and one for all subsequent departures) in recognition of the fact that the observed distribution of first departures from home is significantly different from the distributions of succeeding departures. In addition, two multinomial logit models were estimated (a home based model and a non-home based model) so that home was only considered as a potential destination when the individual was at a non-home location.

either ignoring one or more dimensions of choice (e.g., mode, destination, departure time, tour length, etc.) or assuming independence among the various dimensions. One of the first attempts to model the full complexity of individual travel behavior (i.e., to explicitly incorporate the interdependent nature of the individual's choices) was made by Adler (1976). The basic underlying hypothesis of Adler's theoretical model is that households develop needs for non-home activities and make trade-offs between the desire to meet each need as it arises and the transportation expenditures required for travel. Households were assumed to choose a complete daily travel pattern based on its attractiveness (or utility) relative to other possible travel patterns. This attractiveness was expressed as a function of the attributes of the destinations selected for non-work activities, the total time spent performing non-home activities, the remaining household income after travel expenses and the households' socioeconomic characteristics. In addition, a variable--"scheduling convenience"--was developed to measure the "degree to which a travel pattern fits the schedule of household activities." Scheduling convenience was divided into two main components: (1) the allocation of household activities among activity sites (as measured by the total number of sojourns contained in the pattern) and (2) the allocation of sojourns among tours (as measured by the number of sojourns per tour). This latter component allowed Adler to incorporate explictly the households' trade-offs between single and multiple sojourn travel. The effects of a variety of transportation policies on an aggregate sample were predicted using an empirical model (a multinomial logit model) developed in accordance with the theory and the forecasts indicated that the average number of sojourns per tour decreased from the base value for each of the policies tested. This resulted from either an increase in the number of tours (in the case of travel incentive policies) or a decrease in the number of sojourns (in the case of travel disincentive policies). For transit-oriented policies, shifts in the use of multiple-sojourn tours were not significant enough to result in major changes in the relative proportion of home and non-home based trip links. In the case of the auto-oriented policies, however, the number of non-home based links decreased at a substantially higher rate than home-based trip links. Although Adler's use of individual travel patterns as the primary unit of travel demand is significant, several questions were left unanswered:

(1) How many alternative daily travel patterns does a household consider when making its decision?

(2) How does the temporal distribution of activities affect "scheduling convenience"?

(3) How does household interaction affect the choice of travel pattern?

6. Fully Integrated Pattern Approaches

The need to examine the entire collection of choices made by an individual was also recognized by Recker et al. (1980) in their empirical analysis of household activity patterns. In this study, an analysis framework was developed whereby the impacts of various transportation policies on individual's current daily behavior (i.e., activity patterns) could be quantitatively assessed. Individual activity patterns were transformed using pattern recognition techniques (a Walsh-Hadamard[9] transformation) and the resulting pattern coefficients were cluster analyzed using a k-means clustering algorithm. The pattern centroids were then inverted using associated inversion formulae to produce representative activity patterns which depicted the mean response pattern of all the individuals associated with a particular group. These representative activity patterns can be thought of as distinct market segments, in which all the members of a specific segment exhibit similar travel/activity behavior (i.e., choice of activities, activity time allocations, sequencing of activities, etc.) Upon completion of the classification phase, multiple discriminant analysis was used to determine the relative influence of various household and urban form characteristics on the representative activity patterns. Results based on a sample of 665 individuals in Orange County, California showed that the activity patterns of the sample population could be classified into nine representative patterns. In addition, it was found that employment status, role in the household, residential housing density and employment density were the dimensions that best discriminated the representative patterns. To illustrate the advantage of activity pattern analysis over conventional trip-oriented methodologies with respect to policy impact estimation, various daily restrictions on total vehicle miles traveled

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[9] Welchel, J.E. and D.F. Guinn (1968). "The Fast Fourier-Hadamard Transform and Its Use in Signal Representation and Classification," EASCON 1968 Record, pp. 561-573.

and gasoline purchases were imposed on the sample and tabulations of the total number of people unable to execute their observed activity patterns were performed. The effectiveness of trip-chaining in counteracting the travel restrictions was also assessed via simulation. In the first simulation, a "chained" activity pattern was constructed by: (1) removing intermediate trips to and from home and (2) linking successive non-home activities. This procedure was carried out subject to the following constraints:

(1) The original non-home activity locations were fixed, and

(2) The original temporal sequence of the non-home activities was fixed.

The second simulation relaxed the constraint regarding original temporal sequence but imposed additional constraints on the timing of certain non-home activities. Results showed that a larger number of individuals were able to execute their activity pattern under travel restrictions by trip chaining and rearranging their activity sequence than simply by trip chaining. In addition, it was demonstrated that the impacts of travel restraint and the benefits of trip chaining and activity re-sequencing are not uniform across the population.

A second attempt at identifying general categories of urban travel behavior and the salient characteristics that give rise to this behavior was undertaken by Pas (1981). Although the entire activity pattern was chosen as the basic analysis unit, the methodologies employed to classify the behavior were quite different from those of Recker et al.

In the first step of the approach, Pas developed an index to measure the degree of similarity between pairs of activity patterns and used this to construct a similarity matrix. This similarity matrix was then transformed, using the method of principal coordinates,[10] into a set of coordinates in Euclidean space. Finally, Ward's clustering algorithm[11] was used to group those patterns that were closest to each other in the Euclidean space (i.e., those patterns that were most similar). In addition, an investigation into the relationships between various demographic variables (e.g., age, marital status, employment status) and the activity pattern types was performed with the aid of the likelihood ratio chi-squared statistic. The empirical results indicated that a population's activity/travel behavior could be grouped into a small number (6-12) of categories without a significant loss in information and that certain demographic characteristics such as sex and number of children under twelve years of age influence the group membership. These results are similar to those obtained by Recker et al. despite the use of two different sets of analysis techniques.

Another research effort directed at developing an adequate framework for the analysis of complex travel behavior was undertaken by Kitamura et al. (1980). Unlike the two studies mentioned previously that considered the quantification and categorization of entire patterns of human behavior, this study sought to develop a set of fundamental properties

[10] Gower, J.C. (1966). "Some Distance Properties of Latent Root and Vector Methods Used in Multivariate Analysis," Biometrika, Vol. 53, pp. 325-338.

[11] Ward, Jr., J.H. (1963). "Hierarchical Grouping to Optimize an Ojective Function," Journal of American Statistics Association, Vol. 58, No. 301, pp. 236-244.

concerning individual's spatio-temporal behavior (as depicted by various characteristics of their space-time paths). It was postulated that these properties, once empirically tested, would then serve as an appropriate foundation for the construction of a comprehensive theoretical framework. A simple stochastic-process model integrating the concepts of the space-time prism and the intervening opportunities approach to trip distribution was used to explore some of the basic relationships between tour size (i.e., number of sojourns), sojourn duration, sojourn location and time of day. Statistical tests resulted in the verification of the following set of spatio-temporal properties:

(1) The probability of returning home (i.e., completing a tour) is an increasing function of both time and distance from home.

