this would imply a general decline in average vehicle size per household. The fuel-conservation implications of such trends cannot be determined until automobile usage patterns of multiautomobile households are more fully examined. The relationship between household size and vehicle size should also be explored.

More extensive data sources are required in order to develop a more complete understanding of consumer attitudes and behavior toward small automobiles. Data limitations forced us to use correlational methods, with one exception. The interrelationship between consumer attitudes and behavior should be studied more fully through the use of causal models (5, 6). This would necessitate the collection of new data sets that can more properly reflect consumer socioeconomic and attitudinal effects on automobile and light truck purchases.

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Rationale for an Alternative Mathematical Approach to Movement as Complex Human Behavior

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This paper contains arguments and data analysis for a new mathematical approach for the study of human behavior such as intraurban travel. Current disaggregate models are criticized because of their unrealistic axioms about (a) the simplicity of behavior incorporated in the concept of the dependent variable, a trip; (b) the constancy, ad hoc differentiation, or random variability of choice sets between persons; and (c) the complexity and uniformity of decision strategies and rules about how utilities for options are formed and manipulated. Arguments are advanced for more realistic approaches to movement; for inductive data analysis to specify new descriptive choice models, based on different assumptions; and hence for a consistent underlying microeconomic theory that is based on more realistic axioms for the ultimate derivation of improved analytic models of travel. The paper contains exploratory small-sample analysis to demonstrate that, by reconceiving movement as complex, hypotheses can be formulated that fit standard kinds of travel data as well as current models that have different, less realistic assumptions. Movement is thought of as (a) a sequence of events differentiated by time and space coordinates, (b) choice sets that individuals and groups find systematically limited and variant because of the spatial properties of cities, and (c) decision strategies that are simpler and more variant than currently believed because of the differences in choice sets. This paves the way for the further development of the alternative approach proposed for the study of movement as complex human behavior.

Recent well-known criticisms of disaggregate utility-theory-based models of movement come from diverse sources (1-4). The realism of a number of different assumptions has been questioned. Specifically, it has been asserted that models of spatial and other travel choices:

1. Do not provide a realistic description of the group movements that they attempt to predict, since they ignore decisions about the sequence of a household member's activities during a given decision period (5-9);
2. Assume that limited sets of the socioeconomic characteristics of individuals and characteristics of given options (such as the travel time differences to

designated alternative destinations) are the major determinants of the demand for recurrent movement [the models thus underemphasize and do not explore the relative effects on behavior of many other possibly important variables, especially those spatial and temporal variables beyond the individual's control (institutional variables) that influence the supply (numbers and kinds) of available options] (5, 10, 11);

3. Assume that each individual confronts an identical, complicated choice situation (choice sets containing at least two alternatives for modes, destinations, activities, trip times, respectively); however, in many instances individuals have a very limited number and few kinds of alternatives in their choice sets, to the extreme of no options or missing preferred alternatives because of spatial, temporal, and other constraints (1, 12, 13); and

4. Assume that all individuals form, manipulate, and maximize utilities in the precise and complicated strict utility-maximizing way, even for simple routine behaviors like travel (9, 14).

Strict utility-maximization is an evaluation procedure whereby, given a set of alternatives, an individual, for each member of the set in turn, first, evaluates the part-utilities of each attribute of an alternative; next, sums them (or uses some other combination rule) to estimate an overall unique utility for each alternative; and then allocates choices over each pair of alternatives in accordance with the ratio of their total utilities.

REALISTIC DESCRIPTIVE AND EXPLANATORY VERSUS CLASSIC DEDUCTIVE MODELING

The criticisms of these unrealistic assumptions in current mathematical models of movement and, by implication, of the same assumptions in the models' most widely accepted choice-theory base in microeconomics (3) seem well founded (15). No matter how well any theory or model predicts, a better alternative will always be one that might predict as well but also incorporates more realistic assumptions. The simultaneous appearance of a number of writings that reassess the realism of an established theory or a model derived therefrom is indicative of the timeliness of a search for the better alternative.

A far more interesting rationale stems from the growing recognition in the late 1970s of an apparent cleavage in the goals of, and hence the priorities accorded to, the normal criteria of realism and predictive-forecasting accuracy for the assessment of models of human social systems. It is well accepted that theories and models of human social behavior, including those of movement, inevitably reflect the personal political mores of their authors (16). One reason for this is that choices that reflect such mores exist and must be made among the typically many kinds of language terms for the same kinds of human phenomena in modeling (for example, between social classes and role-complex-related groups to describe humans in cities). The debate on value freedom in theories and models for human social behavior has therefore necessarily turned on the political and other biases built into the theories and models per se, rather than on the political and other biases in the use of results of objective research, as in the physical sciences (17).

Choice of political orientation therefore takes priority over, and precedes, scientific work on human behavior, and, given this, only the range of political perspectives directed toward major modifications of such behavior through collective action now have credibility in the so-called advanced societies that are preoccupied with crisis situations, such as energy shortages and race relations. This contrasts with the goals of physical scientists who are concerned with natural phenomena, which can generally be defined in neutral language, and whose intent is to identify the objective laws of their behavior, so that useful adaptations to such laws (rather than modifications of them) can be made by predicting the behaviors of the phenomena accurately. The effect of the primarily radical political orientation of scientific studies of human social behavior (including movement) may be argued to require the reversal of priorities of evaluation criteria for theories and models from accurate prediction to realistic explanation.

It is a truism that social systems, including cities and their movement patterns, are dynamic. Major decisions in both public and private sectors are directed toward altering current trends through changing the behaviors (manipulating the rules regulating the behaviors) of human populations. Policy issues in the urban transportation area, for example, by the late 1970s, encompassed debates on how to alter the habits of urban populations for energy conservation, the redesign of urban neighborhoods and traffic flows, the servicing of latent demand in sprawling suburban cities with paratransit, increasing the mobility of the elderly and handicapped, downtown revitalization, and adequate public service delivery, including health care. It is imperative to identify correctly the causes of, and the decision mechanisms behind, individual and group behaviors in order to be able to identify, modify, and manipulate those variables and the relations between them that could induce change most effectively. Hence, the requirement that axioms or assumptions in analytic theories and thence in derived policy-related models of human social behaviors be realistic and that such assumptions be correctly related causally to human actions. For human social systems, realistic explanatory theories and models from a variety of political perspectives will provide for a necessary diversity of potential treatments of urban and other problems. Less emphasis is desirable on classical analytical-deductive work, in which the realism of axioms or assumptions can be disregarded.

Both the progress-of-science and societal problem-solving arguments for more accurate assumptions in theories and models for movement are different from the standard arguments originally advanced for developing behavioral models in the late 1960s and early 1970s (18, 19). The original rationale for disaggregate models of movement seems to have been that, by incorporating accurate assumptions about individual decision making, theories and models would be better predictors. Although this argument still holds, the more recent arguments seem now to make the strongest case for still more behavioral approaches to the study of movement to meet inseparable scientific and political goals. Within this general perspective, the demand for new theory for, and models of, spatial and other kinds of travel behavior, without any of the key unrealistic assumptions of the present ones, seems timely and well founded.

