

Spatial Behavior in Transportation Modeling and Planning

Reginald G. Golledge
Department of Geography and
Research Unit on Spatial Cognition and Choice (RUSCC)
UCSB, Santa Barbara, CA
golledge@geog.ucsb.edu
Fax: 805-893-2731

Tommy Gärling
Department of Psychology
Göteborg University, Göteborg, Sweden
Tommy.Garling@psy.gu.se
Fax: +46 (0)31 773 4628

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Introduction

The demand for transportation services is a derived demand based on the needs of people to perform daily and other episodic activities. There have been two dominant approaches to investigating this derived demand: (a) studies focused on the spatial behavior of people, that is, the recorded behavior of people as they move between origins and destinations (e.g., Hanson & Schwab, 1995), and (b) an examination of the decision-making and choice processes that result in spatially manifest behaviors (e.g., Ben-Akiva & Lerman, 1985; Ortúzar & Willumsen, 1994). The former approach has been typified by the development of methods for describing and analyzing activity/travel patterns. The latter is typified both by structural models which involve modeling the final outcomes of decision processes but paying little attention to the cognitive processes involved in determining the final decision concerning movement in space, and behavioral process models paying particular attention to the cognitive factors involved in decision-making as well as to the final choice act (Golledge & Stimson, 1997).

Structural models are built on assumptions such as utility maximization, complete knowledge, optimality, and lack of individual differences among the population. Behavioral models have been built on assumptions of satisficing principles, non-optimal behavior, constrained utility maximization, and individual differences across the population. The structural models usually represent the aggregate movement activities of populations, while the behavioral models are disaggregated representations of the behaviors of individuals or households. Another chapter in this book focuses on structural models; in this chapter we review research on disaggregate spatial behavior as the source of information about behavioral travel choice models.

Transportation modelers and planners need knowledge of travel behavior, including route choice, mode choice, destination choice, travel frequency, activity scheduling, commuting behavior, and pre-travel and en-route travel decision making. Since the 1970s, most modeling emphasis has been based on random utility theory. Different travel options are assumed to have an associated utility which is defined as a function of the attributes of the alternative and the decision maker's characteristics. Ben-Akiva (1997) and Ben-Akiva, M. E., McFadden, D., Abe, M., Böckenhold, U., Bolduc, D., & et al. (1997) provide a recent summary of the state of the art in modeling individual travel choices. They claim that there are few satisfactory existing structural models and claim that there is a need for "behavioral realism" which involves considering heterogeneity of travel preferences, a variety of decision strategies, differentiation between individual and joint decision making for travel, improved consideration of information, and traveler's states of knowledge (e.g., their cognitive awareness or cognitive maps of the travel environment). Many of these concerns have been the focus of the activity-based approach which emphasizes both travel and the spatial decisions that influence movement behavior (Jones, Dix, Clarke, & Heggie, 1983; Kitamura, 1988; Axhausen & Gärling, 1992; Ettema & Timmermans, 1997; Bhat & Koppelman, 2000).

One concern with many of the structural models derived from random utility theory has been their unrealistic behavioral assumptions. Foremost among these has been the assumption of utility maximization which has allowed the development of models in an optimization framework. But, as part of the activity-based approach, the growing concern with the cognitive demands of travel has led to substantial research into human spatial behavior. This research has

included a search for simple measures of spatial ability, individual differences within populations, attitudes towards risk and uncertainty, and variability in path selection criteria. In addition, it is now commonly recognized that decision processes are often dependent on the time of day that travel is to take place and the type of information about network and traffic conditions that is available at that time. To understand day-by-day variability in traffic volumes and network usage, research has been undertaken on the episodic intervals needed for pursuing different types of activities (Recker, McNally, & Root, 1986 a, 1986b; Zhou & Golledge, 2000). It has also been recognized that many travel decisions are secondary effects of the choice of locations for home and work.