(2) The average sojourn duration decreases as the number of sojourns in the tour increases.

(3) The average trip length to sojourn locations decreases as the number of sojourns in the tour increases.

(4) The number of tours performed by an individual increases with the number of available autos and the number of children in the household.

There are several important behavioral implications associated with these spatio-temporal properties. First, the dependence of the spatial distribution of sojourn locations on the number of sojourns, the interrelationship between sojourn duration and the number of sojourns and the interrelationships between tour continuance, time of day and distance from home <u>all</u> imply that the time-homogeneity and history-independence assumptions contained in the Markovian approach are inappropriate for the analysis of individual travel behavior. Second, the negative correlations between the number of sojourns and both the average sojourn duration and the average trip length suggest trade-offs between competing objectives--a feature that could be incorporated in a mathematical model of the individual decision process. Third, the strong correlation between the number of tours and the composition of the household (i.e., the number and ages of children in the household) indicates that the presence of children in the household place additional demands and constraints on the other family members which often results in a larger number of tours. This last hypothesis illustrates the need to include the effect of inter-personal household linkages in the theoretical framework.

7. Activity-based Approaches

Although it has been widely acknowledged that travel is a "derived demand," it is only recently that there has been a shift in research emphasis from trip-based analysis frameworks to activity-based analysis frameworks. A pioneer in the area of activity-based approaches to complex travel behavior has been the Transport Studies Unit (TSU) in Oxford, England. Using the information obtained via in-depth interviews, the researchers at TSU developed a theoretical framework that placed individual travel behavior within the context of household activity scheduling behavior. More specifically, individual travel patterns were seen as resulting from a complex household interaction process which occurs as a consequence of both the interdependent nature of household members' activity schedules and the presence of environmental constraints. Jones (1977) and his TSU colleagues attempted to gain some insight regarding the household interaction process with the aid of their Household Activity Travel Simulator (HATS). This interactive gaming device involves the use of visual display equipment in an in-depth, group interview situation. Each household member is first asked to construct his/her current activity schedule by placing a series of different colored blocks on a time line that represented the twenty-four hour day. The length of each block is proportional to the duration of the activity which it represents and a separate color is used for each different activity type (including travel). After being informed of a specific policy change, the household members are then asked to rearrange their activity schedules. In addition to the information on the specific adaptations made by the individual household members (as provided by the "new" activity schedules), the interviewer is also able to obtain information about the actual household interaction process (e.g., priorities, preferences, etc.). Results from actual applications of HATS in West Oxfordshire (school hour revisions) and Basildon (alterations in bus service) indicate that the reallocation of activities among household members often takes place after changes are made in the transportation or activity system. Althogh this technique is extremely useful in small scale exploratory studies, it is clearly inappropriate for large scale studies involving a wide range of policy options.

Several researchers have attempted to incorporate the TSU framework into mathematical models of activity scheduling behavior. Damm (1979) chose to view activity scheduling behavior as a series of non-home activity participation decisions. Following the recommendations of Jones (1977) and Heggie (1977),[12] Damm divided the twenty-four hour day into five time periods: (1) the time prior to the trip to work, (2) the time during the trip from home to work, (3) the time at work, (4) the time during the trip from work to home and (5) the time after the trip to home. The individual was assumed to choose between participating or not participating in a non-home activity during each of the five time periods. A decision not to participate was seen as an implicit decision to maintain one's current location (during time periods 1, 3 and 5) or travel destination (during time periods 2 and 4). It was also assumed that the individual's choice regarding length of participation in non-home activities was conditional on his/her choice of whether or not to participate and therefore a separate model was estimated for activity duration. Embodied in this framework is a recognition that certain in-home activities are discretionary in nature and therefore, compete with out-of-home activites for a "place" in the individual's activity schedule. This competition was incorporated in the model with the introduction of a variable representing the time allocated to discretionary activities in time periods other than that being evaluated. Estimation of the models revealed that the variable, "time spent in other periods," was significant (i.e., interrelationships exist

[12] Both Jones and Heggie agree that the twenty-four hour day should not be treated as a continuous block of time but instead should be divided into a progression of discrete time periods to better understand the interdependence of an individual's time/space decisions.

among the various temporal and spatial decisions made by an individual throughout the day) although its effect was not uniform across all time periods (i.e., certain time periods are planned more separately than others). The effects of socioeconomic variables were also not uniform across the time periods as individuals were influenced more by household characteristics in time periods involving the home (periods 1 and 5) than those involving the work site (periods 2, 3 and 4). Two variables that served as surrogate measures of the effect of household competition for automobiles (i.e., workers per auto in period 1 and auto accessibility for non-workers in periods 2, 3 and 4) also proved significant, indicating the interdependence that exists among individual household members. In spite of the compromises made during the construction of various proxy variables, Damm's efforts have provided much insight not only into the relative influence of various factors but also into the interrelationships among these factors. Several issues, however, were not addressed in the methodology, including:

(1) How can the choices of mode and destination be integrated into the model framework?

(2) How does an individual decide on a particular non-home activity sequence during a given time period?

(3) What are the time periods associated with non-working individuals?

Van der Hoorn (1981) also modeled individual travel behavior as a subset of the total activity pattern using a disaggregate model/simulation system. Multinomial logit models, developed for both the choice of activity and location, were incorporated in a simulation system that generated the individual's activity pattern. The simulation system was similar to the one developed by Tomlinson et al. (1973), with the exception that the fixed "apriori probabilities" used by Tomlinson et al. were replaced by those estimated from the logit models. Since the simulation system addressed aggregate behavior, the logit models were aggregated using a three-stage process. First, the population was classified into 21 subgroups based on car ownership and urbanization levels. Second, the average values of the explanatory variables were calculated and included in the logit models. Third, the average subgroup choice probabilities generated in the second step were weighted by the proportion of the subgroup contained in the total population to yield total aggreage shares. Although Van der Hoorn's model, like that developed earlier by Damm, explicitly accounts for the trade-offs between staying at home and traveling to non-home destinations, only two non-home locations (in town and outside town) were included in the model. In addition, mean travel times were employed in the model under the assumption that they were representative of the travel by any individual in a particular subgroup. Finally, all locations with travel times greater than their corresponding durations were eliminated from the individual's choice set, which resulted in the exclusion of several observed choices.

In general, much of the recent research has provided insight into the degree of choice available to individuals (or households) when making their decisions. Unfortunately, almost all of the research also suffers from the same limitation--an inability to provide any information on the specific set of alternatives (i.e., the choice set) considered by an individual during the decision process. Although many authors have speculated that the number of alternatives actually considered by an individual is much less than the total number of potential alternatives, they have as yet been unable to systematically incorporate this premise into a theoretical framework. An exception to this is the work of Clarke and Dix (1980). As a preliminary step in the development of a mathematical model of choice set formulation, a combinatorial algorithm (CARLA[13]) was used to generate all the feasible permutations of a given set of activities (i.e., alternative activity schedules). In recognition of the need to maximize computational efficiency, constraints on the timing of activities were introduced into the model prior to the generation of the permutations. These constraints consist of two basic types:

(1) supply side constraints (e.g., stores are only open during certain hours) and

(2) institutional constraints (e.g., meal times can only be shifted by 45 minutes either way).