A number of approaches to develop such new models for movement seem possible at this point. First, there is the possibility of exploring successive modifications to existing models, such as the logit and probit, with the goal of improving both their predictive accuracy and their explanatory ability by modifying one or another unrealistic assumption in turn (20-23). Since such models are basically used to forecast aggregate urban travel flows, on the assumption that, once identified through a set of coefficients that link travel to signifi-

cant independent variables, current patterns of behavior and decision processes will continue at least in the immediate future. This approach can be used to furnish better numbers for the ongoing highway and transit investment decisions that must be taken now. Second, there is the possibility of developing simulation models that will isolate the reasons for individual and group responses to a specific political activity, such as staggering work hours or changing school hours in a suburban city. The household activity-travel simulator developed at Oxford and described by Jones in a paper in this Record is one such device (8, 24). This work can meet immediate policy needs for investigating how to try to modify behaviors without necessarily estimating precisely the numbers of persons who make different kinds of behavioral changes. Such research appears better oriented toward some of the newer political requirements for models of movement than simpler and earlier macro-scale forecasting approaches.

Finally, a need remains for research to explore the development of new explanatory mathematical models and a consistent, revised underlying economic theory of demand that have far less grossly unrealistic assumptions than present versions. The emphasis at the moment should not be on the predictive or forecasting accuracy of the models or of the theory produced, or on immediate policy applications at local levels, but rather on the rewriting of models of movement in a rigorous explanatory mode and, by using the insights so gained, to restructure the underlying microeconomic theory base (25). By rewriting more realistically the microeconomic theory now used to derive models not only of human responses to any transportation-related political action, but also, for example, models of housing and employment demand, the generic basis of many kinds of urban policy can be appropriately restructured. This will supplement piecemeal approaches to urban systems, which militate against obtaining conceptually or methodologically comparable findings and well-integrated and consistent results in practice. All this does not, of course, deny the urgency also of developing models of movement to meet immediate urban transportation needs.

RESTRUCTURING THEORY

The assumptions in policy-related models that should be changed first are not just those that current work in the literature on movement suggests as the most urgently in need of revision but should also include important general axioms of microeconomic theory. Since a more detailed review of the travel literature concerning these assumptions and a critical discussion and evaluation of them is already available elsewhere (9), only a summary statement of the three principal axioms selected is provided here:

1. The individual and collective behaviors to be explained or predicted by any theory or model are simple (that is, are single, observable, recordable, and measurable events) not complex (that is, sequences of events in space and time). For example, in models of movement, the behaviors to be explained have generally been assumed to be trips by individuals, where a trip is a single movement by a person from one stop to another.
2. The individual behaves by making a choice from a set of alternatives, where the set always contains at the very least two (and usually many) alternatives for each individual and where the set is either constant between individuals or varies between them in some arbitrary way or in some random fashion, defined by an arbitrarily selected probability density function. This assumption is incorporated in both the standard strict and random utility versions of the multinomial logit model of choice behavior and some applications and modifications of them (26) (we call this the constant-choice-set axiom).
3. The individual's decision making is extremely complicated. Specifically, all individuals in a population make all decisions in the strict utility-maximizing way in all situations. This is incorporated into travel-demand models through assuming the strict utility-maximizing decision strategy for all kinds of travel choices (20).

Ongoing research, therefore, has three major goals. The first goal is to investigate human behavior as a complex phenomenon and, in particular, here, to explore the mathematical reconceptualization and measurement of the individual's travel as an example of such complex behavior, to indicate the feasibility of dependent variables defined at an increased level of complexity for modeling. The second goal is to develop a causal model of choice-set formation for the individual, assigning probabilities to any alternative included in the set, to handle the implausibility of the constant-choice-set axiom. The third goal is to identify the simpler decision strategies that different individuals might use to select alternatives in situations of different degrees of complexity, as defined by the numbers and kinds of alternatives in choice sets, and to attempt to develop mathematical choice models for them. This follows from recent advances in choice theory in psychology that emphasize the variability of decision strategies between individuals in problem-solving situations of different degrees of complexity (27).

In sum, our research is directed toward the use of data analysis to specify an explanatory and descriptive rather than a deductive and predictive model for the individual, and thence for appropriate population groups, of the general form:

$$P(j) = P(j\Sigma A), P(j/j\Sigma A) \qquad (1)$$

where

- j = the individual's complex behavior (to be defined);
- A = the choice set of alternatives from which j is selected for the individual;
- $P(j\Sigma A)$ = a causal model that assigns alternatives to the choice set for the individual; and
- $P(j/j\Sigma A)$ = the appropriate decision strategy for the selection of an alternative, assuming that there is more than one alternative in the choice set for the individual.

(At the moment, Equation 1 ignores possible complex interdependencies between its different right-hand side, and right-hand side and left-hand side, components.)

The relaxation of the constant-choice-set axiom and the related development of the model for the individual's choice set in Equation 1 is the most important goal for future research, as indicated by trends in the literature. [For detailed discussion of the diverse important but hitherto analytically intractable urban policy-related issues it opens up see another article (25).] Inquiry into the determinants of the individual's choice set now has a relatively long though spasmodic history; however, as yet, no satisfactory model of choice-set formation has been developed. Over a decade ago, North American geographers investigated the relations between the

individual's opportunity set for spatial choice (all his or her spatial alternatives in a city), his or her cognitive opportunity set (known alternatives), and his or her choice or contact set (all those alternatives ever used) (28, 29). So-called choice-set generation problems were also noted independently in the mid-1970s in the United States, first in connection with spatial-choice modeling by both geographers and engineers (1, 30, 31) and later in connection with mode-choice modeling (32, 33). Independently, workers in Europe began inquiring into the ways in which many possible constraints limit options individuals have for decisions, in many cases reducing options to very few, one, or none (5, 8, 12, 22, 24, 34-36). At the moment, little is known about the nature, number, and relative importance of the many variables now postulated to form the choice sets for different decisions made by the different individuals in different situations.

Recent European work emphasizes the relative significance of institutional constraints. Such constraints are often encountered by the individual or group in the form of the detailed spatial distributions of activities (residences, work places, or shops) and their scheduling within the city (urban space-time or spatial constraints). Such spatial constraints need detailed definition and measurement for large population groups for all kinds of travel decision, and their relative significance vis-à-vis variables more under the individual's control in forming choice sets and influencing behaviors (such as sociodemographics influencing time and money budgets) needs to be assessed for different kinds of individuals and population groups. The development of a causal descriptive model of the individual's choice set could clearly be assisted by inductive data analysis that uses comparable sociodemographic, travel-diary, and geocoded land-use data sets for large samples of individuals in a number of areas in advanced societies (13, 25).

The development of a causal model of the individual's choice set will not only help answer some theoretical questions but could also have some immediate policy implications. The investigation of the relative importance of spatial aspects of institutional constraints and their relation to movement will distinguish those individuals and population groups whose behaviors are determined largely by institutional constraints on choices. These behaviors are best altered through collective action aimed at changing urban spatial and temporal organization, such as through changing places of employment and shopping destinations by controls on residential densities and proximities to transit lines. Alternatively, the development of a choice-set formation model will also discriminate which population groups have behaviors that could be better modified through strategies that rely on alterations by the individual of his or her behavior through manipulating personal constraints, such as time and money budgets.

From the perspective of the long-term development of theory, exploration of actual choice-set formation models for the individual, as outlined here, could permit the explicit incorporation in microeconomic theory of precise statements about important connections between institutional behaviors (that is, societal decision making at the macro level), and observable individual behaviors at the micro level (like travel), through intervening variables that define the space-time structure of the modern metropolis. In the present view, institutions create the differential distributions of activities in space and time that form the varying, tangible day-to-day environments of human beings. These distributions help form choice sets for individuals and groups, which in turn circumscribe the possibilities for their behavior by controlling their access to resources and thus affect in subtle and important ways the distribution of social costs and social benefits in urbanized societies.

