Product Attributes. In Urban Travel Demand Forecasting, HRB, Special Rept. 143, 1973, pp. 146-174.
4. W. Recker and R. Stevens. Attitudinal Models of Mode Choice: The Multinomial Case for Selected Nonwork Trips. Transportation, Vol. 5, 1976, pp. 355-375.
5. T. Golob, R. Dobson, and R. Gustufson. Multidimensional Scaling of Consumer Preferences for a Public Transportation System. General Motors Research Laboratory, Warren, MI, GMR-1368, 1973.
6. R. Dobson and J. F. Kehoe. Disaggregated Behavioral Views of Transportation Attributes. TRB, Transportation Research Record 527, 1974, pp. 1-15.
7. P. R. Stopher, B. D. Spear, and P. O. Sucher. Towards the Development of Measures of Convenience for Travel Modes. TRB, Transportation Research Record 527, 1974, pp. 16-32.
8. G. C. Nicolaidis. Quantification of the Comfort Variable. Transportation Research, Vol. 9, 1975, pp. 55-66.
9. D. Hensher and P. McLeod. Towards an Integrated Approach to the Identification of the Transport Determinants of Travel Choices. Transportation Research, Vol. 11, 1977, pp. 77-93.
10. D. Brand. Approach to Travel Behavior Research. TRB, Transportation Research Record 569, 1976, pp. 12-33.
11. G. A. Kelly. A Theory of Personality. Norton, New York, 1955.
12. J. D. Carroll. Individual Differences and Multidimensional Scaling. In Multidimensional Scaling (S. Nerlove, ed.), Seminar Press, New York, 1972, Vol. 1.
13. P. E. Green and V. Rao. Conjoint Measurement for Quantifying Judgmental Data. Journal of Marketing Research, Vol. 8, 1971, pp. 355-363.
14. R. M. Johnson. Trade-Off Analysis of Consumer Values. Journal of Marketing Research, Vol. 11, 1974, pp. 121-217.
15. R. M. Johnson. A Simple Method for Pairwise Monotone Regression. Psychometrika, Vol. 40, 1975, pp. 163-168.
16. J. H. Ward. Hierarchical Grouping to Optimize an Objective Function. Journal of the American Statistical Association, Vol. 58, 1963, pp. 236-244.

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Interdependencies in Activity Behavior

David Damm

The research reported here stems from an increased awareness that many of a person's decisions to travel and hence to participate in activities are dependent both on the decisions of the person's household and on the full set of the person's daily activity decisions. An approach to modeling these interdependencies that treats the demand for activities explicitly and postulates a choice process constrained by both temporal and spatial variables is developed here. By using conventional home-interview data (from Minneapolis-St. Paul), it is demonstrated that hypotheses about complex travel-activity behavior can be tested without costly new surveys. The results confirm the need to account for interdependencies and point to many potentially fertile directions for policy-oriented as well as theoretical research.

The purpose of this paper is to present an approach to explaining travelers' behavior in the context of household- and work-related activities. The constraints imposed on a person's scheduling of activities (and therefore travel) by his or her household or workplace are explicitly treated and, rather than consider trips or activities in isolation, an entire day's activities and trips are examined simultaneously. It is evident that whether a person participates in an activity, at what time, for what duration, and by what mode is often determined by the decisions and needs of others, especially others in a person's household.

Prior research on interdependencies of travelers' decisions in constrained environments is briefly outlined. Next, the major features of the conceptual model (hypotheses about causality) and analytic theory used for an operational model are sketched. This model is then tested empirically with conventional home-interview data. Because the evaluation of policies such as variable working hours could be better conducted with further research in this area, the final sections address the implications of the effort reported here and the most fruitful future directions.

RESEARCH CONTEXT

Hägerstrand (1,2) and Lenntorp (3,4) have developed theories of welfare as defined by both spatial and temporal constraints of an urban system. That is, the more opportunities a person can reach in time and space, the greater is his or her welfare. By assuming that any individual has an activity program to be realized each day, these researchers have tried to measure the number of alternative ways (possible paths) in which a program could be accomplished. Simulation models applied to actual urban areas have been developed and the effect of changes in policy (e.g., expanding bus service or installation of day-care facilities) on a person's welfare have been explored (3-6). Burns (7) has used the concepts to develop theoretical measures of benefit.

Westelius (8) has examined the process by which participation in activities is scheduled. The existence of fixed places of activity in addition to the home strongly influences decisions of whether or not to stop there. Cullen and Godson (9) have pointed out the range of flexibility within a person's set of activities to be real-

ized. Here the concept of fixity is also incorporated, in that home and work are "pegs" around which other activities are organized. In a further refinement, Jones (10) has made clear that people are continually confronted with the choice of participating at their current location versus participating elsewhere and consequently needing to travel. In addition, Heggie (11) has stated that a person's day is probably composed of "separate and constrained time periods rather than a continuous block." Westelius has shown that any given choice made during a day is only in some cases made independently of other such choices. Vidaković (12, 13) has acknowledged this fact by developing models treating the daily decisions in time and space as interdependent units.