The input required by the model included a list of the activities to be scheduled, their corresponding durations, and the temporal constraints. The output of the model consisted of all the "feasible" permutations of the activities (i.e., all those permutations that did not violate the

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[13] Combinatorial Algorithm for Rescheduling Lists of Activities

constraints). Activity data obtained from a study of school hours changes in Burford, England (both "before" and "after" data) was used to test the model and the results showed that in 65% of the cases, the chosen activity schedule was generated as one of the alternatives in the choice set. Although the authors point to the need for further development of the model (e.g., the incorporation of inter-personal linkages, destination choice, changes in activities), preliminary results have demonstrated the feasibility of using a combinatorial approach to the choice set problem.

8. Research Directions

Despite the myriad of behavioral hypotheses presented throughout this review, it has been possible to identify three basic concepts which hold particular promise for the development of a comprehensive theory of complex travel behavior. The first of these concepts involves the role of travel in individual daily life. It has become widely acknowledged that the demand for travel is derived from the need to participate in various activities at specific locations and, therefore, individuals' travel choices should be viewed as arising from a more fundamental set of activity participation choices. The second concept concerns the environment in which activity participation decisions are made. Choices regarding activity participation are not unlimited, but are instead subject to a variety of constraints such as the spatial/temporal distribution of activity locations, the spatial/temporal obligations of the individual (e.g., the need for employed individuals to spend a fixed amount of time at a fixed location), and the transportation modes available for use by the individual. Much of the prior research that has focused exclusively on observed choice has been unable to explain the more "complex" aspects of travel behavior (e.g., trip chaining) due to an inability to distinguish between those choices that are available to an individual and those that are not. An explicit recognition of the manner by which various constraints act to limit the choices available to an individual will not only eliminate infeasible courses of action from consideration but also allow a much wider range of policies (e.g., flextime, changes in the operating hours of service facilities, ridesharing) to be analyzed. A third concept (and one that is closely associated with the second) relates to the interdependent nature of individual's activity participation decisions. At any point in time, an individual's current decision is influenced both by previous actions as well as by future intentions, and all of these are influenced by the decisions of other household members. These interdependencies result from:

(1) Individuals can only be at one location at any given time.

(2) Individuals can only change their location by consuming time (and this is a limited quantity).

(3) Different activity locations are not available at all times and at all locations.

(4) Certain activities require the participation of more than one individual (household member).

As a result of these interdependencies, there exists a need to analyze the entire set of individual activity participation decisions as a whole, instead of analyzing each individual decision in isolation from the others.

In addition to identifying several concepts that should serve as the basic foundation for the development of a comprehensive theoretical framework, the review of the literature has also revealed several "key" issues that must be addressed during the operationalization of the theoretical framework:

(1) choice set specification

(2) household interaction

(3) trade-offs among competing objectives

Although spatial/temporal constraints help to delineate the set of potential alternatives available to the individual (i.e., the opportunity set) they fail to identify those alternatives actually considered by the individual (i.e., the choice set) when making his/her decision. Many authors have speculated that the choice set is much smaller than the opportunity set as a result of the individual's lack of complete knowledge and his/her limited ability to process information and make decisions. However, this concept has not yet been incorporated in any mathematical model. Another concept that has not yet been incorporated explicitly into a mathematical model of complex travel behavior involves household interaction. Previous investigations into the effects of household interaction on individual travel behavior have been limited to statistical analyses of several variables (e.g., number of workers per household, number of children per household, number of automobiles per household, etc.) which serve as proxies for the actual set of interactions among household members and, therefore, have been unable to provide any information about how changes in the daily behavior of one individual affects the other members of the same household. Finally, although many researchers have indicated that individual's activity participation decisions are suboptimal as a result of trade-offs among competing objectives (e.g., the trade-off between in-home and non-home activity time), most mathematical models contain only one objective (e.g., utility maximization) and therefore, assume strict optimizing behavior on the part of the individual. Consequently, there is a need to employ a methodology that recognizes explicitly the existence of a multiplicity of conflicting objectives and provides information concerning the individual's resolution of these conflicts.

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APPENDIX

LITERATURE TAXONOMY

AUTHOR(S) (DATE)	MAJOR THEME	UNDERLYING THEORY/HYPOTHESES	PRINCIPAL METHODOLOGY	MAJOR ASSUMPTIONS
Adler, Thomas J. and Moshe E. Ben-Akiva (1979)	Trip Chaining	Travel arises from a household choice process in which the alternatives that are considered are complete daily travel patterns	Utility maximization with a multinomial logit model	The utility to a household from a given travel pattern is a function of net non-home activity duration, remaining income after travel expenses, attributes of the activity sites, socioeconomic characteristics and scheduling convenience. The household's choice set is a random subset of the travel patterns of all surveyed households in the same traffic district.
Ben-Akiva, Moshe E., Len Sherman and Brian Kullman (1978)	Non-Home Based Travel	Trip makers at non-home locations are faced with the choice of returning home or traveling to another non-home location. If a traveler chooses the latter, he/she must then decide between alternative destinations.	Utility maximization with a joint choice logit model	Each traveler's decision is independent of any previous decisions. Separate models are estimated for auto and transit trips (i.e., mode choice is not included with the other choices)
Bentley, Gillian, Alex Bruce and David Jones (1977)	Intra-urban Journeys and Activity Linkages	No underlying theory was presented. The purpose of the study was to provide information on the number of journeys made in a week, the activities undertaken on each day and the activity linkages that occur within journeys.	A frequency distribution of return trips to home by stage of journey is estimated. The parameters of the distribution were chosen so as to minimize χ^2	None
Burnett, K. Patricia (1976)	Development of Dynamic Models of Travel Behavior and Traveller Origins	Spatial form (as observed in the point patterns of the origins of travelers to a destination) is related to spatial processes (as characterized by the individual's process of learning about destinations and his/her changing use of them).	A circular normal probability density function is estimated for the distribution of traveller origin points about a destination. A linear learning model is estimated for the probability of selecting a destination during the next time period.	The population surrounding the destination of even density and the individuals at each distance are identical. There are no biases in accessibility. The length of time before an individual chooses a particular destination is determined by: (1) the probability of an individual having an initial contact with the destination on his/her first trip, (2) the nature of his/her learning experience during succeeding trips for the activity, and its feedback effects on the initial destination choice probability.