The study of spatially defined choice sets, therefore, leads into the study of some special important and invisible aspects of social welfare that arise from different combinations of the relative effects of cooperative collective institutional actions (choice sets) and individual decision making (related decision strategies) for different population groups. Although, of course, this may not be the only way in which institutions affect individuals and groups, and although the operation of institutions through spatial constraints may not be relevant for all individuals in all decision situations, current research indicates that these might be fruitful questions to explore. Revised versions of microeconomic theory for these purposes could draw on descriptive choice-set formation models like the one proposed here to provide for a more rigorous treatment of the differential effects on human groups of collective action primarily directed toward changing institutions: for example, changing the housing market, changing the hiring practices of different kinds of firms in different kinds of locations, changing social roles. Current microeconomic theory assumes institutions and their reflections in the distance properties of land uses in urban systems are exogenous, and therefore, in practice, unchanging and equitable, which is especially revealed in the constant-choice-set axiom of the models of movement derived from it and outlined above. Microeconomic theory itself and derived policy-related models thus permit neither a satisfactory realistic explanation of behavior, well-informed speculation about differential impacts of institutional evolution on social access-to-opportunity costs for individuals and groups, nor the possibility of policies for some of the more radical but not necessarily undesirable social, economic, and environmental transformations that urban systems could still undergo.

Against this grand perspective, the initial tasks of the remainder of this paper appear extremely limited. Some preliminary data analysis is conducted to substantiate that some key alternative assumptions to standard ones might be feasible for future model and theory development. The alternatives are

1. The individual's behavior is complex;
2. Choice sets are restricted and might vary in a systematic way, through the effects of differential access, between persons and hence groups; and
3. Decision strategies might be both simpler than commonly conceived and also vary with differences in individuals' situations, as defined by the numbers and kinds of alternatives they confront.

The strategy of the remainder of the paper is to develop statistical hypotheses that are consistent with each and all of these assumptions and then to demonstrate that there is no acceptable grounds for rejecting them, by use of data from standard records of travel behavior. Since the latter are as well fitted by existing choice-theory-based models like the logit incorporating alternative assumptions, there is evidence of an equifinality problem, the normal resolution of which is to progress in the direction of the theory or models with the more realistic and more plausible properties. This seems clearly the direction indicated by Equation 1 and this paper.

MATHEMATICAL RECONCEPTUALIZATION OF MOVEMENT AS COMPLEX HUMAN BEHAVIOR

Travel as a Path in n-Dimensional Space

In both aggregate and disaggregate approaches to movement, the overt behavior to be predicted or explained, the trip, is a link between two stops, and purpose or activity, frequency, mode, time of day, and destination are the principal choices that the individual confronts for the conduct of each trip. Such choices manifest themselves, at the macro level, in the relative frequencies of trips of each kind. When choice theory is used for the modeling of movement, therefore, the trip is theoretically the unit of (derived) demand, though there are many varieties of trips from which to choose. One of the implications of treating movement and any other behavior as a complex rather than a simple phenomenon is, therefore, that it could lead to a redefinition of the unit of demand in both derived models and underlying theory.

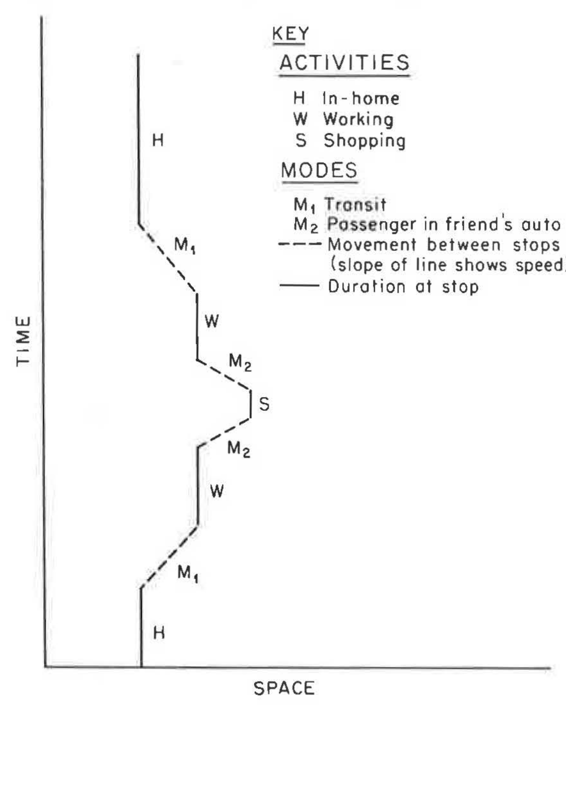
American geographers Marble, Nystuen, and Curry were the first to conceive of travel as an example of complex behavior, by considering trip making as home-to-home circuits (37). They divided movement by individuals into single-purpose (simple trip) and multiple-purpose (complex trip) travel (38, 39) and attempted to study the linkages of stops on multiple-purpose travel. Considerable emphasis was put on the statistical analysis of longitudinal travel data for individuals in order to define as rigorously and as objectively as possible the kinds of multiple-purpose trips that persons in cities tend to make (38, 40, 41). One work by Hanson and Marble in 1971 contained sophisticated statistical manipulations of a flow matrix of travel linkages between land use types. This approach enabled some patterns in the land use or activity site linkages of a sample of individuals to be determined. Patterns in the linkages of other aspects of trips (such as the linkage of modes to successive stops), were not, however, investigated. In addition, the relations of patterns of trip linkages to certain sociodemographic characteristics of individuals (such as race, class, age, culture, and sex) were explored (28, 42, 43). The contribution of this conceptualization of movement and related data analysis was its emphasis on the following:

1. That the complexity of an individual's behavior lies in the fact that it consists of a sequence of events differentiated by locations in space and time (for example, travel is a sequence of trips that link stops with space and time coordinates), and
2. That such complex behaviors of individuals linked to sociodemographic characteristics can be identified, comprising systematic behaviors that should be susceptible to normal scientific explanation through disaggregate modeling and theory-development procedures (7).

In the middle of the 1970s, as work in the disaggregate modeling of destination choice progressed in the United States, the question of the linking of trips by individuals, especially of nonwork trips, became important. The notions of trip chains, journeys, tours, and travel patterns appeared (23, 44, 45) and extended, although inadvertently, the earlier conceptualization of movement as complex behavior as trip linkages and multiple-purpose travel on home-to-home circuits. The appearance of the later concepts of chaining revealed not only a recognition that movement as a complex behavior is in fact a linking of events (trips) in a sequence differentiated by space and time dimensions but also that this may entail linkage and differentiation on other dimensions as well, such as trip destination (land use), activity (purpose), and mode dimensions (23, 45). Little work has been carried out on its implications, namely, that empirical research is required on longitudinal trip data for individuals (admittedly not readily available) to establish what, if any, kinds of multidimensional linkage patterns exist. So far, complex trip making has been arbitrarily divided into some simple classes, for example, trip sequences linked by purposes other than work and those not so linked or those tied to residential destinations and those not so tied (9, 20, 45).

