activity-based travel analysis to more traditional methods of travel analysis and forecasting. For example, Susan Hanson provides an interesting account of the way in which insights gained from activity-based work stimulated her interest in the spatial characteristics of intraurban labor markets. Further, she points out that although she is examining the journey-to-work she is doing so in a fundamentally different way than she would have if not for her involvement, over a long period of time, in activity-based travel analysis. Hani Mahmassani, on the other hand, refers to the possible application of activity-based research in analysing and predicting the demand for public services other than transportation, including water supply.

Third, there is general agreement that the activity-based approach has enriched our understanding of travel behavior, although there are differences of opinion as to the degree to which this is true. There is also general agreement that activity-based travel analysis has a role to play in the future development of urban travel behavior modeling and analysis, particularly given the changes in technology and socio-demographics that are currently taking place and that are likely to influence travel behavior and transportation system needs for the remainder of this century and into the beginning of the next one. For example, Lidia Kostyniuk notes the value of activity-based travel analysis in the context of understanding the travel needs and desires of tomorrow's elderly segment of the population, while Frank Koppelman refers to the contribution of activity-based travel analysis in understanding future goods distribution patterns in the context of changes in the time allocation patterns of both men and women to work and other activities. There is little doubt among the contributors to this section of the special issue that our ability to understand the transportation implications of advances in telecommunications technology is considerably enhanced by the activity-based approach to travel demand analysis.

I hope that the material included in Part A of this special issue of *Transportation* will provide readers of the journal with a useful perspective on the field of activity-based travel analysis; especially, its potential future contributions to the understanding and forecasting of urban travel behavior and the demand for other goods and services.

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Review paper

An evaluation of activity-based travel analysis

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Abstract. This paper is a review and assessment of the contributions made by "activity-based approaches" to the understanding and forecasting of travel behavior. In their brief history of approximately a decade, activity-based analyses have received extensive interest. This work has led to an accumulation of empirical evidence and new insights and has made substantial contributions toward the better understanding of travel behavior. However, practical applications of the approach in transportation planning and policy development have been scarce. Based on an analysis of the inherent characteristics of the activity-based approach, a review of recent (after the 1981 Oxford conference) developments, and a synthesis of the findings from past empirical studies, this study attempts to evaluate the contribution made by activity-based analyses and determine the reasons for the limited practical application. Recommendations are made for the future development of activity-based analysis as a science of travel behavior and as a tool in the practice of transportation planning and policy development.

1. Introduction

In their brief history of approximately a decade, activity-based analyses have received much attention and have contributed substantially toward the better understanding of travel behavior. New light has been shed on many aspects of travel behavior. Known problems have been reexamined within new frameworks, and many conventional approaches and surrogate relations that travel behavior analysts traditionally embraced have been critically reviewed. Activity-based analyses have pointed out the problem of premature empiricism where observable "causal" factors are hastily related to indicators of travel behavior – a tendency that may unfortunately have proliferated throughout the field of travel behavior analysis. The Conference on Travel Demand Analysis: Activity-based and Other New Approaches (Carpenter & Jones 1983), held at Oxford in 1981, is a milestone in the growth of the field of activity-based travel analysis.

At the same time, the history of activity-based analysis contains sharp self-criticisms, including concerns that its development is fragmented and lacks a sound methodological foundation, that the "plethora of research directions . . . has made only marginal contributions toward a new theoretical basis" (Recker & McNally 1986), but that this lack of cohesive theory is "compensated for by a profusion of concepts and methods" (Golob & Golob 1983). Also expressed are concerns with limited practical application of activity-based analyses (Pas 1986b). These viewpoints scattered in the recent literature appear to warrant an analysis and assessment of the progress made in the past by, and contributions anticipated in the future from, activity-based travel analyses. This paper is an attempt to achieve this assessment.

This review is divided into two segments: activity-based analysis as a science of travel behavior, and activity-based analysis as a planning tool. The former segment (section 2) addresses the questions:

- How much progress has been made toward construction and validation of a theory of travel behavior?
- What empirical information about travel behavior has been accumulated since the 1981 Oxford conference?
- Has this accumulation of empirical information led to new conjectures or theories?
- "Better understanding" is a phrase cherished in this field, but do we have a better understanding of travel behavior now than we did in 1981?

In the latter segment (section 3), the impact of activity-based analyses on transportation planning practice is evaluated. The discussion was motivated by the observation,

> roughly a decade has passed since the origin of activity-based research and . . . during this period there has been only one identifiable application of a formal activity-based model in the actual policy analysis (Pas 1986b).

The key question underlying the discussion is whether activity-based analysis can be useful for planning or whether it is primarily a research tool. This issue has prompted the exploration of reasons for the lack of planning application of activity-based analysis. A brief assessment of the future of activity-based travel analysis (section 4) concludes this paper. Because of the emphases of this effort, the literature review contained in this paper is not comprehensive. In particular, studies before the 1981 Oxford conference are not included. Previous reviews of the literature in this field can be found in, e.g. Wigan & Morris (1981), Damm (1983), Golob & Golob (1983), Pas (1985), and Clarke (1986).

The discussions of this paper are based on the belief that prediction of individuals' travel behavior is an essential component of transportation planning and policy analysis. It is viewed that the ultimate mission of travel behavior research is to develop the capability to predict how individuals respond to changes in their travel environments and how the responses are temporally correlated. If it were not for this conviction, a different assessment of activity-based travel analysis would have been made.

Definition and areas of investigation

In the proceedings of the 1981 Oxford conference, Goodwin (1983) states that

> the core of work reported showed a great degree of consensus on what the term 'Activity Approaches' means – namely the consideration of revealed travel patterns in the context of a structure of activities, of the individual or household, with a framework emphasising the importance of time and space constraints. This was common ground.

This broad definition of activity-based travel analysis is also adopted here.

This emphasis defines the areas of investigation for activity-based travel analysis. Pas (1985) summarizes these areas as:
- demand for activity participation;
- activity scheduling in time and space;
- spatio-temporal, interpersonal, and other constraints;
- interaction in travel decisions over time;
- interaction among individuals; and
- household structure and roles.

Adaptation and changes in travel behavior over time will also be included in the discussion of this paper. This subject follows the emphasis in the field of activity-based travel analysis on the time dimension and adaptation to changes in the travel environment (Jones et al. 1983; Clarke 1986), and is generally referred to as "dynamic" analysis of travel behavior.

An overview of recent developments

Table 1 presents a list of activity-based studies of travel behavior that have been reported largely after the 1981 Oxford conference, grouped into the subject areas defined above. Additional contributions are grouped under: policy applications, activity models, and methodological developments. The majority of the recent development is concentrated in four areas, activity participation and scheduling, interaction in travel decisions, household structure and roles, and analysis of dynamic aspects.

The development in the first area, activity participation and scheduling, comprises largely descriptive analyses based on observational instruments derived from theoretical considerations. The time-geographic paradigm of Hagerstrand (1970) continues to be the backbone of the analyses of this category. The recent work in this area includes a conceptual analysis of activity substitution (Salomon 1985) and additional empirical analyses of time use (Palm 1981; Allanam et al. 1982).

Table 1. Recent activity-based travel analyses (since 1981 Oxford conference).

