# URBAN TRANSPORTATION MODELLING: THE ACTIVITY-BASED TRAVEL ANALYSIS APPROACH[1]

by

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## INTRODUCTION

The field of urban transportation modelling is now roughly forty years old. From its early beginnings as a field dominated by engineers, it has grown and matured into a multi-disciplinary field of study. To date, researchers in this field have developed three general approaches to urban transportation modelling, namely, the classical, disaggregate, and activity-based approaches. The evolution of these approaches was influenced by the changing transportation planning issues, the participation of researchers from different academic disciplines, and breakthroughs in computer, electronics and other related technologies. The first half of this paper provides an historical review of the three approaches but the main focus is on the activity-based travel analysis approach. Besides being the latest to be developed, the activity-based approach has the most comprehensive analytical framework for building a theory of travel behavior. The last half presents in detail the fundamental elements of the approach and current research directions.

## HISTORICAL CONTEXT

The evolution of urban transportation modelling approaches is described in this section in order to provide an historical perspective on the development of the activity-based travel analysis approach. The focus will be on the forces that shaped model development which include: (a) the changing planning agenda and policy issues; (b) advances in computer technology and software engineering; and, (c) infusion of ideas and techniques from other disciplines such as urban and regional science, economics, statistics, phsychology, and geography. Through the years, these forces brought about changes in the theoretical framework, analytical techniques, data needs, and practicality of the various approaches to urban transportation modelling.

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**First Decade (Mid 1950's to Mid 1960's)**

It is generally recognized that the first urban transportation models were developed more than forty years ago as part of the pioneering comprehensive transportation planning studies conducted in the United States, namely, the Detroit Metropolitan Area Traffic Study in Michigan and the Chicago Area Transportation Study in Illinois. These and other similar studies conducted during this decade were aimed at producing comprehensive land use and transportation plans to address highway expansion all over the United States. Planning and construction of the Interstate Highway System were in full swing. At the same time, metropolitan areas were growing fast and more and more roads were being built to accommodate the expected rapid increase in the number of motor vehicles. The main concern of transportation engineers was to design road network systems to accommodate rapid growth and an urban lifestyle centered around the automobile. From this mindset was born what we now know as the classical four-step transportation planning model.

The classical approach to transportation modelling consists of a sequence of four models, namely: (a) trip generation; (b) trip distribution; (c) mode split; and, (d) traffic assignment. Several variations from this basic sequence have been developed over the years. Examples include direct demand models which collapse all four models into one step; combined generation-distribution models; trip-end mode split models which alters the basic sequence by putting mode split before trip distribution. However, these four models have withstood the test of time by remaining to be the core components of most modelling packages being used today.

Since the analytical framework of the classical approach is based mainly on physical laws, Pas (1988) had called this decade as the Social Physics Era of travel demand modelling. Trip distribution models, for example, were formulated based on Newton's Gravitational Law. Another example is Howe's (1962) work trip model which was based on electrostatics theory. Most other models were purely empirical deductions and without much behavioral bases.

Data is organized according to traffic analysis zones. Being so, the classical approach has come to be popularly known also as the aggregate approach. Data requirements of classical models were so extensive that more than half of the total budget for typical transportation planning studies went to data collection, reduction, and analysis.

Model implementation was typically on main-frame computers, batch-mode, and with no graphics. Hence, data preparation and maintenance for model applications were extremely cumbersome, particularly for studies involving analysis of alternative transportation and land use scenarios. Data validation and model calibration became arduous tasks for transportation modelers since they had to sift through reams of textual output. With the level of computer technology at that time, model execution took inordinate lengths of time even for just a single pass of the four-step model. Consequently, very limited alternatives analysis could be done within any given time and budget. More importantly, accuracy of model results could not be sufficiently ascertained to some level of confidence and therefore were viewed with skepticism.

**Second Decade (Mid 1960's to Mid 1970's)**

When the transportation planning agenda shifted emphasis from the long-run, systems-level planning of the first decade to the short-run multi-modal planning and management of transportation systems, the classical approach proved to be inappropriate in addressing the wide range of policy issues that had to be analyzed because it was extremely cumbersome and time-consuming to apply, required too much data, and could only address very limited issues. Altshuler (1981) noted that the main policy issues in the U.S. in the mid-1960's were: (a) high energy requirements of auto-oriented urban systems; (b) air pollution; (c) high rates of fatalities and personal injuries due to road accidents; and (d) inadequate transportation for those without access to automobiles. Interestingly enough, these issues are no different from what we are now confronted with in Metro-Manila. The strategies to address these issues include improving public transportation services and encouraging automobile users to shift to public transportation modes. It became necessary to have models which are versatile and can quickly and inexpensively predict the impact of various policies designed to reduce automobile usage (e.g., through carpooling) and increase public transport patronage.

Consequently, a major innovation in travel demand analysis was developed using a disaggregate modeling approach based on discrete choice analysis methods. Stopher and Meyburg (1975) presented a comprehensive overview of the theory and practice relating to this approach. This approach is described as being behavioral primarily because its theoretical basis comes from the economics of consumer behavior and the psychology of choice behavior. The advantages of this approach are well-documented in the literature (e.g., Tye et al., 1982; Stopher and Meyburg, 1975; Hensher and Stopher, 1977). By mid-1970s, this approach had become widely accepted as a viable method for urban travel forecasting and as a tool for analysing a wide variety of policy alternatives and transportation system management issues (Stopher, Meyburg and Brog, 1979). A brief sketch of the transportation applications of discrete choice analysis is described by Ben-Akiva and Lerman (1985). The initial successes in the application of this approach led to a series of U.S. Federal Highway Administration projects devoted to the refinement of the approach and its continued dissemination to practitioners (Tye et al.,1982). Lerman (1983) provides a state of the art review and Horowitz (1983) provides a state of the practice review of this approach.

