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Authors

Recker, Will
McNally, Michael G.
Root, Gregory S.

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**A Methodology for Activity-Based
Travel Analysis: The STARCHILD Model**

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Will Recker
Michael G. McNally
Gregory S. Root

Department of Civil Engineering and
Institute of Transportation Studies
University of California, Irvine
wwrecker@uci.edu, mmcally@uci.edu

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Institute of Transportation Studies
University of California, Irvine
Irvine, CA 92697-3600, U.S.A.
<http://www.its.uci.edu>

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A Methodology for Activity-Based Travel Analysis: The STARCHILD Model

by
W. W. Recker, M. G. McNally, G. S. Root

University of California, Irvine
Irvine, CA 92717, USA

Abstract

This paper presents a policy sensitive approach to modeling travel behavior based on activity pattern analysis.

The approach includes the formulation of a theory of complex travel behavior based on a recognition of the full range of interdependencies associated with an individual's travel decisions in a constrained environment. In the approach advanced travel is viewed as input to a more basic process involving activity decisions. A fundamental tenet of this approach is that travel decisions are driven by the collection of activities that form an agenda for participation; the utility of any specific travel decision can be determined only within the context of the entire agenda.

Based on the theory, an operational system of models, STARCHILD (Simulation of Travel/Activity Responses to Complex Household Interactive Logistic Decisions), has been developed to examine the formation of household travel/activity patterns employing a simulation approach in combination with techniques of pattern recognition, multiobjective optimization and disaggregate choice models. Initial empirical verification of the system of models is presented based on results obtained from a sample data set.

Conclusions are drawn concerning the merits of activity-based procedures relative to traditional approaches to travel demand modeling.

Rationale

Empirical findings have documented that individuals employ a wide variety of strategies when faced with restrictions imposed by transportation policies (e.g. decreased transit service, gasoline restrictions). These strategies range from simple modal shifts to more complex adaptations involving trip consolidation (i.e., chaining), activity rescheduling and destination substitution. Conventional travel demand models, however, are unable to reflect (and hence, predict) these complex responses as a result of several theoretical shortcomings. In addition, estimation of the likely impacts of various activity system policies (e.g. flextime, extended hours for service facilities) is outside the realm of the present models. This paper attempts to address these shortcomings by restructuring the prevailing microeconomic theory of travel behavior in a manner that facilitates an increased understanding of complex travel behavior and provides an additional capacity for analyzing policy impacts.

Why are Conventional Approaches Unsuitable?

Several authors (Heggie, 1978; Burnett, 1978; Hanson, 1980) have discussed in detail both the limitations of current disaggregate models as well as the basic underlying assumptions that give rise to these limitations; only a brief discussion of these is presented here. A serious shortcoming of available theoretical frameworks is the use of individual trips as the basic unit of analysis. Despite the widespread acknowledgement that travel is a "derived" demand (i.e., the demand for

travel is derived from a more basic need to participate in various activities at specific locations), most of the operational travel demand models have ignored the activities that give rise to the need for travel and have, instead, focused exclusively on travel itself. By ignoring the relationship between activities and travel, these models are unable to provide any meaningful information about how changes in the activities themselves affect individuals' travel behavior. In addition, by focusing on individual trips (as opposed to a sequence of trips), the current models assume that the individuals' travel decisions are independent from any consideration of previous or future actions, thus implying a "memoryless" decision maker.

A second major problem associated with current models is their failure to incorporate explicitly the effect of constraints on individual travel behavior. Most of the models have focused on the explanation and prediction of the individual's observed choice without any consideration of how various constraints interact to restrict the range of choices available to the individual. Researchers at the Lund School of Geography in Sweden have demonstrated that the set of activity (and hence, travel) options available to an individual at a particular time is determined, in part, by his/her obligations to be at certain locations during specific times (e.g. work, home), the distribution (both spatial and temporal) of activity locations and the characteristics of the transportation system (e.g. availability, connectivity and speeds of various modes). Another set of constraints that has been ignored by current models is that which originates from the household as a result of the interaction among family

members. Individuals do not exist in isolation, but instead are members of larger units (households) and, therefore, their decisions concerning travel and activities are influenced to some extent by the needs and constraints associated with other household members. As an example, consider a two-member household that owns one automobile. Any decision to utilize the automobile for a particular length of time by one member of the household will eliminate all of those activities that require the use of automobile from the set of potential alternatives available to the other member during that same time period.

The proper specification of the individual's choice set is another problem that is inherent to the current models. Although environmental and household constraints (when properly incorporated) delineate the set of feasible alternatives available to an individual, they fail to identify those alternatives that are actually considered by the individual. Many authors have speculated that the size of the latter set is much smaller than the former as a result of the individual's limited ability to process large amounts of information and make decisions. However, this concept has not yet been incorporated systematically in any mathematical model.

Finally, current disaggregate models assume that individuals make their decisions based strictly on the concept of utility maximization. Given a set of alternatives, an individual is viewed as determining the utility (usefulness) of each alternative based on a set of characteristics (attributes) and then selecting the one alternative that offers the highest utility. In contrast recent studies of choice in the

field of psychology have indicated that individuals do not always employ the same decision strategy but rather that decision strategies vary with the level of complexity associated with the decision.