Activity participation and scheduling in time and space

Allaman et al. (1982); Beckmann, Golob & Zahavi (1983a, 1983b); Kitamura (1984a); Kitamura & Kermanshah (1983, 1984); Palm (1981); Recker & Kitamura (1985); Salomon (1985); Supernak (1984); Wigan (1983)

Spatio-temporal, interpersonal, and other constraints

Landau, Prashker & Alpern (1982); Landau, Prashker & Hirsh (1981)

Interaction in travel decisions

(a) *Trip chaining analysis*: Barnard (1986); Golob (1986); Horowitz (1982); Kitamura (1983, 1984b, 1985); Kondo & Kitamura (1987); Mazurkiewcz (1985); Narula et al. (1983); O'Kelly (1981); O'Kelly & Miller (1984); Southworth (1985a, 1985b); Thill (1985); Thill & Thomas (1987)
(b) *Multi-day travel behavior*: Hanson & Huff (1982, 1985, 1986, 1987, 1988); Hirsh et al. (1986); Huff & Hanson (1986); Jones & Clarke (1988); Kitamura (1988); Koppelman & Pas (1984, 1985); Pas & Koppelman (1985, 1986)
(c) *Interaction among individuals*: Koppelman & Townsend (1987); Townsend (1987)

Household structure and roles

Ampt (1983); Chicoine & Boyle (1984); Hanson & Hanson (1981); de La Morsangliere & Raux (1983); Kostyniuk & Kitamura (1986a); McDonald & Stopher (1983); Pas (1984); Pickup (1985); Raux & Rosenbloom (1986); Zimmerman (1982)

Adaptation, other dynamic aspects

Clarke, Dix & Goodwin (1982); Dix & Layzell (1986); Golob & Meurs (1987); Golob, van Wissen & Meurs (1986); Goodwin (1986); Goodwin & Layzell (1985); Hirsh, Prashker & Ben-Akiva (1986); Hocherman, Prashker & Ben-Akiva (1984); Kitamura & van der Hoorn (1987); Kostyniuk & Kitamura (1987); Mahmassani, Chang & Herman (1986); Mahmassani & Chang (1987)

Policy applications

Knippenberg & Clarke (1984); Knippenberg & Lameijer (1985)

Activity models

Van der Hoorn (1983); Jones et al. (1983); Recker & McNally (1986); Recker, McNally & Root (1986a, 1986b)

Methodological developments

(a) *Data collection, interview methods*: Ampt, Bradley & Jones (1987); Bradley, Jones & Ampt (1987); Golob, Schreurs & Smit (1986); Pas (1986a)
(b) *Classification, measurement*: Bachi, Reichman & Salomon (1987); Koppelman & Pas (1985); Recker, McNally & Root (1985); Pas (1983, 1984, 1988)
(c) *Constraints*: Swait & Ben-Akiva (1986)
(d) *Analysis of dynamic aspects*: Golob & Meurs (1986); Hensher (1986, 1987); Hensher & Wrigley (1986); Kitamura (1986, 1987); Kitamura & Bovy (1987); Lyon (1984); Smith, Hensher & Wrigley (1986)

The recent contributions in the area of interaction in travel decisions are divided in Table 1 into three categories: trip chaining analysis, analysis of multi-day travel patterns, and interpersonal interaction. The first area contains new theoretical model developments as well as empirical investigations. The second is a new area in which the effort focuses on characterization and modeling of multi-day behavior. Theoretical model developments are notable in the third area.

A number of studies, mainly empirical, have been conducted in the area of household structure and roles. Overall, the results of these studies support the conjecture that household structure significantly influences the activity and travel patterns of household members, and they point to complex interaction between household structure and gender. A controversy exists, however, as to the predictive effectiveness of household structure variables (McDonald & Stopher 1983).

Empirical findings on dynamic aspects of travel behavior (e.g. response lags, inertia, learning, cohort effects) are now being accumulated at a rapid rate. While some are based on repeated cross-sectional surveys, others use results of panel surveys or data gathered through experiments. The breadth of approaches and the extensiveness of interests held by the researchers in this area promise that this rapid rate of development will continue in the near future.

Methodological developments in data collection, classification of activity patterns and dynamic analysis of behavior, are included in the recent work in the activity-based area. Recent advances also include a few examples of policy applications and efforts to develop comprehensive models of activity-travel behavior. These developments are referenced in Table 1 and discussed in detail in the next section.

2. Activity-based approach as travel behavior science

This section presents a summary and assessment of the contributions made in the past by the activity-based approach toward the theoretical explanation of observed travel behavior. The section is divided into two parts. Following a summary of the contributions in the first part, current challenges in the field are discussed in the second part.

Past contributions

The central conceptual framework of the activity-based approach exists as an integration of aspects of time geography and human activity analysis. As Pas notes, this has

> required travel demand analysts to (a) reconsider the definition of the phenomenon being modeled, (b) give more explicit recognition to the derived demand nature of travel and (c) pay more attention to the sociodemographic characteristics of individuals and households that affect the demand for activity participation . . . and that often constrain activity and travel choices (Pas 1985).

The importance of the contributions made by the activity-based approach seems indisputable in this respect.

Conceptual, theoretical and methodological developments

The main thesis of the activity-based analysis of the Oxford group is that household lifecycle predominantly determines what members of a household do, hence their travel behavior (Clarke, Dix & Goodwin 1982). An important factor in defining lifecycle stages is the presence of children. It is noted that

> . . . the single most important 'discovery' of activity work to date has been the importance of children – not primarily because of their trips . . . but because the very fact of children in a household imposes highly complex and binding constraints on the activities and travel patterns of all other members of the households (Goodwin 1983).

This is a fact that can be immediately appreciated. However, this very fact has been only remotely reflected in existing transportation planning models, usually through the use of household size as the sole descriptor of household structure. A likely consequence is the dubious predictive capability of these models.

Extensive analysis has been made on the association between activity-travel patterns and household lifecycle, the latter being considered as a surrogate of activity needs and constraints (Jones et al. 1983; de La Morsangliere & Raux 1983; Kostyniuk & Kitamura 1986a). More fundamental consideration of the mechanism of trip making has also led to a review of the effectiveness of household and person attributes that have been believed to be "predictors" of travel behavior. For example, recent results indicate that the effectiveness of household car ownership as a predictor declined as motorization progressed (Kitamura & Kostyniuk 1986; Kostyniuk & Kitamura 1986b).

Progress has also been made in the area of constraints on activity and travel behavior. A few analyses have used commonly available measurements (e.g. typical store hours or typical work schedules) to infer the constraints that govern each individual's behavior (Landau et al. 1981, 1982).

The concept of a time-space prism (Hagerstrand 1970; Burns 1979) has been used in formulating several empirical analyses (Beckmann et al. 1983a, 1983b; Kitamura et al. 1981; Kondo & Kitamura 1987). Swait & Ben-Akiva (1986), in the context of choice-set formation in discrete choice analysis, developed a probabilistic model that incorporates constraints.

If needs for activities induce trips and if an individual's daily itinerary comprises a cohesive set of activities in the time-space dimension, then the conventional approach which examines each trip in isolation will offer at best an imperfect setting for behavioral analysis of urban travel. With the intent of investigating travel behavior more meaningfully, researchers have examined the individual's or household's travel pattern in its entirety. Most of the work comprises classificatory analyses that extract the salient dimensions along which variations in daily travel patterns can be effectively captured (Pas 1983, 1984; Koppelman & Pas 1985; Recker, McNally & Root 1985). Some, on the other hand, attempt to reduce the dimensionality by applying sequencing schemes (Kitamura & Kermanshah 1983, 1984). Also notable in the development are applications of structural equations systems and other multivariate techniques to daily travel patterns, multi-day behavior, and panel observations (Golob 1985, 1986; Golob & Meurs 1987).

The classificatory methods are extended to analyze multi-day travel patterns (Koppelman & Pas 1985; Pas & Koppelman 1985, 1986; Hanson & Huff 1986; Huff & Hanson 1986) or to enumerate feasible activity-travel patterns (Recker et al. 1986a, 1986b). For example, Pas & Koppelman (1985, 1986) and Pas (1988) utilize their classification scheme of daily travel patterns in order to characterize a multi-day travel pattern in terms of the daily patterns it contains. The development of analytical methods for multi-day travel behavior constitutes an important methodological contribution.