Since the analytical framework of this approach is based heavily on random utility maximization formulations which are calibrated using efficient statistical sampling and estimation methods, Pas (1988) had called this decade as the Econometric Era of travel demand modelling. The most popular models of this decade are those based on the multinomial logit formulation because of its reasonably accurate predictive ability and less cumbersome calibration. Although the disaggregate approach is very versatile that it can be used in a wide range of applications, it has been largely and most successfully used in mode choice analyses.

Data is organized at the individual or household level. That is why it is called the disaggregate approach. Disaggregate models significantly reduced the required data for model calibration and application, and made better use of data collected from traditional transportation surveys. New survey methods and statistical sampling techniques were also developed specifically for disagreggate modelling.

Meanwhile, the classical modelling approach continued to improve its analytical framework and computational methods as it also benefited from the research results obtained as part of the development of the disaggregate approach.

Furthermore, advances in computer technology enabled model implementation to take place on mainframe and minicomputers with limited graphics capability and interactive terminals (Lewis, et al, 1989). More sophisticated algorithms such as stochastic equilibrium models and more complex statistical calibration techniques could already be computed within reasonable time. Most transportation analysis packages were still made up of large integrated programs but some were beginning to be modularized. However, data preparation and maintenance for computer implementation were still as cumbersome as before.

Despite the fact that the disaggregate approach represents a considerable advance over the classical approach, some still believe that it has many fundamental limitations and that it is not truly behavioral (Jones, 1977; Heggie, 1978; Burnett and Thrift, 1977; Burnett and Hanson, 1979; Horowitz, 1983). These shortcomings, which were summarized by Recker et al. (1986a) spurred the development of the activity-based approach to travel demand analysis in the next decade.

### Third Decade (Mid 1970's to Mid 1980's)

The development of the activity-based travel analysis approach started in the mid-1970's. Being the main topic of this paper, the activity based approach will be covered in greater detail in the last half of this paper. For now, I will only describe its evolution from an historical perspective and highlight significant developments in the transportation modelling field during this decade.

Criticisms against the classical and disaggregate approaches and arguments in favor of the activity-based approach have been documented extensively (see e.g., Damm, 1983; Jones, 1983; Kutter, 1981). Essentially, these arguments are derived from the notion that the activity-based approach is more behavioral than its predecessors and hence more theoretically appealing. On the practical side, the activity-based approach promises to be superior in that it can potentially address a wider range of policy issues and planning problems. Jones (1983) describes in detail these potential applications.

In addition to its theoretical appeal and practical applications, the development of the activity-based approach opened up new avenues for rethinking the whole process of transportation planning. The most significant of these is Hagerstrand's advocacy of the physicalist perspective from where his concept of time-space prisms was derived. It is expected that further development of the activity-based approach will yield new operational planning or analytical techniques embodying the philosopies of this approach.

During this decade, which Pas (1988) termed as the Human Activity Analysis and Psychological Measurement Era, many aspects of the classical and disaggregate approaches were enhanced due to the work of activity-based researchers and those involved in the use of psychological measurement techniques to quantify relatively abstract transportation system attributes (e.g., comfort, convenience, reliability, and safety) and users' perceptions, attitudes, and beliefs (Pas, 1988).

The prevailing planning issues also provided a big push towards the development of the activity-based approach. Most significant were the energy crisis brought about by the 1973-1974 Arab oil embargo and the fiscal crisis brought about by high levels of public spending. These crises shifted transportation planning focus from high-cost, capital intensive strategies to low-cost transportation system management strategies (Altshuler, 1981). Transportation planners began to realize that road expansion and investments in mass transit systems which normally requires large amounts of government subsidy to survive would not alleviate urban transportation problems. Instead, focus was directed towards better utilization of existing infrastructure through transportation systems management (TSM) techniques. With this change in focus, the emergence of the activity-based approach was indeed very timely as it afforded transportation planners with a rich source of new solution ideas and analytical methods.

Data requirements for modelling were still organized either at the zonal, household, or individual level depending on the application, but activity-based researchers began to realize that traditional transportation surveys which typically captured cross-sectional data were not adequate to address the activity-based research agenda. Hence, new survey methods had to be developed such as those for collecting panel (i.e., longitudinal) data and qualitative information.

We also witnessed significant developments in the computer implementation of urban transportation models. Microcomputers became accessible and transportation modelling programs on mainframes were being converted for microcomputer implementation. Database management systems, computer graphics, and interactive or menu-driven programming approaches also started to make their way into microcomputer-based transportation modelling systems.

**Fourth Decade and Beyond (Mid-1980's to the Future)**

In the mid-1980's to the present, the main transportation concerns were the ever-increasing traffic congestion in metropolitan areas, environmental degradation particularly air pollution, and road safety. These concerns are not really new. Traffic congestion and road safety are perennial issues and environmental concerns have been the subject of political movements during the early seventies. However, the difference lies in the greater resolve of governments to address these concerns and the use of advanced telecommunications, control, and information technologies to develop enhancements to traditional solutions and entirely new solution approaches. This decade is also marked by significant breakthroughs in computer technology and software engineering that are radically changing the way we view, analyze, and solve urban transportation problems.

The activity-based approach still remains to be the latest analytical framework for urban transportation modelling. Activity-based researchers have preoccupied themselves with developing techniques for dynamic analysis and modelling using panel data. Pas (1988) termed the fourth decade as the Dynamic Analysis Era. Meanwhile, the classical and disaggregate approaches were further enhanced with incorporation of more sophisticated algorithms which have become implementable with the advent of powerful computers.

Over the last five years or so, computer implementation of the classical four-step modelling approach has been greatly improved with the use of relational database management systems (RDBMS), graphical user interfaces (GUIs), and programming techniques which enabled transportation modellers to setup, digitize, calibrate, and validate a large-scale urban transportation model within a very short period of time. Data management and model maintenance are easily done. The speed of model execution has increased markedly compared with previous implementations. For example, one complete pass of the four-step model for an 800-zone transportation model can be completed in less than thirty minutes on an AT (80286), 16 MHz microcomputer.