How Does This Approach Differ?

The approach advanced in this paper is based on a comprehensive theory of individual travel behavior that positions travel in a broader context than in single-trip methodologies (Recker et al, 1983). In this approach travel is viewed as input to a more basic process involving activity decisions. A fundamental tenet of this approach is that travel decisions are driven by the collection of activities that form an agenda for participation and, as such, cannot be analyzed on a link-by-link basis. Rather, the utility of any specific travel decision can be determined only within the context of the entire agenda.

A significant element in the development involves a model of individual choice set formulation that includes both the effect of environmental/household constraints and that of individual limitations with respect to information processing and decision making. An alternate view of utility maximization and its relationship to decision making is presented in which the utility of a decision is comprised of two components: (1) the outcome of the decision and (2) the decision process itself.

A comprehensive activity-based modeling system, STARCHILD (Simulation of Travel/Activity Responses to Complex Household Interactive Logistic Decisions), has been developed which offers one possible direction for

the implementation of such approaches in transportation planning and analysis. The synthesis of the model uncovered many of the challenges facing the continued development activity-based frameworks:

1. Analysis of household interaction and the specification of individual activity programs.
2. Combinatorics related to the generation of feasible activity programs.
3. Reduction of feasible courses of action to a set of distinct alternatives.
4. Specification of the choice set formation protocol.
5. Specification of the actual choice set.
6. Activity pattern choice model.

The discussion presented herein centers about these issues and suggests a systematic approach toward their resolution.

General Approach

The STARCHILD model that has been developed to examine the formation of household travel/activity patterns utilizes a simulation approach comprised of six stages:

- (1) Specification of individual activity programs from an examination of household activity programs and constraints, and the interactions between the household members given the existing supply environment.

- (2) Generation of the set of feasible, individual travel/activity patterns through a constrained, combinatoric scheduling algorithm.
- (3) Identification of distinct members of the set of feasible travel/activity patterns by means of pattern recognition techniques.
- (4) Identification of a non-inferior (perceived) pattern set for individual choice utilizing a multi-objective programming approach.
- (5) Specification of a representative activity pattern set (if necessary), forming the choice set for each household member, utilizing pattern recognition and classification theory.
- (6) Formulation of a pattern choice model, which specifies individual travel/activity pattern choice probabilities.

The proposed methodology is discussed in detail in the following subsections, and a schematic overview of the model is provided in Figure 1.

Module 1. Analysis of Household Interaction and the Specification of Individual Activity Programs

In light of the interactive household forces that affect the formulation of individual activity programs, it is necessary to simulate these interactions to adequately treat the issue of activity program generation.