The analysis of multi-day behavior is necessarily complex because it is concerned with more involved decision processes. The increased analytical difficulty due to this added complexity is a price worthy to pay as a better understanding and characterization of travel behavior may be obtained by shedding light on the planning and scheduling of activities and travel over several days. It is anticipated that the evolving typological analyses – development of classification schemes and correlative analysis of travel patterns and sociodemographic attributes – will continue to offer important clues for travel behavior analysis.

With the same intent of capturing daily travel behavior in its entirety, characteristics of the linkages between trips have been extensively studied. This work includes critical examination of the validity of Markovian assumptions when applied to trip chaining behavior (O'Kelly 1981; Kitamura 1983), evaluation of the statistical significance of the linkage (Kitamura 1984b), exploration of the interdependence among activities linked by trips

(Kitamura & Kermanshah 1983, 1984; O'Kelly & Miller 1984), and mathematical formulation of the distribution of the number of stops in trip chains (Mazurkiewicz 1985). The development also includes practical application of the trip chaining concept by means of simulation (Southworth 1985a, 1985b) as well as econometric models in which trip chaining behavior is formulated as a discrete choice of alternative travel patterns (Barnard 1986) or as a process of maximizing time dependent utilities of activities (Horowitz 1982).

Recker et al. (1986a, 1986b) offer a model system, called STARCHILD, which enumerates feasible activity-travel patterns and selects the ones most likely to be chosen by household members of given characteristics. The spatial continuity of trips is maintained and trip chaining behavior is properly represented in the model. This computer-oriented model system adheres to the principles of the activity-based approach while effort has been made to base the model system to the extent possible on measurements available from standard travel surveys. In this sense, STARCHILD is quite complementary to the Household Activity Travel Simulator (HATS; Jones, et al. 1983), which is a home interview instrument that solicit from the respondents possible household activity-travel patterns that may be adopted in response to changes in the travel environment.

Several theoretical models of trip chaining behavior have been developed (Narula et al. 1983; Kitamura 1985; Thill 1985; Kondo & Kitamura 1987). Narula et al. (1983) view trip chaining as a result of the household's rational decision on shopping, where storage costs and travel costs are the major components that determine shopping frequencies and trip chaining. The model, which can be viewed as a theoretical model of trip generation as well as trip chaining, is constructed on an assumption similar to that in Westerious (1973) who postulated that random accumulation of needs triggers trip making. Thill (1985) develops a model also in a utility maximization framework considering multiple goods and multiple shop locations for an idealized setting. Also for an idealized case, Kitamura (1985) derives the spatial distribution of stop locations assuming that the individual minimizes travel cost when selecting stop locations and sequencing the visits.

Common among the works in this group is the intent to derive characteristics of trip chaining behavior based on utilitarian principles. They are typically based on simplifying assumptions and are developed for abstract settings, and therefore may apply only to the simplest real world problems. In addition, some of the models may not be empirically verifiable. Nonetheless, they contribute to the understanding of travel behavior, offer frameworks for empirical analysis, and serve as the basis on which more practical models can be constructed.

The analytical scope of the field has been expanded into the area of collective travel behavior by household members. Koppelman & Townsend (1987) and Townsend (1987) define household utility as a function of each individual household member's utility, which in turn is defined in terms of the satisfaction from activity participation, altruism, and the amount of goods consumed. Task allocation among household members is formulated as a utility maximization process under time budget constraints while considering the productivity of each household member in respective tasks. Assuming a specific functional form for each model component, Koppelman & Townsend (1987) derive expressions for the amount of time allocated to household members by activity type. The effort integrates economic and sociological concepts and attempts to establish an analytical basis in the area where past contributions have been conceptual or empirical in nature. The effort is an initial and encouraging step toward analytical and quantitative models of household activity and travel behavior.

Increasing attention has been directed toward dynamic aspects of travel behavior. This is in part due to the fact that use of longitudinal observation of behavioral units permits more direct observation of change in contributing factors and change in activity engagement and travel behavior, making possible precise characterization of adaptation behavior and identification of causal relationships. The focus on dynamic aspects is a natural outgrowth of the emphases of the activity-based analysis and reflects the desire to determine the causal structure among household attributes, activity engagement, and travel behavior. Note that activity choice and scheduling involve the time dimension and their thorough understanding can be obtained only by tracing behavior over time. This is the same viewpoint that motivated multi-day analysis of activity and travel behavior In addition, behavioral adaptation may span longer time periods, even years and decades. This recognition has led to recent analyses of habit formation and persistence (or behavioral inertia), hysteresis in behavior, and cohort effects (Goodwin 1977, 1986; Clarke, Dix, & Goodwin 1982; Goodwin & Layzell 1985; Kitamura & van der Hoorn 1987; Kostyniuk & Kitamura 1987).

The emphasis on dynamic aspects of travel behavior has induced new developments in observational, as well as analytical, methods. Notable is the series of analyses by Mahmassani and his colleagues based on observation of departure time decisions by commuters in a simulated, but realistic and real-time, environment (Mahmassani, Chang & Herman 1986; Mahmassani & Chang 1987). The experimental method used in this work appears to be suitable for studying learning, habit formation, and other dynamic aspects. Methodological developments motivated by the need to better capture and test dynamic properties of travel behavior can be found in Lyon (1984), Hensher (1986, 1987), Hensher & Wrigley (1986), Kitamura (1986, 1987), and Kitamura & Bovy (1987). Although not every dynamic analysis of travel behavior is necessarily an activity-based analysis, it is evident that activity-based analysis will benefit from adopting dynamic viewpoints when identifying behavioral relationships.

Empirical findings

The past accumulation of empirical results offers consistent indications that household lifecycle is an important factor associated with travel behavior. Gender and work status have also been found as "prime determinants of variation in activity behavior" (Damm 1983). We now have a much better grasp of the relationship between activity and travel patterns and household strucute. A regrettable tendency, however, is that past analyses tended to stop when the statistical results had proven the basic theses of the activity-based approach, e.g. that household structure, especially the presence of children, fundamentally influences household members' activity and travel patterns.

Another problem that is prevalent among empirical analyses of activity and travel patterns is the frequent application of statistical methods that may not adequately capture the complex nature of the research subject. Behavioral hypotheses are often examined while considering only a few variables without controlling for other contributing factors. A case of ecological fallacy is the likely consequence of such a marginal analysis. It is unfortunate that hypothesis testing has not necessarily been performed within multivariate contexts and that controls for statistical tabulations have not always been sought by referencing to suitable conceptual frameworks. In addition, discrepancies across studies and across data sets in the definitions of even such basic concepts as the trip, have made synthesis of empirical results a difficult task, especially for those more recent analyses that rely on nonconventional trip data. Despite these limitations, the recent accumulation of empirical results offers many important insights into activity and travel behavior.

There are common indications that the effect of gender supersedes the effect of employment on trip rate for certain activities, most notably shopping. Raux & Rosenbloom (1986) report pronounced differences between comparably situated men and women in their travel behavior and stated responses to possible changes. Pickup (1985) discussed women's low mobility in the context of their social position and the constraints on job opportunities and car availability that arise from this position. Hanson & Hanson (1981) show that working married women make slightly more multi-stop trip chains than do non-working married women. Analyses of multi-day travel behavior have offered consistent indications that women's travel patterns are more variable than those of men (Pas & Koppelman 1986; Jones & Clarke 1988). This tendency is interpreted as an indication of gender differences in activity engagement and constraints. An important extension that these

advances point to is the longitudinal analysis of gender effects in order to assess the role that gender will play in the future.

