SYNTHESIS OF PAST ACTIVITY ANALYSIS APPLICATIONS

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ABSTRACT

This review describes the emergence of the central ideas within the activity analysis paradigm and their application to travel forecasting. We posit that three interconnected processes of "ideas applications" form the basis of scientific development. The first is conceptualization and theory building. The second is empirical tests and applications: here, we make a distinction between those in which activity patterns are considered as segmentation variables in travel models, and those in which travel is incorporated into activity patterns. The third process is the self-conscious evaluation of the interplay between theory and application: we call this last the "reflexive nexus." We provide examples of studies which demonstrate these processes; most studies emphasize one over the others. This framework places the pathways toward implementing activity-based travel demand forecasting into more of a cyclical, and less of a linear, historical context. One example is given of how all three processes have contributed to a particular of model of activity scheduling. We conclude that activity analysis continues to develop within waxing and waning periods of inductive theory construction and deductive theory testing. Extending activity analysis to the realm of travel forecasting should provide intellectually more satisfying forecasting tools and lead to improved theory.

1. INTRODUCTION

We intend this review to provide a map of activity analysis as applied to travel decisions of households. We make no claim to providing a complete and detailed map of the terrain; neither do we wish to leave the reader wandering in the wilderness. Rather, we intend to point out some of the major landmarks of activity analysis, to give the reader an overview of what activity analysis has accomplished and a perspective on how these accomplishments came about, and to prepare and motivate the reader to explore the terrain of activity analysis and its applications. We offer the following definition of, and motivation for, activity analysis before moving on to fill in our map.

1.1 WHAT IS ACTIVITY ANALYSIS?

Several reviews of the activity analysis literature have been written (e.g., Damm, 1983; Jones, 1983; Kitamura, 1988; Jones *et. al*. 1990; Axhausen and Gärling, 1992; Jones, 1995). Describing activity analysis, Damm (1983) states:

> "These [activity] decisions are not necessarily identical to or made simultaneously with travel decisions…Instead of focusing on what people do between activities, [activity analysis] researchers look at what people do between trips. In this vein, it seems more appropriate to refer to activity scheduling…especially if we assume that activities are more important than trips."

Jones *et. al*. 1990 provide this definition of activity analysis:

> "[it is a] framework in which travel is analyzed as daily or multi-day patterns of behaviour, related to and derived from differences in life styles and activity participation among the population."

These definitions contain two essential, and from the perspective of travel demand forecasting, revolutionary, ideas: the primacy of activities over travel and the primacy of people over vehicles. These ideas both allow, and require, that we begin to incorporate the wide variety of personal and social influences that shape both our expressed activity and travel choices, and more importantly, our freedom to act.

The practitioner of activity analysis generally takes the household to be the source of activity participation. Individual households and their members are the behavioral units that are the source of activity participation. Household members' choices of activities are mediated by systems of constraints that include the structure of family relationships within the household and by the resources available to the household. "Travel" occurs when people move from one activity to another separated in space and time.

Activity analysis defines a set of problems for study. This set includes, but is not limited to, studying how households create activity schedules, mapping activities in time and space, examining the linkages between people created by the roles they play within their households and other social groups to which they belong, tracing the resource allocations and constraints that limit activity choice, and as an outcome of these, examining the physical movements of people by specific modes and routes. Transportation researchers, planners and designers are concerned with these last outcomes, that is, with the choices of travel mode and timing, trip duration, and distance of the trips that link activities. With such information, existing transportation infrastructure can be managed, and new transportation systems and technologies evaluated.

1.2 WHY ACTIVITY ANALYSIS?

Any number of other recent articles and reviews reiterate the common arguments for shifting from a pre-occupation with where vehicles go, to analysis of what people do. The reasons may be summarized as being of two general types. First, there are criticisms of the inability of vehicle- and trip-based analyses to provide accurate models of travel and travel behavior. Second, vehicle and trip based models are not fully amenable to changing policy contexts that require managing transportation infrastructure and resources. Within the older "four step" transportation research and planning paradigm, the connections between land uses (which are aggregates of the types of activities that may be completed within a given geographic space) and travel were *ad hoc* models of trip attraction, trip generation, and travel impedance. The aspiration of activity analysis has always been to replace these *ad hoc* empirical specifications with testable theories of human behavior.

1.3 HOW DO WE DO ACTIVITY ANALYSIS?

As a transportation research paradigm, activity analysis is concerned with how households connect activities separated in space and time. To study how these connections are made, the activity analyst requires the understanding of several things: why households and their members engage in different activities, including the linkages between people that are the result of (or perhaps create) their household and social roles; the physical and social environments that provide opportunities for activities, resources to access these activities, and the constraints that limit access; how households and their members learn those environments; and how people process their activity needs and their knowledge of their environments to develop schedules of activities. These requirements have spawned searches for theories of activity participation, development of new data collection techniques (e.g., activity diaries and interactive interview and survey methods), and novel applications of mathematical techniques and models (e.g., pattern recognition algorithms, simultaneous equation systems, synthetic generation of households and vehicle fleets, and production systems).

1.4 CHARTING OUR COURSE

We take the distinction between activities and travel, and the primacy placed upon activities, as the point of departure between activity analysis and traditional "four-step" transportation planning and forecasting. In Section 2, we describe several key "emerging features" of activity analysis (Jones *et. al.*, 1990). No one of these features identifies an application as an "activity analysis," yet together they constitute the essence of this approach in which "activities are more important than trips." This section provides a little more definition of activity analysis for those readers to whom it may be unfamiliar, before exploring how we have arrived at where we are today.

Then, in Section 3, we trace the manner in which the underlying ideas of activity analysis have been applied. We present the history of the development of scientific knowledge in general, and activity analysis in particular, as intertwined paths of inductive processes of theory building and deductive processes of theory testing and empirical application. We identify three areas of "idea application": development of activity analysis as a framework for conducting forecasting, empirical tests and applications, and the reflexive interplay between theory construction and empirical testing and application.

The social theorist Anthony Giddens writes:

> "'Reflexivity' hence should be understood not merely as 'self consciousness' but as the monitored character of the ongoing flow of social life. To be a human being is to be a purposive agent, who both has reasons for his or her activities and is able, if asked, to elaborate discursively upon those reasons…" (1984).