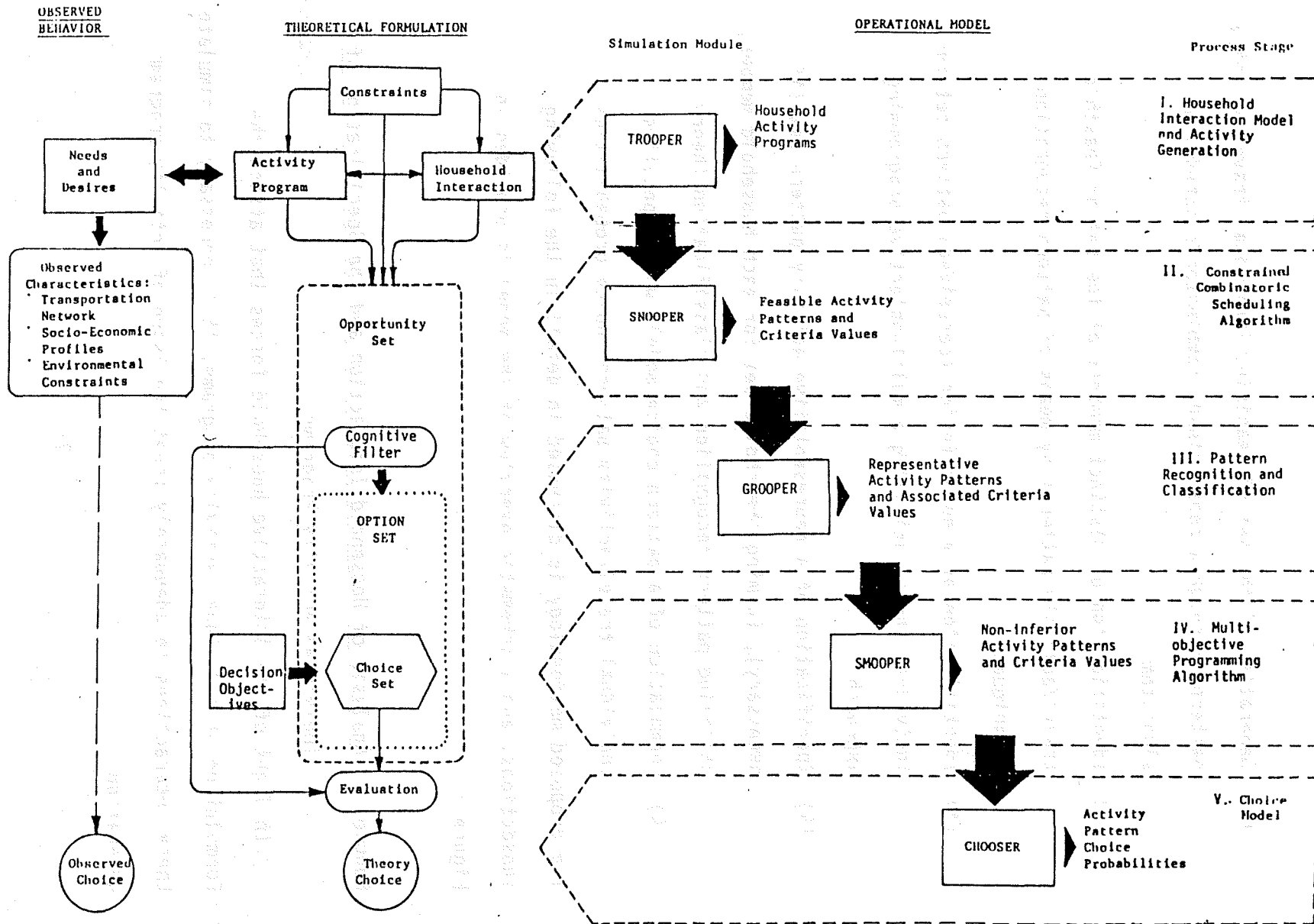


Figure 1. Activity Pattern Formulation Schematic

Although opinions differ on the actual decision-making unit, whether the household or the individual, household interactions do constrain the range of alternatives available to the individual. It is assumed that the household itself has an activity program, that is, a list of activities that can be classified as subsistence (such as work or school), maintenance (such as shopping or personal business), or leisure (general social/entertainment/recreational). Certain activities are associated with specific individuals (particularly subsistence activities) and must be completed by that individual. Other activities provide the household utility, but not from the necessary participation of specific individuals (such as maintenance shopping), and are assigned by the household through some constraint process.

If activities are assigned to individuals according to their flexibility, beginning with subsistence activities which by definition are least flexible in space, time and participation, the ability of household members to perform more flexible activities is iteratively reduced as each activity is assigned. The ability to perform remaining activities is greatly affected by the distribution of the activity locations, the necessary activity durations, destination time constraints and the availability of transport modes within the household, the latter a function itself of the assignment of inflexible activities.

A series of household, in-home constraints reduce the assignment potential, as household members interact jointly, in and out of the home, and share the household automobile(s). The assignment of the automobile

itself may be a function of activity priority to the household, or a function of individual priority over the automobile.

The first simulation module (TROOPER) models these interactive forces internally, so that the resultant individual activity program (or programs) reflects these household constraints.

Module 2. A Constrained, Combinatoric Scheduling Algorithm for the Generation of Feasible Activity Programs

Once the set of activity programs corresponding to each household member is specified, the set of feasible activity patterns is generated through a constrained, combinatoric scheduling algorithm (SNOOPER), the second module of the simulation package (see Figure 1).

The simulation is based on a single premise--the set of opportunities available to each household member is contained in the set of all feasible activity patterns which that member could indeed perform, given his/her activity program. Two rather prominent issues present themselves in this process--the computational problem of generation and the pragmatic issue of interpretation. The latter issue will be detailed in the discussion of the simulation's third module (SMOOPER). The former issue is approached through the constrained combinatoric scheduling algorithm. The algorithm has six sequential elements:

1. Integration of the Activity Program
2. Activity Combinatorics
3. Modal Combinatorics
4. Schedule Feasibility

5. Activity Scheduling

6. Activity Pattern Specification

The first of six basic elements of this module integrates the activity program of a single household member into the simulation procedure. Whereas the generation of the activity programs required the simultaneous consideration of the desired household program with each individual member, the resulting interaction forces are now imbedded in the constraints of the individual. For example, a household requirement to be home at a certain hour is represented as a mandatory, planned activity, fixed at home, at that time. Any pattern violating this fixity would be deemed infeasible.

The individual activity program incorporates five separate data arrays:

- (1) the Program Parameter Data (PPD) vector,
- (2) the Activity Program Data (APD) array,
- (3) the Modal Availability Data (MAD) array,
- (4) a Coupling Constraints Data (CCD) array, and
- (5) an Activity-Distance Data (ADD) array.

The PPD vector identifies the individual, his/her household, the number of planned activities, the location of the household, and the endpoints of his/her travel day. The latter two variables result from the interaction analysis in the TROOPER module and serve to restrict the simulation period in response to individual constraints.

The APD array forms the individual activity program itself, representing the set of planned activities for that individual and the

corresponding spatio-temporal characteristics of each activity. Each row of the array identifies a specific planned activity, including only those home activities that are distinctly planned in advance or specified by household constraints (thus, excluding the conventional "return home" trip). Each activity is described by a row vector of characteristics which serve to identify the activity, its desired duration and location, and spatial, temporal and transportation constraints.