With respect to the interaction of members of a household and decisions to participate in daily activities, the household activity travel simulator (HATS) (10, 11, 14), a set of display equipment used by household members in interviews, has demonstrated that a person may adapt to a changed environment (e.g., a new bus schedule or a change in school hours) causing a change in responsibilities in a more complex fashion than might be predicted with conventional travel-demand models. For example, instead of there being a shift of mode, another member of the household would take over the responsibility (e.g., grocery shopping).

Several researchers have focused on the factors that seem to explain which individuals participate in activities. Chapin (15) and Brail and Chapin (16) have idenfied work as a central structuring element and "role," as defined by sex, family responsibilities, and working status, as one of the most critical variables in differentiating individuals. Kutter (17) isolates homogeneous groups that seem to have similar activity schedules along lines parallel to those used by Chapin to define the role variable. Hanson and Hanson (18) have also examined differences in travel-activity behavior and found an unequal distribution of responsibilities within the family (i.e., between men and women).

A few studies have been conducted by developing multivariate models of choice in constrained environments, such as a treatment of complex trip-making behavior by modeling an entire day's travel (19), exploration of the determinants of duration allocated to various activities over a day's time (20, 21), and estimation of models for a whole day that are noteworthy for their explicit accounting of both the home and the place of work as fixed points from which discretionary trips to activities are made (22-24).

In summary, it is evident from prior research that there are many situations in which decisions on whether or not to participate in an activity should not be represented as if they were made independently of (a) any of another household member's decisions, (b) the entire set of such daily decisions, or (c) decisions made by others at a person's fixed places other than home (e.g., work). Further, such decisions should be examined with respect to the constraints that limit the number of feasible alternatives a person has in time and space. Similarly, it should be recognized that a household's division of roles and responsibilites also limits how a person disposes of discretionary time.

MAJOR FEATURES OF THE APPROACH

First we need to postulate theoretically how activities are scheduled in time and space. Utility maximizing is used as a decision rule to explain the choices of whether or not to participate in an activity. Then the resulting conceptual framework is made operational so that its most promising hypotheses can be tested.

The need to travel is primarily derived from the need to participate in activities. Consequently, the conceptual model stresses the nature of activities. It is instructive to differentiate activities by their individual levels of fixity. Participation in a work-related activity, for example, is clearly more fixed for most people than participation in a recreational activity. Generally, a worker's place and time of employment can be considered fixed. Together with his or her place of residence and timing of necessary activities at home (sleeping, eating, etc.) we can describe the basic schedule on a typical workday as home-work-home. However, we have very little understanding of the decision making of those who do not simply go from home to work and back home. The focus here is consequently to understand and predict decisions to deviate from this basic schedule (i.e., to add one or more activities to an otherwise obligatory schedule).

Although the causal mechanisms represented in Figure 1 treat activities in the home only indirectly, by focusing on the decision to participate in nonhome-nonwork activities, they are implicitly included. Consider the organizational scheme resulting from focus on workers with a work trip. If we consider the activities at home and at work to be fixed in time and space, we can view a person's day as divided into five time periods with respect to these two fixed areas of activities:

1. Prior to the work trip,
2. During the trip from home to work,
3. During work,
4. During the trip from work to home, and
5. After the work trip.

A decision not to participate in a nonhome-nonwork activity is also a choice to continue at a person's current location (in periods 1, 3, and 5) or do nothing more than travel between home and work (in periods 2 and 4). In effect, a person often evaluates the utility derived from not leaving home as much as the utility derived from leaving home to take part in outside activities, because some in-home activities are actually discretionary in nature and compete with out-of-home or nonwork activities for a part of an individual's total time budget or activity program.

At the top of Figure 1 are the longer-run decisions, a set of factors about which an individual and those in his or her household decide or that are at least considered over a longer period of time (e.g., participation in the labor force, car-ownership level, or the division of roles in a household). These factors collectively influence the three sets of factors immediately below, which in broad terms can be thought of as demand (needs and program) and supply (constraints). Given this demand and supply, we then observe an activity schedule, represented here by the decision whether to participate in an activity (i.e., deviate from an obligatory schedule) and, if so, for how long.

In Figure 2 we see not only that each member generates both personal and household-level needs to be met by participation in activities outside the home, but also that not all members of the household are in a position to fulfill such needs. Depending on the particular mixture of roles in a household, any individual will have out-of-home responsibilities that meet the needs of the household as a unit (e.g., grocery shopping). In the same way, an individual's life-style, employment status, and roles (together with a myriad of other economic and psychological factors) combine to influence the needs that an individual experiences apart from the context of the household. All these familial and personal needs produce an activity program that a person would like to complete over some time frame.