Some well-known work in the mathematical reconceptualization of travel as complex behavior has, however, been carried out to permit this kind of empirical research, primarily at the University of Lund, Sweden (10, 34, 46), and the Transport Studies Unit at the University of Oxford, England (8, 24, 35, 36). The two-dimensional geometric representation of the individual's movement as a space-time path (Figure 1), apparently attributable originally to Hagerstrand (47) and then to Lenntorp (34) and reappearing in various guises in Thrift (46) and Dix (24), represents a first attempt to depict what an individual's movement might be, once it is granted that he or she does not make a trip but makes a sequence of trips to different places (stops) over time. However, although work at both Lund and Oxford has involved the collection of detailed individual travel data, the data have been used for different policy and modeling approaches than have been taken here, so that a still sharper mathematical reconceptualization of movement as complex behavior has not been delineated and neither has a design for related statistical analysis of longitudinal trip records to investigate repetitive patterns for individuals and population groups to demonstrate the tractability of the notion of movement as complex behavior as a dependent variable in models and theory.

Figure 1. The individual's path in time and space dimensions.



One of the less obvious features of the representation of the individual's movement in Figure 1 is that, by portraying it just as a line in two-dimensional space (time of day and distance), information about other aspects of travel (activities, modes, destination type, and location) is collapsed into that space. Technically, Figure 1 is a simplified geometrical representation of the individual's travel as a path in n dimensions, one

Figure 2. Sample diagrams for representing the individual's path in n dimensions through a series of two-dimensional cross sections.

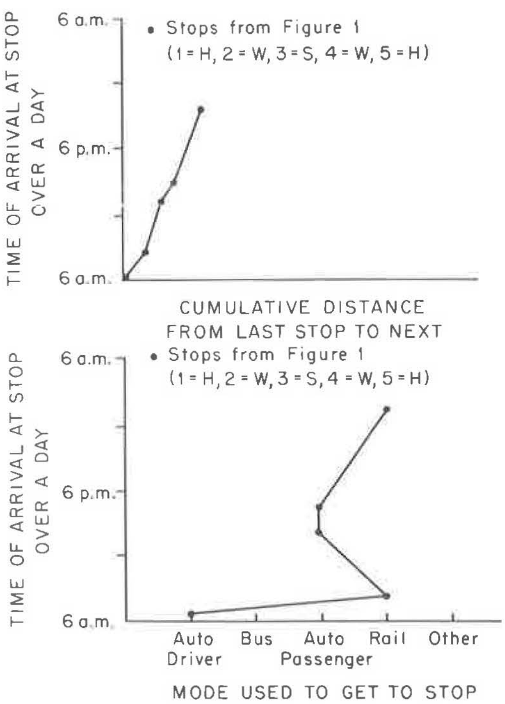


Table 1. Distribution of sample households and individuals in Uppsala, Sweden, by life-cycle group.

Group Characteristics	Number of Sampled Households	Number of Sampled Individuals
Head of household 67 or older	19	25
Head of household between 50 and 66, no children living at home	21	32
Head of household between 18 and 49, single persons only	23	26
Head of household between 18 and 49, two-person household with no children	5	11
Head of household between 18 and 49, at least one adult, at least one child over 7 years, and no pre-school children	11	24
Head of household between 18 and 49, at least one adult, and at least one child less than 5 years of age	13	26
Total	92	144

being time of day, another being distance from last stop to the next, and the others representing the remaining important aspects of travel as a complex behavior that have been considered, namely, mode, activity, land use type, and location of destination. The path, properly represented in the n-dimensional space, would become a line that joins a sequence of points, which represent stops, and each stop possesses a set of coordinates (or values) on a separate axis giving, at least, time of arrival at stop, distance from the last stop, location of present stop, mode used to get to stop, activity conducted at the stop, and land use at the stop. (It is clear that any other important aspects of travel could be portrayed on further dimensions, such as duration of stay at a stop.) The more rigorous geometrical representation of the individual's daily travel as a path in n dimensions is shown in Figure 2.

The immediate questions for future empirical, modeling, and theoretical work therefore become, What do individuals' trip records look like when represented in this fashion as complex behaviors, and, more importantly, is there any indication of less complex multiple-trip sequences (linking only one or two, and one or two kinds of, modes, activities, or destination types); and, are there any apparent tendencies for groups of individuals to have patterns or the same types of paths? For the purpose of this paper, it is sufficient to show that (a) paths apparently tend to be less rather than more complex; (b) individuals of the different groups tend to have different typical paths; and (c) at least some statistical methods exist to measure (classify) paths into a few classes so that complex behaviors could comprise some kind of well-behaved variables for model and theory development.

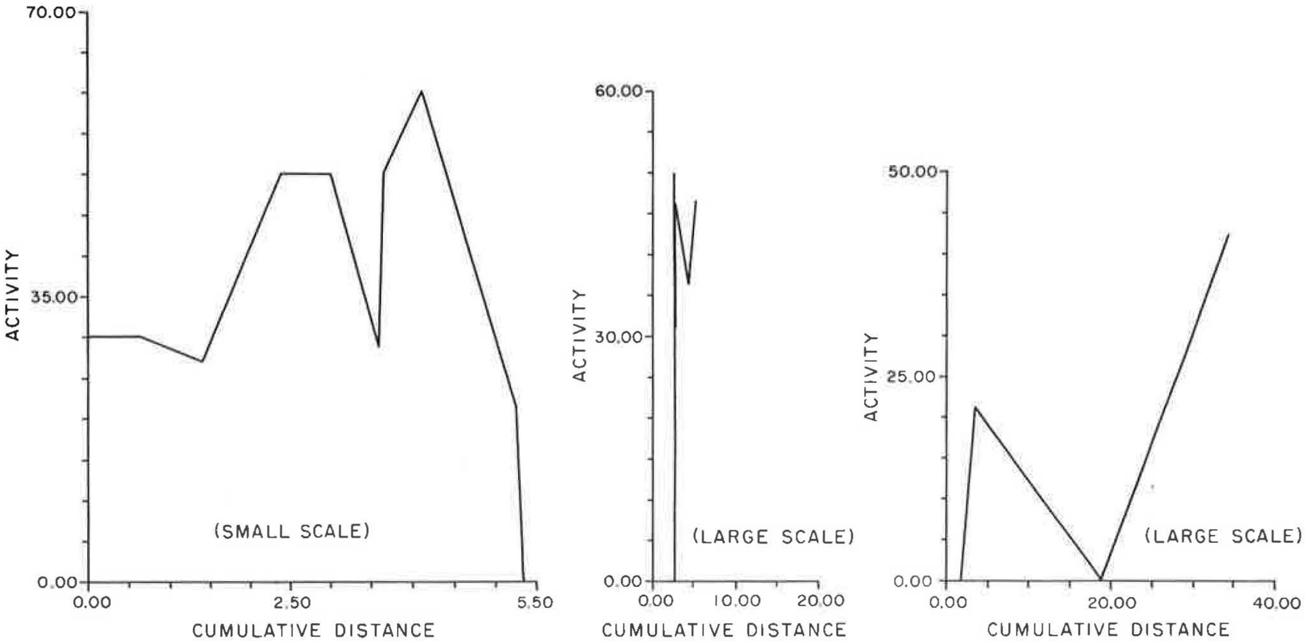
Data to document the present conceptualization of travel and to answer the questions raised should conform to the following requirements: It should consist of recent trip records for a random sample of individuals, of varying sociodemographic characteristics, where each individual's record is comprised of each stop visited in sequence over a time period, and details of the activity of the stop, times of arrival at the stop, the mode used to get to the stop, the precise point location of the stop, the land use at the stop, and the distance from the last stop. The Uppsala data set, a collection of the longitudinal travel records over 35 days for a sample of 144 individuals in 92 households in Sweden in 1971, was the only available data set that met all of these requirements.