In the generation, both activity duration and activity location appear as simplifications of actual behavior. Treating duration as deterministic, while simulating the actual observed pattern, does not consider the affects of scheduling in planning the activity. Although numerous past studies (e.g. Kitamura, et al., 1981) have indicated a correlation between sojourn duration and tour length, the simulation model presently treats these variables independently. Activity duration is thus planned in advance. The impact of stochastic effects on duration is incorporated into the model structure in the estimation of utility in which activity durations are sampled from hypothesized distributions based on activity type, tour characteristics and the individual trip maker. Duration is fully simulated for insert activities. For planned home activities, the associated planned duration represents a minimum stay, and the program simulates extended durations.

The destination choice issue is more complex, particularly from the standpoint of an acceptable solution methodology. The assumption in the model is simply that the destination is planned with the activity.

The potential is present to introduce variable destinations for unplanned activities, that is, those activities arising during the travel day. If unplanned activities are restricted to take place within existing simulated tours, the reduction in space-time flexibility from other activities, tours, or pegs in the activity pattern could produce a tractable destination choice set. Although modeled as a separate issue, this problem is beyond the scope of the present integrated simulation model.

The temporal availability of the household automobile(s) is input through the MAD array. This data reflects the time periods in which an individual has an automobile available for use. This array may be considered fixed, or may be updated as the automobile becomes available through the scheduling of other individuals within the household. The array may be extended to discriminate among various household automobiles.

Ordering of activities may be specified in the Coupling Constraints Data (CCD) array. If a certain activity must precede or follow any other activity(ies), the CCD array is utilized to remove from the simulation any sequence of activities containing an unacceptable order. The CCD array is augmented within the program to eliminate those sequences which violate timing constraints.

The final array which completes the activity program is the Activity-Distance Array (ADD). At present this array is computed externally, and is appended to the activity program for input to the second module (SNOOPER). The TROOPER module is to be programmed to produce this array directly.

The ADD array represents the spatial separation between the the locations of each planned activity (including the home location). It is necessary in the combinatoric scheduling element of this module to produce proper activity timing based on travel time between location pairs. These travel times are by free-speed automobile. Adjustments for alternate modes may be made; however, public transit must be treated independently due to obvious spatial and temporal restrictions.

Combinatorics are introduced in the module's second element through a two-stage process. The individual's activity program consists of a list of planned activities with no consideration of intermediate, unplanned, return-to-home trips. The simulation process, however, in consideration of all feasible activity patterns, must generate all possible variations of simulated tours which incorporate the planned sojourns of the program. All tours are formulated as ultimately home-based. Potential intermediate home activities are inserted at each possible location of each activity ordering, generating all potential tour arrangements. (The duration of these inserted home activities is simulated in the fifth element of the module.) The first sequencing stage produces the number of intermediate home inserts, and the second stage iteratively produces all permutations of the activities.

Combinatorial algorithms are frequently limited by the rapid increase in potential arrangements as additional "items" are included. For example, increasing the number of planned activities from four to five produces an order of magnitude increase in the number of distinct combinations (from 192 to 1,920). The increase in potential arrangements

becomes somewhat intractable computationally at 6 planned activities (23,040 distinct orders). Several factors reduce this potential problem including coupling constraints and evidence of activity program size from various data sets.

The second element performs a test for violations of coupling constraints, both specified and implied. Any sequence which violates an activity constraint is removed from consideration. The simulation element performing this test also avoids all additional sequences which contain the misspecified orderings. This is accomplished in a manner similar to Clarke (1980).

Modal choice is introduced to the simulation procedure by a similar combinatoric procedure. The assumptions of the simulation are:

- (1) Each tour is completed utilizing a single mode, and
- (2) a change in mode may occur only at home.

Under these assumptions, each sojourn in a tour is accessed by the same mode, and since tours are defined in this study as home-based, only at a home activity (either planned or discretionary (inserted)) may a change of mode occur. In other words, each tour is mode specific, the mode choice decision assumed to occur when the tour is initiated.

Use of a coded travel network facilitates modal analysis for private modes, given the spatial and temporal flexibility of the automobile. The inclusion of walking trips is possible through a modification of the network, and possibly a distance restriction for pattern feasibility. The integration of public travel modes, however, is considerably more complex due to the their characteristic inflexibility--both spatial and

temporal. The restrictions of fixed routes and fixed schedules produce more rigorous constraints on the feasibility of any given pattern. A test for spatial connectivity, by a specific public mode, must be performed followed by a calculation of travel time based on the appropriate schedules.

The issue of connectivity for transit involves not only the consideration of direct routes, but also connectivity through transfer to intersecting routes. This, of course, complicates the timing calculations as the scheduling problem must consider the transfer route, and its temporal availability. To complicate matters further, the feasibility of the entire simulated tour must be established rather than feasibility on a link by link basis as with automobile. Since it has been assumed that changes in mode may occur only at home, a restriction imposed by combinatorics, a tour is mode specific. If any one link of a tour cannot be successfully completed, due either to system connectivity or suitable scheduling, then that tour and simulated pattern become infeasible.

In the transit sub-module, a feasibility test for spatial connectivity is made and a maximum distance restriction placed on walk trips (if desired) to ensure overall feasibility of the tour. Once feasible modal sequences are assigned, a test of scheduling feasibility is performed.