In the contemporary information technology-dominated society of the 21st Century, it has become more widely accepted that the quality, quantity, and timing of information will critically affect travel choices. Travelers can only choose from options of which they are aware, so information affects choice set generation and is instrumental in defining feasible opportunity sets for each trip purpose (Kwan, 1994). Sources of information include the learning that takes place with environmental experience as well as information obtained from secondary sources, such as mass media. To date, considerable research has focused on the task of predicting travelers' use of information sources (Polydoropoulou & Ben-Akiva, 1998; Abdel-Aty & Jovanis, 1998; Liu & Mahmassani, 1998 ; Polydoropoulou, Ben-Akiva, Khattak, & Lauprête, 1996; Abdel-Aty & Jovanis, 1996; Khattak, Schofer, & Kopelman, 1995; Mannering, Kim, Ng, & Barfield, 1995; Adler, Recker, & McNally, 1993). Limited research has examined how travelers' perception and memory of the transportation environment (i.e., travel experience) influences activity and travel choice (but see Jha, Madanat, & Peeta, 1996; Kaysi, 1992; Iida, Akiyama, & Uchida, 1992; Gärling, Kwan, & Golledge, 1994). A paucity of material at this stage also relates to the issue of spatial abilities (but see Stern & Leiser, 1988; Deakin, 1997; and Khattak & Khattak, 1998). In addition, Svenson (1998) and Gärling & Golledge (2000) summarize theories related to the cognitive base of decision-making processes. They point out that humans have limited information processing capabilities, must represent information from long-term memory in a limited-capacity working memory to solve spatial tasks, and often apply heuristic rules to simplify decision-making rather than attempting to determine optimal behaviors.

What has been of concern to researchers on spatial behavior (with its implication for transportation modeling and planning) is an understanding of the different regimes for using spatial information. Following ideas offered by psychologists such as Piaget & Inhelder (1967) and Siegal & White (1975), Freundschuh (1992) (see also Gärling & Golledge, 2000, for a similar analysis) identifies three different stages or conditions of environmental knowing. The first consists of persons with landmark knowledge (called declarative knowledge or geographical facts). This is fundamentally place knowledge and consists of location-specific factual information. Persons who develop route knowledge are able to link landmarks in sequences and develop routes. This second type of spatial knowledge includes information of distances and directions from their navigation and is sometimes referred to as procedural knowledge. The third condition involves comprehending the layout of landmarks and understanding the integration of routes into networks. It is variously referred to as map knowledge, survey knowledge, or configurational knowledge. Freundschuh's (1992) analysis of the relative ease with which people can travel through regular grid networks as opposed to irregular networks indicated that the most critical factor influencing this type of behavior is spatial ability. He concluded that the use of

models assuming homogeneous spatial abilities is unrealistic. His findings have focused considerable ongoing research to determine the nature of spatial abilities which appear to be most influential in travel behavior (Golledge, 1992; Gärling, Laitila, & Westin, 1998). Thus, it has become a matter of record that people have different methods of encoding spatial data, and that their knowledge of physical space and built environments is organized in identifiable ways.

The results of this research tend to indicate that travelers with landmark knowledge can only recognize familiar surroundings but are not able to use this knowledge to complete a trip to a new location. These travelers must rely on ancillary information such as maps or on directions from others, are captive to the route that is provided for them, and have limited ability to substitute route segments or to take shortcuts. On the other hand, travelers with route knowledge learn a specific set of rules for navigating from any given point to any other given point following a set of landmarks in strict order. Such travelers can recall routes from memory, but usually only one route at a time. Travelers with configurational knowledge have an understanding of the nature of the network and are able to mentally compute spatial relations required to link landmarks and develop routes, even to destinations that have not been previously visited. They are more likely to be able to construct new routes in response to changing travel conditions and are likely to have the greatest number of feasible alternative destinations and routes stored in memory. They have a dynamic understanding of the transport environment, can take shortcuts or select alternative routes when faced with congestion or other adverse travel conditions, and are the most self-confident travelers in the population.

As detailed in other chapters of this book, developments entailing such a detailed analysis of individuals' spatial and non-spatial knowledge have made necessary a transition from a focus on secondary data (i.e. aggregate travel, usually between arbitrarily defined spatial zones and collected by traffic counts or simplified driver interviews), as opposed to the use by behavioral modelers of primary data, much of which is unobservable except through stated preferences, stated attitudes, or behaviors predicted from knowledge of personal information bases and personal (or household) activity patterns. In practical applications, this has meant a shift from the gravity/entropy models that dominated transportation modeling and planning in the 1960's and 1970's to the variety of formats amenable to disaggregate modeling including logit models, computational process models, and microsimulation models. In the balance of this chapter we will explore the nature of spatial behavior processes and how components of it have been operationalized in such a way that they can be incorporated into modeling and planning activities by processes of contemporary transportation scientists, engineers, and planners.