The individuals in the set were a stratified random sample of persons by life-cycle group; Table 1 gives the definition of the group and the distribution of the sample between groups. For the exploratory purposes of this paper, an initial subsample of 40 individuals was selected randomly; each life-cycle group was represented in the subsample in the same proportion as in the complete sample. The analysis was then repeated by using a larger sample of 100 individuals to check that extremely small sample size did not influence results.

Some sample plots of the paths of the 40 individuals are shown in Figure 3. The total number of plots just for 40 persons numbered 840, so only an illustrative selection can be included. These, however, display some evidence that

1. Individuals have paths with less rather than more complex structures, that is, they use one or two modes per day, limit themselves to a few activities, generally restrict the distance traveled, and do not visit highly dispersed or a large variety of locations;
2. Some of the paths for different individuals exhibit similarity; and

Figure 3. Plots of representations of the n-dimensional paths of selected individuals in the Uppsala data set.



3. There appear to be differences in the paths for persons in different groups, although these are not necessarily simply related to life cycle.

Classifying Paths

This preliminary data display needs to be supported by a description of some simple statistical methodology to show that the paths that represent complex behaviors could be classified rigorously, so that their associations with a number of sociodemographic descriptors could then be defined by using standard multivariate procedures (such as k-way contingency-table analysis). The illustrative approach to the classification of complex behaviors that follows refers to the early geographic work that classified travel in terms of only one possible dimension of a stop (namely the type of land use there, representing the type of destination). The extension of the discussion demonstrates how complex travel represented on additional dimensions could be classified.

The method involves manipulations of a flow matrix. For any sample of individuals, the longitudinal data of travel diaries can be summarized in a square from-to flow matrix in which the rows represent the origin stops and the columns the destination stops in the sequence of out-of-home linkages made over some time period. The initial focus is on the out-of-home linkages made over some time period. First, the analysis centers on the out-of-home land use characteristics of the origin and destination of each linkage; then cells give the number of times people traveled from land use i (e.g., bank) to land use j (e.g., barber shop) in the course of home-to-home circuits (48, 49). By next including a home-home cell to represent the frequency with which individuals ended one home-home circuit and started another one, circuits are linked together and the matrix properly represents flows over any time period (e.g., a day). The home-home cell is an artificial cell that links circuits; as it reflects no movement between two different bases, as do other cells in the flow matrix, it is omitted from subsequent analyses of travel linkages. Because the directionality of the sequence of stops is retained, the matrix is, of course, asymmetric. It is also extremely complex. Our goal is to simplify this complex matrix (a) by identifying which travel linkages occur frequently enough to be considered significant and (b) by identifying groups of land uses that tend to occur together on the same path.

In order to reduce the complexity of the matrix and to identify significant linkages, transaction flow analysis is used. Transaction flow analysis provides a way to eliminate size effects (unequal row and column marginals) that can obscure important patterns and lead to a biased interpretation of the data. The method involves specification of a null or indifference model for determining the expected number of linkages between origins and destinations and then comparison of these estimates with the observed interaction data. The null model used to estimate the number of links is normally specified as a function of the size or the relative importance of the origins and destinations (i.e., of row and column sums); therefore the residuals calculated from this model are free from the effect of different absolute flow levels among land uses. Following Slater (50), the expected flow levels, a^*_{ij}, are specified as:

$$a^*_{ij} = U_i V_j \; ; i = 1, \ldots, m \quad j = 1, \ldots, n \tag{2}$$

where

$$U_i = \sum_j a_{ij} / \sum_i \sum_j a_{ij} \text{ and}$$
$$V_j = \sum_i a_{ij} / \sum_i \sum_j a_{ij}$$

and a_{ij} is the observed interaction between i and j. The residuals from the indifference model are a measure of the strength or significance of the linkages among land uses and, moreover, identify for each land use the other land uses that are linked primarily as origins or primarily as destinations to the land use in question. In this manner transaction flow analysis enables us to determine which cells in the flow matrix contain significant linkages; transaction flow analysis does not, however, tease out groups of land uses that tend to occur

on the same path. In order to classify paths on the basis of land use linkages, principal components analysis of the flow matrix must be performed.

Factor analysis has been used extensively as a grouping or regionalization technique (51, 52). In the analysis of directed flow matrixes a standard R-mode principal components analysis will yield factors that represent destinations that have similar patterns of linkages to the set of origins. The factor scores from an R-mode analysis provide information on the origins that tend to be identified with each factor. Groups of highly interacting land uses (complex travel patterns in one dimension) can be derived by combining sets of land uses that have high factor scores. Thus we identify destinations with similar source patterns (via the factor loadings) and the common sources associated with these destinations (via the factor scores).

An alternative grouping procedure that takes into account the indirect linkages contained in the flow matrix is to use one of the many algorithms available for grouping observations. All grouping algorithms for interaction data must address the problem of unequal row and column sums (53). In our case, this problem can be ameliorated by applying the grouping procedure to the matrix comprised of the residuals from the null independence model described above rather than to the raw linkage matrix. The groups derived from a standard hierarchical grouping procedure suffer, however, from the fact that, at any given step in the aggregation process, the previous groupings are taken as given; hence a globally optimal solution is unlikely.

The classification methods discussed thus far have considered only one aspect (dimension) of each stop in an individual's path. Since we need to be able to classify complex travel patterns in n dimensions we need to consider how these methods could be extended to encompass the dimensions of travel other than simply land use. One approach is to build a flow matrix in which each row and column is a composite of any of the limited number of dimensions of travel considered of interest. Clearly some simplification or refinement is necessary to keep the size of such a matrix manageable. As one possible solution, consider only critical dimensions of a stop: activity type (shop, recreation, work, personal business, social, and home-based activity), mode of travel (automobile, bus, bicycle, or walk), distance traveled from last stop (classified in discrete distance categories), and time of day (also classified in discrete categories). Each row and column then represents a unique combination of activity, mode, distance, and time, and the flow matrix is a record of the individual's path in four dimensions. Analysis of such a flow matrix should yield those activity-mode-distance-time bundles that occur frequently on the same path and enable the classification of paths in four dimensions similar to the typology of travel derived from analysis of the matrix of travel linkages between land uses. The same approach could be extended to paths in a larger number of dimensions, depending on the size of sample of individual daily trip records.

As can be seen from the above, the methods of analysis of the flow matrix are not complicated, given the current statistical procedures in widespread use for segmenting individuals into groups and estimating the parameters of current travel models.

The definition and measurement of travel implies, however, that the unit of demand is a set of stops that has distinguishable properties (location in time and space, mode used to get there, activity or purpose there, and land use type) and that the selection of a set of stops from a larger but still spatially constrained set generates travel as a complex behavior. Thus, the conception of distinct and excessively complicated simultaneous or sequential choices or decisions for trips (modes, destinations and times of day) (54), with simple trips of the different varieties as the unit of demand, relapses into a much less complicated and more plausible notion of what is demanded and how, once it is realized that the redefinition of travel as a complex behavior apparently entails demand for a set of stops for the accomplishment of activities from a rather larger but still spatially constrained set in a city. In urbanized societies in which increasing spatial dispersion and specialization of activities is a dominant feature, this seems an appropriate way of conceiving the origins of recurrent movement.