DATA SOURCES	SAMPLE	POLICY SENSITIVITY	PRIMARY RESULTS/CONCLUSIONS
1968 Washington, D.C. Household Interview Survey	1003 households	Gasoline price, transit in-vehicle time, transit-out-of-vehicle time transit fares (including free transit), limitation on daily non-work auto vehicle miles traveled.	Households travel pattern decisions should be modeled as interdependent choices. The use of multiple-sojourn tours for non-work travel is affected by transportation service levels. The degree to which a given travel pattern meets the substance and the temporal location of a household's needs and the expenditures required for satisfying those needs constitute the travel pattern's utility.
1968 Metropolitan Transportation Commission Household Interview Survey	11,249 individual trips	None	The non-home based models are sensitive to transportation level of service and destination (zone) attractiveness. The models could be improved by further disaggregation of purpose, inclusion of mode choice and time of day.
1969 Watford, England Travel Diaries (one week)	1672 individuals	None	Some evidence is presented for the viewpoint that analysis of journey continuation is more appropriate for studying urban travel patterns than is analysis of individual trips.
1968-1972 Austin, Texas Savings and Loan Branch Customers	3033 trip origins	None	Individual decision mechanisms during learning produce changing destination choice probabilities over time which are ignored in current static models.
1971 Uppsala, Sweden Travel Diaries (five weeks)	Individual trip sequences	None	Future research is needed to develop a learning process that explains the changing point patterns of user origins around multiple destinations. The linear learning model fails to explain the behavior of those individuals who do not display increasing patronage of a destination for an activity.

AUTHOR(S) (DATE)	MAJOR THEME	UNDERLYING THEORY/HYPOTHESES	PRINCIPAL METHODOLOGY	MAJOR ASSUMPTIONS
Burnett, K. Patricia (1978)	Individual Movement Within Urban Spatial Structures	Urban travel is an "adaptive" process in which decision makers search out and learn destinations for different activities. Decision maker's next choice of destination is influenced only by the last.	First-order Markov Process	"Place loyal" assumption--one place is habitually used by each decision maker for any activity "Last place loyal" assumption--individuals tend to visit their last destination for an activity but fluctuate between alternatives over time.
Burns, Lawrence D. (1979)	Transportation, Temporal and Spatial Components of Accessibility	Accessibility is viewed as the freedom of individuals to participate in different activities. The primary focus is on constraints which limit this freedom and on strategies that relax these constraints. The constraints that exist are incorporated in the transportation, temporal and spatial components of accessibility.	The implications of various transportation, temporal and spatial strategies are examined in the context of a diagrammatical representation of human activity that captures the spatial and temporal characteristics of behavioral constraints. Accessibility measures are constructed based on different assumptions to analytically analyze and compare implications of different strategies.	Individuals value their ability to reach locations relative to the activities available at these locations and the amount of time they spend there. The results of various strategies are compared with respect to their effect on the space-time autonomy represented by a single space-time prism.
Cullen, Ian and Vida Godson (1975)	The Structure of Activity Patterns	No underlying theory was presented but instead propositions concerning priorities, constraints, spatial and temporal flexibility of activities and scheduling were introduced as a broad framework within which the aspects of individual's activity patterns were examined.	OLS Regression Factor analysis Discriminant analysis Time series generation Transition probability analysis	Individual behavior is seen as containing highly organized episodes which give structure and pattern to the whole stream of behavior. The issues of optimizing, or satisficing, rational, boundedly rational or irrational behavior are sidestepped by the assumption that behavior varies in the extent to which it is any of these things at different times of the day and in different sequences of events.

DATA SOURCES	SAMPLE	POLICY SENSITIVITY	PRIMARY RESULTS/CONCLUSIONS
1971 Uppsala, Sweden Travel Diaries (five weeks)	Individual trip sequences (sequence length is equal to three	None	Markov models implying adaptive behavior with stationary transition matrices do not capture the adaptive properties of movement within urban spatial structures.
None	Not applicable	Travel velocity, temporal constraints on activities, transportation network geometry, spatial distribution of activities	The speed that an individual can travel must always be changed by a greater percent than the amount of time he has available to produce the same marginal accessibility benefit as the corresponding time increase. The less constrained an individual's freedom in space and time, the greater the attractiveness of a strategy that relaxes the time constraints he confronts relative to a strategy that increases the speed he can travel.
1974 Bedford College, London Travel Diaries (one day)	336 individuals (academic staff and students)	None	Focusing attention upon the structuring importance of organized episodes appears justified. Activities that were arranged with other people and routine activities were the most rigidly constrained in time and space. Activities constrained in space were more common than those constrained in time but spatial constraint did not result in activities acting as "structuring" episodes about which the day was organized as was the case with temporal constraint. The degree of flexibility available to the individual is inversely related to the degree of activity commitment which, in turn, is closely related to whether or not the activity was arranged with others, planned alone, routine or just passively allowed to happen.

AUTHOR(S) (DATE)	MAJOR THEME	UNDERLYING THEORY/HYPOTHESES	PRINCIPAL METHODOLOGY	MAJOR ASSUMPTIONS
Damm, David (1979)	Activity Scheduling in Time and Space	Travel demand is derived from the need to participate in non-home activities. It is therefore hypothesized that people associate a particular level of fixity with each activity in which they participate. The degree to which an activity can be shifted in time and/or space varies and the extent of that variation affects how the activity will be scheduled. Individuals evaluate the utility associated with participation in a non-obligatory activity and that associated with non-participation (either staying at the current obligatory activity or not deviating from the path between obligatory activities) when scheduling their activities.	Econometric models: Probit model (activity participation) Regression model (activity duration)	An individual's day is divided into five time periods with respect to the fixed activities--home and work. Decisions in the various time periods are interdependent. The amount of discretionary time available to an individual in each time period is a function of socioeconomic characteristics of both the individual and the household.
Davis, Christian F., William H. Groff and Thomas E. Steahr (1981)	Temporal and Spatial Flexibility of Activity Patterns and the Potential for Ridesharing	There currently exists a high potential for ridesharing (for both work activities and non-work activities) as a result of the excess capacity of the private automobile and the inherent flexibility of individual's activity patterns. It is futher hypothesized that travel patterns can be adapted to the transportation system and that this adaptation can take place within the constraints established by the pattern of daily activities.	A simulation model is developed to estimate the number of individuals who could utilize a ridesharing program. A series of "scenarios" that are defined by a set of assumptions concerning simulation time period, participation rate, auto and fuel availability and operational characteristics serve as input to the simulation model.	Participation in ridesharing is only limited on the basis of the route deviation constraint--temporal constraints are not incorporated.
Ginn, James Royce (1969)	Multi-purpose Tours in Urban Travel Behavior	Tripmaking is viewed as a stochastic process in which the probability of making a link between two locations given that an arrival at one location took place on the previous link is a function of the utility of the other location, the cost of travel between the two locations and the expected cumulative utility and cost for all other links on the tour.	Dynamic Programming	True optimization is not sought in the stochastic process. Individuals consider future travel behavior when making their current travel decisions. The probability of trip linking is not influenced by temporal constraints.