Figure 1. Factors that influence activity scheduling.

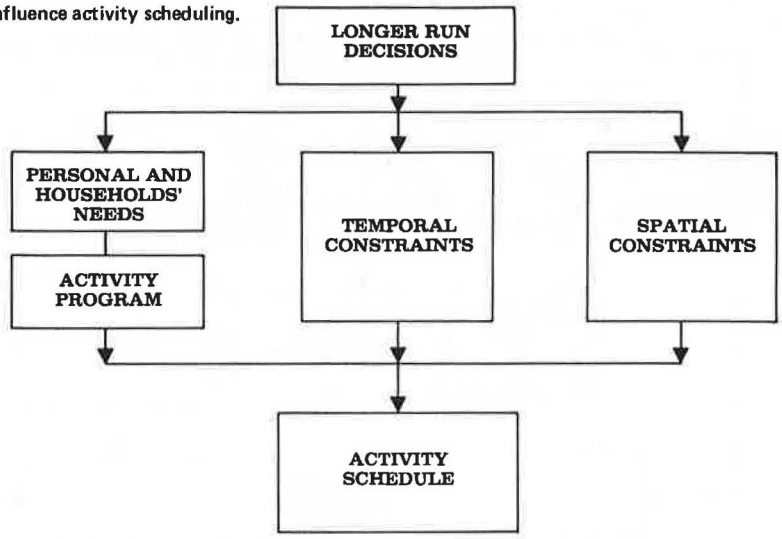


Figure 2. Influences of activities on scheduling.

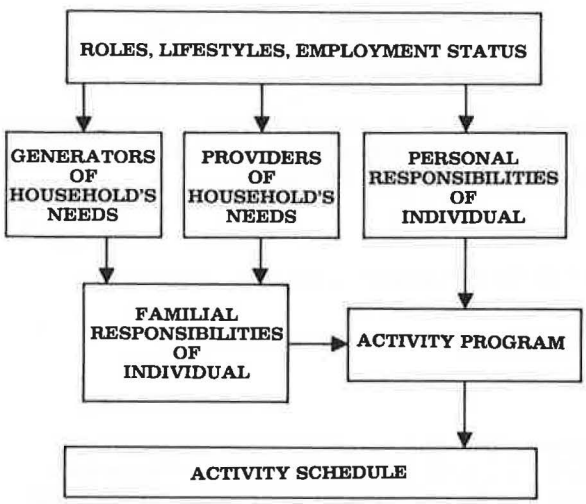
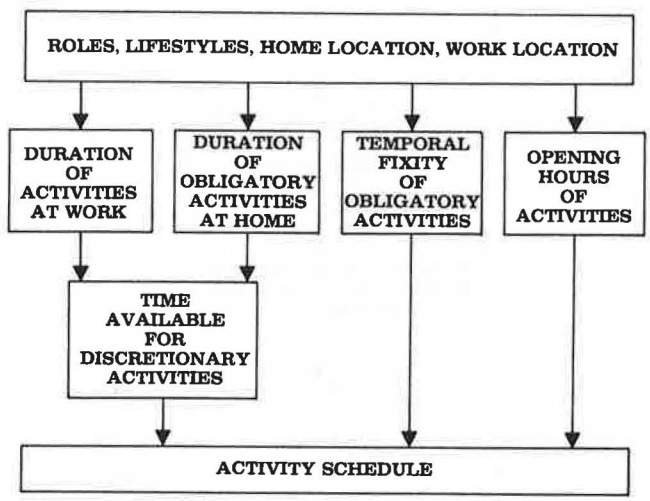


Figure 3. Temporal constraints and activity.



In Figure 3 the duration of a person's work- and home-centered activities (which is partly determined by the chosen life-style) limits the time available for a program of discretionary activities. The temporal fixity of obligatory activities is also partly determined by a person's life-style and other longer-term decisions (e.g., of a professional nature). A person who is required to be at work during prescribed hours and is expected to be home at a set time probably has a very different schedule from one who does not have such requirements. The hours during which various activities are available provide a substantial constraint on the decision making of full-time workers.

In Figure 4, spatial constraints and potential for reaching activities are represented. First, two factors represent more perceptual influences on scheduling behavior: familiarity with surroundings at home and spatial fixity of the workplace. Persons whose workplace is not fixed in space (e.g., construction workers) probably are less familiar with nearby opportunities and hence have a different activity schedule. The transportation facilities available to a person directly affect his or her ability to overcome the spatial constraints. Likewise, the characteristics of the spatial environment (i.e., the density of activities) have an immediate bearing on the set of potential opportunities that could be included in an activity program with respect to a particular place and time.