Once an activity program has been placed in an acceptable order and assigned modes, the simulation model schedules the activities. Using the

earliest and latest unconditional starting and ending times, the desired activity duration, and the travel times between locations, a test for pattern feasibility is formulated based on two constructed vectors:

(1) Earliest Conditional Starting Time

(2) Latest Conditional Starting Time

Pegs established by the unconditional start and the unconditional ending times, the duration of an activity, and the corresponding travel time to or from a second activity, may preclude the given order of activities. For example, consider a desired shopping activity which may be performed from 8:00 A.M. to 9:00 P.M., with an associated duration of one half hour. If a fixed work activity occurs from 9:00 A.M. to 5:00 P.M., the shopping activity may only occur before the work activity if the travel time between the two is less than 30 minutes. However, if the work activity were flexible (that is, the differences between the unconditional pegs is greater than the desired duration) then a greater travel time could be acceptable.

The earliest conditional starting time may be interpreted as the earliest that a particular activity may begin based on the scheduling of previous activities. The latest conditional starting time may be interpreted as the latest an activity may commence given the scheduling restrictions of activities which follow.

The last task of this element is to determine scheduling feasibility of the proposed pattern through a comparison of the earliest conditional starting time and the latest conditional starting time. The scheduling flexibility of various activities (taken here as a positive difference

between the latest and earliest conditional starting times) may produce a range of similar, yet distinct patterns. The number of potential starting times for the initial activity of a sequence is computed based on the flexibility described above.

All succeeding planned activities on the simulated tour are assumed to occur as soon as possible after the execution of the previous activity. The time associated with a scheduling delay due to conditional starting times is considered waiting time. It is important to realize that at no time in the constrained combinatoric scheduling algorithm is any attempt made to establish the superiority, or inferiority, of any given activity pattern. This second program module's sole function is to produce the entire set of feasible activity patterns available to each household member.

The range of start times for inserted home activities is computed through the incorporation of acceptable waiting time. The vector of activity scheduling variation and the computed durations for home inserts enter the actual scheduling algorithm to produce the fully-scheduled activity pattern. A number of pattern variations are produced for each feasible activity sequence, based on the flexibility. However, the nature of the calculation of duration for home inserts ensures that patterns are not formed by extending the waiting time at an activity location by reducing the duration at the previous home insert, producing a series of virtually identical patterns.

The scheduling algorithm is a simple, imbedded, iterative scheme with the number of levels based on the number of activities to be scheduled

and the number of iterations based on the schedule variation of each activity. For an initial start time for the first activity, each subsequent activity is scheduled within the extent allowed, the last activity being tested at all possible variations, for each variation of a previous activity, and so on back to the initial activity. For home insert activities the duration estimated previously is incremented by the dwell time at home and the net result is a full-schedule activity pattern with the order, initial start time, and all durations specified. At the end of each level of the iterative scheme, the pattern specification function is accessed.

The sixth and final element of the second module produces the actual simulated activity pattern in standard form. It is assumed that travel to the first activity is planned such that the arrival time at the activity location is equal to the activity start time with no associated waiting time. For each succeeding activity, the arrival time is set to the previous activity's finishing time plus the travel time between the two locations. The activity start time is taken as the maximum of the arrival time and the earliest unconditional start time. Wait time before activity commencement is the difference between start and arrival times, and activity finishing time is simply start time plus activity duration.

A full pattern is specified for every combination accepted based on:

- (1) insertion of home activities
- (2) activity permutations
- (3) modal permutations, and
- (4) individual activity scheduling.

The simulation is completed for each individual in the household in question, for as many households as desired.

Several observations should be made regarding the constrained, combinatoric scheduling algorithm. First, the algorithm generates the full set of potential activity patterns available to an individual given a specified activity program. No decision rules or basic behavioral hypotheses are invoked, and no claim is made on the nature of the results being representative of an actual individual choice set. The third and fourth modules of the simulation model produce a tractable choice set for the individual and his/her household. The importance of the present module is its simultaneous consideration of the range of choice attributes in the formation of an activity pattern. Not only is sequence and duration simulated, but a fully scheduled activity pattern results. Implicit to the formation of the patterns are the concepts of tours and mode selection and, most importantly, an extensive range of household and environmental constraints are imbedded in the resultant structure.

Module 3. Reduction to a Distinct Pattern Set

The individual's feasible pattern set resulting from the second simulation module may be of considerable magnitude in even a significantly constrained situation. There is not, in general, any guarantee that the alternatives of the feasible set are perceived by individuals as distinct options. Certain sets of activity scheduling decisions, because of their similarity on several dimensions, may be

perceived as indistinguishable and therefore should not be treated as separate options for the individual. When such similarities arise, the set of feasible patterns must be modified in such a way that each of the resulting options is as distinct as possible. Recent empirical research (Recker et al., 1980; 1981; Pas, 1981) has demonstrated the potential of various classification techniques in formulating "representative activity patterns" (RAP's) defining homogeneous groups of distinct patterns. An added result of classification is reduction of the feasible set to a manageable option set, defined by the classification algorithm as independent (in the statistical sense), alternate activity patterns.