More recently, however, the emergence of geographic information systems (GIS) is beginning to further enhance the implementation of the classical four-step model. With GIS, urban transportation models will become seamlessly integrated with other urban models, particularly land use models, thus opening up a wider domain of potential solutions that transportation planners can test and analyze. An important benefit from using GIS as a platform for urban modelling is better and cost-efficient data management. This assumes a setup in which relevant government and private sector organizations share the cost of building up and maintaining a centralized GIS in a metropolitan or regional area. This setup would also improve data consistency and encourage effective communication and coordination among participating organizations.

Future directions in urban transportation modelling revolve around the need to develop models to support research in intelligent vehicle-highway systems (IVHS) technologies. IVHS research is concerned with the development and application of electronic, computer, and information technologies in promoting efficiency and safety in the use of road and rail-based urban transportation systems. Some of the modelling enhancements that need to be developed include: (a) dynamic assignment and endogenous departure times planning models; (b) simulation of complex operational strategies; (c) stochastic processes for introducing non-recurring congestion in typical weekday travel models; (d) choice models that are sensitive to the amount of information available to the traveler; (e) integration of planning and dynamic simulation models; and, (f) explicit representation of predicted operating characteristics in emmissions and fuel consumption models (JHK & Associates, 1992). We can expect that urban transportation models of the future would be able to deal with the dynamic nature of urban traffic and predict impacts of strategies based on improved communications and vehicular control.

## THE ACTIVITY-BASED TRAVEL ANALYSIS APPROACH

### Its Origins and Development

The activity-based approach to travel demand analysis first evolved when social science researchers concerned with the understanding of human activity behavior undertook time allocation studies. Chapin (1974) traced the historical roots of time allocation studies and showed how perspectives from such studies, which emphasized the spatio-temporal aspects of human activity patterns, were eventually adapted in the analysis of urban activity systems and spatial structure. This led to the growth of a body of literature dealing with the time-space or time-geographic approach to the analysis of activity patterns. Much of the work in this field has been done by land-use planners, geographers and architects (Jones, 1977).

Jones (1977) identified two research groups who have contributed significantly to the development of the conceptual foundations of time-geographic activity research. The groups differ primarily in the importance they place on the role of choice and constraints in the understanding of activity behavior. Professor Chapin and his co-workers at Chapel Hill, North Carolina view human activity patterns from the sociological and anthropological perspective. They see these human activity patterns as a reflection of the choices made by individuals in their desire to satisfy their human needs and wants. In constrast, Professor Hagerstrand's group at Lund, Sweden views these activity patterns from a physicalist perspective emphasizing constraints that limit the individual's possible activity patterns. While Chapin is interested in people's preferences so that planning can provide for them, Hagerstrand is concerned with the factors that constrain activity patterns so that planning can relax them. Combining both perspectives provides a potentially powerful approach for analysing urban activity behavior.

When applied to travel behavior analysis, the time-geographic approach considers travel only as one of the various daily activities that individuals do in time and space. The focus is on what motivates individuals to perform activities, how they perceive the activity choices open to them, what value systems and choice processes they use to select and sequence the activities they perform, how the physiological, economic, cultural and spatial factors constrain the activities they can perform, and how they adapt their activity patterns to changes in their external environment. Hence, travel behavior is viewed from a broader perspective and deeper breadth than those taken by classical and disaggregate approaches.

**Fundamental Perspectives**

Recognition of the complexity of travel-activity behavior is a fundamental viewpoint of activity-based researchers. As such, many of the assumptions, theoretical frameworks, and analytical techniques of previous approaches to travel demand modeling have been critically assessed, and many issues have been raised concerning our basic understanding of individual travel behavior. The diversity of research directions and the multitude of analytical methods that exist within the field are indicative of the difficulty of achieving a comprehensive understanding of the intricate mechanisms governing complex travel-activity behavior. While researchers have suggested conceptual frameworks toward the development of a unified theory of travel behavior, much basic research needs to be done on aspects of the theory

Travel is considered a *derived* activity. Travel activity only serves to enable individuals to undertake various urban activities. The focus of the analysis is on the nature of these urban activities and how travel activity organizes or links them in time and space. This view is considerably more complex than those taken by classical and disaggregate approaches. Lost in those approaches are dimensions such as sequencing and direction of travel activities which Hagerstrand argues to be the appropriate representations of the interwoven distribution of activities in space and time (Hensher and Stopher, 1977).

Along with this view of travel, the activity-based approach postulates that an individual's travel pattern is the result of his decisions on how he fulfills his needs to undertake a sequence of activities within the constraints of time and space (Burnett and Thrift, 1977). Other constraints are attitudinal, economic, psychological, physiological, informational, and transportation-related. Hence, travel activity is the result of an individual's decision-making under constrained activity choices.

The unit of analysis is either the individual or household. However, analysis done at the household level is more common due to pragmatic and theoretical reasons (Salomon, 1983). As early as the 1960s, the household has been used as the unit of analysis (e.g. Wooton and Pick, 1967), but it was only recently that most of the empirical work is being done at that level. Kostyniuk and Kitamura (1983) cited several works which describe sociological and economic justifications for household-level analysis. Salomon (1983) refers to studies which criticize household-level analysis due to aggregation problems, but he suggests that such problems can be remedied. Clarke and Dix (1983), on the other hand, refer to another study by Supernak and Talvitie which favor individual-level analysis because, aside from other criticisms they have for household-level analysis, they believe that the individual is the true decisionmaker. Clarke and Dix (1983) suggest that a fairer description of behavioural reality would be that decisions are made by individuals in the context of their respective households.