The Nature of Spatial Decision Making

Human decision-making does not take place in a vacuum. As people age and develop psychologically and intellectually, they accumulate a store of information about environments, the cultural, social, economic, political, legal, and other constraints that limit freedom of choice and freedom of movement, and they develop different levels of spatial abilities and knowledge. Thus, we accept that decision-making is influenced by prior knowledge based on experience and learning of the environments and sociocultural systems in which individuals reside and carry out their activities. For any given problem situation one can assume that either there is stored

experience in memory which can be called on to help solve any given problem, or that knowledge transfer can take place based on experiencing similar situations or based on generalized schemata that people carry over from one environment to another. For example, although a person may never have visited a specific shopping mall before, he or she usually has a generic template or schema of what a shopping center is supposed to be, and this is of help in defining locations for entrances and exits, means of traveling from one level to another, or even in obtaining an understanding of how shops are organized on each level. The same type of schemata may develop in different cultural environments. As another example, U.S. travelers entering different U.S. cities will carry schemata of the transportation network (involving freeways, highways, arterial roads, neighborhood streets, lanes and alleys) which allow them to categorize parts of the unfamiliar network and to use this network in a manner similar to that which they have experienced in other environments (Kwan, Golledge, & Speigle, 1998). This state of prior knowledge and transferable schemata are derived from the personal experiences of traveling through different environments, by examining representations of environments in the form of maps, images, photographs, slide or video presentations, or by developing a configural understanding of an environment from a "birds-eye" view (e.g. from a lookout or by looking through the window of an airplane).

A person has to be motivated to travel. Examples of travel motives include the feeling of hunger or the need to earn a living, or exposure to an advertisement for a job or for a location at which particular wants and needs can be satisfied. The end result is that an individual, acting either for himself or for a group, is motivated to move between an origin and destination. Usually the first step in this motivation process is a search for relevant information. This search will include an attempt to familiarize the individual with selected aspects of the environment. This may include the transportation network and the location of different land uses. The motivated person may also have to collect information about traffic volumes and the daily temporal cycles of movement undertaken by the population as a whole. Some of this information can be obtained from secondary sources such as the Yellow Pages telephone directories, printed or televised ads, communication with neighbors, or examination of printed or electronic maps.

Once information is collected, it is encoded and stored in long-term memory. Thus, each individual builds a "cognitive map" of their unique internal representation of the world around them (Downs & Stea, 1973b). These cognitive maps are simply encoded databases, and there is no evidence that they are actually stored in cartographic format. For the most part, the term is accepted either as a hypothetical construct or is used metaphorically (Kitchin, 1994). Nevertheless, it is assumed that, when faced with a task involving spatial movement, people are - within the limits of their spatial abilities - able to bring previously encoded information from long-term memory into a working memory and potentially arrange it in map-like or other spatial form so that critical movement decisions can be made (Kuipers, 1978). The essence of these decisions is that potential travelers are able to define a behavior space in which their movements will be located. This behavior space consists of a subset of the total environment which may be confined to a particular segment or corridor. Information relevant to the movement process is evaluated in this behavior space as part of the spatial decision-making process (Golledge, 1997b). For example, given a particular need (e.g., food) the behavior space will include a set of feasible alternatives at which the desired food could be obtained. The creation of this behavior space is temporally and locationally dependent. The behavior space for food purchase may, for

example, be quite different when viewed from the perspective of a home base as the source of a trip as opposed to the perspective that would be appropriate if another origin such as work or an educational institution was to be the origin of the trip. In each case, the feasible opportunity set might change. For example, a potential traveler at a home base may choose a feasible alternative which lies in the opposite direction to the workplace; such an alternative would usually not be considered part of the feasible set if viewed from the perspective of the workplace.

Once the behavior space has been determined, the traveler focuses on movement imagery. In this case, a potential route between the current location and the chosen destination will have to be worked out. This will involve making a choice of travel mode; estimating the time/cost/distance of travel to the proposed destination; integrating this particular trip into a multiple stop trip chain if that is the intent of the decision maker; developing travel plans that include optional activities if the desired route is blocked by congestion, hazard, or construction; and assessing or evaluating the likely outcomes of making such a trip.