Further,

> "Thus it is useful to speak of reflexivity as grounded in the continuous monitoring of action which human beings display and expect others to display." (ibid.)

Our ability to monitor and elaborate on, our awareness of, the interplay between theory and application causes us to pursue specific lines of inquiry, e.g., classification of problem domains. This paper itself is one example of a reflexive inquiry.

We will illustrate each process with a few examples only; our intention, as described above, is to highlight important landmarks; other authors in these proceedings are charged with presenting more detailed descriptions of some of the areas of empirical application we briefly describe. This process oriented history puts activity-based approaches into a more cyclical, less linear, historical context. We believe this context addresses concerns with describing developments in activity analysis in a linear sequences of distinct epochs, as raised by Gerardin (1990) in his response to Pas' (1990) review. Before concluding the paper, we show how all three processes have contributed to development one type of one particular model of activity scheduling.

2. FEATURES OF ACTIVITY ANALYSIS

The content of activity analysis is distinguished from other transportation research paradigms by several features. Jones *et. al.* (1990) identify seven "emerging features" of activity analysis:

1) Treat travel as a demand derived from desires and demands to participate in other, non-travel, activities;
2) Focus on sequences or patterns of behavior, not discrete trips;
3) Analyze households as the decision-making units;
4) Examine detailed timing and duration of activities and travel;
5) Incorporate spatial, temporal, and inter-personal constraints;
6) Recognize interdependence among events separated in space and time; and

7) Use household and person classification schemes based on differences in activity needs, commitments and constraints.

Based on the recognized importance of dynamic analysis, the need to examine activities over multiple time periods, and as an extension of Jones' *et. al.* sixth feature, we would add to this list:

8) Analyze activities and travel within longitudinal (dynamic) frameworks.

We illustrate these eight features with studies that include them. This list of examples is of course not a census of activity analysis. Also, we do not attempt to provide complete descriptions of each of the example studies, most of which include several of the features listed above.

1. Travel is derived from demand for participation in non-travel activities. This is simply a statement that very little travel is undertaken for its own sake: most travel is undertaken to engage in an activity at some other location (and future time). This feature has been operationalized in a number of ways. First, a number of theories of activity participation have been proposed, some examples of which are cited later in the paper (Section 3.2). Supernak (1990) develops a conceptual model of "activity utility". One (assumed) attribute of "utility" within his framework is that the utility of separate activities and the disutility of the separate trips to access them are cumulative (though he does not specify over what time period utility accumulates). He points out that by subordinating travel to activities and examining the combined utility of an entire daily activity schedule and the associated disutility of traveling to complete that schedule, one can offer explanations for…

> "…some disappointing results from disaggregate models applied to choices such as mode choice. A modelling effort aimed at minimizing disutility of travel may *easily misrepresent* the actual effort made by traveler i (or, rather, activity participant i) who is trying to maximize the overall utility of the action A (set of actions) that involves both activity and travel." (ibid.) (Emphasis in the original.)

One example of an attempt to operationalize a connection between activities and travel is contained in van Wissen *et. al.* (1991). They estimate a simultaneous dynamic travel and activity time allocation model. While recognizing that spatial dispersion and differences in the quality of activity locations, as well as differences in activity scheduling by individuals, are central to predicting travel based on activity patterns, they adopt a simplified framework in which travel time for each activity is proportional to the amount of time allocated to that activity.

2. Sequences or patterns of activities and travel. Tracing sequences or patterns of activities goes back at least as far as Hägerstrand's (1970) work on time-space paths. Recker *et. al.* (1983) applied pattern recognition algorithms to the problem of identifying patterns in household travel. Huff and Hanson (1986) characterize the degrees of repetition and variation in household travel activity patterns. Pas and Koppelman (1987) identify determining factors in the degree of variation in day-to-day travel of different people. They conclude that people with fewer economic and role related constraints, and those whose personal and household needs do not require daily participation in out-of-home activities, show the highest day-to-day variation in their travel.

Somewhat paradoxically perhaps, many analyses of activity and trip sequences have given particular prominence to the effect of one trip type (activity) on travel. The prototypical example is the work trip, going back to Cullen's (1972) identification of the work trip as a "peg" around which other activities are scheduled. Work trip studies form part of the basis for the three part distinction (home-based work, home-based non-work, and non-home based) employed by many researchers and practitioners today. Other examples of specific trip types that have received attention include Kitamura's (1983) analysis of "serve passenger" trips, Kim's *et. al.* (1994) examination of trip chains that contain shopping trips, and Sands and Smock's (1994) consideration of trips to places of worship.

Trip chaining is one example of how sequences of trips have been analyzed. Analyses of trip chains is an intermediate step between studying single trips and studying activity patterns; while giving attention to the inter-connection of some activities, focusing on single chains may fail to capture the connections between chains. The use of trip chain concepts continues to be emphasized in a number of studies and a session of the 1996 Annual Meeting of the Transportation Research Board appears to have been at least partially devoted to the practical application of trip chaining; three papers from that session deal with this subject (Vovsha, 1996; Schultz and Allen, 1996; Shiftan and Ruiter, 1996). In a departure from trip chaining, Axhausen (1990) proposes a method for combining models of activity chains with models of traffic network flows. Though further from practical application than trip chaining concepts, the recent efforts to develop models of activity scheduling (such as those cited below in Section 3.2) offer the most complete treatment of how households plan to execute sequences of activities.

The idea of patterns of behavior has been contrasted with variance, variability and other measures of non-patterned behavior. The existence of patterns of activity participation is implicit in the seventh item in this list of features of activity analysis. Classification requires that we be able to group households that are more like each other than they are like members of other groups.