At this stage of its development, the activity-based approach is primarily concerned with the understanding of complex travel behavior. Its interest is on the explanation rather than the prediction of travel behavior. The understanding of complex travel behavior requires not only the understanding of individual behavior but also of the household interactions that influence activity behavior (Golob and Golob, 1983). With such ambitious aim, research on this approach has to draw upon knowledge from a wide variety of disciplines resulting in its interdisciplinary nature and diversity of analytical focus and techniques. Recker et al. (1986b) provide a review of this myriad of approaches which they characterize as fragmented and lacking sound methodological foundation. Realizing also that the behavioral hypotheses that have so far been developed are predominantly partial constructs, they propose a comprehensive framework for a theory of complex travel behavior built heavily upon the conceptual developments and empirical results of previous activity-based research.

### Past and Current Research Directions

This section reviews the various theoretical and empirical studies on the development of the activity-based approach. The review is organized according to the three generic components of the approach, namely, generation of the activity program, formation of feasible activity sets, and selection of activity schedule.

The review of the literature on activity-based analysis revealed that studies on travel-activity behavior have been undertaken from two broad perspectives, namely, activity choice behavior and constraints to activity behavior. The former focuses on the decision processes and underlying factors that govern the choice behavior of individuals when faced with alternative activity patterns. The latter focuses on the various constraints (e.g., economic, social, informational, transportation, spatial, and temporal) that limit activity choices. Instead of predicting activity choices, the latter perspective deals with defining how constraints circumscribe potential activity patterns.

The review revealed that research has largely focused on understanding individual decision processes, and identifying the underlying factors that govern activity choice behavior, leaving very little attention devoted to understanding how various constraints influence the formation of travel-activity patterns.

While the activity-based approach is considered as distinct from its predecessors, many of its elements are similar or recast versions of analytical techniques and model formulations found in the classical and disaggregate approaches. This is not surprising since the activity-based approach was developed by building upon the strenghts of its predecessors and expanding its conceptual and analytical framework towards a more comprehensive set of principles the could be the foundation for a theory of travel behavior.

### *Generation of Activity Program*

All activities that an individual undertakes over a period of time constitute an activity program. The definition of an activity varies according to the level of detail required by the analysis. For example, Pas (1984) used a rather coarse definition by categorizing activities as either subsistence (i.e., work and school), maintenance (i.e., shopping and personal business), leisure, or return home. On the other hand Tomlinson et al. (1973), in their analysis of students' daily activity patterns, used a 12-category definition of activities: teaching, private study, eating, drinking, casual social activities, entertainment, private leisure, watching television, personal hygiene, domestic activities, shopping, and sleeping. While Pas aggregated all in-home activities into one category, Tomlinson, et al. defined several categories of in-home activities. The former approach focuses only on the out-of-home activities and is not able to look into possible trade-offs in performing an activity out of the home versus in the home to save on traveling; the latter approach can potentially account for this possibility.

The time period of an activity program usually covers the daily or weekly pattern of activities, although theoretically, longer periods such as monthly, seasonal or annual cycles may also be of interest. These temporal cycles are assumed to be interrelated in that the decisions on what activities will be done in a particular day may be influenced by the activity programs which are of longer duration (Hemmens, 1970).

The activity-based approach defines travel as another activity category which mainly serves to link all other activities in the activity program separated in space and time. In this sense, travel-activity is viewed as a derived demand. The behavioural nature of this approach stems from its perspective of focusing directly on the underlying factors that generate activity programs, and on how travel-activity patterns are formed by individuals who undertake such programs.

In understanding how individuals generate activity programs, the activity-based approach follows Chapin's (1968) schema of the process of activity choices. The schema suggests a motivation-->choice-->activity framework in which the fundamental needs and desires of an individual serve as the motivations to perform activities, based on an examination of the alternatives open to him, his preferences and decision rules. Chapin argues that this is an evolutionary process in which activity choices and the urban environment constantly interact and shape each other through time. In order to develop this schema into a more operational form, several theories or hypotheses have been advanced to establish the link between the motivational component and the activity choices.

Most research dealing with the generation of activity programs hypothesize that urban activity behavior is stable with respect to individual role structures. Fried et al. (1977) suggest that activity behavior such as those involving work or occupation, household and family, extra-familial interpersonal interaction, and leisure and recreation have stable points of reference from the social role commitment of individuals. They further suggest that the variation in role and activity patterns is influenced by the following factors: (a) physical structure of the environment, (b) socio-cultural expectations, (c) individual socio-economic status, (d) life-cycle stage, and (e) residential location. In addition, the concept of life style, as suggested, for example, by Salomon and Ben-Akiva (1982), may be added to this list. The significance of studies on how these factors influence activity behavior cannot be overemphasized. Pas (1984) cites numerous authors who discussed the importance of such studies towards the understanding of travel behavior and the improvement of current practical approaches to travel demand prediction.

This hypothesis on the stability of activity behavior has been the subject of several empirical tests. Damm (1983) provides a comprehensive review of such work and finds great difficulty in comparing empirical results due to wide variations in the definition of activity behavior by different researchers. Nonetheless, he concludes that many well-founded inferences can already be drawn and incorporated into a coherent theory of activity behavior. Damm's study shows that: (a) gender and work status, and to a lesser extent age, occupation, and educational background are principal determinants of individual activity behavior; (b) the stage in the household's lifecycle and the characteristics of the family's children strongly account for the variation in household activity behavior; (c) the interdependencies among members of the household in the performance of their activities is not well understood; and (d) there seems to be fixed activities around which individuals schedule their non-fixed activities. Given these findings, he suggests that more work needs to be done on exploring the nature of the fixity of activities and on performing a systematic comparison of behaviors across types of activities. Studies of this nature can contribute significantly to our understanding of the individual's decision processes concerning activity behavior.