The implications of this for demand theory are obviously profound and beyond the scope of this paper. Some preliminary data analysis becomes even more desirable to substantiate the proposed nature of choice sets and the general contention of this paper that systematic variation of limited sets of options between individuals exists, together with resultant variability in decision procedures. It remains for future research to specify in detail a choice-set-formation model and to discover and to elaborate on precisely what are the decision strategies of individuals in different types of situations, to flesh out the explanatory model of individual and group behavior of Equation 1.

IMPLICATIONS FOR INDIVIDUAL'S ALTERNATIVES AND DECISION MAKING

Hypothesis 1

Hypothesis 1: Given that stops are described by a limited number of critical dimensions, the set of alternative stops for an individual to use in a day may be restricted to one or more, which are described by a limited number of values or categories and perhaps only one value or category of each aspect.

Thus, shopping for other than necessities may be associated only with regional shopping centers, the automobile mode, more than 15 min, and arrive on the way home from work; but shopping for toothpaste may be associated only with local drugstore, walk less than 5 min, and drop by from home after work. The individual might have only one regional shopping center for nonnecessities and one corner drug for necessities to choose. The kinds of associations formed for stops and the number of stops included in the choice set, however, may vary systematically between individuals in different socioeconomic groups and will be dependent on the nature of the spatial environment in which they exist. In operational terms, this implies that, in the individual's trip record, a high degree of correlation should exist between observations of the activity, distance, mode, destination type, destination location, and time of arrival aspects of stops, with repetitions of combinations increasing the degree of correlation. Moreover, the kinds of association should manifest some variation for different types of individuals.

It follows from hypothesis 1 that, if more than one stop exists in the choice set, the individual must find some means for evaluating them to select the set to use. That is, he or she must have some procedure for evaluating the cost and benefits of using the limited number of combinations of activity, destination location, destination type, distance, mode, and time of visit values or categories that describe each possible stop. This implies that some underlying common dimensions might

exist in terms of which all aspects of these combinations can be described and evaluated. Since, in the literature on both the disaggregate and aggreate modeling of movement, travel time and cost have always been either plausibly argued or demonstrated to be of primary importance in regulating movement, and since recent time and money budget studies (55, 56) tend to confirm this, hypothesis 2 can be formulated as follows.

Hypothesis 2

Hypothesis 2: Places as defined in hypothesis 1 are evaluated by each individual on two fundamental dimensions, which could be the time and cost expenditures of using them. Systematic differences could also exist between individuals in the ways places are evaluated in terms of time and cost, depending on sociodemographic characteristics, which reflect possibly varying decision strategies.

In operational terms, this means that the stops in each individual's trip record for a day, defined in terms of their six critical aspects (activity, location, land use, distance, mode, and time of arrival), should exhibit selection in accordance with a model of judgment that conforms to hypothesis 2.

The two hypotheses comprise an initial explanation of observed complex individual travel behavior, as reconceptualized here and as should be manifest, for example, in the daily trip records for the two subsamples of 40 and 100 individuals in the Uppsala data set. Statistical techniques can be used to show that the two hypotheses, by reconceptualizing behaviors as complex, options as limited and variable, and decision procedures as simple and variable too, could fit standard kinds of travel data just as well as the alternative assumptions on which current models of movement and underlying theories are based.

Statistical Tests of Hypotheses

Hypothesis 1

For each of the 40 individuals in each life-cycle group in subsample one, an intercorrelation matrix was prepared to show the Pearsonian simple product-moment correlation coefficient (r) between observations for each pair of aspects for each of the p stops in the individual's day. The Pearsonian simple product-moment correlation coefficient is used here as a measure of pattern (association) and not as a statistic measuring degree of explanation of a causal model, its more normal use. For this reason, no statistical tests of significance are conducted. It is recognized also that r is not strictly an appropriate measure of association between variables that are made up of mixed data (cardinal, ordinal, and ratio); however, it was the best of all measures to meet the requirements of being both a pattern measure and a measure of similarities for input into the INSCAL algorithm for the second phase of the analysis below.

The day when the individual made a maximum number of stops was selected [typically for an individual ($5 \leq p \leq 15$)]. If hypothesis 1 is correct, then the absolute value of each r in the intercorrelation matrix should tend to be high. Moreover, different kinds of association between the variables should be present for different kinds of individuals, some persons perhaps matching bus with regional shopping center and automobile with local convenience stores, and others doing the reverse. This should result in a dispersion of r's (+, -) for each pair of aspects of stops. These expectations proved to be the case when the data for the subsample of Uppsala individuals were analyzed. Tables 2-4 contain a selection of the trip records and intercorrelation matrices for selected individuals to document this. Systematic variation of choice sets between different types of individuals was tested by using multiway analysis of variance of the characteristics of individuals—stage in life cycle (rows) versus the r-values for the individuals (cells), for each possible pair of stop aspects (columns). Frequency distributions of r-values for 40 individuals in the Uppsala sample are given below. (F = relative frequency, $\bar{F}$ = mean relative frequency of r-values, and V_F = the coefficient of variation.)

All Aspect Pairs, All Individuals

r-Value	Number	F	$\bar{F}$	V_F
0 to 0.24	260	0.36	0.37	0.45
0.25 to 0.49	192	0.27	0.27	0.47
0.50 to 0.74	179	0.25	0.25	0.51
0.25 to 0.99	83	0.12	0.12	0.83

Mode and Time of Arrival

r-Value	Number	F	$\bar{F}$	V_F
-1.00 to -0.51	6	0.18	0.06	7.83
-0.50 to -0.01	5	0.15		
0.00 to 0.49	19	0.55		
0.49 to 1.00	4	0.12		

Mode and Land Use

r-Value	Number	F	$\bar{F}$	V_F
-1.00 to -0.51	0	0	0.43	0.86
-0.50 to -0.01	5	0.15		
0.00 to 0.49	12	0.35		
0.49 to 1.00	17	0.50		

Mode and Activity

r-Value	Number	F	$\bar{F}$	V_F
-1.00 to -0.51	7	0.21	-0.12	-3.52
-0.50 to -0.01	12	0.35		
0.00 to 0.49	14	0.41		
0.49 to 1.00	1	0.02		

Mode and Distance

r-Value	Number	F	$\bar{F}$	V_F
-1.00 to -0.51	0	0	0.60	0.38
-0.50 to -0.01	0	0		
0.00 to 0.49	10	0.29		
0.49 to 1.00	24	0.71		

Time and Land Use

r-Value	Number	F	$\bar{F}$	V_F
-1.00 to -0.51	2	0.05	-0.03	-11.22
-0.50 to -0.01	16	0.47		
0.00 to 0.49	15	0.44		
0.49 to 1.00	1	0.02		

Time and Activity

r-Value	Number	F	$\bar{F}$	V_F
-1.00 to -0.51	15	0.44	-0.38	-1.08
-0.50 to -0.01	15	0.44		
0.00 to 0.49	2	0.06		
0.49 to 1.00	2	0.06		

Table 2. Correlation in the individual's daily trip record between aspects of stops from the Uppsala subsample for individual 110 525 (elderly life-cycle group).