The final stage of the decision making process involves implementing the desired behavior and traveling through space between an origin and destination via a particular mode over a segment of the transportation network. At the end of any transaction that is involved with this trip, feedback occurs in that the traveler evaluates and assesses whether the derived behavior satisfies the original demand condition. If it does, then this particular trip may be stored in memory as a potential solution in future task situations of the same type. If not, then evaluation of which part of the constructed process led to failure to meet anticipated levels of aspiration might dictate the necessity for a change in behavior on the next trial (Golledge & Stimson, 1987). This represents part of a spatial learning process. Successful trials can quickly lead to the development of a habitual behavior which then becomes relatively persistent and invariant over time. It is also difficult to extinguish so that, even when a potential trip is temporarily restricted by external events such as congestion, construction, weather, or other form of hazard, the traveler may return to the original spatial behavior once the intervening problem has been surmounted or disappears.

Travel habits represent behaviors that require little conscious decision-making activity prior to their performance (Gärling, Boe, & Fujii, 2001; Gärling & Garvill, 1993). They represent a significant part of the total trip patterns undertaken. The journey to work is often characterized as being a travel habit. In particular, it lends itself to structural modeling and successful prediction of travel. Many other behaviors, however, are not as well entrenched as this type of travel habit. They represent more variable behaviors and may be less easily modeled and predicted by a conventional structural model. Behavioral models have been specifically developed to deal with these variable behaviors that are not easily categorized into a repetitive format. Many types of consumer behavior (apart from food shopping), social behavior, and recreational behavior fall within this latter category.

To briefly summarize this section, studies of spatial behavior have contributed significantly to understanding the decision-making process that goes on prior to the actual selection and implementation of a route choice. Rather than just trying to model revealed behaviors (i.e. the actual traces of movement over the network), models based on spatial behavior attempt to incorporate processes associated with cognitive demands. As we will see later in this chapter,

the use of cognitive information carries with it error and belief baggage that biases information stored in memory and may result in inefficient, inaccurate, or unpredictable behaviors.

Cognitive Maps and Travel Behavior

The focus of this section is to examine the relationship between cognitive maps and travel behavior in urban environments. We do this incrementally, beginning with clarifications of terms relating to cognitive mapping and wayfinding, with an emphasis being placed on selecting paths to destinations by using existing transport networks (particularly road hierarchies). We also introduce concerns relating to the role of trip purpose in path selection and discuss how different purposes spawn different path or route selection strategies. Finally, we examine in detail how environmental structures and considerations impact the interaction between cognitive maps, route selection, and activity choice.

Cognitive maps are our internal representations of experienced environments. These environments can be real or imaginary, but they emphasize place ties with objects or interactions and relate non-spatial characteristics to spatially referenced places. There is as yet no clear evidence that cognitive maps have any formal cartographic structure. However, place cell analysis (Nadel, 1999) suggests that environmentally experienced objects are coded in specific place cells and that, upon repeated exposure to images or representations of specific objects or places, neurons in the same cells at specific places in the brain repeatedly fire. There appears to be insufficient evidence about the internal arrangement of place cells, so we do not know if they are randomly distributed throughout the brain or selectively clustered according to some identifiable spatial criteria. Cognitive maps, thus, are the conceptual manifestations of place-based experience and reasoning that allows one to determine where one is at any moment and what place-related objects occur in that vicinity or in surrounding space. As such, the cognitive map provides knowledge that allows one to solve problems of how to get from one place to another, or how to communicate knowledge about places to others without the need for supplementary guidance such as might be provided by sketches or cartographic maps.

Little research has been completed on the creation of network knowledge and the relationship between network knowledge systems and real world transportation systems. We all realize from personal experience that our knowledge of existing networks is partial. But, if we have an overall anchoring structure or general layout understanding of on-route and off-route landmarks, we can—either by using a travel aid such as a map or by independently accessing cognitively stored information—find our way between specific origins and destinations in urban environments. Sometimes this task is simple, with minimal feasible alternative path structures to be considered. At other times the task is complex and substantial and requires meticulous planning and implementation.

In many countries, the use of the household car (or cars) represents an important form of movement. To satisfy economy of movement, minimize air and noise pollution, achieve door-to-door delivery of drivers and passengers, and guarantee independence in route choice, networks of surface roads have been developed. Usually these are differentiated into freeways, highways, arterials (major and minor), local streets, and lanes or alleys. When making a trip, each

individual must consider how to use the local road hierarchy. These decisions can be made *a priori* (as in a travel plan) or en-route (as in real-time wayfinding). The mere existence of the hierarchy, combined with individual memories of travel experience, leaves the way open for different route-selection strategies to be developed and for different paths to be followed. Thus, one next-door neighbor might try to maximize use of a freeway for, say, a trip to work and maximize use of local streets to facilitate a trip chain on the way home, while another neighbor might use the reverse strategy. Thus, two spatially adjacent householders, going to the same destination, can choose completely different paths. By doing this, their environmental experiences may differ and their cognitive maps may, likewise, be quite different.