Hanson and Hanson (1981) also provide an extensive review of empirical research dealing with the relationship between socio-demographic variables and travel behavior. They observe, however, that the major shortcoming of this body of work is the inclusion of only a few travel behavior dimensions or socio-demographic variables. Also, most of these studies do not consider the spatial and temporal characteristics of travel behavior. No previous work has considered an extensive set of travel behavior measures that can capture the interrelated temporal and spatial characteristics of activity patterns. This is a salient feature of activity behavior that needs further understanding.

Other studies used the hypothesized stability of activity behavior with respect to role structures as a basis for developing models to predict activity behavior or as a technique to improve current travel demand estimation procedures through market segmentation. Kutter (1973) developed the concept of typical or archetypal individuals based on socio-demographic variables. Pas (1984) related activity patterns with role, life style and life cycle variables in order to determine the likelihood of a population subgroup undertaking a particular activity pattern. Oppenheim (1975) used a typological approach to predict urban travel activity from socio-demographic and environmental characteristics. Knapp (1983) investigated the possibility of using national travel survey data to formulate life cycle variables for use in predicting activity patterns. Such approaches to predicting activity behavior are more associative than behavioral. Nevertheless, they can lead to new approaches to travel behavior prediction, market segmentation, and simulation of long-term impacts of demographic changes on activity behavior.

*Formation of Feasible Activity Sets*

As described in the preceding section, an activity program represents the activities that an individual seeks to pursue based on his or her needs and aspirations. These activity programs differ among individuals depending on their socio-demographic characteristics, particularly those related to their social or household roles. In undertaking an activity program, an individual is faced with opportunities as to where and when each activity can be pursued. All the activity sites and their opening and closing times constitute the totality of opportunities provided by the urban area.

However, there are several constraints which limit the opportunities open to an individual. There are temporal and spatial constraints imposed by the physical environment (e.g., the land use and transportation system); constraints imposed by the socio-economic status and psychological disposition of the individual; and constraints imposed by imperfect information (Burnett and Thrift, 1977). The set of all possible combinations of activity sites that can fulfill an individual's activity program is called the *feasible activity set*. It is important to understand the formation of feasible activity sets because it can provide insights on: (a) the nature of an individual's choice set when analyzing activity patterns using discrete choice modeling, and (b) the impacts of land use and transportation on activity patterns.

More importantly, constraints-based analytical approaches to planning and managing transportation systems as exemplified by Hagerstrand's pioneering work on time-space prisms may be further developed. These prisms represent the possible time-space paths that an individual can follow in the urban area given various constraints such as those imposed by the transportation system. The size of these prisms can be viewed as a measure of welfare or accessibility to opportunities provided by the urban environment. Hence, it appears that time-space prisms can be used in developing analytical tools for planning and managing transportation systems. An excellent example is the accessibility methodology developed by Burns (1979).

Hagerstrand argues that rather than predicting activity behavior directly, it could be more fruitful to focus attention on how constraints limit the individual's freedom of action. Due to the complex nature of activity behavior, it's prediction is an extremely difficult task. Therefore, rather than basing plans on behavioral travel predictions, it would be easier to develop plans aimed at relaxing the constraints that circumscribe individual movements, without having to predict individual travel behavior. Hagerstrand (1970) describes in detail his conceptual development of time-space prisms and how they are formed by what he calls capability, coupling, and authority constraints. He also suggests that although many constraints are formulated as general and abstract rules of behavior, we can give them a physical shape in terms of location in space, areal extension and duration in time. In other words, the influence of constraints on activity behavior manifests itself in the spatio-temporal dimensions of activity patterns. Theoretical and empirical studies should be undertaken to understand the spatial and temporal characteristics of activity behavior. However, several authors (e.g., Burnett and Thrift, 1977; Kostyniuk and Kitamura, 1983; Holzapfel, 1986) observe that very limited research has been undertaken in this area.

Several authors hypothesize the existence of fixed activities around which discretionary activities are scheduled according to their flexibility or importance (see e.g., Cullen, 1972; Cullen and Godson, 1975; Kutter, 1973; Chapin, 1974; Oster, 1978). Some activities are believed to be intrinsically fixed in space (e.g., work activity in the short run) or fixed in time (e.g., eating meals). On the other hand, Damm (1983) refers to studies which assume that participation in other less fixed activities is influenced by subjective perceptions, preferences, and attitudes. By studying the nature of and the factors that influence the degree of fixity of activities, we can gain insights that are useful for modeling activity behavior and for managing transportation and the urban environment.

In studying the temporal fixity of activities, some have stressed the importance of looking into the variation of temporal constraints in time so that blocks of free and constrained times during a day can be identified (see, e.g., Heggie and Jones, 1978). A related issue is how this temporal fixity varies during a day, a week, or even during longer time periods. Certainly, there are day-to-day variations in activity behavior, but work in this area is limited by the scarcity of longitudinal data.

Spatial fixity also plays an important role in structuring an individual's daily activity. Depending upon the location of an individual's fixed activity, he or she is faced with different opportunities to participate in discretionary activities (Damm, 1983). Obviously, transportation services available to individuals is a major factor in determining their accessibility to activity opportunities. Damm further points out that we only partly understand how people use non-motorized modes when participating in out-of-home activities. To date, there has been no significant work done in exploring how various modes of transportation influence activity behavior.

There are also a few studies dealing with the effect of imperfect information on activity behavior. It has been suggested that the level of information that individuals have on the opportunities available to them expands or contracts their time-space prisms (see e.g., Parkes and Thrift, 1975). Furthermore, it has been posited that individuals undergo a dynamic learning process about their urban environment which influence their activity behavior (Horton and Reynolds, 1970).