In Figure 5, the activity program and constraints are condensed into one package that influences the individual's decision. If the outcome is positive, at least three decisions are made: where participation will occur (destination), by what mode the activity will be reached, and how long participation will last (duration). We leave the choices of mode and destination in the context of a full set of activity choices to future research.

MODEL DEVELOPMENT

To move from the conceptual framework to empirical testing, we must define a decision rule for the choice of whether or not to participate in an activity. It is useful to assume that a person derives utility from deviating from the basic home-work-home schedule and similar utility from not deviating from it. [An extensive treatment of utility theory as applied to transportation analysis is available elsewhere (25).] It is assumed further that a person chooses the alternative that has the greater utility. By describing the attributes of each alternative and developing utility functions, we can then predict

Figure 4. Spatial constraints and activity.

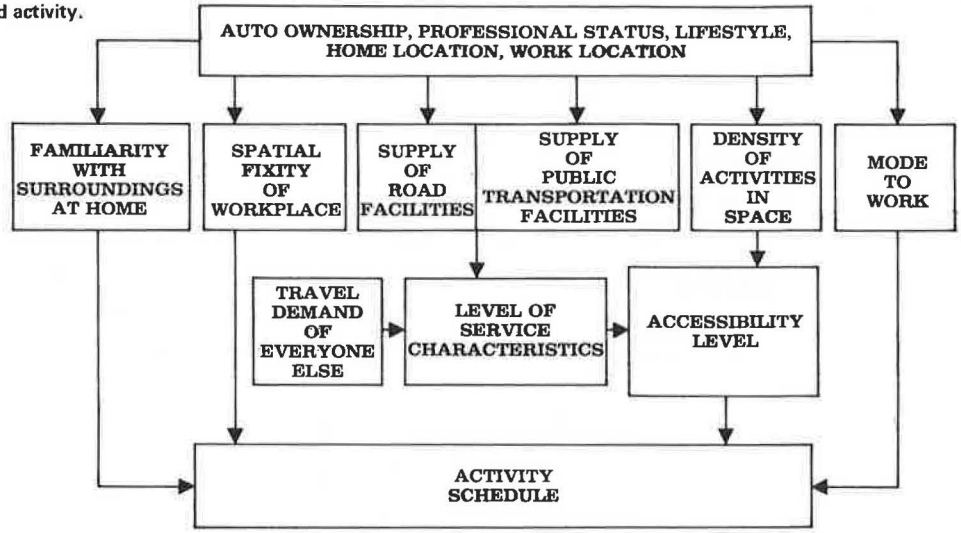
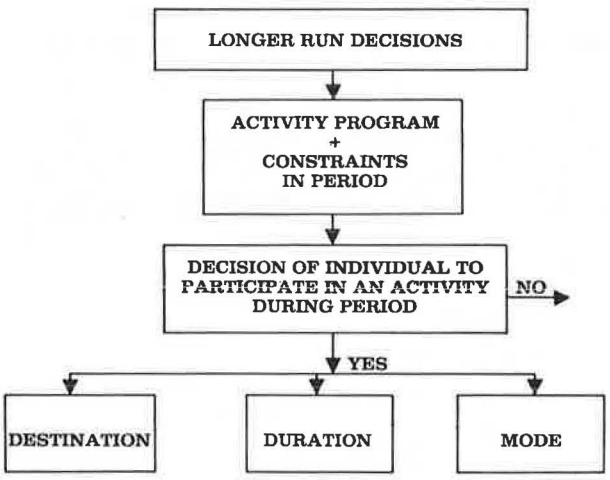


Figure 5. Activity-scheduling decisions.



the outcomes of the choice process for an individual.

With several modifications, we can create a general model of the choice process involved in the scheduling of activities. A full discussion of utility theory used to describe decisions on whether or not to participate in an activity has been developed (26). The model can be summarized by a utility-maximizing process, expressed as

$$\max U(a, b, \delta, X)$$

subject to the following constraints:

$$a_i + b_i + \delta_i C_i = D_i$$
$$D_i - C_i\delta_i \geq 0$$
$$a_i, b_i \geq 0$$
$$\delta_i = 0, 1$$

where

- i ranges from 1 to 5,
- a = discretionary time spent outside a fixed site,
- b = discretionary time spent at a fixed site,
- δ = indicator variable denoting participation (yes or no),
- C = time spent in travel to a discretionary activity,
- D = time spent in discretionary activity,
- U = utility, and
- X = attributes of alternatives.

Because time spent outside a fixed site is of central interest to transportation analysis, the process represented above can be refined to

$$\max U(a, \delta, X)$$

subject to the following constraints:

$$D_i - C_i\delta_i \geq 0$$
$$a_i \geq 0$$
$$\delta_i = 0, 1$$

This is possible since discretionary time spent at a fixed site (b) can be computed once a and δ have been determined. As soon as δ (a vector with five elements) has a value, the problem to be solved is

$$[\partial U(a, X|\delta)]/\partial a_i = 0 \quad \text{if } \delta_i = 1$$

$$a_i = 0 \quad \text{if } \delta_i = 0$$

If $a^*(\delta)$ is the solution, the utility of the activity schedule (defined for a specific value of δ) at the optimal value of a is $U^*(a^*|\delta)$. Since there are many values of δ, we evaluate all possible solutions and choose that which produces the maximal value of $U^*(a^*, X|\delta)$.