3. Analyze households as the decision-making units. We make the following distinction between this feature and the seventh in this list: we illustrate this point with studies of decision-making within households; we will illustrate the seventh point with studies that employ household and person classification schemes as variables to segment the analysis of activity schedules or travel. Examples of recent analyses of decision-making within households include Ahrentzen's *et. al.* (1989) analysis of gender roles in the allocation of space, time and activities within the home, Kiker and Ng's (1990) test of a simultaneous equation model of spousal time allocation under conditions of interindividual and interactivity simultaneity, Solberg and Wong's (1991) test a Gronau model of household allocation of time to leisure, home production, market work and work related travel and Manke's *et. al.* (1994) study of the distribution of in-home labor between women, men and children.[1]

[1] The Ahrentzen *et. al.* (1989) and Manke *et. al.* (1994) studies are concerned with the allocation of space, time, and activities solely within the home and might therefore seem to be out of place in a paper on activity-based applications to travel forecasting. We include them because in-home activities have been widely, and incorrectly, ignored in travel analysis. One study of the effect of work trip duration on non-work trip generation was unable to distinguish whether workers, who were at home, were there because they were ill, on vacation, telecommuting, or on a scheduled day off, because no questions were asked about in-home activities (Purvis *et. al.*, 1996). Further, despite

4. Examine timing and duration of activities and travel. There has been a distinct cycle of methodological developments in the treatment of activity duration. Early efforts analyzed activity duration within the framework of discrete choice models and utility maximizing behavioral models, e.g., Kitamura (1984). Later, van Wissen *et. al.* (1991) applied a system of simultaneous equations to a dynamic analysis of household allocation of time to out-of-home activities and travel. In the latest revisitation to modeling activity duration, hazard models are being applied, e.g., Hensher and Mannering (1994), Ettema, Borgers and Timmermans (1995), and Niemeier and Morita (1995).

5. Incorporate spatial, temporal and inter-personal constraints. Analyses that address one or more of the types of constraints range from time and space constraints explored by Kitamura *et. al.* (1990), to the household roles explored by Niemeier and Morita (1995). A particular focus of this research has been the evolution of gender roles and the reconciliation of personal and professional demands (Hanson and Hanson, 1980; Greico *et. al.*, 1989).

6. Recognize interdependence among events separated in space and time. As one example, a recent study explores the interdependence of separate events within the activity patterns of a single person (Purvis, Iglesias and Eisen, 1996). This study show an inverse relation exists between work trip duration and the frequency of home based, non-work trips: as the duration of the work trip increases, the likelihood of making non-work trips from home, after arriving home from work, goes down.

7. Use household and person classification schemes based on differences in activity needs, commitments and constraints. This statement clearly implies that household and person classification schemes should be based on differences derived from activity participation. It has been far more common though that household and person classification schemes have been based on the characteristics of people. Clarke and Dix (1983) point out that household level classifications are widely used in trip generation models.

Household classifications based on "lifecycles" or "life stages" use socio-economic variables as proxies for differences in activity needs, commitments and constraints. These life stages are defined primarily by the presence or absence of children, age of children, age of heads of household, number of heads of household, and employment or retirement status of household members. Clarke and Dix (ibid.) analyze the relationship between lifecycle groups and time budgets. Their results indicate the existence of systematic variations in how adults in some household types spend their time. There are, however, types of households whose adults' time budgets cannot be clearly distinguished. They reason:

> "That we could not distinguish between [some] groups…on this [lifecycle] basis does not necessarily mean that households in these groups are homogeneous. They comprise families with no children under five and older couples with no children, and although they exhibit similar

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the importance of home as a center of a wide variety of activities, all in-home activities are often grouped together as if they were a single activity. However, the reasons we travel to home at a specific time and at a particular point in a sequence of activities may be linked to a specific activity to be done at home.

activity budgets…they may well experience different constraints on their behaviour which result from the structure of their families." (ibid.) [Ellipses added.]

This result echoes the caution sounded by Brög and Erl (1980) that descriptors of people may not capture the relevant attributes of their subjective evaluations of their objective "situations." Their concern is echoed by empirical work by Kunert (1994), who concludes that "even for well defined person categories, interpersonal variety in mobility behavior is large but has to be seen in relation to even greater intrapersonal variability."

However, analysis of activity participation and travel by socio-economic and demographic groupings can be instructive and may be appropriate for questions of equity. As an example, Hanson (1977) analyzes transportation deprivation of the elderly by comparing their travel to that of the non-elderly population.

Also based on socio-economic classifications, Ferguson (1990), for example, examined how household composition affected choices of residence location and the journey to work; Strathman *et. al.* (1994) compared differences in trip chaining and non-work travel between households grouped by demographic structure.

8. Analyze activities and travel within longitudinal (dynamic) frameworks. There are several reasons for making explicit the several dynamic processes implied in activity analysis. Activity-based approaches are concerned with the analysis of events unfolding over time, and often unfolding over different, but intertwined, time scales. Household and person classifications will change, both as individual households evolve and as all households adapt to changing environmental conditions. We cannot observe Jones' *et. al.* sixth feature without a dynamic framework. Following Hanson and Burnett (1981) and Dix (1981), Lee-Gosselin (1995) recalls the distinction between *expressed choice* and *freedom to act*, and further asserts that "if choice is a process, then understanding behavioural outcomes under constraints requires dynamic measures of freedom to act."

3. TOWARD APPLICATIONS OF ACTIVITY ANALYSIS: THREE PROCESSES OF SCIENTIFIC DEVELOPMENT

We describe here the three processes that underlie the building of an activity analysis framework for forecasting: conceptualization of activity analysis as a set of theoretical constructs, empirical testing and application of those constructs, and the intentional, reflexive interplay between those two processes. We can assign approximate timelines to these processes, but they are not three separate lines. The conceptual development of activity analysis can fairly be said to have been emphasized first, followed by the first empirical tests, and then the first efforts to assess progress, refine theory and formulate new empirical problems. However, these periods do not define distinct epochs, rather they identify three processes that wax and wane in cycles across time. We do not attempt to trace the entire development of activity analysis through these cycles, but rather demonstrate the development of theory, applications and interplay between them by reviewing illustrative developments of each of them.

3.1 CONCEPTUALIZING ACTIVITY ANALYSIS

3.1.1 THE ROOTS OF ACTIVITY ANALYSIS AND THE CONCEPT OF ACTIVITY SPACE

A few studies that we would as classify as activity analysis pre-date Hägerstrand's (e.g., Mitchell and Rapkin, 1954; Chapin, 1965). However, the intellectual roots of activity analysis are found primarily in geographical studies that delineated systems of constraints on activity participation in time-space (Hägerstrand, 1970) or identified patterns of behavior across time and space (Chapin, 1974), and in psychological studies of why people participate in activities and how those motivations are mediated by social structure (Fried *et. al.* 1977).