Activity-based researchers are still in the dark about many dimensions of temporal and spatial constraints on behavior (Damm, 1983). In particular, the role that spatial, temporal and transportation constraints play in shaping travel-activity patterns is an important topic that so far has received relatively little attention. Examples of research issues pertaining to these constraints are as follows: (a) mechanisms followed by households in allocating scarce transportation supply among household members; (b) existence of threshold levels of mobility where significant changes in activity behavior occur; (c) extent of activity pattern choices perceived by individuals as a function of these constraints; and, (d) importance of including transportation supply or mobility-related variables as determinants of urban activity patterns in relation to widely known socio-demographic and spatial determinants. Burnett and Thrift (1977) also raised many issues that need to be explored regarding spatial and temporal constraints. They also refer to the developmental works of Brog, et al. and Lenntrop, who formulated mathematical and simulation models for assessing the impacts of transport and land-use policies on activity behavior. In contrast to conventional and disaggregate approaches to demand analysis, their approach uses environmental data (not diaries) and yields expected time-space budget of each individual's simulated path. Their approach follows Hagerstrand's constraints-based planning philosophy.

*Selection of Activity Schedule*

Several theories have been proposed to explain the behavioral rules that govern the scheduling of activities in time and space. Fried et al. (1977) developed a microtheory which views travel behavior as a socially, psychologically, and economically constrained adaptation process to discrepancies between the person-environment fit. Their theory is essentially a broad conceptual framework dealing with the social and psychological forces that shape travel decisions and behavior.

Many others have modeled activity behavior based on random utility theory. Examples are Adler and Ben-Akiva's (1979) models of nonwork travel and Recker et al.'s (1986a) model of complex travel behavior. Though not yet fully operational, Recker et al.'s model is the most comprehensive and the one that integrates most of the significant developments in activity-based research. The underlying hypothesis in these models is that an individual selects the activity pattern which provides maximum utility.

An entirely different approach for modelling activity behavior builds upon the notion of urban travel linkages, particularly the mutual dependence between transport and land use (Mitchell and Rapkin, 1954). Rather than predict individual activity choice behavior, this approach assumes that activity patterns reflect the functional interdependence between urban land uses. Thus it focuses on the spatial arrangement and the strength of travel linkages between activity locations. Macroscopic regularities in these linkages are utilized in formulating stochastic models of activity patterns (see e.g., Hemmens, 1966; Marble, 1964; Horton and Shuldiner, 1967; and, O'Kelly, 1981). Hanson (1979) discuss the potential usefulness of this approach in analysing the impacts of spatial constraints on activity patterns. This approach is neither behavioral nor microscopic. Its analytical nature is associative, as in the archetypal or typological approaches to predicting activity patterns discussed earlier.

Most empirical studies on urban travel linkages concentrate on measuring the strength of these linkages through an analysis of multiple-sojourn trips or trip chains. Many of these studies use Markovian models even though the time-homogeneity and memoryless assumptions of these models are too restrictive, considering the dependence of activity behavior on time of day and location in the urban area (Kitamura, et al., 1981). Moreover, these macroscopic approaches are basically atemporal and aspatial (Vidakovic, 1977). Very limited research has been devoted to the understanding of the fundamental time and space properties of activity patterns at the microscopic (individual) level. Noteworthy examples are Vidakovic's (1974) harmonic series model of trip chains; Vidakovic's (1977) analysis of the distance parameter of trip chains; Kitamura et al.'s (1981) theoretical development of the basic properties of time-space paths; and Kostynuik and Kitamura's (1983) empirical work on household time-space paths.

## Summary and Conclusions

The activity-based approach to travel demand analysis is rooted in the time allocation and the time-geographic studies of human activity. Its development is due to the efforts of researchers from many academic disciplines, thereby contributing to the rich, diverse and multi-disciplinary nature of this approach. With the changing agenda in transportation planning, the classical and disaggregate approaches to travel demand analysis can not adequately handle the complex issues that analysts face. For example, the impact of innovative non-transport solutions to urban transport problems is difficult to assess using existing methodologies. Non-transport solutions include land use controls, telecommuting, teleshopping, electronic data interchange, and other telecommunications-based solutions. The potential of the activity-based approach in addressing these issues became the major impetus for the development of this approach.

This review of past research showed a wide diversity in the focus and analytical approaches to modeling activity behavior. Research seems to be fragmented, and there is as yet no widely accepted theory of activity behavior. There are recent efforts, however, to provide a more coordinated direction that can integrate the various approaches into a cohesive theory. Still, many believe that more theoretical and empirical work are needed so that the basic and fundamental elements of activity behavior are better understood. Operational activity-based models have not yet been fully developed for practical application. However, the approach has served to improve the application of existing approaches by enabling better model specification and market segmentation.

Most of the theoretical and empirical work in activity-based research has focused on understanding how individuals generate activity programs. The major hypothesis is the existence of a stable relationship between activity patterns and an individual's social role, household's lifecycle stage, and lifestyle. Using data on daily travel patterns, from conventional origin-destination studies, this hypothesized stability has been empirically investigated. Current research directions are focused on designing new survey methods to collect longitudinal data; developing interview techniques to gain insights into the motivation and decision processes of individuals; investigating the day-to-day variability of activity patterns; and developing new mathematical and non-mathematical models of activity participation.

The area that has received little attention is the understanding of how various constraints influence activity behavior. Attitudinal, economic, psychological, social, informational, physiological, transportation, spatial and temporal constraints have all been hypothesized to limit the activity choices perceived by the individual. Most of the work in this area is limited to theoretical or conceptual constructs and are focused on understanding the nature of the degree of fixity of activities in space and time; investigating the interrelationships between the time and space components of activity patterns; and identifying the factors, specially land use and transport factors, which influence activity patterns.

The underlying hypothesis in most activity scheduling models is that individuals are faced with activity choices and that they decide based on some rules of behavior, such as utility maximization. Models of activity choice behavior are mainly based on random utility theory. Stochastic techniques have also been used to model trip linkages at an aggregate, aspatial and atemporal level. At the individual level, mathematical models of trip chaining processes have been used to predict activity patterns or to investigate their fundamental time-space properties.