The basic decisions explained in the above theory are whether or not to spend time in a period (participation) and, if so, how much time (duration). [A fuller treatment of issues associated with developing a testable model is being prepared (26).] In effect, people trade off amounts of time to spend in particular periods by a process that maximizes their utility. However, it is necessary to recognize that the utility function contains both random and systematic components. This means that the optimal value of δ cannot be predicted with certainty. If the error (or random) terms are distributed in some known fashion, it is possible to make probabilistic statements about whether or not a person will participate in a discretionary activity in a time period.

Activity-scheduling behavior can be viewed as composed of both discrete and continuous phenomena. Research that provides a number of useful parallels has been conducted in the areas of modal choice and parking location (27). To illustrate, we have two equations for each time period. In the first, the binary probit, we model the decision of person i to participate in an activity in period t:

$$B_{it} = \alpha\pi^*_{it} + Z_{it}\gamma + \mu_{it} \quad (1)$$

where

- B = utility derived from participation,
- Z = vector of variables related to participation,
- μ = unobserved random variable distributed N (0, 1),
- π^* = duration that would be observed if a person participated in an activity, and
- α, γ = coefficients.

In the second equation, a multiple regression, we model the correlation of duration and a set of explanatory variables conditional on participation of person in period t:

$$\pi^*_{it} = X_{it}\beta + \epsilon_{it} \quad (2)$$

where

- X = variables that explain variations in observed duration,
- ϵ = unobserved random variable distributed N (0, σ^2), and
- β = coefficient.

By estimating a separate equation for duration (for those who participate), we can then infer the length of time during which all persons in the sample would have participated, regardless of their actual observed decision. The vector of expected (or mean) values of duration can then be used as an exogenous variable in the model of participation, under the premise that the decision is influenced by the length of time that a person would like to or need to spend in order to participate. The value of duration observed for participators misstates on the average the value that we would obtain were data on duration available for everyone. Consequently, our analysis includes a correction for selectivity bias in order to obtain statistically consistent estimates. [Details of the procedures used to model the discrete and continuous phenomena together have been presented elsewhere (27-29). The original econometric method was developed by Heckman (30).] By having separate estimates for the two dependent variables, it is also possible to extract the direct and indirect effects of variables that I feel belong in both Equations 1 and 2.

RESULTS

The home-interview survey (and its associated data) conducted in Minneapolis-St. Paul, Minnesota, in 1970 (31) met minimal criteria and was easily accessible within reasonable time constraints. By isolating the observations that could be used in testing the operational model (e.g., full-time workers who made a work trip on the day of observation), 2345 cases were defined. Since travel diaries for an entire day were available, the existence and duration of participation in a nonwork-nonhome activity could be established by means of the ending and beginning times of all trips.

The main goal was to separate the systematic from the random components so that some probabilistic statement could be made about the behavior of different groups in the population. By using both statistical tests and a priori beliefs, the final models were selected. Generally, a variable was omitted if it was weak theoretically and statistically, if its effect on the dependent variable appeared largely to be already represented by some other variable, or both. The available data were used to provide approximations to factors hypothesized to have causal influence (see Figures 2, 3, and 4).

Since the home interviews reported travel behavior and person-level data for all members of a household over five years of age, a relatively good basis existed for creating proxy variables for interdependence. At the household level, several variables (e.g., number of children aged 5-15) represent determinants of familial responsibilities. Variables such as the number of nonworking adults, access of nonworkers to a car, or work status of spouse partly indicate the extent to which persons other than the observed worker can meet a household's needs. The number of daily trips made by others in the household (an average per person) is to some extent a proxy for both generators and providers, since the propensity to travel could correspond to activeness (and hence more needs to be fulfilled) but could also correspond to readiness to travel in service of others' needs. Finally, the variables for age, sex, and disposable income serve as indirect measures of the differences we observe in personal as well as familial responsibilities.

The temporal constraints are the least understood and have the fewest obvious empirical referents of all the causal factors. By using the time spent in other periods of the day, we proxy the effect of various activities competing for scarce time. In addition, this variable allows testing whether decisions made over several time periods are interdependent.

Whatever the exact amount of time a person may have available, it is important how flexible the obligatory schedule is. (For example, a person working on an assembly line cannot usually deviate from the perscribed working hours, whereas a self-employed carpenter may be free to begin and end working whenever he or she pleases.) The closest proxy was two dummy variables for whether a person began or ended work outside conventional hours (after 9:00 a.m. or 6:00 p.m.). These variables also served as proxies for being able to take advantage of conventional opening hours of commercial establishments. Finally, a dummy variable for temporal proximity to the weekend was defined.