The same is also the case for the effect of age because its impact on travel behavior may vary over time. For example, Kostyniuk & Kitamura (1987) hypothesize that the age at which a person went through the period of intensive motorization may have permanent effects on travel behavior, constituting cohort effects. If such cohort effects are present, travel behavior of individuals in a given age group would not exhibit stability over time. An example of such effects is given in Goodwin & Layzell (1985).

Analyses of multi-day behavior have shown that an individual's daily travel pattern varies across days and typologies of day-to-day variations have been developed (Hanson & Huff 1982, 1986, 1987; Koppelman & Pas 1984, 1985; Pas & Koppelman 1985, 1986; Huff & Hanson 1986). Epirical investigation has been made into the level of variability, i.e. how "random" or "repetitive" multi-day travel behavior is (Hanson & Huff 1982, 1987, 1988; Huff & Hanson 1986; Kitamura 1988). It is anticipated that further investigation into the question will reveal characteristics of activity planning and scheduling behavior.

Advances have also been made in the areas of time use, time budget, and daily travel patterns (Palm 1981; Kitamura & Kermanshah 1983, 1984; O'Kelly & Miller 1984; Supernak 1984; Golob 1986b). Notable is the indication that the total time spent outside the home is not proportionally related to trip generation (Gunn 1981; Kitamura 1984a). These empirical results call for more rigorous examination of the linkage between time use (and activity patterns) and travel patterns.

Preliminary results have been obtained on the interaction among household members (Kostyniuk & Kitamura 1982; de La Morsangliere & Raux 1983). Further accumulation of empirical results, however, appears to be necessary before any conclusive statements can be made. In addition, it is desired that future empirical analyses be more tightly structured on some theortical ground, and that competing theories of task allocation, time use, and other relevant aspects of household behavior be empirically examined using observed activity and travel patterns. The work by Koppelman & Townsend (1987) offers a useful guideline for such future effort.

Available empirical results of dynamic analyses offer a strong indication that behavioral response is neither spontaneous nor symmetric. Kitamura & van der Hoorn (1987) report that trip rates for certain activities remain relatively unchanged after a change in employment status. Consequently, those who just gained jobs do not immediately exhibit the same trip rate as those who have had jobs, suggesting the presence of response lags and habit persistence. An example of asymmetric response is given by Goodwin & Layzell (1985) and Goodwin (1986); an increase in the trip rate that follows an increase in car ownership tends to be larger than a decrease in the trip rate following a decrease in car ownership. These results indicate that travel behavior cannot be adequately explained by contributing factors that are observed concurrently with the behavior; travel behavior depends upon the history of contributing factors and perhaps on the past trajectory of behavior itself.

The emerging results of empirical dynamic analyses point to the important role played by habitual elements in observed activity and travel behavior. For example, a "lifestyle" that an individual has acquired over time may have more profound effect on his activity behavior than does the travel environment surrounding him at a given time point. The implication of the results extends beyond activity behavior; traditional models of travel behavior based on cross-sectional data may be seriously biased because of response lags and habit persistence, and because activity and travel behavior depends upon its past history. If this bias is in fact not negligible, the forecasts produced by cross-sectional models, which virtually all practical planning models have been, are of questionable quality.

Current challenges

New results are accumulating rapidly in both methodological and empirical areas of activity-based travel analysis. However, many challenges remain in the subject areas that are central to the activity-based approach, namely, the mechanisms of activity decision-making, in particular, in-home and out-of-home activity substitution.

Treating travel demand as derived demand

One of the frequently repeated theses is that demand for travel is a derived demand. A brief reflection would convince us that this is an appropriate viewpoint to adopt. Therefore, it is often argued, we must understand the mechanism of activity engagement, i.e. what activity we pursue, when and where, how long, with whom, in what sequence, and how the engagement patterns are interrelated over time. This set of decisions is of course interrelated with the availability and ease of transportation between potential activity locations.

At the conceptual level, Lancaster's utility formulation (1966) neatly applies to this problem. If the concept of utility maximization is acceptable and if a utility function can be identified at all, an array of mathematical programming methods are applicable. However, the problem at hand is, at the simplest, a discrete choice-continuous allocation problem with correlated multiple alternatives, combined with the traveling salesman problem, problem of collective decision-making, and household coupling constraints which is in part a logistic problem. This is an overwhelming problem. In fact no model has been constructed that determines activity patterns on the sole basis of the utility maximization principle.

The existing models are much simpler than what such a utility-based formulation would mandate and far away from being an "operational" model of human activity behavior. While activity participation and time allocation have been modeled at the level of total daily time expenditure (e.g. Allaman et al. 1982), there is a wide gap between these models and models of daily activity and travel patterns. A unique exception is STARCHILD discussed earlier (Recker et al. 1986a, 1986b). The question remains, however, whether this model adequately depicts the mechanism of activity generation.

A well-known example of an activity model is due to Westelius (1973) who adopted the concept of stochastic needs generation when constructing his simulation model. As noted earlier, economists have applied inventory theory to determine the needs for shopping and frequency of shopping trips (Narula et al. 1983). These examples offer a basis for future effort toward realistic and practical models of activity generation and scheduling.

The success of such future effort depends on the quality of data used for hypothesis testing and model development. Conventional origin-destination data sets easily accessible to travel behavior analysts, do not contain information on in-home activities and their trip purpose categories tend to be too gross to determine the characteristics of out-of-home activities. In addition, their survey periods are typically limited to one day. These data limitations are among the factors that have hindered basic research in activity-based travel analysis. Future effort must circumvent the problem of scarce availability of suitable data sets and the difficulty of collecting new data by introducing appropriate behavioral assumptions and model formulations. It is encouraging that a knowledge base to develop such assumptions appears to have been formed through recent analyses of multi-day behavior, household interaction, trip linkages, and dynamic aspects of activity and travel behavior.

In-home and out-of-home substitution

Of particular importance, it is argued, is the substitution of in-home and out-of-home activities, e.g. choice of dining out or preparing a meal at home. It is argued that "several writers have talked of activity patterns in the context of travel studies, but almost without exception this has been a semantic rather than a conceptual adjustment . . . By ignoring in-home activities, however, most of the travel-related activity research has failed to grasp the full potential of the human activity approach: the ability to study linkages between people and through the day, and the facility for examining optional journeys as the outcome of (typically) in-home vs. out-of-home activity trade-offs" (Jones 1979). The importance of the issue has been eloquently pointed out. However, only one researcher (Salomon 1985, 1986) has addressed the problem so far. Quantitative models and empirical analyses remain to be seen.

Observing historical trends by analyzing conventional origin-destination survey results, one may find that social-recreation trips in the evening have decreased (e.g., Kostyniuk & Kitamura 1984, 1986a). This decrease may be attributable to the increased ownership of television sets and other home entertainment devices. Even without such an empirical indication, one can easily see that the in-home activity of watching television may substitute for an out-of-home recreational activity. The almost absolute absence of analysis in the field at either theoretical or empirical levels, then, indicates that this intuitive understanding alone does not offer adequate guidance to study the mechanism of substitution in a meaningful way.

It is interesting to note that in-home/out-of-home activity substitution does not uniquely determine travel demand because of in-home activities that generate trips. For example, consider watching rental video-cassette movies at home, clearly an in-home activity. In order to engage in this activity, one must go out and rent video cassettes first, then return them afterward (thus this in-home activity generates two out-of-home stops). Another example: choice of dining out, eating take-out food at home, or cooking and eating at home. The choice involves three alternatives to fulfill the needs of eating that comprise combinations of cooking, shopping (buying take-out food), eating, and travel.