The activity-based travel analysis approach to urban transportation modelling is the result of a healthy cross-fertilization of ideas and techniques from various disciplines, namely, engineering, urban and regional science, economics, statistics, psychology, sociology, and geography. It has the most comprehensive analytical framework for building a theory of travel behavior. Its contribution to date is mainly on providing transportation modellers with conceptual bases from which practical models are developed. With current the trend towards seeking out novel urban transportation solutions, some of which may affect individual life styles and urban activity behavior, the activity-based approach appears to be the most logical starting point for analysis and modelling.

## BIBLIOGRAPHY

Adler, T., and M. Ben-Akiva, (1979). "A Theoretical and Empirical Model of Trip Chaining Behavior". *Transportation Research-B*. Vol. 13, pp. 243-257.

Altshuler, Alan (1981). *The Urban Transportation System: Politics and Policy Innovation*. Massachussetts: MIT Press.

Ben-Akiva, M., and S.R. Lerman, (1985). *Discrete Choice Analysis: Theory and Application to Travel Demand*. Massachussetts: MIT Press.

Burnett, K.P., and S. Hanson, (1979). "A Rationale for an Alternative Mathematical Paradigm for Movement as Complex Human Behavior". *Transportation Research Record*. No. 723, pp. 11-24.

Burnett, K.P., and N.J. Thrift, (1977). "New Approaches to Understanding Travel Behaviour". In *Behavioural Travel Modelling*. David A. Hensher and Peter R. Stopher, eds., Croom Helm Ltd., England, pp. 116-134.

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

Chapin, F.S. (1968). "Activity Systems and Urban Structure: A Working Schema". *Journal of the American Institute of Planners*. Vol. 34, pp. 11-18.

Chapin, F.S., (1974). *Human Activity Patterns in the City: Things People Do in Time and Space*. Wiley and Sons, New York.

Clarke, M., and M. Dix, (1983). "Stage in Lifecycle - A Classificatory Variable with Dynamic Properties". In *Recent Advances in Travel Demand Analysis*. Susan Carpenter and Peter M. Jones, eds., Gower Publishing Co. Ltd., England, pp. 215-231.

Cullen, I., (1972). "Space, Time and the Disruption of Behavior in Cities". *Environment and Planning*. Vol. 4, pp. 459-470.

Cullen, I., and V. Godson, (1975). "Urban Networks: The Structure of Activity Patterns". In *Progress in Planning*. D. Diamond and J.B. MacLaughlin, eds., Pergamon Press, England, Vol. 4, Part 1.

Damm, D. (1983). "Theory and Empirical Results: A Comparison of Recent Activity-based Research". In *Recent Advances in Travel Demand Analysis*. Susan Carpenter and Peter M. Jones, eds., Gower Publishing Co. Ltd., England, pp. 3-33.

Fried, M., J. Havens, and M. Thall, (1977). "Travel Behavior: A Synthesized Theory". *National Cooperative Highway Research Program Final Report No. 8-14A*. Prepared by the Laboratory of Psychosocial Studies, Boston College, Massachusetts.

Golob, J.M., and T.F. Golob, (1983). "Classification of Approaches to Travel Behavior Analysis". In *Travel Analysis Methods for the 1980s*. Transportation Research Board Special Report No. 201. National Research Council, Washington, D.C., pp. 83-107.

Hagerstrand, T., (1970). "What About People in Regional Science". *Papers of the Regional Science Association*. Vol. 24, pp. 7-21.

Hanson, S., (1979). "Urban Travel Linkages". In *Behavioral Travel Modelling*. D. Hensher and Peter R. Stopher, eds., Croom Helm Ltd., England, pp. 81-100.

Hanson, S., and P. Hanson, (1981). "The Travel Activity Patterns of Urban Residents: Dimensions and Relationships to Socio-demographic Characteristics". *Economic Geography*. Vol. 57, pp. 332-347.

Heggie, I.G., (1978). "Putting Behavior into Behavioural Models of Travel Choice". *Journal of the Operations Research Society*. Vol. 29, pp. 541-550.

Heggie, I.G., and P.M. Jones, (1978). "Defining Domains for Models of Travel Demand". *Transportation*. Vol. 7, pp. 119-125.

Hemmens, G.C., (1966). *The Structure of Urban Activity Linkages*. Center for Urban and Regional Studies, Chapel Hill.

Hemmens, G.C., (1970). "Analysis and Simulation of Urban Activity Patterns". *Socio-Economic Planning Science*. Vol. 4, pp. 53-66.

Hensher, D.A., and P.R. Stopher, (1977). "Behavioural Travel Model". In *Behavioural Travel Modelling*. D.A. Hensher and P.R. Stopher, eds., Croom Helm Ltd., England, pp. 11-51.

Holzapfel, H., (1986). *Trip Relationships in Urban Areas*. England: Gower Publishing Co. Ltd.

Horowitz, J.L., (1983). "Evaluation of Discrete-Choice Random-Utility Models as Practical Tools of Transportation Systems Analysis". In *Travel Analysis Methods for the 1980s*. Transportation Research Board Special Report No. 201., National Research Council, Washington, D.C., pp. 127-137.

Horton, F.E., and D.R. Reynolds, (1970). "Effects of Urban Spatial Structure on Individual Behavior". *Highway Research Record*. No. 332, pp. 136-148.

Horton, F.E. and P.W. Shuldiner, (1967). "The Analysis of Land Use Linkages". *Highway Research Record*. No. 165.

Howe, R.T. (1960). "A Theoretical Model for Work Trip Patterns". *Highway Research Board Bulletin*. No. 253.

JHK & Associates, (1992). "IVHS Benefits Assessment Framework - Conceptual Approach to Model Enhancement". A report prepared for the Volpe National Transportation Systems Center, U.S. Department of Transportation, Washington, D.C., USA.