As analysts looking into households' lives through the often murky window of our survey instruments, we are faced with the question of whether observed routines in household activity choices are behavioral responses to the apparent complexity of all possible activity choices. The realm of all possible activity spaces through which a household might move is, from the observers perspective, quite complex. It was part of Hägerstrand's (1970) admonition that the analyst could construct a more tractable problem by paying attention to people, not the myriad possibilities of the world. He argued for the need to examine spatial relationships as expressions of human behavior and for a set of organizing principals around which to begin such an examination (ibid.). Thus, his *space-time prisms* were the more confined regions of time and place in which a person could exist. Discontinuities of existence in time are not allowed and a person's possible locations in space at one point in time are determined in part by their locations in space at preceding points in time and anticipated locations in the future. Understanding the constraints which form the boundaries of those prisms, we reduce the area of space and time we must search to find the activity schedule the person actually executes, that is, Hägerstrand's *time-space path.*

HOW CONSTRAINTS SEGMENT THE TIME-SPACE PRISM

Central to defining the shapes and sizes of these prisms and the paths through them, Hägerstrand proposed a typology of constraints: capability constraints, coupling constraints, and authority constraints. Capability constraints arise from biological requirements and the tools available to an individual. Some capability constraints, notably biological constraints such as sleep and sustenance, follow the individual throughout their time-space path, but are typically satisfied at a single, home location and require a certain minimum amount of time.

Different travel modes impose different capability constraints on our movement through space and time. Distances between activity locations can be mediated by movement (of people or goods) or communication by either inherent physical abilities or the use of tools. Thus we travel by a combination of certain physical functions and tools—walking, bicycles, buses, autos, etc. We communicate either directly through our senses or by communications technology. Thus the time-space prism through which an individual moves can be divided into regions of varying accessibility, depending on her physical capabilities and the availability to her of different travel and communication tools.

While capability constraints define the limits of our time-space prism, our path inside that prism is determined in large part by coupling and authority constraints. Coupling constraints "define where, when, and for how long, the individual has to join other individuals, tools, and materials in order to produce, consume and transact." (ibid.) To get a haircut, we must arrive at the barber shop during the hours it is open, and if we are particular, on a day our favorite barber is working. Paid employment may require that we interact with other people and tools on a particular schedule at one or more locations. Authority constraints define *domains* within the time-space prism to which an individual either controls the access of other individuals or to which his access is controlled.

Empirical research has shown that household travel can be explained by this framework of constraints. For example, Kitamura, Nishii, and Goulias (1990) show that choices of timing and location for non-work activities by commuters are consistent with a set of hypotheses based on the constraints Hägerstrand proposes. Those authors found that coupling constraints (shop opening times) and authority constraints (work start times) severely limit the number of non-work trips made before work. Because of authority constraints and capability constraints, non-work activities made during work-time are tightly clustered in space around the work location and tend to be either work-related trips or trips to eat. Non-work trips made after work access a wider variety of activities, and though spatially clustered around home, are not as tightly clustered as either before- or during-work trips.

Niemeier and Morita (1995) argue that "work trips" in general should be considered multi-purpose trips since non-work activities are frequently accessed on the trip from work to home (though less so on the trip from home to work). They further show that the differing roles and responsibilities of women and men within households impact relative activity duration for shopping during these trips between work and home. For a given participation by a woman or a man in shopping, the woman is likely to spend more time on the activity. Thus, they also demonstrate how household responsibilities systematically shape the time-space prisms of household members.

TIME-SPACE PRISMS AND HOUSEHOLD ACTIVITY SPACE

Our use of the phrase *activity space* to describe the sets of activities that households access is based on definitions used by Horton and Reynolds (1971) in their initial development of an analytical framework to examine the effects of urban spatial structure on individual behavior. If Hägerstrand defined the limits of the time-space prism; Horton and Reynolds provided additional insight into how households choose paths within the prism.

They defined *objective spatial structures* as the location of a household relative to the objective locations of potential activities and their associated objective levels of attractiveness. By "objective" they mean that relative locations are measured by some standard meter, e.g., changes in degrees of latitude and longitude, applied to all locations. This objective spatial structure contains linear features (e.g., transportation networks, commercial "strips"), nodes (e.g., shopping centers, individual residences or manufacturing plants) and surfaces (e.g., residential population densities). Further, they define a household's *action space* as that group of all locations or nodes within the objective spatial structure about which the household has information and the subjective utility the household associates with those known locations. This subjective utility may be a function of linear features connected to the node (e.g., how accessible is the location by various transportation networks) and surfaces in which the node is embedded (e.g., whether the location is perceived to be located in a safe area). Finally, they define the *household activity space* as the subset of all locations in the action space with which the household has direct contact as the result of day-to-day activities. Thus a household's *activity space* can be described by a set of realized *paths* through Hägerstrand's *time-space prism.* The home location, as the point from which all else in the activity space is perceived, is itself part of the activity space.

Horton and Reynolds go on to postulate a theory of learning that directs activity space formation and change. While a household may reach a point where its activity space remains relatively stable, all that is required to produce a change in the activity space is for the household to add one location to its activity space from its current action space or delete one location from its existing activity space. A change in the action space itself requires learning of a new feature of the objective spatial structure and forming an initial assessment of its subjective utility. Changes in the objective spatial structure typically take place outside the control of a single household. Such changes are typically long-lived additions or removal of nodes (e.g., a new shopping mall), linear features (e.g., a new bus route), and surfaces (e.g., agricultural land newly incorporated into a city for urban development).

3.1.2 ACTIVITIES ACROSS TIME

Very early in its conceptual development, activity analysis focused increased attention of transportation researchers on the dimension of time. Time is conceptualized as being both unidirectional and constant in its flow. We can change the speed and direction we travel through space, but not the speed and direction of either time itself or our movement relative to it; we are unable to stop the flow of time or reverse our course. Therefore, time serves as a different organizing principle for much of human activity than does space. We use time to order activities throughout time periods of different lengths. We progress through time, but do so in socially constructed, as well as “natural” or biologic, periods and cycles. We may schedule today in detail, plan next month, and speculate about next year, all while moving through “life stages” identified by changing household structures, peer and social group memberships, careers and lifestyles.