DATA SOURCES	SAMPLE	POLICY SENSITIVITY	PRIMARY RESULTS/CONCLUSIONS
1970 Minneapolis-St. Paul Household Interview Survey	2345 individuals (full-time workers)	Household income, auto ownership levels, changes in working hours	There appear to be three categories of causal factors with respect to activity scheduling behavior: needs/activity program, temporal constraints and spatial constraints. No socio-economic variable was statistically significant in all time periods--individuals were influenced more by household factors in periods having "home" as the reference point (Periods 1 and 5) than in periods with work as the reference point. Activity participation and duration decisions in different time periods are interdependent. Interaction between household members also has an effect on activity decisions. Specific types of activities should be isolated and analyzed in the general framework.
1979 Windham, Connecticut Planning Region Household Interview Survey	600 households	Maximum allowable route deviation, participation rate, occupancy rate	There exists a significant unused people-moving capacity in the highway/automobile system in the area studied. Significant reductions in VMT were shown to be possible even with the crude matching algorithm.
Hypothetical land use patterns	Not applicable	Spatial distribution of opportunities	The model results in a higher level of multi-purpose tours than is revealed in actual data, thus indicating the need for additional constraints.

AUTHOR(S) (DATE)	MAJOR THEME	UNDERLYING THEORY/HYPOTHESES	PRINCIPAL METHODOLOGY	MAJOR ASSUMPTIONS
Hanson, Susan E. (1980)	The Importance of the Multi-Purpose Journey to work in Urban Travel Behavior	The journey to work (a frequent multiple-purpose trip) plays a major organizational role in the household's overall travel pattern.	Transaction Flow model Principal Components analysis	None
Hemmens, George C. (1970)	Simulation and Analysis of Urban Activity Patterns	There exists a long run interaction between the wants/needs of individuals (as expressed in their activity choices) and the opportunities available to them in the urban environment. Since activity patterns are carried out in connection with both the land use system and the transportation system, by focusing attention on the activity patterns themselves one can better understand the interaction between these two systems.	Markov process (with ^{2} and ANOVA tests for determining whether the transition probabilities are independent of time)	Choice of activity is influenced by the time of day, the duration of the activity and the spatial distribution of activity sites.
Horowitz, Joel (1976)	The Effect of Travel Time and Cost on the Frequency and Structure of Automobile Travel	The frequency of non-work auto tours by households without access to transit is a decreasing function of time and cost. Households without access to transit for non-work travel tend to compensate for increases in time and cost by (1) increasing the number of destinations in non-work tours, (2) visiting non-work destinations while traveling between home and work and (3) visiting non-work destinations during work-based tours. Changes in travel time and cost result in changes in the frequencies of auto visits to (1) shop destinations and (2) non-shop, non-work destinations by households that do not have access to transit for non-work travel.	OLS Regression	The travel time is the average travel time from home to the non-work destinations visited by the households located in the traffic district. The travel cost is the average cost of operating an automobile between home and the non-work destinations visited by the households located in the traffic district.

DATA SOURCES	SAMPLE	POLICY SENSITIVITY	PRIMARY RESULTS/CONCLUSIONS
1971 Uppsala, Sweden Travel Diaries (five weeks)	92 households	None	Many stops of a non-obligatory nature are combined with the journey to work and therefore, this journey holds implications for mode choice as well as for the level of transactions in several types of retail establishments.
1962 Buffalo, New York Household Interview Survey	16,000 households	None	To understand the spatial structure and functioning of an urban area one must focus on the activity patterns of people. A higher incidence of multiple activity journeys seems to occur in households characterized by high levels of auto availability, suburban location and small family size.
1968 Washington, D.C. Area Transportation Survey	15,600 households	None	Results are consistent with the hypothesis that travel time can have a substantial effect on the frequency of non-work auto travel by households lacking access to transit. Auto operating costs do not have a statistically significant association with any of the travel frequency variables. Reductions in non-work travel frequency associated with increases in travel time appear not to be compensated by increases in the average number of non-work destinations visited per auto tour. Rather, the frequency of auto driver visits to non-work destinations is reduced. Changes in auto operating costs have no effect on the average number of non-work destinations visited per tour.

AUTHOR(S) (DATE)	MAJOR THEME	UNDERLYING THEORY/HYPOTHESES	PRINCIPAL METHODOLOGY	MAJOR ASSUMPTIONS
Horowitz, Joel (1978)	Nonwork Travel Demand	Household's choice of tour frequency and destination is sensitive to household characteristics and transportation level-of-service. Households have limited travel resources (e.g., time, money, autos) and as a result, consider both past travel decisions and future travel needs when making current travel decisions.	Utility maximization with a hybrid discrete choice/ stochastic process model Three stage estimation procedure: (1) maximum likelihood (2) nonlinear regression (3) OLS regression	Households are the basic decision-making units. Automobile is the only mode available for non-work travel. Tours that originate or terminate at work are ignored. The sequence of sojourns within tours is not considered. Variables characterizing the travel times and costs associated with trips between non-work destinations are not included.
Horowitz, Joel (1981)	Traveler Response to Gasoline Allocation Strategies	Different procedures for allocating gasoline will have different effects on gasoline consumption, price, travel frequency, choice of multi-destinational travel and choice of mode.	Utility maximization with two travel demand models: (1) multinomial logit model (work trip mode choice) (2) hybrid discrete choice/ stochastic process model (non-work travel demand)	In estimating non-work travel, each household was randomly assigned a non-work destination choice set. When a household's gasoline supply is constrained, gasoline consumption and monetary expenditures for work travel and non-work travel are perceived and evaluated in a similar manner. Gasoline shortages cause percentage reductions in weekend gasoline consumption that are equal to the percentage reductions in weekday gasoline consumption for non-work travel.
Jacobson, Jesse (1978)	Non-work Activity Duration	Activity patterns (not travel) are the basic unit of demand and result from a two-stage choice process involving: (1) choice of activity duration (2) choice of travel pattern (conditional on activity duration)	Simultaneous equations (limited dependent variable)	Accessibility is used to describe the characteristics of the individual's travel pattern for a given activity. Individual's choice of destination and mode alternatives vary with the activity performed, therefore to compute the accessibility for a particular activity, different models of destination and mode choice are estimated for different activity types. Destination choice sets are randomly determined.
Jones, Peter M., Martin C. Dix, Michael I. Clarke and Ian G. Heggie (1980)	Activity-Based Approach to Understanding Travel Behavior	No underlying theory was presented at the outset. The main objective of this study was to obtain a better understanding of household travel behavior and to develop an analytical and modeling capability that would enable the knowledge to be applied in transportation planning.	Cross-tabulations of trip "circuits" (i.e., tours) Multivariate Discriminant Analyis Cluster Analysis Household Activity Travel Simulator (HATS) Combinatorial Algorithm for Rescheduling Activities (CARLA) Demographic Simulation Model	An activity-based framework (i.e., travel is viewed within the context of activities) is a more appropriate analysis framework than a trip-based framework. The household is the basic decision making unit. Individuals place an importance on synchronizing time spent at home for family activities and therefore linkages between household members and temporal constraints are as important as spatial constraints.