The third simulation module (GROOPER) has been developed and implemented to identify an independent pattern set through the specification of representative activity patterns. Although the present formulation has focused on a method explicitly devised for pattern analysis--a multiple scale, scoring function classification technique, the potential for analysis by other techniques is imbedded (such as pattern transformation by Walsh/Hadamard or Haar transformation algorithms).¹

The variables used in the scoring function are specified directly from the set of feasible patterns. Additional attributes may include accompanying individuals and activity waiting time (pre- and post-). The variables are listed in the original order of activities in the activity

¹These transforms are discussed explicitly in Recker et al. (1980). A rotational transform is used, the transformed data matrix reduced, classified and inverted, and the representative patterns are produced.

program to ensure that characteristics of a specific planned activity will be compared with similar characteristics in alternate patterns for the same planned activity. Pattern sequence is implicit to the classification process. This procedure follows intuitively since activity information should be compared with similar information in alternate patterns to produce meaningful representative patterns.

Several feasible patterns are randomly selected and assigned as representative patterns to initiate the scoring function for each individual. A range of desired groupings (i.e. number of RAPs) is specified, influenced perhaps by the size of the feasible pattern set, or by limitations associated with a realistic choice set.

The random assignment of patterns commences an iterative process where succeeding patterns are assigned to the RAP with which it is scored closest. After all patterns are assigned, new RAPs are estimated, and the assignment process repeats. The process converges when all feasible patterns are assigned to the "best" representative activity patterns, and the process is stabilized. The algorithm provides for alternate random initialization points and automatically adjusts the range of RAPs acceptable at each iteration.

The pseudo F-ratios associated with each homogeneous grouping (RAP) executed are compared, with the pattern set associated with the maximum F-ratio considered the "best" distinct pattern set. The full set of feasible activity patterns generated in the constrained, combinatoric scheduling algorithm are now depicted as "members" of a limited set of fully specified, representative activity patterns. The opportunity set

of feasible patterns is now reduced to the option set of representative patterns.

The observed activity pattern for each household member, translated into classification variables, is then compared to each RAP in the selected option set. A pairwise comparison is made by re-entering the pattern recognition algorithm, utilizing the option set RAP's as the random patterns, and assigning the observed pattern to the "best" RAP.

Module 4. Specification of the Choice Set Formation Model

Implicit in the approach outlined above is the assumption that the number of representative activity patterns (i.e., alternatives) resulting from the pattern recognition/classification algorithm is of sufficiently small size so that the individual decision maker can compare the utility of each alternative and select the one that maximizes his/her utility. However, those individuals who have very few constraints imposed on them by their environment will have, in general, a large number of opportunities available to them which, in turn, may result in a large number of distinct alternatives. Recent studies in the fields of psychology and marketing research have presented evidence that there exists a strong relationship between the complexity associated with a choice situation and the decision rule used by an individual. Results obtained from controlled experiments conducted by Payne (1976) and Park (1976) revealed that individuals often use non-compensatory decision rules (often some type of conjunctive rule) in complex choice situations and compensatory decision rules in choice situations involving small

numbers of alternatives. Forester (1977) states in his conclusions that transportation researchers and planners should ". . . consider the possibility of non-additive decision rules and test a broad range of choice models before adopting any one model as an explanation of individual choice behavior." As a preliminary attempt at investigating whether individuals do, in fact, employ different decision mechanisms based on the size of the decision problem, a prototype choice set formation model has been formulated, wherein the choice of a specific activity pattern is viewed as a multi-objective decision problem.

One concept that is inherently tied to decision making in the presence of multiple, conflicting objectives is the concept of non-inferiority. A feasible solution to a multiple-objective decision-making problem is non-inferior if there exists no other feasible solution that will yield an improvement in one objective without causing a degradation in at least one other objective.

It is assumed that individuals maximize the utility they can achieve from the set of non-inferior opportunities (as opposed to the set of total opportunities); i.e., the feasible opportunities actually evaluated using a utility maximization decision rule are those opportunities judged by the individual to be non-inferior based on his/her decision objectives.

In concert with this approach, a multi-objective programming algorithm has been developed that identifies those solutions that are non-inferior based on a set of decision objectives. The algorithm (SMOOPER) initializes the first feasible activity pattern as non-inferior and iteratively adds subsequent non-inferior patterns to the set. Any

pattern within the set which subsequently is found inferior as new patterns are added is deleted from the non-inferior set. Once these non-inferior solutions are identified they are input to the classification algorithm (to determine the choice set) and choice probabilities can then be estimated.

Module 5. Specification of the Pattern Choice Set

The reduction of the distinct feasible activity pattern set to the subsidiary non-inferior set was executed primarily to eliminate inferior pattern alternatives from individual consideration. The effect of this operation also produces a more tractable alternative set. Figure 1 depicts the translation of the opportunity set, made up of feasible patterns, into the option set composed of non-inferior patterns. If desired, the size of this option set may be reduced further by application of the fifth module, REGROOPER, to produce a distinct choice set of any size mandated either by computational limitations or theoretical implications. (The tradeoff in the reduction is, of course, the clarity of the definition of the patterns in the choice set.)