In addition to the complexity of the mechanism of activity substitution, data availability is a serious problem here because existing cross-sectional time use data may not constitute an appropriate data base; cross-sectional variations in time allocation may reflect largely differences in time use across individuals, but not substitution between in-home and out-of-home activities for a given individual. Activity substitution is inherently dynamic whose mechanisms may not be easily inferred without using longitudinal observation of the same individuals (or stated responses to hypothetical changes as in Ampt et al. 1987). New findings may have to be obtained after a substantial amount of effort has been spent in data collection and analysis. Initial insights may be gained by case-by-case illustration of how an in-home activity may or may not be substituted for an out-of-home activity and may or may not suppress the needs for travel. It is desired that a simplified, unifying principle will follow such insights.

Constraints

Constraints imposed on activity engagement, scheduling, and travel are another central component of activity-based approach. As noted in the previous section, progress has been made in the analysis of constraints on travel behavior. In many empirical studies lifecycle stages are considered as a surrogate for the magnitude of constraints as well as that of activity needs. However, only a few studies have been able to examine specific constraints that regulate observed behavior. The use of lifecycle stages, role, and other variables has offered interpretable results, but has not led to the determination of the effect of specific constraints. Lack of data again is a problem. Empirical analysis and hypothesis testing have been hindered in the area of interpersonal linkages as well because of the limited data availability. An exception is the effort by Brog and his colleagues who used special surveys to gather information on microscopic factors governing travel decisions (Brog & Erl 1983).

Summary

Progress has been made at a respectable rate with new emphases on multi-day behavior and dynamic aspects of activity and travel behavior. New methodologies have been proposed and theories have been constructed for the exploration of daily activity and travel patterns and examination of the extremely complex decision rules govering observed behavior. The development has indeed been substantial so as to establish a new, solid body of literature comprising theoretical and empirical studies that span far beyond the conventional viewpoint that each trip can be analyzed in isolation irrespective of the other trips made in pursuit of the individual's daily activity program.

Challenges yet remain, however, in the areas of activity generation, substitution, constraints, and interpersonal interaction. While important theoretical contributions have been made recently in these areas, hypothesis testing and quantification of behavioral characteristics have been lagging behind, largely due to the lack of suitable data. Circumventing the data problem is one area that future basic analysis in the activity-based area must address.

The accumulation of empirical results has been rapid. Hypotheses originating from basic concepts in the activity-based approach have been extensively tested and additional pieces of evidence have been obtained in support of such hypotheses. However, not many new insights have been gained from recent empirical studies. This may be attributable to the apparent triviality of empirical findings, which is a consequence of the fact that these findings depict familiar and often too obvious aspects of everyday life. Presumably the limited observational schemes used in some of the analyses have failed to portray the complex decision process underlying travel behavior. Theories and conceptual frameworks of activity and travel behavior have not always been translated into tightly formulated and statistically testable behavioral theses that would offer new insights into everyday affairs and aid in drawing meaning out of the triviality. Better integration of theoretical and empirical efforts of activity analysis also remains to be a future challenge.

3. Activity-based analysis as a planning tool

The impact of activity-based travel analysis on transportation planning practice is reviewed in this section. The practical impact of activity-based analysis may not be immediately clear because of its orientation toward conceptual development. Nonetheless, the approach has undoubtedly influenced the modeling and forecasting effort in transportation planning. Applications of activity-based methods with specific planning or policy objectives, however, are few and far apart. Reasons for the scarcity of application are explored in this section.

Contributions to transportation planning

The existing applications of activity analysis to policy evaluation have shown that this approach can be used to determine which households and individuals will be affected by a new policy and how they will adapt to the change. These applications have pointed out that responses not expected by the analyst are possible and in many cases such responses lead to undersirable impacts (Jones et al. 1983).

One of the early examples of the value of fundamental understanding of travel behavior is the observation that needs and constraints associated with daily activities may limit the effect of certain planning initiatives. For example, Adiv (1983) hypothesizes that commuters are reluctant to use public transit because of the convenience that driving offers in engaging in extra activities during the commuting trip. Similarly, commuters may be reluctant or unable to participate in carpools because pursuing non-work activities will be too arduous if they do not take their own cars to work (Pas 1983). The activity-based analysis has shown that the effect of a planning option may be overstated if the fact that each trip is an integrated part of the individual's daily travel is disregarded and the resulting mitigating effect is overlooked.

The emphasis the activity analysts have placed on, among others, the time dimension, constraints, lifecycle, and interaction among household members, appears to have led to more widespread use of household role, work schedule and lifecycle-stage variables in travel behavior modeling. For example, a series of investigations was made at the New York Department of Transportation into the effectiveness of lifecycle stages in trip generation analysis (Chicoine & Boyle 1984). The standard set of variables considered in the model development effort in travel demand analysis may have been extended to include those variables that activity analyses have focused on.

An interesting question regarding the efficiency of data collection procedures arose as a derivative of multi-day travel analysis. Assuming a simple cost function for data collection, Pas (1986a) offers a procedure by which the optimal number of days to collect travel diary information in a survey can be determined while balancing the cost of the survey and the precision of model estimation. Pas (1987) also offers a new interpretation of the goodness-of-fit statistics of trip generation models based on his analysis of variations in trip generation across days. It is anticipated that further practical contributions will be made in the areas of sampling and survey design as more analyses are accumulated in the area of multi-day travel behavior.

Activity-based analyses of joint activity participation and travel by household members appear to be leading to a new approach to the estimation of car occupancy and the conversion of person trips to car trips. In the conventional approach, the number of person trips generated by household members is estimated in trip generation analysis using mainly household characteristics. These person trips are converted to car trips by first applying a modal split model and then applying an average car occupancy by purpose. The latter is determined completely independent of the trip generation analyses. From the viewpoints of activity analysis, it is clear that car occupancy is determined by household members' decision to participate in activities together, to chauffeur other members, or to car-pool with other individuals. If this decision systematically varies across households, it is conceivable that the conventional approach may lead to erroneous prediction. A study by Ostrom & Stopher (1984) points out some of the problems of the conventional average occupancy approach. The emphasis that activity-based analyses places on the interaction among household members and the emerging analytical frameworks for household behavior offer a promise that significant contributions will be made in the near future toward improved prediction of car occupancy.

As noted earlier, a critical examination of origin-destination survey results from the viewpoint that travel demand is a derived demand has led to results suggesting that car ownership, one of the traditional predictors of trip generation, may be a surrogate for the true determinants (Kitamura & Kostyniuk 1986, Kostyniuk & Kitamura 1986b). Possible effects of factors that have not been considered in the past, e.g., habit persistence, have also been suggested (Goodwin & Layzell 1985). Such developments in the field of activity-based travel analysis may in the future lead to a re-evaluation and overhaul of existing travel demand forecasting procedures, especially trip generation models.

Current challenges

As the discussion of the previous section suggests, activity-based analysis has begun to make an impact on transportation planning methods and practice. Because of the short history of the field, it is not appropriate to judge its effectiveness as a planning tool at this point in time. The focus of this section is on the reasons why the activity-based approach has not been used extensively in transportation planning. This is by no means to suggest that the approach is not useful in transportation planning. To the contrary, it is the author's belief that the activity-based approach can contribute immensely to the improvement of the current transportation planning practice.

Why are activity-based analyses not widely used?
The Household Activity Travel Simulator (HATS) has been applied in two case studies involving school hour changes and discontinuation of but services (Jones et al. 1983). This method was also applied in the Netherlands to assess the impact of altered bus schedules (Knippenberg & Clarke 1984; Knippenberg & Lameijer 1985). The applications are thus far limited to non-capital planning options.