DATA SOURCES	SAMPLE	POLICY SENSITIVITY	PRIMARY RESULTS/CONCLUSIONS
1968 Washington, D.C. Area Transportation Survey	890 households	None	The hypothesis that households consider both past travel decisions and future travel plans when making current travel decisions is confirmed. Increases in household size and auto ownership lead to increases in tour and sojourn frequency. The effect of income, however, depends on household characteristics.
1968 Washington, D.C. Area Transportation Survey		Travel time, auto ownership, household income, auto fuel economy	The disaggregate demand modeling framework has been estended by including gasoline allocation via white market coupons and traditional rationing in the forecasts of traveler responses to gasoline shortages. Multi-destination travel has also been incorporated. Sensitivity tests indicate that when price-based allocation methods are used, the effective market clearing price of gasoline is highly sensitive to the travel environment.
1970 Minneapolis-St. Paul Household Interview Survey	1431 individuals	In-vehicle travel time, out-of-vehicle time, out-of-pocket cost, possession of driver's licenses	Non-work activity programs are sensitive, at least in the short run, to the level of service of the transportation system. Decreases in the work duration do not increase significantly the duration of weekday non-work activities. Some evidence exists that estimation of models of activity duration for different population groups would yield coefficient estimates that are significantly different from those estimated on a full cross-section of the population.
1976 Banbury, England Household Interview Surveys (one week)	196 households	Changes in work hours, school hours, shopping hours, activity durations, transportation level of service	Individual's travel behavior arises from the process of scheduling a set of activities within a particular time period. Activity scheduling decisions are made within the constraints of the space-time environment and the constraints imposed by household interaction. The use of stage in family lifecycle as a classification variable accounts for major differences in household's travel behavior. Stage in family lifecycle has dynamic properties that can be used to simulate demographic and behavioral changes in a population over time.

AUTHOR(S) (DATE)	MAJOR THEME	UNDERLYING THEORY/HYPOTHESES	PRINCIPAL METHODOLOGY	MAJOR ASSUMPTIONS
Kitamura, Ryuchi, Lidia P. Kostyniuk and Michael J. Uyeno (1980)	Basic Properties of Urban Time-space Paths	No underlying theory was presented but instead several macroscopically observable properties of urban time-space paths were used to construct hypotheses regarding individual's travel/activity behavior. These hypothses were then statistically tested on an empirical data set.	An abstract model integrating the concepts of space/time prisms, trip linkages and the intervening opportunities approach to trip distribution is used as a tool for extracting spatio-temporal properties of time-space paths. Weighted least squares regression and logit multiple classification analysis is used to test the hypotheses.	The study area is represented as a linear city (i.e., people's movement is one dimensional). Opportunities are homogeneously distributed in the linear city with a constant density. Speed of travel is invariant regardless of time and location. Activity decisions are made sequentially. Mode choice is not considered. Only non-work activities are considered.
Kobayashi, Kenzo (1976)	An Activity-Based Demand Model	Travel patterns are a function of the time required for travel and the time spent participating in activities.	A serial queueing model is used to estimate the number of trips attainable by an individual within his/her available time. A cost-effectiveness function is then maximized to obtain the optimal visiting rate.	The service times for the activity system and transportation system queueing stages are exponentially distributed. All queueing stages are independent. The effect of making a trip to a particular activity increases with increasing time spent at the activity. Socioeconomic factors do not influence travel patterns.
Landau, Uzi, Josepn Prasnker, Bernard Alpern and Moshe Ben-Akiva (1980)	Destination Choice Set Modeling	Constraints on an individual's freedom to move through space and time affect the individual's selection of shopping location. Compulsory activities (i.e., work and school) may make it impossible for an individual to reach a particular location while it is open. Activity program constraints influence the amount of time that an individual is willing to budget for shopping, which in turn determines the set of locations he/she can reach.	An algorithm was developed to calculate the maximum amount of time an individual could spend at each shopping location. This was calculated based on constraints placed on the individual by his/her activity pattern (the fixed activity portion) and exogenous factors such as store locations, travel times, store hours and shopping duration. All locations that cannot be reached by the individual are eliminated from the choice set.	Any retail location that can be reached by an individual is included in his/her choice set (i.e., no minimum shopping duration is incorporated in the model). Mode choice is not dealt with explicitly in the model. Non-workers have no temporal constraints imposed on them by their activity program.

DATA SOURCES	SAMPLE	POLICY SENSITIVITY	PRIMARY RESULTS/CONCLUSIONS
1965 Detroit Area Transportation and Land Use Study (TALUS)	1806 individuals (without work trips)	None	The probability of returning home is an increasing function of the time when and the location where the transition occurs. The average sojourn duration is dependent on the number of sojourns in the tour. The spatial distribution of the sojourn locations is dependent on the number of sojourns. A strong correlation exists between the number of tours and lifecycle status.
Hypothetical	Not applicable	Travel time, activity duration	The activity-based queueing model is a representation of the activity selection schema which states that trip motivation is derived from two sets of needs--fundamental and supplemental. The total number of visits serves as an index of satisfaction level of supplemental needs and the cost-effectiveness of each trip serves as an index of satisfaction level of fundamental needs.
1972/73 Tel-Aviv, Israel Housenold Interview Survey.	8841 individuals	Changes in work hours, school hours, shopping hours, activity durations, transportation level of service	Restricting choice sets via spatial/temporal constraints can improve the prediction accuracy of already existing shopping destination choice models. Choice set definitions can be used to develop improved measures of accessibility that are sensitive to temporal constraints and strategies directed towards increasing the amount of time available to individuals.