In many urban environments, traffic control measures such as one-way streets and limited on-street parking can also influence path selection and, consequently, the nature of the detail that is georeferenced in the cognitive map. Apparently, to facilitate communication and development of a general understanding of complex environments, people tend to define “common anchors”—significant places in the environment that are commonly recognized and used as key components of cognitive maps—and idiosyncratic or “personalized anchors” that are related to a person’s activities (e.g., specific work place or home-base) (Golledge, 1990). These anchor the layout or structural understanding of an environment (regardless of its scale). Objects and features in an environment “compete” for a traveler’s attention, with the most successful reaching the status of common anchor—recognized by most people and, consequently, incorporated into all their cognitive maps. Other features and objects are less successful in general, but might achieve salience for a specific trip purpose (e.g., “the odd-shaped building where I park in order to go to my favorite restaurant”). Minor pieces of information are attached to anchors and act as “primers and fillers”—the second, third, or lower orders of information experienced but used only in selected ways and with varying frequencies.

Individual differences exist in the degrees of knowledge about places, locations, or landmarks and other components of a route or network (Allen, 1999). There is also evidence that there are developmental changes in the ability of humans to learn both route and survey information (Piaget and Inhelder, 1967). Recent researchers have criticized the strict Piaget type sequential/developmental theory of spatial knowledge acquisition, particularly as interpreted by Siegel and White (1975) (e.g., Liben, 1981; Montello, 1998). Still, there appear to be recognizable differences between preschool, preteen, teenage, and adult spatial abilities, both in terms of environmental learning and success in navigating or wayfinding. There is also some evidence that males and females acquire different types of knowledge and use different types of strategies in their wayfinding tasks. In particular, it has been suggested that women use more landmarks and are more likely to use piloting strategies (i.e., travel from landmark to landmark in succession) while males tend to use more orientation and frame related processes for wayfinding (e.g., Self & Golledge, 2000) and “head out first in the general direction” of a destination. What complicates things even further is that humans do not all behave the same way in the same environments, partly because of different levels of familiarity, partly because of different spatial abilities, partly because of different motivations to travel, partly because of different trip purposes that require them to give different saliencies to environmental features, and partly because people react differently to considerations of geographic scale and its impact on the comprehension of environments (see Bell, 2000).

Allen (1999) suggests that the most widely recognized spatial abilities from psychometric analyses are visualization, speeded rotation, and spatial orientation. Visualization concerns the ability to imagine or anticipate the appearance of complex figures or objects after a prescribed transformation such as occurs during a paper-folding task. Speeded rotation, sometimes called spatial relations, involves the ability to determine whether one stimulus is a rotated version of another. Orientation is the ability of an observer to anticipate the appearance of an object from a prescribed perspective, such as being able to point to an obscured object in a real or imagined space.

These spatial abilities appear to fall into one of three families: a) concerning the stationary individual and manipulable objects; b) a stationary or mobile individual and moving objects; and c) a mobile individual and stationary objects. Wayfinding appears to be more related to the last of these groupings. Spatial abilities, therefore, are an important component of making and using cognitive maps, as well as playing a critical role in human wayfinding.

Sholl (1996) suggests that travel requires humans to activate two processes that facilitate spatial knowledge acquisition—person-to-object relations that dynamically alter as movement takes place, and object-to-object relations that remain stable even when a person undertakes movement. The first of these is called egocentric referencing; the second is called layout or configurational referencing. Given this conceptual structure, it is obvious that poor person-to-object comprehension can explain why a traveler can become locally disoriented even while still comprehending in general the basic structure of the larger environment through which movement is taking place. Error in encoding local and more general object-to-object relations can result in misspecification of the anchor point geometry on which cognitive maps are based.