The incorporation of time into activity analysis remains problematic, in large part because of inadequate conceptualizations of time itself. Prince (1978) observes that while it is sometimes convenient to conceive of time as a “fourth dimension”, it is in fact fundamentally different from the spatial dimensions. Among the differences he identifies: we cannot combine temporal and spatial units; there are no time equivalents for area and volume; space is omni-directional while time is conceived to be uni-directional and irreversible. Leach (1966) argues that all concepts of time can be reduced to two basic ideas: uni-directional change and repetition or cycles. Yet this possible simplification ignores that uni-directional change and cycles have both physical and social meanings, which may change depending on the degree of uni-directional change (how far in the past, or how far in the future) and the length of the cycle (from diurnal cycles to the birth and death of succeeding generations.) We should also add that subjective notions of time are not very straightforward either, and vary across cultures.

The lack of a unified conceptualization of time in activity analysis has lead to a variety of treatments of time. Some practitioners treat time as a resource to be allocated; others treat it as a constraint on the allocation of other resources; still others treat travel time as a cost, while simultaneously treating all other time as either a resource or constraint for other, non-travel, activities. Further, activities can be ordered in sequence through time; starting and ending times for activities can be chosen: these choices must often be made simultaneously since many activities cannot overlap in time. Thus activity order and duration are often interrelated choices, that themselves may be affected by past activities and expectations of future ones.

A recent effort to inform the resolution of some of these issues is Pas and Harvey's (1991) review the time use literature. They point out mutual benefits to transportation researchers and time use researchers of a increased interaction between the two fields. Transportation research in general, and activity-based approaches in particular, could benefit from advances in data collection methods and empirical knowledge of household time use; time use research could benefit from the treatment of time use within a spatial context.

Recently, considerable attention has been given to the problem of activity scheduling, which raises questions as to the meanings of time. Many of these questions could be ignored so long as we took an observed activity schedule as given and looked for patterns and regularities in travel associated with that activity schedule. And though there have been several studies of activity choice and activity duration choice (e.g., Hensher and Mannering, 1994), most have been conducted within the context of a single, short time period. That is, activity choice and duration have been studied for the period of (most often) one day, but few of these studies have considered how household planning for other time periods (say, the week) affected the scheduling (activity participation and duration choices) for the day under consideration. Some exceptions are Huff and Hanson (1986) and Pas (1988). The former examined differences in activity participation between daily, weekly and monthly time periods. The latter examined some interactions between daily and weekly travel-activity patterns. Pas hypothesized a two-step process in which weekly behavior is determined first, then conditional choices are made regarding daily travel-activity. His analysis did not reject the hypothesis that socio-economic characteristics of the respondents affected their choices of weekly patterns, but not the conditional choices of daily activities and travel.

3.1.3 THEORIES OF ACTIVITY PARTICIPATION

The activity analysis paradigm has yet to develop or adopt a comprehensive theory of activity participation. The lack of such a theory was not such a problem so long as we were concerned only with problems that took activity schedules as given. Lacking such a theory though, we are unable to assess either motivations for choosing to participate in a given activity or decisions as to when and for how long to engage in an activity. Lacking such a theory, any modeling of the selection and prioritization of activities, that is, any empirical application of activity programming or scheduling models, will be necessarily *ad hoc*.

Chapin (1978) applied a simple theory based on Maslow's "hierarchy of needs" (Maslow, 1970) to his investigation of differences in activity patterns between different socio-economic groups of people. In their application of a "situational approach" to explaining household activity patterns, Brög and Erl (1983) emphasized an individual's subjective evaluations of the "…certain number of options [given] by his environment; this is the objective situation." They caution against expecting that socio-economic variables will account for the situational contexts, and suggest that, to understand behavior, a chain of "objective circumstance—personal perception—subjective situation—individual decision—behavior" must be modeled (Brög and Erl,1980). Tonn (1983a, 1983b) delineated a system of activity participation, but acknowledged he had to draw on an eclectic blend of psychological theories and maxims, none of which he concluded could be regarded as widely accepted. Several analyses of activity participation and duration have employed utility theory—whether strictly interpreted or incorporating some variation, such as satisficing rather than maximizing rules for choices among alternatives. Examples include Adler and Ben-Akiva, 1979; Damm and Lerman, 1981; Kitamura and Kermanshah, 1983; Kitamura, 1984; Kawakami and Isobe, 1986; Recker *et. al.* 1986a, 1986b; and Munshi, 1993.

The choice of this "rational" model has been contested on several counts. Gärling *et. al.* (1993) argue that discrete choice models (a subset of utility-based models) cannot model the interactions between choices or between choosers and that utility models attempt to reduce inherently non-comparable elements of choices to a single scalar. Of these, the more compelling argument is the lack of interaction between choosers (decision makers), especially within the context of activity analysis which explicitly recognizes collections of decision makers (households) as the source of fundamental constraints, resources, and activity participation. Studies from Jones, *et. al.* (1983) to Lee-Gosselin (1990) to Kurani *et. al.* (1994) have demonstrated the role of the household in shaping activity participation and travel.

Bhat and Koppelman (1993) have proposed a framework of individual activity program generation. It views individual's needs as emanating solely from membership within a household. "Subsistence" and "maintenance" activities are viewed as generated by the household. "Leisure" activities are viewed as arising from the needs of each individual. Their proposed structure of household decision making starts with the generation of subsistence and maintenance needs. In the case of subsistence, these needs are measured by the employment status, income, and work hours of the two households heads. The subsequent allocation of subsistence and maintenance activities to household members is mediated by automobile ownership. This allocation serves as input to individual decisions about leisure. One limitation of the framework, as noted by the authors, is that it is restricted to couples and "nuclear" families.

3.2 EMPIRICAL TESTS AND APPLICATIONS

The second process concerns the testing and application of empirical specifications—models—of theoretical constructs. Here, it will be useful to distinguish between two approaches which differ in how travel and activities are linked. We label applications in which travel models function differently for different segments of the study population, depending on differences in the household activity patterns of those segments, as "segmentation" approaches. "Integrated" applications are those in which travel is integrated as a endogenous element of household activity patterns. This distinction is alluded to in a section of Jones' *et. al.* (1990) review on the contributions of activity-based travel research to applied modeling: they distinguish between improved specifications of existing trip-based models and the development of activity based models. They observed that the latter contributions were "much less developed" than the former.