AUTHOR(S) (DATE)	MAJOR THEME	UNDERLYING THEORY/HYPOTHESES	PRINCIPAL METHODOLOGY	MAJOR ASSUMPTIONS
Landau, Uzi, Josepn Prasnker and Michael Hirsh (1980)	Trip Generation Models and Temporal Constraints	An individual's decision to travel for a particular purpose depends not only on the characteristics of the specific activity involved, but also on the characteristics of his/her entire daily activity pattern. Temporal constraints influence household decisions regarding whether or not to travel, what time to travel and for what (non-work) purposes.	Linear probability models were estimated via OLS regression	A sequential choice process is assumed where at the first stage the household decides whether or not to perform a trip for a specific purpose during the day and in the second stage a decision is made as to what period. Two models are estimated for the second stage decision--the first estimating the probability of any member of the household making a trip during a particular time period and the second estimating the probability of a specific household member making a trip during a particular time period.
Lenntorp, Bo (1976)	Individual Movement Possibilities in Space-Time Environments	Movements by an individual over time can be represented by a continuous path which reveals the interdependence between events with respect to time and space. The locations an individual can visit are limited by both temporal and spatial constraints, in addition, to the restrictions imposed by the specific activities contained in the individual's activity program.	A combinatorial simulation model (PESASP) was developed to calculate the total number of potential space-time paths that an individual could follow in the execution of a particular activity program.	The simulation model is used to study the situation of an individual in an environment that does not include any other individuals (i.e., household interaction is ignored).
Lerman, Steve R. (1979)	Trip Chaining	Non-work travel is substantially more complex than travel to work due to a large degree of substitutability between alternative non-work destinations, alternative times and the higher sensitivity of non-work trip frequency to transportation level of service.	Utility maximization with a multinomial logit model (joint choice of mode and destination) Semi-Markov Process (choice of first departure from home, subsequent departures from home and departures from non-home locations)	The individual's home is treated as a special state. One home state is the initial location of the individual and the second set of home states are defined as the return trips to home. The dwell time distributions are independent of destination and mode choice.
MacKay, David B. (1971)	Consumer Movement Patterns	Shopping travel is viewed as the result of three interrelated decisions: (1) the decision whether or not to shop (2) the decision of how many stops to make (3) the decision of which stores to visit These decisions are influenced by household characteristics, store characteristics, individual's perception of store characteristics and past shopping decisions.	A sequential three-stage dynamic discriminant analysis.	Different consumer movement heuristics are tested in the model. These include: (1) single stop distance minimization, (2) sequential distance minimization, (3) total distance minimization and (4) total distance minimization (for short (trips) and sequential minimization (for long trips).

DATA SOURCES	SAMPLE	POLICY SENSITIVITY	PRIMARY RESULTS/CONCLUSIONS
1972/73 Tel Aviv, Israel Household Interview Survey	732 households	None	The explanatory power of temporal constraints is more significant in the models representing choice of time period for individual household members than in the models representing the behavior of the household as a whole. This indicates that the appropriate behavioral unit is the individual not the household. Temporal constraints were significant in the leisure trip models (e.g. social-recreacion, entertainment, etc.) but not significant in the maintenance trip models (e.g. shopping, personal business). A simultaneous equation model may yield even more promising results.
1967 Stockholm, Sweden Telepnone Survey	202 individuals (each individual had visited both his/her workplace and at least one food store)	Public transit network (travel times, routes, frequency), spatial distribution of activity sites	The simulation model generated the observed sequence in 90% of the cases. The set of alternatives generated by allowing the activity sequence to vary is twice as large as the set generated under the restriction of fixed sequence and four times as large as the set generated under the restriction that the sequence had to contain food stores of the same size as the observed stores. Auto users have three times as many alternatives as public transport users.
1969 Rochester, New York Household Interview Survey	Individuals	None	Sample enumeration and Monte Carlo simulation of individual trip patterns appears feasible for problems of reasonable size. The assumption of time homogeneity with respect to transition probabilities requires additional testing.
1970 Tinley Park, Illinois Shopping Trip Survey	2114 individuals	None	The incidence of multi-stop shopping is higher for those families that have a higher degree of mobility and live further from retail centers. The distance traveled between the consumer's home and the retail center is greater on multi-stop shopping trips than on single-stop shopping trips. The ratio of multi-stop to single stop shoppers is higher for small purchases than it is for large purchases.

AUTHOR(S) (DATE)	MAJOR THEME	UNDERLYING THEORY/HYPOTHESES	PRINCIPAL METHODOLOGY	MAJOR ASSUMPTIONS
Nystuen, John D. (1967)	Simulation of Intraurban Travel	Travel behavior is the complement of spatial location, that is travel behavior is in part determined by the arrangement of facilities and in part determines that arrangement. Optimal travel behavior for a trip will involve multiple-purpose shopping whenever there exists at least one center containing all the trip purposes demanded, if the center is at a distance less than the sum of the distances to sources of the demand at different locations.	A spatial association index of store types is constructed along with a temporal probability function of returning home and both are used in a stochastic simulation model to predict what kinds of and how many visits will be made on a tour, given the first purpose of the tour.	Demands for travel vary in a random manner over short time periods. The attraction of each location depends on current utility to the customer and the relative position of the customer at each moment in a given time period. Home is a special location, the utility of which increases with time spent away from it. Choice of locations on a tour depends on the probable maximum net return for the entire tour, and this return is re-evaluated after each visit.
Oster, Clinton V. (1973)	Multiple Destination Travel	One of the principal incentives for multiple destination travel is to obtain a savings in the time and money cost of travel, thereby lowering the total costs of the goods and services obtained via travel.	OLS Regression Trip Frequency Model	The savings in travel resources gained from multiple destination tours is estimated using two alternative methods. The first alternative assumes that the household would have made a separate single destination tour to the same destination. The second alternative assumes that a different destination is visited via a single destination tour. The length of the tour (i.e., travel time and distance) is assumed to be the average travel time and distance for all single destination tours made for the same purpose by other households living in the same census tract.
Pas, Eric I. (1981)	Analysis of Daily Urban Activity Patterns	The activity pattern is considered the appropriate unit of analysis due to the interdependence of travel and activity behavior. It is hypothesized that general categories of urban travel behavior exist and can be identified by analyzing empirical data.	A similarity matrix is constructed in which the elements are measures of the similarity between pairs of activity patterns. Principle coordinates analysis and Ward's clustering algorithm are applied to the similarity matrix to group similar patterns. Linear logit models are used to analyze the relationships between activity pattern types and socio-demographic characteristics.	The similarity index is composed of two attributes; activity and time of day, with the activity dimension considered twice as important as the time dimension. Activity sequence is not considered explicitly in the similarity index.

DATA SOURCES	SAMPLE	POLICY SENSITIVITY	PRIMARY RESULTS/CONCLUSIONS
1960 Cedar Rapids, Iowa	143 individual	None	The degree of correspondence between actual and simulated travel patterns lends support to the belief that spatial arrangement may be used to predict individual movement. Recognition of the functional hierarchy of centers may eliminate some of the excessively high linkages predicted by the model.
1971 Fresno-Clovis, California Household Interview Survey	1620 households	Household size, number of workers per household, auto availability	The variation of household members' use of workplace related tours with differences in household characteristics suggests that, as the demographic characteristics of the population change, the aggregate travel patterns of the population will change also.
1977 Baltimore, Maryland Household Interview Survey	236 individuals	None	Daily activity patterns can be classified into a relatively small number of groups without the loss of an undue amount of information. Group membership can be explained by particular socio-demographic characteristics of the individuals undertaking the patterns.