It can be argued that demand analysis for non-capital projects is valued less than that for capital intensive projects since one can always modify or redo the project at little additional cost if it is not successful. The citizen participation mechanisms well established in the United States can also be used to assess (albeit in a biased way) whom and how the proposed project may impact. Indeed this appears to be how bus routes and service frequencies are modified in many cases. Why would one need to bring in an activity-based travel researcher when an announcement of the proposed change and public hearings (or even a local newspaper article and the subscriber's letters and telephone calls) may offer adequate input? If this is a typical perception held by planning agencies and transit operators, it is not surprising that the activity-based approach has not found widespread application.

Lack of uniform methods
In terms of the nature of the forces that drove its development, the activity analysis field is fundamentally different from the area of disaggregate choice analysis. The thrust for the latter development was improved statistical efficiency, economy in data collection, and versatile policy applicability. The development was strongly methodology and application oriented. Indeed the product, the multinomial logit model, is easy to understand, inexpensive to estimate, and usually offers sensible results (see, e.g. Horowitz 1985).

The activity-based approach was initiated with almost entirely reversed emphases. Its data collection was based on "in-depth" interviews, which are by no means economical and large samples are practically impossible to obtain. Prediction was least emphasized. Instead, "understanding" was the initial main focus; rather than statistically quantifying relationships among objectively defined household and person attributes, network level of service and land use variables, activity analyses sought to reveal why such relations existed.

In light of the historical emphases and the factors that induced the developments of the two approaches, it is not surprising that activity-based analyses tend to lack rigidly structured, quantitative methods or analysis procedures. The development in the field is crystallized as a set of concepts or conceptual relationships rather than as a collection of models and procedures.

The field of activity-based analysis, however, is not devoid of methodological development. The in-depth interview format and instrument (HATS; Jones et al. 1983; Bradley et al. 1987), a method to enumerate feasible paths (CARLA; Jones et al. 1983), classification schemes of complex travel patterns (Pas 1983, 1988), and a predictive model of complex travel patterns (STARCHILD; Recker et al. 1986a, 1986b) constitute definite methodological developments. Nevertheless, most of activity analysis is based on conventional or ad hoc experimental and statistical procedures. Importantly, no activity-based model has been offered that can be readily applied to a wide range of planning and policy problems.

Reliance on option-specific interviews and lack of spontaneity
A cricital difference between the activity-based analysis (in its narrower sense) and the conventional aggregate and disaggregate approaches is that, without relying on special interviews, an activity-based analysis does not produce a forecast that serves as a basis of decision making. In-depth interviews are essential for acquiring the types of information needed in an activity-based analysis. Moreover, it is not typical, if not impossible, to extract general, quantitative relationship between policy parameters and travel behavior from in-depth interviews; possible responses must be ascertained for each planning alternative under consideration. Now, it is obvious that potential planning alternatives must be clearly defined before one can possibly obtain interviewees' responses to them. On the other hand, an interview is an expensive process that cannot be repeated every time a new alternative emerges for consideration. As a consequence, activity analysis based on in-depth interviews will lack spontaneity.

Resistance to change on the part of practitioners and lack of effort to lay out how new concepts can be applied on the part of activity analysts
It is conceivable that the reluctance among the practitioners to adopt new approaches has hindered the practical use of activity-based analysis. It is at

the same time probable that activity analysts have not informed the practitioners how the new concepts and methods in activity-based analysis can be practically applied. For example, while use of lifecycle variables in trip generation was considered by practitioners (e.g. Skinner 1984), activity analysts have not supplied them with a conclusive statement as to what is the best classification of lifecycle stages. This in turn leads to the lack of funding for applied activity-based analysis, forming a vicious circle.

Ignorance of practical significance
Activity-based analyses have identified many new research subjects such as activity substitution, multi-day behavior, and interpersonal linkages. These are all of academic importance and pursuit of them will undoubtedly advance travel behavior science. However, it has not been explicitly stated or even examined whether the incorporation of these concepts into transportation planning practice will make any appreciable difference in the outcome. For example, consider again the use of lifecycle to improve trip generation analysis. It remains to be seen how much improvement a lifecycle variable will yield in predicting trip generation. It may be worthy to analyze the entire phase of forecasting, including the forecasting of the future distribution of lifecycle stages, and examine whether overall improvement can be obtained using lifecycle, or whether it will make no appreciable difference. It is equally important to examine in what planning context such a refinement becomes essential.

4. Future

Activity-based analysis has offered many valuable perspectives and concepts to travel behavior analysis. It has inspired many researchers and has led to widespread application of its conceptual framework to many aspects of travel behavior using various data sources. The effort is now starting to provide practical input to transportation planning.

Future development in the field seems to hinge on further fundamental research on the subjects that comprise major ingredients of activity-based analyses, i.e. activity generation, in-home/out-of-home activity substitution, constraints, scheduling, and interpersonal linkages. Little has been revealed about these aspects of activity-travel behavior.

Future research may benefit from attempts to identify the general principles at work, i.e. an effort to extract the common factors from microscopic observations with the aid of conceptual relationships and simplifying assumptions. It is desirable that measurable and simple relationships embodying behavioral principles are obtained. This was done, although as an

afterthought, in the case of the gravity model of spatial interaction. This is also the case for discrete choice models. The logistic binary response curve had long existed and was used in 1962 to model travel mode choice (Warner 1962). A multinomial extension of the binary logit model was given in 1969 (Theil 1969). Finally a utilitarian underpinning of the multinomial logit model was later provided (McFadden 1974).

Activity-based methods may not necessarily serve effectively as predictive models for large-scale, capital-intensive planning projects. Even with substantial research efforts, activity-based analyses may not yield practical predictive models of travel behavior in a foreseeable future. However, there is no reason to believe that the activity-based approach is useful only in basic research of travel behavior. To the contrary, there are many areas of transportation planning to which activity-based approaches can contribute.

For example, consider the impact of sociodemographic changes such as increasing proportions of working women, single parents, and elderly drivers, on travel demand in urban areas. Such changes cannot be thoroughly treated within the conventional framework that disregards the unique characteristics of activities pursued by individuals in these segments. The impact of rapidly advancing telecommunication technologies is another example that can be best assessed using the activity concept. The activity-based approach does not exist as a mere theoretical exercise. A large number of planning and policy questions can be most appropriately addressed within the framework of activity-based travel analysis.

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References

Adiv, A. (1983) The structure of work-trip based on analysis of trip diaries in the San Francisco Bay Area. In: S. Carpenter & P. Jones (Eds.) Recent Advances in Travel Demand Analysis (pp. 117–36). Gower, Aldershot, England
Allaman, P.M., T.J. Tardiff & F.C. Dunbar (1982) New Approaches to Understanding Travel Behavior. NCHRP report 250. Transportation Research Board, Washington, D.C.

Ampt, E. (1983) The social well-being of children. Paper presented at the International Conference on Interpreting and Valuing Transport's Role in Social Well-being, Noordwijk, The Netherlands

Ampt, E., M. Bradley & P.M. Jones (1987) Development of an interactive, computer-assisted stated preference technique to study bus passenger preferences. Paper presented at the 66th Annual Meeting of the Transportation Research Board, Washington, D.C.

Bachi, R., S. Reichman & I. Salomon (1987) Geostatistical measures for analyzing activity spaces: application to longitudinal data. Paper presented at the 66th Annual Meeting of the Transportation Research Board, Washington, D.C.