Spatial constraints limit the activity space in which a program can be performed. The accessibility level represents the ease with which a person can reach opportunities. Because this metric is generalized over both automobile and transit, a variable was also created for the mode chosen to go to work, which presumably captures the effect of limitations imposed by having to travel either together with others in a car or in a bus that has a fixed route and schedule. A dummy variable for whether or not someone has a driver's license also indicates a person's ability to travel alone and hence be less dependent on others' schedules. Whether the location of work and actual destination of work coincide is an indicator of the fixity of a person's workplace. Those who do not have such a coincidence would have less knowledge of the options in an area and hence less likelihood of spending time on nonwork activities. The variable for years lived at a residence approximate a person's familiarity with activities outside the home. The logarithmic form indicates that the additional knowledge or information gained decreases with tenure.

Five equations were developed for whether or not a person decides to participate in an activity, and another

Table 1. Comparison of participation equations across time periods.

Variable	Period 1 Result	Period 1 Best Fit	Period 2 Result	Period 2 Best Fit	Period 3 Result	Period 3 Best Fit	Period 4 Result	Period 4 Best Fit	Period 5 Result	Period 5 Best Fit
Constant	-0.008	-0.17	-0.22	-3.55	-4.56	-4.83	0.02	0.70	0.08	0.18
Duration of work	-0.007	-3.61	-0.03	-5.06	-0.006	-2.07	-0.008	-5.40	-0.005	-2.84
Time spent in other periods	-0.003	-3.85	0.002	3.12					-0.004	-5.75
Friday	0.12	5.36	-0.27	-4.58					0.23	2.78
Leave work after 6:00 p.m.							-0.10	-1.69	-0.85	-8.30
Arrive at work after 9:00 a.m.	1.20	11.79	0.51	6.35						
Accessibility	0.08	2.20	0.07	4.14	0.03	1.21	0.03	2.35	0.02	1.22
Fixity of workplace					-0.19	-1.27	-0.24	-2.74		
Logarithm of years lived at residence	-0.03	-0.89							0.032	0.93
Mode to work			-0.55	-6.19	0.28	2.50	-0.09	-1.37		
Driver's license	0.14	2.03	0.49	3.87	-0.45	-2.72	0.27	1.82	0.40	2.33
Access of nonworkers to car			0.10	1.44						
Drivers per car	-0.12	-2.05								
Working spouse					-2.31	-4.92				
Number of children aged 5-15									0.08	3.89
Number of nonworking adults	0.25	2.95	-0.14	-3.96			-0.17	-3.54		
Trips per others in household	0.04	1.19	-0.05	-2.71	0.04	2.31	0.06	4.90	0.17	12.38
Logarithm of disposable income	-0.05	-1.52	0.20	2.97	0.43	3.60				
Age	-0.01	-3.26					-0.006	-2.35	-0.009	-3.38
Sex			0.73	6.45						
Predicted duration	0.0004	0.14	-0.03	-5.18	0.002	0.55	-0.0002	-0.28	-0.002	-1.0
ρ^2	0.76		0.57		0.65		0.38		0.17	

Note: period 1 = prior to the work trip; period 2 = during the trip from home to work; period 3 = during work; period 4 = during the trip from work to home; and period 5 = after the work trip.

Table 2. Comparison of duration equations across time periods.

Variable	Period 1 Result	Period 1 Best Fit	Period 2 Result	Period 2 Best Fit	Period 3 Result	Period 3 Best Fit	Period 4 Result	Period 4 Best Fit	Period 5 Result	Period 5 Best Fit
Constant	2.19	2.12	0.21	1.11	-1.23	-1.76	0.64	4.45	1.12	5.30
Duration of work	-0.44	-1.65	-1.10	-6.23	-1.00	-3.76	-1.55	-6.51	-0.39	-2.25
Time spent in other periods	-0.26	-2.50	-0.11	-1.87	-0.07	-1.35	-0.33	-3.98		
Friday									16.89	2.19
Accessibility	-7.47	-1.93			4.94	2.60	2.67	1.34	-2.08	-1.29
Fixity of workplace					-24.80	-1.86				
Mode to work					18.20	1.67				
Access of nonworkers to car			12.40	1.58	-6.43	-0.92	23.47	2.04		
Logarithm of disposable income			6.54	1.27	41.58	2.21	11.04	1.70	-3.70	-1.20
Number of nonworking adults	-16.89	-2.43								
Working spouse							61.15	1.52		
Number of children aged 5-15	6.75	1.48			-2.58	-1.22				
Trips per others in household	11.94	3.59	-2.89	-1.64					5.00	2.62
Age							-1.57	-3.77	-0.38	-1.53
Sex	-36.21	-1.91			22.95	1.81			-39.84	-4.14
Selectivity bias correction	-0.32	-0.45	0.41	2.39	-0.74	-1.37	-0.42	-9.13	-0.15	-1.08
$\bar{R}^2$	0.17		0.23		0.19		0.29		0.05	