AUTHOR(S) (DATE)	MAJOR THEME	UNDERLYING THEORY/HYPOTHESES	PRINCIPAL METHODOLOGY	MAJOR ASSUMPTIONS
Recker, Wilfred W., Gregory S. Root, Michael G. McNally, Michael J. Cirrincione and Harry J. Schuler (1980)	Analysis of Individual Daily Activity Patterns	Activity patterns are used as the basic unit of travel demand under the hypothesis that trip making can be better understood when trips and activities are linked into sets of tours and analyzed as a collection of individual actions and interactions. With this framework travel behavior is defined on the basis of knowing how individuals allocate time and sequence activities.	Walsh-Hadamard Transformation Cluster Analysis Multiple Discriminant Analysis Trip Chaining Simulation Model	Activity type and distance from home were the salient dimensions used to classify the activity patterns. All in-home activities were assumed to be temporally flexible in the resequencing phase of the trip chaining simulation model.
Stephens, John D. (1976)	Daily Activity Sequences and Time-Space Constraints	Time-space constraints and levels of activity commitment are the critical determinants of activity sequences in time-space.	Monte Carlo simulation	"Level of activity commitment" was defined in terms of an individual's judgment about the extent to which an activity could be performed at different times and/or different places. Individuals were grouped according to their allocation of time to various activities and their observed activity sequence to distinguish those people with highly structured pattern from those with loosely structured patterns.
Swidersky, Detlef (1981)	Simulation of Spatially and Temporally Coordinated Activity Sequences	Activity sequences and travel patterns are the result of the interaction between spatially and temporally coordinated activity sequences. Individual choice is influenced by subjective knowledge of the objective environment.	Semi-Markov Process	The subjective evaluation of the destinations, their attainability and functional connections are determined by probability measures for the destinations. The orientation within the network is determined by transition probabilities.
Tomlinson, Janet, Norm Bullock, P. Dickens, P. Steadman and E. Taylor (1973)	Simulation of Individual's Daily Activity Patterns	At an aggregate statistical level, the regularities of behavior that can be observed provide sufficent overall information to model activity patterns, without the need to explain the actions and choices of individuals. The concern is with simulating the distribution of individuals to activities and locations over a day as a result of restrictions imposed by the spatial distribution of facilities and administrative/social constraints on activity timing.	Entropy maximization with a simulation model	The proportion of time spent in various activities will remain constant over a given time period. The proportion of people starting an activity in any one time period is independent of their previous activity. The distribution of individuals to activities and locations is made subject to the availability of locations and to the constraint that the total amount of travel time in the time budget for the whole population is maintained. Activity sequence is not considered in the model.

DATA SOURCES	SAMPLE	POLICY SENSITIVITY	PRIMARY RESULTS/CONCLUSIONS
1976 SCAG/CALTRANS (California) Household Interview Survey	665 individuals	Gasoline rationing, restriction on daily vehicle miles traveled	Distinct market segments based on similarities in travel/activity behavior (i.e., activity patterns) were identified in addition to the socioeconomic and urban form characteristics that best discriminate between the various market segments. Potential impacts of various transportation-related policy options on the daily activity patterns of individuals were also examined using the same analysis framework.
East Lansing, Michigan Travel Surveys	University students	None	The simulation performed reasonably well in establishing activities to be associated with periods of high commitment and constraint but failed in its ability to accurately estimate activity sequences over the whole day and for periods of low commitments and constraint.
Hypothetical	Not applicable	None	The relative location of an activity site affects the probability of coordinating visits to other activity sites on the same tour.
1972 Reading University, England and Leicester University, England Activity Surveys (one week)	100 university students	Travel times, temporal distribution of activity sites	In general, the model reproduces the distribution of the population to activities and locations fairly accurately.

AUTHOR(S) (DATE)	MAJOR THEME	UNDERLYING THEORY/HYPOTHESES	PRINCIPAL METHODOLOGY	MAJOR ASSUMPTIONS
Van der Hoorn, Toon (1981)	An Activity Model	Travel is a derived demand (i.e., travel does not supply utility but is a necessary complement to the performance of activities at different times) and therefore, it should be modeled as a subset of the total activity pattern.	Utility maximization with two multinomial logit models (location choice model and activity choice model) Simulation model	The 24-hour day is divided into 96 quarter hours. At each quarter hour the fraction of the population engaged in mandatory activities at each location is set equal to the observed fraction in the database. The remainder of the population is either engaged in previously started discretionary activities or "free" to be assigned to an activity/location combination. Location choice is limited to three locations: at home, in town and outside town. Average travel times between each pair of locations for all individuals of all person groups were calculated separately per activity type, car availability class and degree of urbanization.
Vidakovic, Velibor (1974)	Trip Chaining	Decisions in time-space are influenced by both prior actions and future intentions and should be treated as an integrated whole.	Harmonic series, probability distributions/χ^2-tests	There exists a relationship between distance traveled between activities and trip chain size. There is also a relationship between the frequency of arriving at non-home destinations and trip chain size.
Westelius, Ovar (1973)	Urban Travel Patterns	Trips to substitutable activities take place when an individual's need to visit a location reaches a prevailing threshold value or when the threshold value declines below the latent need (i.e., when the distance has been redued due to a trip to another location).	Stochastic simulation model	An individual's need to travel to non-home activities only changes when the individual is at home. Substitutable activity types are only located in centers and each center contains all of the activity types. An individual always visits the center closest to his/her home when making trips for substitutable activities.
Wheeler, James O. (1972)	Urban Activity Linkages and Multiple-Purpose Travel	A basic reason for linking trips is to reduce the transportation outlays. The spatial arrangement of activity locations influences the way in which activities are combined in tours. Certain activity types have a higher propensity for inclusion in multiple purpose trips than others.	Factor analysis Transaction Flow Analysis Markov Process	The trip linkage analysis is performed without any consideration of the temporal dimension (i.e. temporal homogeneity is assumed with respect to the transition probabilities) Home trips are not included in the trip linkage analysis.

DATA SOURCES	SAMPLE	POLICY SENSITIVITY	PRIMARY RESULTS/CONCLUSIONS
1975 Netherlands Activity Diaries (one week)	1100 individuals	None	Since all activity choices are taken into account, trade-offs between staying at home or leaving home can be made visible in the model system. The inclusion of temporal constraints on discretionary activities and constraints imposed by mandatory activities (i.e., work, school) allow a much wider range of policies to be examined.
1968 Amsterdam Travel Diaries (two days)	500 individuals	None	Individuals travel choices over the entire day are highly interrelated and must be modeled accordingly.
1968 Stockholm, Sweden Household Interview Survey	6,027 individuals	Spatial distribution of activity locations, temporal constraints on travel for substitutable activities.	Increasing distance between the individual's home and the nearest center results in a larger mean number of activities per chain and a greater proportion of activities at substitutable activity types made in connection with fixed activity visits. Increasing concentrations of substitutable activities to a few centers results in an increasing proportion of substitutable activities made in connection with visits to a center.
1965 Lansing, Michigan Tri-County Regional Origin-Destination Survey	1,830 individual trips	None	There is a high propensity of multiple-purpose trips involving shopping, personal business and social activities. A large number of segments of multiple-purpose trips focused on the primary commercial/business areas of the city but a higher than expected (under the assumption of origin-destination independence) number of segments connected peripheral areas.