3.2.1 SEGMENTATION APPROACHES

It is our sense that the observation of Jones *et. al.* (ibid.) is still true today. They observed that the application of activity analysis concepts by planning organizations appears to be following a path leading toward adjustments to existing travel demand models through the incorporation of new independent variables, the creation of linked sub-models to incorporate interdependencies (e.g., those caused by the interaction between household members roles and household vehicle availability), and the development of new dependent variables. Another "adjustment" application would be the use of "activity variables" to segment travel demand models, that is to estimate distinct models for different households depending on some measure of activity participation.

As noted in the companion paper in this conference by Lawton (1996), since 1990, there has been "a gradual progression in the USA, of expansion of the scope of the (MPO) travel survey and a gradual transformation into a household activity survey," starting with Boston and Los Angeles. The initial stages of this progression favored the segmentation approach. Purvis *et. al.* (1996) model the effects of work trip duration on non-work trip generation. They estimated separate models to predict two dependent variables: the total number of home-based shop/other trips and home-based social/recreation trips.

3.2.2 INTEGRATED APPROACHES

Activity analysis aspires to provide a framework for analyzing travel demand. Recognizing that travel is derived from activity participation, much of the recent research on activity scheduling is directed at integrating travel into activity participation models. Such an integrated approach would allow for more complex household adaptations to be modeled. To the extent the motivation for improved travel demand forecasting tools is the need to better manage existing facilities, and to the extent that this need is driven by real or potential congestion due to the lack of resources or desire to build new capacity, we are forced to recognize that characteristics of trips affect the formation of activity schedules. A trip based model would not predict increases in evening peak travel due to congestion (an increase in the cost of the trip). An integrated activity/travel model, that includes joint decision making within households, household scheduling of activities and travel outside the evening peak, and other features of activity analysis (discussed below), could explain why individual households would choose an adaptive strategy (e.g., linking a non-work activity to the evening commute trip home) which, when summed across an urban area, results in still greater (or longer lasting) congestion.

We provide examples of empirical tests and applications within two recent areas of investigation—dynamic analysis and household activity scheduling. Our examples form neither an exhaustive nor exclusive list. Again, our examples are few because our aim is to point out a few landmarks and because the other authors at this conference will cover several empirical applications in greater detail. Also, we note that our first class of examples—dynamic analysis—and the specific examples we give—micro-simulation and structural equation systems—do not represent activity analysis, per se. We remind ourselves that it is the conceptual framework, not the analytical tools, that defines activity analysis.

DYNAMIC ANALYSIS

Dynamic analysis is the study of unfolding events over time, and the search for relations in the sequencing, duration and accumulation of events. In an earlier review of activity analysis, Pas (1990) states that "Within the last five years [circa 1985], we entered what undoubtedly will come to be known as the era of dynamic analysis, or as Wrigley (1986) terms it, 'the era of longitudinal data analysis.' " Two approaches toward developing applications of dynamic analyses are *micro-simulation* and *structural equation systems*. We place studies from the latest round of interest in dynamic analysis within our classification of empirical applications because they are largely efforts to develop longitudinal analysis techniques. Wrigley (ibid.) identifies two earlier rounds of interest in longitudinal analysis in the field of human geography. These periods of earlier interest were focused more on conceptual development and data collection methods. In the applications cited below, the data analyzed are from the Dutch National Mobility Panel.

Micro-simulation is distinguished from other empirical applications by the manner in which the aggregation problem is addressed. One stumbling block in the path to forecasting models has been the question of how to aggregate highly detailed household analyses up to representative samples. Micro-simulations generate "synthetic" households who, in aggregate, form a representative sample of the study population at the start time of the simulation. The future travel of these "electron-citizens" is modeled based on their simulated life trajectories. These trajectories can include changes in life stage (or some other socio-economic and demographic measures), residential location, vehicle ownership and other variables.

In MIDAS (Kitamura and Goulias, 1991), a dynamic model of travel behavior is combined with a "demographic accounting system" in which

> "household evolution over time is modelled at two levels, the household and the individual. The building block of the household evolution is the household type transition. Around this transition, household members are made to change education, drivers' license holding, employment, and personal income."

Mobility for each generation (year) of synthetic households is then modeled based on the characteristics of the household in the current generation and their travel (mobility) in their previous generation. This work provides some of the basis and background for the current development of TRANSIMS and AMOS, a micro-simulation model system of daily travel and activity.

Structural equation systems: Golob (1990) describes one application of a model based on a structural equation system. The specific empirical problem he addresses is determining the relationships between income, car ownership, car travel and transit travel as those relationships change over time. Golob describes a structural equation model as:

> "…a specific type of simultaneous equation system in which the variables are divided into two sets—endogenous variables and exogenous variable—and each equation in the system represents the direct effect of one variable upon another variable." (ibid.)

Further, with respect to dynamic analysis,

> "[structural equation] models can incorporate changes over time…of several variables simultaneously, while also including lagged causal relationships between variables." (ibid.) [Ellipses added.]

HOUSEHOLD ACTIVITY SCHEDULING

The development of models of activity scheduling has proceeded through several cycles of theorizing, empirical testing, and reflexion. This development included the design of activity and travel choice models based on the economic theory of utility maximization and subsequent adjustments to these models to reflect information costs and utility satisficing. Most recently, a number of models have been developed around alternative assumptions of human decision making capabilities and processes. These alternatives to utility maximization assume more limited cognitive ability, the use of heuristics (cognitive short cuts), or rule-based decision procedures. The behavioral basis of these models is not in economics, but in cognitive psychology (Simon, 1990; Heath *et. al.* 1994), everyday problem solving (Sinnott, 1989) and artificial intelligence (Hayes-Roth *et. al.* 1979; Hayes-Roth and Hayes-Roth, 1979; McCalla and Schneider, 1979).