Although there are many electronic, hardcopy, and other technical aids that can be used as wayfinding tools, humans nevertheless most frequently tend to use their cognitive maps and recalled information as travel guides. There are three different types of knowledge usually specified with relation to travel behavior. One is route knowledge (or systematic encoding of the route geometry by itself). A second is route-based procedural knowledge acquisition that involves understanding the place of the route in a larger frame of reference, thus going beyond the mere identification of sequenced path segments and turn angles. A third type is survey or configural knowledge implying the comprehension of a more general network that exists within an environment and from which a procedure for following a route can be constructed.

An individual need not have a correctly encoded and cartographically correct “map” stored in memory to be able to successfully follow a route. Route knowledge by itself requires that a very small section of general environmental information is encoded. In its pure form, the route is completely self-contained, anchored by choice points and on-route landmarks and consisting of consecutive links with memorized choice points and turn angles between the links. The integration of specific routes is a difficult task, but apparently not an impossible one, for many people develop either skeletal or more complete representations of parts of urban networks through which their episodic travel takes place.

Finding and following a route usually also entails many stages of information processing on the part of the traveler. Due to the working of these processes, errors or omissions in the cognitive

map are compensated for by the acquisition of relevant information from the environment that helps solve wayfinding problems.

Human Wayfinding

Many animals, birds, and insects, after controlled or random searches for food or water, return to their home base using a procedure called “path integration.” This involves constant updating of one’s position with respect to home base. After achieving a goal (e.g., finding food), they can return directly to home via a shortcut. There is no need to recall a route just traveled or to retrace it. Called “dead reckoning” by human navigators (e.g., pilots), this strategy can also be used by humans, but, because of travel mode and transport network requirements, usually is not used.

It is becoming more common to differentiate between navigation and wayfinding. Navigation implies that a route to be followed is predetermined, is deliberately calculated, and defines a course to be followed between a specified origin and destination. Wayfinding is taken more generally to involve the process of finding a path between an origin and a destination that has not necessarily previously been visited. Wayfinding can thus be identified with concepts such as search, exploration, and incremental path segment selection during travel.

Navigation seems to imply that a distinct process is used to define a specific course, either to get to a predetermined known or unvisited destination or to allow the traveler to return home without undue wandering or error. The principal types of navigation include piloting (or landmark-to-landmark sequencing of movement) and path integration (dead reckoning) that allow direct return to the origin without the need for storage and recall of the route being traveled.

Navigation is usually dominated by criteria such as shortest time, shortest path, minimum cost, and least effort, or with reference to specific goals that should be achieved during travel. Wayfinding is not as rigidly constrained, is purpose dependent, and can introduce emotional, value and belief considerations, and satisficing constraints into the travel process. Whereas navigation usually requires the traveler to preplan a specific route to be followed, wayfinding can be more adventuresome and exploratory, without the necessity of a pre-planned course that must be followed. While, for some purposes, travel behavior will be habitualized (thus lending itself to the navigation process), for other purposes, variety in path selection may be more common (indicating more of a wayfinding concern).

Whether predetermined or constructed while traveling, a route can be said to have a certain legibility. This is the ease with which it can become known and traversed. This is based on the number and type of relevant cues or features both on and off the route that are needed to guide the movement decisions. It also reflects the ease with which these cues can be organized into a coherent pattern. Legibility influences the rate at which an environment is learned. Most human travelers in urban environments seek to gain legibility for the routes they travel on both a regular (habitual) or intermittent basis.

Human wayfinding is very dependent on trip purpose. The question as to whether specific purposes are better served by certain types of wayfinding strategies remains unresearched. For example, journey to work, journey to school, and journey for convenience shopping may be best served by quickly forming travel habits over well-specified routes. Such an action would

minimize en-route decision-making, and often the resulting route conforms to shortest path principles. However, journey for recreation or leisure may be undertaken as a search and exploration process requiring constant locational updating and destination fixing. Thus, as the purpose behind activity changes, the path selection criteria can change, and, as a result, the path that is followed (i.e., the travel behavior) may also change. Recent work on Intelligent Highway Systems (IHS) and Advance Traveler Information Systems (ATIS) has shown that humans sometimes respond to advance information on congestion or the presence of obstacles by substituting destinations, by changing departure times (particularly early morning), by delaying or postponing activities, or by selecting alternate routes (particularly in the evenings) (Chen & Mahmassani, 1993). All these produce different travel behavior in response to changing environmental circumstances. Cognitive maps must be very versatile to allow such behavioral dynamics.