Jones, P.M., (1977). "New Approaches to Understanding Travel Behavior: The Human Activity Approach". In *Behavioural Travel Modelling*. D.A. Hensher and P.R. Stopher, eds., Croom Helm, Ltd., England, pp. 55-80.

Jones, P.M., (1983). "The Practical Application of Activity-based Approaches in Transport Planning: An Assessment". In *Recent Advances in Travel Demand Analysis*. S. Carpenter and P.M. Jones, eds., Gower Publishing Co. Ltd., England, pp. 56-78.

Kitamura, R., L.P. Kostyniuk, and J. Uyeno, (1981). "Basic Properties of Urban Time-Space Paths: Empirical Tests". *Transportation Research Record*. No. 794, pp. 8-19.

Knapp, R.H., (1983). "Life Cycle Stages and the National Travel Surveys". In *Recent Advances in Travel Demand Analysis*. S. Carpenter and P.M. Jones, eds., Gower Publishing Co. Ltd., England, pp. 247-265.

Kostyniuk, L.P., and R. Kitamura, (1983). "An Empirical Investigation of Household Time-Space Paths". In *Recent Advances in Travel Demand Analysis*. S. Carpenter and P.M. Jones, eds., Gower Publishing Co. Ltd., England, pp. 266-289.

Kutter, E., (1973). "A Model for Individual Travel Behaviour". *Urban Studies*. Vol. 10, pp. 233-256.

Kutter, E., (1981). "Some Remarks on Activity-Pattern Analysis in Transportation Planning". In *New Horizons in Travel-Behavior Research*. P.R. Stopher, A.H. Meyburg, and W. Brog, eds., D.C. Heath, Boston, pp. 231-252.

Lerman, S.R., (1983). "Mathematicals Model of Travel Demand: A State-of-the-Art Review". In *Travel Analysis Methods for the 1980s*. Transportation Research Board Special Report No. 201, National Research Council, Washington, D.C., pp. 114-126.

Lewis, S., P. Cook, and M. Minc, (1990). "Comprehensive Transportation Models: Past, Present and Future". *Transportation Quarterly*, Vol. 44, No. 2, pp. 249-265.

Marble, D.F., (1964). "A Simple Markovian Model of Trip Distributions in a Metropolitan Region". In *The Regional Science Association Western Section Papers*. W.S. Peters, ed., Urban Systems Committee of Arizona State University, Tempe.

Mitchell, R., and C. Rapkin, (1954). *Urban Traffic: A Function of Land Use*. Columbia University Press, New York.

O'Kelly, M.E., (1981). "A Model of the Demand for Retail Facilities, incorporating Multistop, Multipurpose Trips". *Geographical Analysis*. Vol. 13, pp. 134-148.

Oppenheim, N., (1975). "A Typological Approach to Individual Urban Travel Behavior Prediction". *Environment and Planning*. Vol. 7, pp. 141-152.

Oster, C., (1978). "Household Tripmaking to Multiple Destinations: The Overlooked Urban Travel Pattern". *Traffic Quarterly*. Vol. 32, pp. 511-529.

Parkes, D.N. and Thrift, N., (1975). "Timing Space and Spacing Time". *Environment and Planning A*. Vol. 7, pp. 651-670.

Pas, E., (1984). "The Effect of Selected Socio-demographic Characteristics on Daily Travel Activity Behavior". *Environment and Planning A*. Vol. 16, pp. 571-581.

Pas, E., (1988). "Is Travel Demand Analysis and Modelling in the Doldrums?". Paper presented at The 1988 Oxford COnference On Travel And Transportation. *New Developments in Dynamic and Activity-based Approaches*. Oxford, England.

Recker, W.W., M.G. McNally, and G.S. Root, (1986a). "A Model of Complex Travel Behavior: Part I - Theoretical Development". *Transportation Research A*. Vol 20, No. 4, pp. 307-318.

Recker, W.W., M.G. McNally, and G.S. Root, (1986b). "A Model of Complex Travel Behavior: Part II - An Operational Model". *Transportation Research A*. Vol. 20, No. 4, pp. 319-330.

Salomon, I., (1983). "Life Style - A Broader Perspective on Travel Behavior". In *Recent Advances in Travel Demand Analysis*. S. Carpenter and P.M. Jones, eds., Gower Publishing Co. Ltd., England.

Salomon, I., and M. Ben-Akiva, (1982). "Life-Style Segmentation in Travel-Demand Analysis". *Transportation Research Record*. No. 879, pp. 37-45.

Stopher, P.R., and A.H. Meyburg, (1975). "Behavioral Travel-Demand Models". In *Behavioral Demand Models*. D.C. Heath, Massachusetts, pp. 3-53.

Stopher, P.R., A.H. Meyburg, and W. Brog, (1979). "Travel-Behavior Research: A Perspective". In *New Horizons in Travel-Behavior Research*. D.C. Heath, Massachusetts, pp. 3-34.

Tomlinson, J., N. Bullock, P. Dickens, P. Steadman, and E. Taylor, (1973). "Model of Student's Daily Activity Patterns". *Environment and Planning*. Vol. 5, pp. 231-266.

Tye, W.B., S.M. Kinnucan, D. Nelson, and T. Tardiff, (1982). "Application of Disaggregate Travel Demand Models". *National Cooperative Highway Research Report No. 253*. National Research Council, Washington, D.C.

Vidakovic, V., (1974). "A Harmonic Series Model of the Trip Chains". In *Transportation and Traffic Theory*. D.J. Buckley, ed., Elsevier, New York.

Vidakovic, V., (1977). "A Distance Parameter of the Trip Chain Process". In *Proceedings of the Seventh International Symposium on Transportation and Traffic Theory*. T. Sasaki and T. Yamaoka, eds., Institute of Systems Science Research, Kyoto, Japan.

Wooton, H.J. and G.W. Pick, (1967). "A Model for Trips Generated by Households". *Journal of Transport Economics and Policy*. Vol. 1, pp. 137-153.