Stop Aspects	Mode	Time	Land Use	Activity	North-South Location	East-West Location	Distance
Mode	-	-0.70	+0.33	-0.66	-0.54	+0.67	+0.99
Time	-0.70	-	+0.68	+0.99	+0.75	-0.99	-0.69
Land use	+0.33	+0.68	-	-0.69	+0.70	-0.64	+0.34
Activity	-0.66	+0.99	-0.69	-	+0.79	-0.99	-0.66
North-South location	-0.54	+0.75	+0.70	+0.79	-	-0.77	-0.56
East-West location	+0.67	-0.99	-0.64	-0.99	-0.77	-	+0.67
Distance	+0.99	-0.69	+0.34	-0.66	-0.56	+0.67	-

Table 3. Correlation in the individual's daily trip record between aspects of stops from the Uppsala subsample for individual 130 101 (elderly life-cycle group).

Stop Aspects	Mode	Time	Land Use	Activity	North-South Location	East-West Location	Distance
Mode	-	-0.25	+0.71	+0.31	+0.13	-0.18	+0.78
Time	-0.25	-	-0.38	+0.45	+0.64	+0.87	-0.46
Land use	+0.71	-0.36	-	+0.27	+0.04	-0.36	+0.74
Activity	+0.31	+0.45	+0.27	-	+0.96	+0.70	+0.34
North-South location	+0.13	+0.64	+0.04	+0.96	-	+0.87	+0.15
East-West location	+0.18	+0.87	-0.36	+0.70	+0.87	-	-0.24
Distance	+0.78	-0.46	+0.74	+0.34	+0.15	-0.24	-

Table 4. Correlation in the individual's daily trip record between aspects of stops from the Uppsala subsample for individual 151 410 (middle aged with children group).

Stop Aspects	Mode	Time	Land Use	Activity	North-South Location	East-West Location	Distance
Mode	-	-0.48	+0.17	-0.73	-0.75	-0.83	+0.72
Time	-0.48	-	+0.37	-0.18	-0.35	-0.24	+0.02
Land use	+0.17	+0.37	-	+0.04	-0.23	-0.19	+0.08
Activity	-0.73	-0.18	+0.04	-	+0.53	+0.63	-0.49
North-South location	-0.75	-0.35	-0.23	+0.53	-	+0.90	-0.24
East-West location	-0.83	-0.24	-0.19	+0.63	+0.90	-	-0.38
Distance	+0.72	+0.02	+0.08	-0.49	-0.24	-0.38	-

Land Use and Distance

r-Value	Number	F	$\bar{F}$	V_F
-1.00 to -0.51	1	0.03	0.32	0.94
-0.50 to - 0.01	1	0.03		
0.00 to 0.49	24	0.71		
0.50 to 1.00	8	0.24		

The analysis-of-variance results were disappointing but could indicate that more, and more appropriate, sociodemographics need to be included in the analysis. The data set did not, however, contain additional sociodemographics for such an analysis. The repetition of the analysis for the larger subsample of 100 individuals showed no difference in results.

Hypothesis 2

The correlation coefficients in the matrices for individuals, such as those of Tables 2-4, comprise measures of similarity between the different aspects of stops for each person. These coefficients are the best kinds of similarities (distance or proximity) measures for input into an M D S scaling algorithm, which fits the INSCAL model of the evaluation of stimuli to data. The algorithm and the model can be used with the data for the Uppsala individual trip records to test hypothesis 2 in the following way (57).

Assume that the six critical aspects of stops in the individual's choice sets comprise stimuli for the individual. Then associations between the aspects of stops might not only reflect the restricted nature of the options in the choice sets but also the degree of similarity (proximity, discriminability) of the stimuli that define stops when they are evaluated on no more than two basic dimensions by each and every individual. The

Table 5. Correlations between distances between stimuli (aspects of stops) in two-dimensional INSCAL configurations and input similarities (proximities) data for stimuli.

Individual	r-Value	Individual	r-Value
1	0.881 361	21	0.550 332
2	0.828 531	22	0.528 632
3	0.691 990	23	0.646 401
4	0.820 661	24	0.640 377
5	0.820 961	25	0.734 304
6	0.512 941	26	0.773 128
7	0.733 039	27	0.567 975
8	0.631 778	28	0.718 454
9	0.617 555	29	0.849 543
10	0.609 835	30	0.648 269
11	0.358 989	31	0.816 215
12	0.640 775	32	0.732 914
13	0.840 689	33	0.621 152
14	0.831 145	34	0.581 234
15	0.764 530	35	0.851 186
16	0.609 176	36	0.764 260
17	0.619 236	37	0.812 975
18	0.816 674	38	0.836 420
19	0.874 279	39	0.795 324
20	0.873 872	40	0.793 309

Note: Group correlation = 0.895 483.

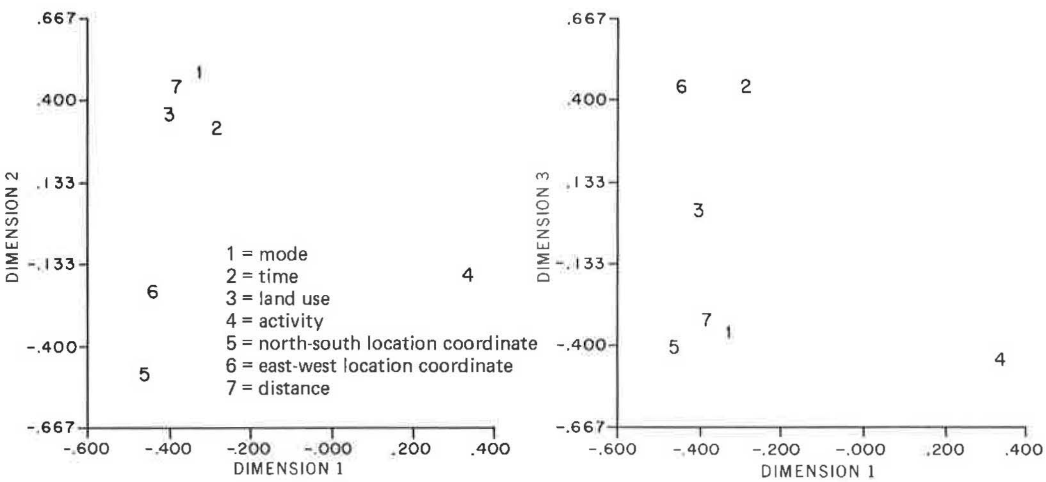
Table 6. Variability of weights for individuals in the Uppsala subsample on dimensions 1 and 2.

Individual	Dimension 1[a]	Dimension 2[b]	Individual	Dimension 1[a]	Dimension 2[b]
1	126.91	142.35	21	102.55	131.60
2	75.09	76.20	22	56.03	65.87
3	113.99	107.46	23	58.74	101.31
4	112.12	131.28	24	66.04	110.62
5	73.52	99.78	25	77.06	105.54
6	29.82	86.15	26	48.05	62.73
7	49.07	51.40	27	112.51	149.58
8	99.98	135.09	28	20.21	78.80
9	62.61	85.81	29	38.06	31.88
10	70.73	125.66	30	122.07	101.07
11	20.61	47.17	31	38.14	49.10
12	36.40	47.95	32	115.23	108.05
13	48.42	69.13	33	59.12	56.31
14	95.78	124.13	34	75.15	72.14
15	67.64	69.07	35	112.42	101.32
16	49.44	59.22	36	116.85	86.59
17	67.63	115.13	37	79.23	67.21
18	106.92	129.67	38	86.31	88.14
19	87.39	88.68	39	54.53	60.49
20	109.44	108.22	40	61.52	70.25

[a] For dimension 1, t-tests of the difference between the means of weights for each pair of life-cycle groups were significant at the 5 percent level in only 3 of 21 pairs. The coefficient of variation of all weights is 30.2 percent.