Some early models of activity scheduling attempted to make modifications to utility maximizing frameworks in accordance either with activity analysis concepts or alternatives to rational models of human cognitive ability and process. The CARLA model of Jones *et. al.* (1983) identified a subset of feasible alternative schedules according to a system of constraints similar to Hägerstrand's. Root and Recker's (1983) STARCHILD model selected a schedule from all possible schedules based on satisficing, rather than maximizing, rules.

The most recent activity scheduling models are built around the architecture of production systems. For example, Gärling *et. al.* (1989) proposed, and then further described and developed (Gärling, Kwan and Golledge, 1994), a model known as SCHEDULER. It is a production system, described as

> "…a set of rules in the form of condition-action pairs that specify how a task is solved…[it] is also conceived as being realized in a cognitive architecture featuring a perceptual parser, a limited-capacity working memory, a permanent long-term memory, and an effector system" (Gärling, Kwan and Golledge, 1994). [Ellipses added.]

The SCHEDULER framework is limited to individuals' (rather than households') choices of activities, activity duration and departure times, all within a specified period of time.
In another activity scheduling modeling effort, Ettema *et. al.* (1993a) appeal to Simon (1990), (Hayes-Roth and Hayes-Roth, 1979) and Gärling (1993) to argue that production systems represent suitable frameworks for the activity scheduling problem. They do point out that one problem with production systems is the lack of calibration methods and data to estimate and evaluate the efficacy of any given production system in replicating activity scheduling. To overcome the data problem, Ettema *et. al.* (1993b, 1994) develop an interactive, computer program, Method of Activity Guided Information Collection (MAGIC), to collect data on individuals' activity scheduling behavior.

3.3 THE REFLEXIVE NEXUS

The final process we review here are what we have called "reflexions". Two types of these efforts are those that define appropriate contexts and domains for the application of theories and empirical tools, and those that summarize accumulated experience and thinking, link empirical and theoretical advances (and failures to advance), and provide a vision for future development.

3.3.1 DEFINING CONTEXTS AND DOMAINS

Heggie and Jones (1978) wrote one of the early papers within activity analysis that delineated distinct realms with different possibilities for modeling and measurement. Their four domains were defined according to the degree of dependence between decisions along two dimensions: interpersonal and spatio-temporal. The four domains were identified as: (i) independent; (ii) spatio-temporally linked; (iii) inter-personally linked; and (iv) linked on both dimensions. The last two domains were subdivided according to whether the linkages function predominately within or between households. They argued that utility maximizing models of behavior were appropriate for the first domain, of fully independent decisions, but that there were few utility maximizing solutions known for any of the three inter-dependent domains—all of which form the largest part of problems of interest in activity analysis.

Lee-Gosselin (1995) has recently reviewed the realm of interactive data collection methods directed at transport user response in future situations. He distinguishes "stated response" methods from "stated preference" methods and develops a taxonomy of the former which subsumes the latter. The taxonomy is based on the degree to which both constraints and behavioral outcomes are either provided by researchers or elicited from participants. Traditional stated preference work specifies both constraints and behavioral responses (choice sets). Other classes of stated response techniques include "stated tolerance" (behavioral outcomes given, constraints elicited), "stated adaptation" (behavioral outcomes elicited, constraints given) and "stated prospect" (both behavioral outcomes and constraints elicited).

3.3.2 LANDMARK REFLEXIVE EVALUATIONS

The process of developing theories, methods and applications has spawned periodic reviews whose aim went well beyond simply summarizing the record of progress to date. Many of these have attempted to both describe progress and to identify areas in which progress must still be made: particular concepts may have not withstood empirical evaluation; appropriate empirical tools might not have yet been developed; or new concepts had only been recently revealed.

Three such reviews are Jones (1983), Pas (1990), and Jones, Koppelman and Orfeuil (1990). Jones' (1983) early review summarizes the main concepts of activity analysis and provides an assessment the areas of application up to 1983. He develops a typology of six types of potential and actual applications: problem recognition and policy generation, data collection, data analysis, modeling, evaluation, and public participation and policy coordination. He concludes there had generally been significant applications within the first three types, but that applications to modeling, evaluation and public participation and policy coordination lagged. With respect to modeling, Jones identified three areas in which activity analysis could contribute: definition of choice sets, specification of appropriate variables and model structures, and development of new forms of models.

Pas (1990) wrote perhaps the most openly self-conscious reflexion on activity analysis. He wrote

> "It is important…for us to step back every once in a while…to assess what it is we are doing, why we are doing it, and how we are doing it." (ibid.) [Ellipses added.]

The title of his work—"Is travel demand analysis and modeling in the doldrums?"—suggests there was a felt need to address criticisms that recent approaches, including activity analysis, were not progressing rapidly enough toward practical travel demand models. Indeed, he develops a linear history of the subject matter of travel demand analysis and modeling from which the reader might infer that activity analysis was in danger of being supplanted by "dynamic," or longitudinal analysis. Perhaps to counter this impression, he cites Goodwin (1983) who states "…dynamic analyses are inherent to the most rewarding development of activity analysis."

Pas concludes that from a researcher's perspective, travel demand analysis and modeling were not in the doldrums based on the high level of research activity and the number of new ideas generated. However, he does concede

> "…from the point of view of transportation planning practice, it is clear that travel forecasting models have seen little change in recent years. In particular, the activity-based approach has seen little direct application." (ibid.)

The review by Jones, Koppelman and Orfeuil (1990) distinguishes activity analysis from "established procedures," traces methodological developments ranging from data collection to quantitative modeling, describes areas of actual and potential policy applications and provides their perspective on an action agenda. That action agenda is directed toward the two challenges they believe faced activity analysis in the late 1980s: first, to clarify concepts, refine methods and simplify approaches; and second,

> "…to demonstrate the practical usefulness of these approaches, with particular emphasis on the improved ability to understand and predict travel behaviour in a manner which enhances transportation service decision making." (ibid.)

Their assessment of the application of activity analysis to transportation planning mirrors that of Pas and other reviewers. Jones, Koppelman and Orfeuil endorse the conclusions presented by Mahmassani (1988); who in turn summarized those of Kitamura (1988). In short, those conclusions were that the contributions of activity analysis to practical planning tools was limited and fragmentary, activity analysis itself had yet to develop an identifiable and accepted theoretical base, and no clear methodological direction had been charted. What is clear from these reviews at key reflexive moments in the past, is that researchers and practitioners of activity analysis were acutely aware that their aspiration to transform transportation planning tools remained largely unfulfilled. It remains to be seen whether the 1995 New Orleans Conference will provide a landmark reflexive evaluation of a different kind.