The same objectives defined and utilized in the fourth simulation module to identify non-inferior patterns are reapplied to estimate their corresponding value for each RAP, one of which is identified above as the observed pattern choice. This last element thus produces a well-specified choice set defined along the same dimensions for analysis through a desired choice model, the sixth and final module of the simulation model.

Module 6. Activity Pattern Choice Model

Any existing choice model (e.g., random utility (LOGIT) or non-compensatory may be utilized to establish pattern choice based on the specified choice set from the fifth module. Currently, the model is based on a multinomial logit choice model.

Results of Preliminary Estimation of Prototype Choice Model

Initial testing of the STARCHILD model structure was accomplished by means of a preliminary estimation of the activity/travel pattern choice model. Utility measures consistent with those components outlined in the attendant theoretical development of the model (Recker, et al, 1983) were computed for each representative activity pattern (RAP) contained in the derived choice sets of each of 79 individuals in a sample of respondents to the 1979 Windham travel diary survey (Davis, et al, 1981). The actual variables used in the prototype model specification are identified in Table 1.

A multinomial logit model of selection of activity/travel pattern was then estimated using only these variables, i.e., those which arise directly from the theoretical development. The results of the estimation are displayed in Table 2. The model was able to predict 63% of the observed activity/travel patterns correctly. ("Correct" in this sense is taken to mean that the predicted probability of the observed choice is greater than that of a nonobserved alternative.) For the degrees of freedom associated with the estimation a t value of approximately 1.66 is required for statistical significance at the 0.05 level. The

TABLE 1
VARIABLE DEFINITIONS

<u>VARIABLE</u>	<u>DEFINITION</u>
TRAVEL TIME:RU&U	Travel time to activities deemed either unimportant or relatively unimportant to the well being of the household
TRAVEL TIME:VI&I	Travel time to activities deemed either important or very important to the well being of the household
TRAVEL TIME:HM	Travel time to discretionary in-home activities that occur between trips to out-of-home activities
WAIT TIME	Time spent waiting (at the activity location) for a scheduled activity to commence
HOME TIME:S&N	Time spent at home either alone or with some (but not all) other members of the household
HOME TIME:ALL	Time spent at home with all other members of the household
POTENTIAL:ACT	A measure of the potential to meet unplanned activities should such need arise
POTENTIAL:TRAV	A measure of the expected travel time to meet unplanned activity needs
RISK:RU&U	A measure of the probability of not being able to participate in a planned activity, that is deemed either unimportant or relatively unimportant to the well being of the household, due to stochastic variations in travel time and/or activity duration
RISK:VI&I	A measure of the probability of not being able to participate in a planned activity, that is deemed either important or very important to the well being of the household, due to stochastic variations in travel time and/or activity duration

TABLE 2

ESTIMATION RESULTS CHOICE OF ACTIVITY/TRAVEL PATTERN

VARIABLE	COEFFICIENT	STD. ERROR	t
TRAVEL TIME:RU&U	-.13302E 01	.22048E 01	-.603
TRAVEL TIME:VI&I	-.13495E 01	.65779E 00	-2.052
TRAVEL TIME:HM	-.11002E 01	.58350E 00	-1.885
WAIT TIME	-.44620E 00	.28281E 00	-1.578
HOME TIME:S&N	.30058E-01	.16110E-01	1.866
HOME TIME:ALL	-.11369E 00	.53885E-01	-2.110
POTENTIAL:ACT	-.70914E 00	.77945E 00	-.910
POTENTIAL:TRAV	.32048E 00	.15835E 01	.202
RISK:RU&U	.72933E 00	.56425E 00	1.293
RISK:VI&I	-.54147E 00	.24722E 00	-2.190

PERCENT OF CHOICES PREDICTED CORRECTLY = 63%

estimated coefficients of the variables are all plausibly signed and offer some interesting preliminary conclusions regarding trip chaining and complex travel behavior in general.

Travel time associated with activities in an individual's program that are judged as unimportant to the well being of the household was found to be insignificant in the choice of activity/travel pattern. The explanation of this result is rooted in an understanding of the nature of the types of activities which typically fall within this category (i.e., "unimportant") in the sample. Such activities typically were of the nonrepetitive, sporadic variety (e.g., spectator sports, movies and theatre, restaurant, etc.). The implication is that, because these are "rare" events, not much attention is devoted to "fine tuning" the repetitive portion of the activity/travel pattern to minimize travel to these activities. A second feature typical to these activities is that they tend to involve more than one member of the household. Since for the sample there was only one mode of travel considered (automobile), all potential travel time savings associated with the activity/travel pattern choice alternatives involved complex travel behavior (i.e., trip chaining) of one form or another. The implication is (expectedly) that trip chaining is not conducive to activities involving coordination among several individuals.

Conversely, travel time associated with important activities was found to be a significant determinant of the choice of patterns involving trip chaining behavior. These activities tend to be repetitive and involving only the traveler.

The variable TRAVELTIME:HM measures the time required to return home following an out-of-home activity rather than continuing on to the out-of-home activity scheduled next in the activity program. As such, it reflects the additional travel time associated with non-trip-chaining behavior. The results indicate that individuals indeed are sensitive to this additional time commitment associated with nonoptimal (in the travel sense) travel behavior.