[b] For dimension 2, t-tests of the difference between the means of each pair of life-cycle groups were significant at the 5 percent level in only 6 of 21 pairs. The coefficient of variation of all weights is 34.8 percent.

Figure 4. Plot of three-dimensional group spaces and weight spaces derived from INSCAL analysis of trip records of aspects of stops used in a day.



aspects (stimuli) that define the stops for each individual during a day should, therefore, comprise a configuration that is recoverable in a two-dimensional mental space, with each aspect (stimulus) discriminated along each dimension. However, interindividual differences should exist in recovered configurations, with systematic differences between groups of individuals, which indicate differences in evaluation procedures.

The INSCAL model and algorithm allow for interindividual differences in the evaluation of stimuli (aspects of stops) in the above ways by

1. Testing the goodness of fit to the similarities data for stimuli, for n different individuals, of n matching stimuli configurations, each in a two-dimensional space;
2. Producing a group or overall configuration for all individuals as a composite of the individual ones, providing a basis for comparison of the latter; and
3. Allowing for individual differences in configurations through variation in the weights in the function used to fit the similarities (distance) data for each individual, where the function relates the individual and group configurations in the following way:

$$d^i_{jk} = \left[\sum_{t=1}^{r} w^i_t (x_{jt} - x_{kt})^2 \right]^{1/2} \quad (3)$$

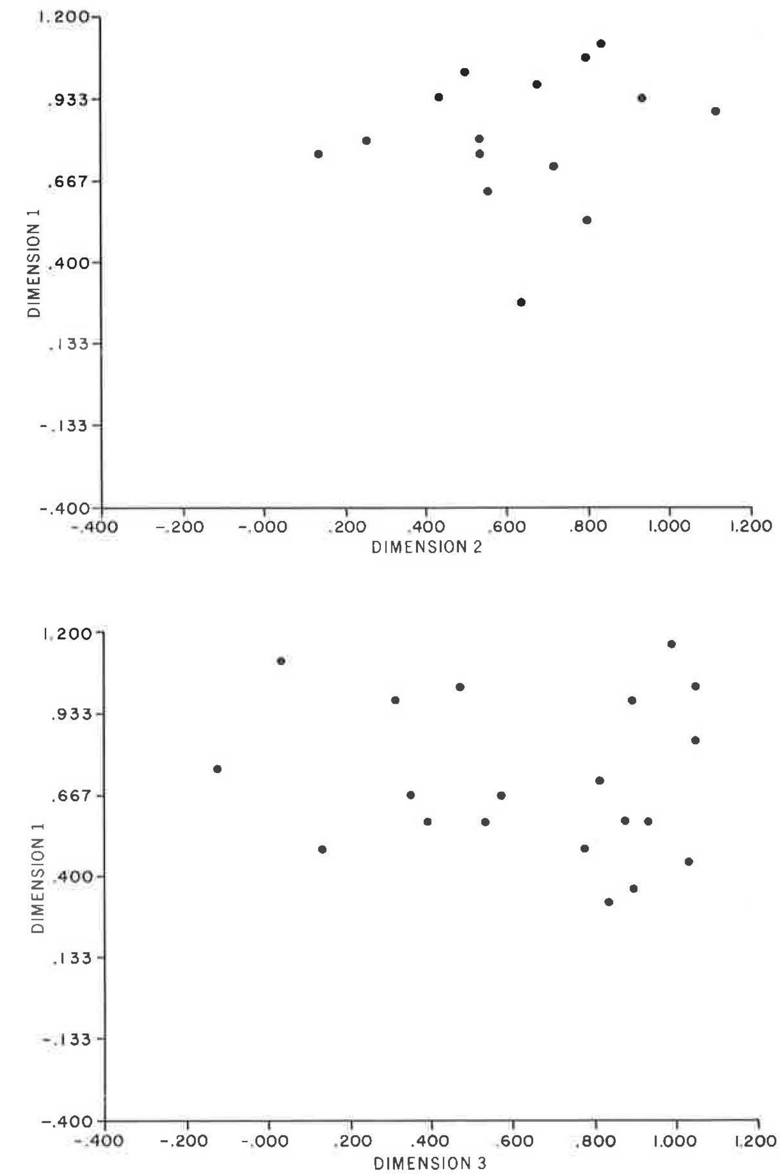
where

d^i_{jk} = the distance (similarity) between the j th and the k th stimulus for the i th individual,
r = the number of underlying dimensions (here assumed to be 2),
x_{jt} and x_{kt} = the values of the stimulus on each dimension, and
w^i_t = the weights for each dimension, specific to the individual.

On the basis of the preceding discussion, we would expect that, if hypothesis 2 is true and by using the kinds of intercorrelation matrices of Tables 2-4 for each individual as proximities input to the INSCAL algorithm:

1. Configurations of stimuli (the six critical aspects

Figure 5. Plot of three-dimensional group spaces and weight spaces derived from INSCAL analysis of trip records.



of each stop) are recoverable for each individual in a two-dimensional space, with a very good match of the distances between stimuli in each individual configuration to the input similarities (proximity) measures;

2. Stimuli are well discriminated (spaced out) on each dimension in individual and hence group configurations; and

3. There is considerable interindividual variation in weights for each dimension, with statistically significant differences in the weights (and hence configurations and evaluations) for individuals in different life-cycle groups.

The results of the data analysis for the small subsample of 40 persons conform with these expectations, as shown in Tables 5 and 6. The match of the recovered group and individual configurations to the input data is excellent, as measured by the generally high r-values in Table 5, for each individual and for the group, between the distances represented by the input data and the recovered distances for each configuration. This demonstrates that, as hypothesized, two fundamental dimensions are probably used for evaluation, most probably travel time and cost. The expected high interindividual variability in weights appears (Table 6) and, therefore, the possibility of grouping individuals in some manner to minimize intragroup and maximize between-group variance in them (and thus group configurations or evaluation functions); however, the expected association of weights simply with life-cycle group through standard multiway analysis of variance did not appear and there is no evidence as to precisely how evaluation procedures vary between groups, only that they do. Perhaps, again, some further sociodemographic variables should be included to help partition the population better (for example sex, marital status, income, and occupation) as well as life-cycle stages. These were not available in the Uppsala data set.

A repetition of the analysis by using the large 100-individual subsample yielded generally similar results, except that a third dimension of minor importance appeared (see Figures 4 and 5). This could be a dimension associated with service, also prominent in disaggregate-travel-modeling literature.

CONCLUSION

The exploratory data analysis for both hypotheses seems

sufficient to support the contention that, once it is granted that the individual's recurrent movement is an example of complex behavior and definable as a path in n-dimensional space, then it may be generated by the evaluation of a limited number of spatially defined options in terms of only several criteria, probably time and cost considerations. This is also consistent with the supposition that, although movement is complex from a researcher's point of view, it is more likely to be viewed by most persons as a routine question, not as a major decision or investment question (6). It is therefore plausible that travel options are few and decision making is simple. Choosing, as far as the individual is concerned, is not complicated problem solving in complicated situations, as our current models and theories assume. The results of the data analyses are also consistent with systematic variations in complex behaviors, spatially constrained options, and simple decision rules and strategies for population groups. It remains for further research to develop the mathematical explanatory models and theory for the analysis of human behaviors that allow behaviors to be complex and options and evaluations to be simple and permit all three to vary by population group.

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