4. AN EXAMPLE OF THE THREE PROCESSES AT WORK

The three processes of scientific development and the distinction between segmentation and integration approaches to the treatment of activity analysis and travel demand models provides a framework for examining the overall development and application of the concepts of activity analysis. We cite a series of reports detailing efforts to produce a particular model of activity scheduling to show how those efforts build on processes of scientific development as they have evolved in activity-based approaches; how scheduling models represent one more cycle in our efforts to deepen our understanding of travel demand; and how our desire to develop activity-based forecasting tools is linked to our aspirations for better theory.

The specific example we discuss is work on activity scheduling reported in Ettema *et. al.* (1993a,b; 1994). As a first step in classifying this work, activity scheduling models have attempted to take what we earlier defined as an "integrated" approach: travel is treated as endogenous to the creation of schedules of activities, schedules which when executed (possibly with mid-schedule adjustments) produce observed activity and travel patterns.

Based on models created from both simulated data and data collected through the use of the interactive computer experiments, Ettema *et. al.* conclude that their Simulation Model of Activity Heuristics (SMASH) reacts in plausible fashion to changes in spatial and temporal conditions, produces schedules that contain a high proportion of activities from the agenda of activities to be scheduled, and that schedules tend to be created in order to minimize travel times. Results of the interactive data collection experiment indicate that, within the confines imposed by the program, respondents plan in a fairly simplistic manner. Also, characteristics of activities—their priority on the agenda (the list of all activities that are to be scheduled, if possible, within the current scheduling process), duration, starting times, and ending times—are correlated to the scheduling processes: addition, deletion and substitution and the differential importance of nine schedule attributes. For example, once added to a schedule, high priority activities are less likely to be deleted than are low priority activities. Also, activities that are rescheduled or deleted tend to have shorter duration, earlier start times and less time pressure. Travel time minimization appears to have less effect on the scheduling of activities that are scheduled for earlier in the day than on activities scheduled for later in the day.

We see evidence of the processes of scientific development both in the developments in activity analysis that lead up to of Ettema's *et. al.* work and within their efforts. The behavioral models employed in activity-based applications have moved through cycles of induction-deduction-reflexion that lead from utility maximizing, to adjustments to maximizing (e.g., incorporation of information costs, satisficing), to a variety of non-utility models. In a review of activity scheduling models, Kurani and Kitamura (1996) observe that one advantage of production systems is they can be programmed to model more than one behavior or decision making process. Thus, production systems allow further formulation and testing of theories of decision making.

Ettema's *et. al.* choice of a production system is based on theoretical work spanning Simon (1978), Hayes-Roth and Hayes-Roth (1979), Simon (1990), and Gärling *et. al.* (1993). The interactive data collection revealed a simplified scheduling process. Schedules were built almost solely through additions to the current schedule. Very few deletions or substitutions were made during the scheduling experiments; only after a complete schedule had been articulated were adjustments made to the schedule. This is contrast to the findings of Hayes-Roth and Hayes-Roth (1979) whose work showed a great deal of incremental plan changes. Thus, while building on previous theoretical developments, the divergence of results regarding how activity schedules are constructed between Ettema *et. al.* and the Hayes-Roths suggests a need for continued reflexion, development and testing.

As one example of developments in empirical methods, we refer to our prior discussion of the changes in the treatment of activity duration models, from disaggregate choice models to hazard models (Section 2). Ettema *et. al.* (1995) participated in this development themselves, writing on the application of hazard models to activity choice, timing, sequencing and duration.

5. CONCLUSIONS: PORTENTS OF ACTIVITY-BASED TRAVEL FORECASTING

In writing this interpretation of the development of activity analysis, we have argued that the course of activity analysis can best be traced through three processes: conceptual and theoretical development, empirical testing and application, and the self aware monitoring of the progress and interaction of the first two. This process orientation puts activity-based approaches into a more cyclical, and less linear, historical perspective. We believe this cyclical perspective addresses concerns with the description of the development of activity analysis as linear sequences of distinct epochs raised by Gerardin (1990) in his response to Pas' (1990) review. In particular, Gerardin (1990) argues that "Far from forming a sedimentary evolution, the thirty-five years of research development described by Eric Pas should enrich themselves mutually." He concludes that, "research proceeds in such a way that progress is not linear, but by stop and start."

While we agree with Pas' descriptive history of activity analysis as a series of epochs of distinct emphasis on different problems, we have presented a process oriented history to explain what drives us from one epoch to the next. In contrast to Gerardin, we would describe research as progressing not "by stop and start," but through cycles of induction and deduction, driven by our own monitoring of those cycles and our ability to provide purposive and discursive elaboration both of those cycles and of our awareness of them—or more to the point, of our awareness that we are the purposive agents of those cycles.

In this context, the application of activity-based approaches to travel demand forecasting is not a point in a linear history, nor a layer in a sedimentary history; it is neither a stop nor a start, but one more turn of the wheel. In this conference, itself a reflexive exercise, we may well choose the direction of the next cycle, the pathway we will construct toward activity-based travel forecasting tools. In progressing along that path, we can expect to further elaborate our theories.

One choice that will likely define the direction of that pathway is the choice between making incremental adjustments to existing travel demand forecasting tools or developing activity models in which travel is determined endogenously. In the short term, the incremental approach has the attraction of having already started and of having provided some positive results—it may represent the next turn of the wheel for activity based travel demand forecasting. The perspective we have developed here reminds us though that we should be prepared for the cycles to keep moving. We should be prepared for subsequent cycles, which may well involve a wholesale reformulation of travel demand forecasting into an integrated activity-travel approach in which travel is determined endogenously in activity participation.

Whatever the specific direction, our guess is that applications of activity-based methods will play a major role. And beyond that? If we were to go out on a limb, prospecting into the future and say where the next turn after that may point us, it would have something to do with what we might call "post-modern" models of time-use—models which better represent travelers' propensities to favor predictability or spontaneity.

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