Note: Periods are the same as in Table 1.

five equations for duration were estimated with data on persons who actually participated in an activity during a particular time period. Not assuming that decisions made in different time periods are independent has statistical consequences. Although several possibilities were considered (all 10 equations as a simultaneous system or a standard single-equation method), the approach used here is to define explanatory variables for the models in each time period that reflect some characteristic of the other four periods. When we are trying to explain duration, for example, it is useful to know how much time a person spent in other time periods, since, to the extent that decisions across periods are interrelated, time is allocated more jointly than sequentially. Because including an exogenous variable that is actually a composite of the endogenous variables of the other four durational models violates the assumptions of ordinary least-squares regression, it is necessary to implement a two-stage least-squares estimation procedure. First, durations are estimated for everyone without a simultaneous term, and the expected (mean) values for people who actually participate are used to calculate the time spent in other periods. In this way, we avoid risking correlation of the error terms and explanatory variables in each model.

The results of estimation are shown in Tables 1 and

2. In some cases the outcomes of estimation are unequivocal and a clear inference can be made. In other cases, however, outcomes are either contradictory or ambiguous enough to make inference a tenuous enterprise. In the context of strict hypothesis testing, several variables would be dropped (i.e., not significant at the 90 percent level of confidence) that are nevertheless reported here because of their theoretical interest. It is hoped that future work in this field can closely scrutinize such variables. Summary measures of the overall fit of the data to the model are given along with the results of each equation. For the regression equation, $\bar{R}^2$ is used to indicate the proportion of variation in the dependent variable explained by the equation, corrected for the number of explanatory variables used. In the probit equation, ρ^2 is used. It is calculated as 1 - [(log likelihood of the equation before estimation)/(log likelihood of the equation after estimation)].

In general, the findings support the judgment made about the causal factors operating to influence the behaviors of interest: whether someone participates in an activity and, if so, for how long. Further, the empirical results tend to support the division of the causal variables into the three categories—activity program or needs, temporal constraints, and spatial constraints. One of the unique features of the empirical analysis is the division of the day into five time periods, each with its own associated equations to be estimated. The interrelatedness among decisions made in the different time periods is captured by the variable of time spent in other periods; its coefficient performs as expected. That is, almost all the coefficients of this variable are negative, indicating that the more time that is allocated to other periods, the less there is for the current period. The mixed results for the variables used to proxy the effect of interdependence within a household on an activity schedule indicate both the complex nature of the behaviors in question and the need for further research in this field.

CONCLUSIONS

It is patently clear that people's behavior is vastly more complex than the simple shifts (e.g., from automobile to transit) that most available empirical models would lead us to infer. By ignoring trip consolidation or shifting of responsibilities within a household, we risk serious misprediction. Our operational model is a first step toward lessening this risk when assessing the impact of policies that alter spatial or temporal constraints (e.g., variable working hours, four-day workweek). Using traditional travel-demand models to assess the impact of such policies often misrepresents people's likely responses, since choices are usually assumed to be made independently of others. If analysts better understood the factors that influence how activities are arranged in time and space, they would also be in a stronger position to recommend a much wider range of alternatives for providing for the activity needs that underlie travel demand.

At least three directions should be pursued in future research. First, specifications of empirical referents for theoretical constructs should be expanded. This work would be expedited with access to data sets that include duration and purpose of in-home activities, opening hours of major activities, degree of flexibility of arrival and departure times, and related nonvehicular information. Certainly, analysis of particular activities would improve specifications. Second, other approaches to representing the theory analytically should be evaluated. Third, it seems appropriate to reformulate an entire system of demand models so that demand for activities can be fully integrated into transportation analysis.

In this way an expanded approach to transportation policy can emerge. Transportation systems management, for example, would have to be rethought so that policies such as changed opening hours or flexible working hours could be used more consciously to achieve such political goals as reduced vehicle kilometers of travel. We can then begin to develop a more realistic and useful approach to urban transportation problems.