Barnard, P.O. (1986) Modelling Shopping Destination Choices: A Theoretical and Empirical Investigation. Ph.D. thesis. Department of Economics, University of Adelaide, Adelaide, Australia

Beckmann, M.J., T.F. Golob & Y. Zahavi (1983a, 1983b) Travel probability fields and urban spatial structure: 1. Theory, and 2. Empirical tests. Environment and Planning A,15: 593–606, and 727–38

Bradley, M., P. Jones & E. Ampt (1987) An interactive household interview method to study bus provision policies. Paper presented at the 15th PTRC Summer Annual Meeting, Bath, England, September

Brog, W. & E. Erl (1983) Application of a model of individual behaviour (situational approach) to explain household activity patterns in an urban area and to forecast behavioural changes. In: S. Carpenter & P. Jones (Eds.) Recent Advances in Travel Demand Analysis (pp. 250–70). Gower, Aldershot, England

Burns, L.D. (1979) Transportation, Temporal, and Spatial Components of Accessibility. D.C. Heath, Lexington, Massachusetts

Carpenter, S. & P. Jones (1983) Recent Advances in Travel Demand Analysis. Gower, Aldershot, England

Chicoine, J.E. and D.K. Boyle (1984) Life-cycle concept: a practical application to transportation planning. Transportation Research Record 987: 1–7

Clarke, M. (1986) Activity modelling – a research tool or a practical planning technique? In: Behavioural Research for Transport Policy (pp. 3–15). VNU Science Press, Utrecht, The Netherlands

Clarke, M.I., M.C. Dix & P.B. Goodwin (1982) Some issues of dynamics in forecasting travel behaviour – a discussion paper. Transportation 11: 153–72

Damm, D. (1983) Theory and empirical results: a comparison of recent activity-based research. In: S. Carpenter & P. Jones (Eds.) Recent Advances in Travel Demand Analysis (pp. 3–33). Gower, Aldershot, England

Dix, M.C. & A.D. Layzell (1986) Behaviour changes in chainging populations: problems and proposals for policy-directed longitudinal studies. In: Behavioural Research for Transport Policy (pp. 55–79). VNU Press, Utrecht, The Netherlands

Golob, J.M. & T.F. Golob (1983) Classification of approaches to travel-behavior analysis. In: Travel Analysis Methods for the 1980s, Special report 201 (pp. 83–107). Transportation Research Board, Washington, D.C.

Golob, J.M., L.J.M. Schreurs & J.G. Smit (1986) The design and policy applications of a panel for studying changes in mobility over time. In: Behavioural Research for Transport Policy (pp. 81–95). VNU Press, Utrecht, The Netherlands

Golob, T.F. (1985) Analyzing activity pattern data using qualitative multivariate statistical methods. In: P. Nijkamp, H. Leitner & N. Wrigley (Eds.) Measuring the Umeasurable (pp. 339–56). Martinus Nijhoff, Dordrecht, The Netherlands

Golob, T.F. (1986) A non-linear canonical correlation analysis of weekly trip chaining behaviour in the Netherlands. Transportation Research A, 20A: 385–99

Golob, T.F. & H. Meurs (1986) Biases in response over time in a seven-day travel diary. Transportation 13: 163–81

Golob, T.F. & H. Meurs (1987) A structural model of temporal change in multimodal travel demand. Paper presented at the 66th Annual Meeting of the Transporation Research Board, Washington, D.C.

Golob, T.F., L. van Wissen & H. Meurs (1986) A dynamic analysis of travel demand. Transportation Research A, 20A: 401–14

Goodwin, P. (1977) Habit and hysteresis in mode choice. Urban Studies 14: 95–98

Goodwin, P. (1983) Some problems in activity approaches to travel demand. In: S. Carpenter & P. Jones (Eds.) Recent Advances in Travel Demand Analysis (pp. 470–74). Gower, Aldershot, England

Goodwin, P.B. (1986) A panel analysis of changes in car ownership and bus use. Traffic Engineering and Control 27: 519–25

Goodwin, P.B. & A.D. Layzell (1985) Longitudinal analysis for public transport policy issues. In: G.R.M. Jansen, P. Nijkamp & C.J. Ruijgrok (Eds.) Transportation and Mobility in an Era of Transition (pp. 185–200). North-Holland, Amsterdam

Gunn, H.F. (1981) An analysis of travel budgets into mandatory and discretionary components. Paper presented at the PTRC 9th Summer Annual Meeting, University of Warwick, England

Hagerstrand, T. (1970) What about people in regional science? Papers of the Regional Science Association 24: 7–21

Hanson, S. & P. Hanson (1981) The impact of married women's employment on household travel patterns: a Swedish example. Transportation 10: 165–83

Hanson, S. & J.O. Huff (1982) Assessing day-to-day variability in complex travel patterns. Transportation Research Record 891: 18–24

Hanson, S. & J.O. Huff (1985) Implications of analysis of multiday data for spatial choice modeling. Paper presented at the 64th Annual Meeting of the Transportation Research Board, Washinton, D.C.

Hanson, S. & J.O. Huff (1986) Classification issues in the analysis of complex travel behavior. Transportation 13: 271–93

Hanson, S. & J.O. Huff (1987) Systematic variability in repetitious travel. Paper presented at the 66th Annual Meeting of the Transportation Research Board, Washington, D.C.

Hanson, S. & J.O. Huff (1988) Systematic variability in repetitious travel. Transportation (in this issue)

Hensher, D.A. (1986) Model specification for a quasi-dynamic discrete-continuous choice automobile demand system in discrete time using panel data. Working paper No. 11. Dimensions of Automobile Demand Project, Macquarie University, North Ryde, Australia

Hensher, D.A. (1987) Issues in the pre-analysis of panel data. Transportation Research A, 21A: 265–85

Hensher, D.A. & N. Wrigley (1986) Statistical modelling of discrete choices in discrete time with panel data. In: Behavioural Research for Transport Policy (pp. 97–116). VNU Science Press, Utrecht, The Netherlands

Hirsh, M., J.N. Prashker & M.E. Ben-Akiva (1986) Dynamic model of weekly activity pattern. Transporation Science 20: 24–36

Hocherman, I, J.N. Prashker & M. Ben-Akiva (1984) Estimation and use of dynamic transaction models of automobile ownership. Transportation Research Record 944: 134–41

Hoorn, T. van der (1983) Experiments with an activity-based travel model. Transportation 12: 61–77

Horowitz, J. (1982) Modeling traveler responses to alternative gasoline allocation plans. Transportation Research A,16A: 117–33

Horowitz, J. (1985) Travel and location behavior: state of the art and research opportunities. Transportation Research A,19A: 441–53

Huff, J.O. & S. Hanson (1986) Repetition and variability in urban travel. Geographical Analysis 18: 97–114

Jones, P.M. (1979) New approaches to understanding travel behaviour: the human activity approach. In: D.A. Hensher & P.R. Stopher (Eds.) Behavioural Travel Modelling (pp. 55–80). Croom Helm, London

Jones, P.M. & M. Clarke (1987) The significance and measurement of variability in travel behaviour: a discussion paper. Transportation (in this issue)

Jones, P.M., M.C. Dix, M.I. Clarke & I.G. Heggie (1983) Understanding Travel Behaviour. Gower, Aldershot, England

Kitamura, R. (1983) A sequential, history dependent approach to trip chaining behavior. Transporation Research Record 944: 13–22

Kitamura, R. (1984a) A model of daily time allocation to discretionary out-of-home activities and trips. Transportation Research B,18B: 255–66

Kitamura, R. (1984b) Incorporating trip chianing into analysis of destination choice. Transportation Research B,18B: 67–81

Kitamura, R. (1985) Trip chaining in a linear city. Transportation Research A, 19A: 155–67

Kitamura, R. (1986) Linear panel analysis of travel behavior. Technical report. Netherlands Institute of Transport, Rijswijk, The Netherlands