Time spent waiting for scheduled activities to commence was found to be only marginally significant in the choice process. However, in that waiting time in this estimation is principally a product of chaining behavior, there is a weak conclusion that limited temporal availability of activities tends to divert choice from patterns which involve extensive trip chaining.

The results on the HOMETIME variables indicate a tendency among individuals to choose activity/travel patterns which allow them to be home at times when either no or only some other members of the household are there while permitting them to be away from home when all other members of the household are home. A potential explanation of this result is that the fewer the household members at home the more likely that an in-home need that arises must be met by the traveler. A clear example of this explanation is exhibited by a household with small children in which both spouses work. The need for one spouse to return home directly following work may be removed by virtue of the other spouse being home.

The estimated coefficients associated with both POTENTIAL variables tested insignificant. Although considerable additional investigation of alternate constructs of these measures is warranted, the preliminary indication is that individuals are not sensitive to the possibility of unforeseen events arising when constructing their planned activity/travel pattern.

Finally, the results associated with the RISK variables indicate that the additional travel time to home while between activities, which biases choice toward patterns which involve trip chaining, may be counterbalanced by the risk involved in stringing (i.e., chaining) activities together. This risk is due to stochastic variations in duration and/or travel time which may cause participation in one or more of the activities to become infeasible. This effect, according to the model results, is pronounced in cases involving activities deemed important to the household. Although insignificant, the sign of the coefficient of the RISK:RU&U variable tends to indicate that trip chaining behavior may be favored in accessing activities which are of a discretionary nature.

It must be emphasized that these results are preliminary, and represent only one specification of a complex model system which is itself in prototype form. While encouraging, the results also open many aspects of the model system to further investigation and refinement.

Directions for Future Research

Directions for future research fall generally into two categories: 1) refinement and testing of the model system and 2) application of the model system to policy issues.

Much work is needed in the continued refinement and testing of the model system. Rather than attempt to identify areas of potential concern (they are both too many and too specific), it suffices to state that the model system proposed is a first draft of an extremely complex system (both from theoretical as well as operational viewpoints) that remains virtually untested. And, although initial empirical results are encouraging, they should in no way constitute final validation of either the model process or the theory advanced.

From a policy perspective, the research provides a potential methodology whereby the impact of various transportation-related policy options on the travel/activity behavior of individuals can be assessed. Consistent with the theory advanced in this research, travel behavior is seen as resulting from activity scheduling behavior. This activity scheduling behavior is subject to constraints imposed by the specific characteristics of the transportation, activity and household systems (i.e., the spatial/temporal connectivity of activity locations by travel modes and the interaction between household members). Any policy that changes the characteristics of the transportation, activity or household system will therefore change the nature of the constraints imposed on the individual, which in turn, will alter the individual's set of

alternatives. Policies that may be investigated based on this framework include:

- (1) Changes in operating hours of activity locations (e.g., stores, banks, schools)
- (2) Flexible work hours (flex time)
- (3) Restrictions on total daily auto vehicle miles of travel (VMT)
- (4) Changes in the spatial distribution of activity locations

To estimate the impact that these various policies have on activity scheduling behavior (and hence, on travel behavior) the following procedure could be employed:

- (1) The new set of constraints imposed on the individual by the proposed policy is specified and input to the simulation model,
- (2) The set of feasible activity patterns resulting from the new constraints is calculated,
- (3) The new feasible activity patterns are classified to construct the new choice set, and
- (4) Using the choice model parameters estimated previously, choice probabilities for the new pattern alternatives are obtained.

Any policy involving a change in the operating hours of a specific activity type can be incorporated by simply changing the temporal availability parameter associated with that activity type. For example, flextime can be introduced into the model by increasing the temporal availability of the "work" activity and allowing the start time of the "work" activity to occur over some period of time (as opposed to being constrained to occur at a particular point in time). The duration of the

work activity, however, would remain unchanged. To estimate the impacts of a restriction on total automobile travel, the total daily automobile VMT associated with each feasible activity pattern could be calculated and all those patterns having VMT in excess of the limit are eliminated from the individual's opportunity set prior to the implementation of the classification and choice models. The impacts of changes in the spatial distribution of activities could be estimated by changing the observed locations of the activities contained in the individual's activity program. In addition to these transportation-related policies, the impacts of the introduction and utilization of new modes of travel (e.g., electric vehicles) could also be estimated, by specifying the following vehicle design parameters:

- . speed
- . range (the amount of time that the vehicle can be used before it needs recharging)
- . recharge time (the amount of time before the vehicle can be used again)

As with the other policies discussed above, these design characteristics impose a new set of constraints on the individual which would be used to generate a new set of feasible activity patterns. Once these new opportunities are generated, the choice set is created and new choice probabilities can be estimated.

In addition to forecasting an individual's activity pattern changes in response to policy-induced alterations in the transportation and activity systems, the proposed methodology may also be used to provide

information regarding the range of potential opportunities (and hence, possible choices) available to individuals. This information can then be used to identify segments of the population most impacted by policy alternatives.

These and a wide range of other policy issues may be analyzed using the model system developed in this phase of the research, contingent, of course, on final validation of the model.

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