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REFERENCES

1. T. Hägerstrand. The Impact of Transport on the Quality of Life. Department of Geography, Lund Univ., Sweden, Rapporter och Notiser Series 13, 1974.
2. T. Hägerstrand. What About People in Regional Science? Papers of the Regional Science Association, Vol. 24, 1970, pp. 7-21.
3. B. Lenntorp. Paths in Space-Time Environments. Lund Univ., Sweden, Lund Studies in Geography, Series B, No. 44, 1976.
4. B. Lenntorp. A Time-Space Structured Study of the Travel Possibilities of the Public Transport Passenger. Department of Geography, Lund Univ., Sweden, Rapporter och Notiser Series 24, 1976.
5. J.D. Stephens. Daily Activity Sequences and Time-Space Constraints. In Time-Space Budgets and Urban Research: A Symposium (B.D. Holly, ed.), Department of Geography, Kent State Univ., Kent, OH, 1976, pp. 21-69.
6. P. Henseler and G. Ruesch. Verteilungswirkungen der Verkehrspolitik. Der Oeffentliche Sektor, Vol. 4, No. 1/2, June 1978.
7. L.D. Burns. Transportation, Temporal and Spatial Components of Accessibility. Heath, Lexington, MA, 1979.
8. O. Westelius. The Individual's Pattern of Travel in an Urban Area. National Swedish Building Research, Stockholm, Document D2, 1972.
9. I. Cullen and V. Godson. Urban Networks: The Structure of Activity Patterns. In Progress in Planning, Vol. 4, Part 1, Pergamon, New York, 1975.
10. P. Jones. Identifying the Determinants of Destination Choice. In Identification and Evaluation of the Determinants of Travel Choice (D.A. Hensher, ed.), Saxon House, New York, 1977, Chapter 9.
11. I. Heggie. Putting Behavior into Behavioral Models of Travel Choice. Transport Studies Unit, Oxford Univ., Working Paper 22, 1977.
12. V.S. Vidaković. A Study of Individual Journey Studies: An Integrated Interpretation of the Transportation Process. In Theory of Traffic Flow and Transportation (G.F. Newell, ed.), Elsevier, New York, 1972, pp. 57-70.
13. V.S. Vidaković. A Harmonic Series Model of the Trip Chain. In Transportation and Traffic Theory (D.J. Buckley, ed.), Elsevier, New York, 1974, pp. 375-386.

14. P. Jones. Methodology for Assessing Transportation Policy Impacts. TRB, Transportation Research Record 723, 1979, pp. 52-58.
15. F. S. Chapin, Jr. Human Activity Patterns in the City. Wiley, New York, 1974.
16. R. K. Brail and F. S. Chapin, Jr. Activity Patterns of Urban Residents. Environment and Behavior, Vol. 5, No. 2, 1973.
17. E. Kutter. A Model for Individual Travel Behavior. Urban Studies, Vol. 10, 1973, pp. 235-258.
18. S. Hanson and P. Hanson. The Impact of Social Roles on Urban Activity Patterns: The Case of Working Men and Women. Geographical Review (in preparation).
19. T. J. Adler. Modeling Nonwork Travel Patterns. Department of Civil Engineering, Massachusetts Institute of Technology, Cambridge, PhD. thesis, 1976.
20. J. H. Bain. Activity Choice Analysis, Time Allocation, and Disaggregate Travel Demand Modeling. Department of Civil Engineering, Massachusetts Institute of Technology, Cambridge, M. Sc. thesis, 1976.
21. J. Jacobson. Models of Nonwork Activity Duration. Department of Civil Engineering, Massachusetts Institute of Technology, Cambridge, Ph.D. thesis, 1978.
22. C. V. Oster, Jr. The Structure of Intra-Urban Household Travel. Department of Economics, Harvard Univ., Cambridge, MA, Ph.D. thesis, 1977.
23. C. V. Oster, Jr. Household Trip-Making to Multiple Destinations—The Overlooked Urban Travel Pattern. Traffic Quarterly, Vol. 32, 1979, pp. 511-530.
24. C. V. Oster, Jr. Second Role of the Work Trip—Visiting Nonwork Destinations. TRB, Transportation Research Record 728, 1979, pp. 79-82.
25. T. A. Domencich and D. McFadden. Urban Travel Demand: A Behavioral Analysis. North-Holland, Amsterdam, 1975.
26. D. Damm and S. R. Lerman. A Theory of Activity Scheduling Behavior. Environment and Planning (in preparation).
27. R. B. Westin and D. W. Gillen. Parking Location and Transit Demand. Journal of Econometrics, Vol. 8, 1978, pp. 75-101.
28. D. Damm. Toward a Model of Activity-Scheduling Behavior. Massachusetts Institute of Technology, Cambridge, Ph. D. thesis, 1979.
29. E. J. Miller. A Disaggregate Choice Model of the Retail Firm. Department of Civil Engineering, Massachusetts Institute of Technology, Cambridge, Ph. D. thesis, 1978.
30. J. Heckman. The Common Structure of Statistical Models of Truncation, Sample Selection, and Limited Dependent Variables and a Simple Estimator for Such Models. Annals of Economic and Social Measurement, Vol. 5, 1976, pp. 45-49.
31. A Summary Report of Travel in the Twin Cities Metropolitan Area. Metropolitan Council of the Twin Cities Area, St. Paul, MN, 1974.

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