Kitamura, R. (1987) A panel analysis of household car ownership and mobility. Proceedings of the Japan Society of Civil Engineers, No. 383/IV-7: 12–27

Kitamura, R. (1988) An analysis of weekly activity patterns and travel expenditure. In: R.G. Golledge & H.J.P. Timmermans (Eds.) Behavioral Modeling Approaches in Geography and Planning (pp. 399–423). Croom Helm, London

Kitamura, R. & P.H.L. Bovy (1987) Analysis of attrition biases and trip reporting errors for panel data. Transportation Research A,21A: 287–302

Kitamura, R. & T. van der Hoorn (1987) Regularity and irreversibility of weekly travel behavior. Transportation 14: 227–51

Kitamura, R. & M. Kermanshah (1983) Identifying time and history dependencies of activity choice. Transportation Research Record 944: 22–30

Kitamura, R. & M. Kermanshah (1984) A sequential model of interdependent activity and destination choice. Transportation Research Record 987: 81–89

Kitamura, R. & L.P. Kostyniuk (1986) Maturing motorization and household travel: the case of nuclear-family households. Transportation Research A, 20A, 3: 245–60

Kitamura, R., L.P. Kostyniuk & M.J. Uyeno (1981) Basic properties of urban time-space paths: empirical tests. Transportation Research Record 794: 8–19

Knippenberg, C. van & M.I. Clarke (1984) Taking account of when passengers want to travel. Traffic Engineering and Control 25: 602–05

Knippenberg, C. van & I. Lameijer (1985) Simulation studies as a tool for determining public transport services in rural areas. In: G.R.M. Jansen, P. Nijkamp & C.J. Ruijgro (Eds) Transportation and Mobility in an Era of Transition (pp. 323–33). North-Holland, Amsterdam

Kondo, K. & R. Kitamura (1987) Time-space constraints and the formation of trip chains. Regional Science and Urban Economics 17: 49–65

Koppelman, F.S. & E.I. Pas (1984) Estimation of disaggregate regression models of person trip generation with multiday data. In: J. Volmuller & R. Hamerslag (Eds) Proceedings of the 9th International Symposium on Transportation and Traffic Theory (pp. 513–31). VNU Science Press, Utrecht, The Netherlands

Koppelman, F.S. & E.I. Pas (1985) Travel-activity behavior in time and space: methods for representation and analysis. In: P. Nijkamp, H. Leitner & N. Wrigley (Eds) Measuring the Unmeasurable (pp. 587–627). Martinus Nijhoff, Dordrecht, The Netherlands

Koppelman, F.S. & T.A. Townsend (1987) Task allocation among household members: theory and analysis. Paper presented at the 5th International Conference on Travel Behavior, Aix-en-Provence, France, October

Kostyniuk, L.P. & R. Kitamura (1982) Life cycle and household time-space paths: empirical investigation. Transportation Research Record 879: 28–37

Kostyniuk, L.P. & R. Kitamura (1984) Temporal stability of urban travel patterns. Transport Policy and Decision Making 2: 481–500

Kostyniuk, L.P. & R. Kitamura (1986a) Household lifecycle: predictor of travel expenditure. In: Behavioural Research for Transport Policy (pp. 343–62). VNU Science Press, Utrecht, The Netherlands

Kostyniuk, L.P. & R. Kitamura (1986b) Changing effects of car ownership on household travel patterns. Transportation Research Record 1085: 27–33

Kostyniuk, L.P. & R. Kitamura (1987) Effect of aging and motorization on travel behavior. Transportation Research Record (forthcoming)

Lancaster, K.J. (1966) A new approach to consumer theory. Journal of Political Economy 85: 132–57

Landau, U., J.N. Prashker & B. Alpern (1982) Evaluation of activity constrained choice sets to shopping destination choice modelling. Transportation Research A,16A, 3: 199–207

Landau, U., J.N. Prashker & M. Hirsh (1981) The effect of temporal constraints on household travel behavior. Environment and Planning A,13: 435–48

Lyon, P.K. (1984) Time-dependent structural equations modeling: a metholology for analyzing the dynamic attitude-behavior relationship. Transportation Science 18: 395–414

Mahmassani, H.S., G.-L. Chang & R. Herman (1986) Individual decisions and collective effects in a simulated traffic system. Transportation Science 20: 258–71

Mahmassani, H.S. & G.-L. Chang (1987) Travel time prediction and information availability in commuter behavior dynamics. Paper presented at the 66th Annual Meeting of the Transportation Research Board, Washington, D.C.

Mazurkiewicz, L. (1985) A statistical model of a multitrip spatial-interaction pattern. Environment and Planning A,17: 1533–39

McDonald, K.G. & P.R. Stopher (1983) Some contrary indications for the use of household structure in trip-generation analysis. Transportation Research Record 944: 92–100

McFadden, D. (1974) Conditional logit analysis of qualitative choice behavior. In: P. Zarembka (Ed) Frontiers in Econometrics. Academic Press, New York

Morsangliere, H. de La & C. Raux (1983) Structure of the family and trips behavior. Paper presented at the World Conference on Transport Research, Hamburg

Narula, S., M. Harwitz & B. Lentnek (1983) Where shall we shop today? A theory of multiple-stop, multiple-purpose shopping trips. Papers of the Regional Science Association 53: 159–73

O'Kelly, M.E. (1981) A model of the demand for retail facilities, incorporating multistop, multipurpose trips. Geographical Analysis 13: 134–48

O'Kelly, M.E. & E.J. Miller (1984) Characteristics of multistop multipurpose travel: an empirical study of trip length. Transportation Research Record 976: 33–39

Ohstrom, E.G. & P.R. Stopher (1984) Automobile occupancy, vehicle trips, and trip purpose: some forecasting problems. Transportation Research Record 987: 8–13

Palm, R. (1981) Women in nonmetropolitan areas: a time-budget survey. Environment and Planning A,13: 373–78

Pas, E.I. (1983) A flexible and integrated methodology for analytical classification of daily travel-activity behavior. Transportation Science 17: 405–29

Pas, E.I. (1984) The effect of selected sociodemographic characteristics on daily travel-activity behavior. Environment and Planning A,16: 571–81

Pas, E.I. (1985) State of the art and research opportunities in travel demand: another perspective. Transportation Research A,19A: 460–64

Pas, E.I. (1986a) Multiday samples, parameter estimation precision, and data collection costs for least squares regression trip-generation models. Environment and Planning A,18: 73–87

Pas, E.I. (1986b) Workshop report, workshop on activity analysis and trip chaining. In: Behavioural Research for Transport Policy (pp. 445–50). VNU Science Press, Utrecht, The Netherlands

Pas, E.I. (1987) Intrapersonal variability and model of goodness-of-fit. Transportation Research A, 21A: 431–38

Pas, E.I. (1988) Weekly travel-activity patterns. Transportation (this issue)

Pas, E.I. & F.S. Koppelman (1985) Analysis of multiday travel-activity patterns. Paper presented at the 64th Annual Meeting of the Transportation Research Board, Washington, D.C.

Pas, E.I. & F.S. Koppelman (1986) An examination of the determinants of day-to-day variability in individuals' urban travel behavior. Transportation 13: 183–200 (reprinted with corrections, Vol. 14, pp. 3–20)

Pickup, L. (1985) Women's travel needs in a period of rising female employment. In G.R.M. Jansen, P. Nijkamp & C.J. Ruijgrok (Eds) Transportation and Mobility in an Era of Transition (pp. 97–113). North-Holland, Amsterdam

Raux, C. & S. Rosenbloom (1986) Employment, childcare and travel behavior: France, the Netherlands, the United States. In: Behavioural Research for Transport Policy (pp. 363–79). VNU Science Press, Utrecht, The Netherlands