Travel Plans and Activity Patterns

Activity patterns consist of a sequence of activities carried out at different locations in space. In the activity-based approach (Jones, Dix, Clarke, & Heggie, 1983; Kitamura, 1988; Axhausen & Gärling, 1992; Ettema & Timmermans, 1997; Bhat & Koppelman, 2000), the tenet is that such activity/travel patterns are the outcome of predetermined interrelated choices sometimes referred to as activity scheduling (Doherty & Miller, 1997). The cognitive representation of choices of destination, mode, departure time, and route contingent on choice of activity has been termed a travel plan (Gärling, Bök, & Lindberg, 1984; Gärling & Golledge, 1989; Gärling, Gillholm, Romanus, & Selart, 1997). Wayfinding is usually controlled by a travel plan.

Understanding activity choice has a long history. Different approaches have been offered by: (i) Chapin (1974), the pioneer of activity based approaches whose work concerned characteristics of activity patterns and their relationship with socio-psychological propensity factors; (ii) Hägerstrand (1970), who emphasized which activity patterns can be realized in particular spatial-temporal-functional settings; (iii) Burnett & Hanson (1982) who advocated a constraints approach, suggesting utility maximizing models such as discrete choice models and stated preference/choice models were all based on the unrealistic assumption that individuals were free in choosing the alternatives they liked the best; (iv) Smith et al. (1982) suggesting the development and use of computational process models based on choice heuristics rather than utility maximizing behavior and acknowledging imperfect information and sub-optimal choice making; and (v) Miller & Salvini (1997) who proposed microsimulation models which are used to aggregate the behavior of each individual in a population via simulation processes

The simplest of all behavioral models are single facet models, usually based on panel or diary data and addressing specific characteristics such as trip chaining, departure time decisions, and activity time allocation. Activity frequency analysis and activity association have been examined by Ma & Goulias (1999) who used a Poisson model to predict the frequency of activities related to subsistence, maintenance, and out-of-home leisure. Other models of this class include that of Kockleman (1999), Lu & Pas (1997, 1999), Golob (1998), and Lawson (1999). An innovative contribution is to use structural equations to simultaneously estimate the relationship between socio-demographics, activity participation, and travel behavior including the number of stops,

time of travel, mode of travel, and the number of trip chains. Golob & McNally (1995) used a structural equation model to analyze activity participation in the travel behavior of couples, using the dominant categories of work, maintenance, and out of home discretionary activities.

Activity duration and time allocation modeling can be found in the work of Kitamura, Nishii, & Goulias (1988), Kitamura, et al. (1992), and Robinson, et al. (1992). The emphasis here was on log-linear models examining the commuter duration and work duration as opposed to time allocated to other activities. Kitamura, Chen, & Narayanan (1998) incorporated activity duration into a model of destination choice. The systematic variation of activities across the days of the week have been examined by Hanson & Huff (1982), Koppelman & Pas (1984), Huff & Hanson (1986), Pas & Koppelman (1987), Pas & Sunder (1995), Ma & Goulias (1997), and Zhou & Golledge (2000).

Pre-Travel and En-Route Decisions

The past decade or so has seen a paradigm shift in transportation modeling and planning to focus attention on more effective management of travel. The major incentive has been an obvious need for the development of traffic control strategies rather than strategies focused on providing more infrastructure. As societal changes such as flex time working hours, telecommuting, and in-car dynamic, real time reception of advance travel information have become more important, modeling and planning attention has been focused on understanding travel behavior. Achieving such a goal is hypothesized to help reduce travel demand by the suppression/selective elimination of redundant, unnecessary trips, by targeting single occupant vehicles at peak periods of commuting, and reducing driver frustration, stress, and road rage by providing in-car, en route, or pre-travel information about routes and traffic conditions. As more data has been collected by survey research, travel diary, and interview procedures, a more comprehensive understanding of the reasons for trip making and route selection has evolved. In association with this knowledge accumulation has come more detailed examination of the decision-making characteristics of potential drivers, their spatial abilities, and their individual differences with respect to travel preferences. In general, this has produced a body of research designated “Intelligent Transportation Systems” (ITS) which covers the more effective control of traffic and more efficient transmission of information to actual or potential travelers. Much of this concern has drawn on the activity-based approach described in the last section.

A major goal of ITS is the reduction of congestion and accidents or hazards that are associated with surges in traffic volume. A significant part of ITS is the Advance Traveler Information System (ATIS). This consists of in-vehicle information and ex-vehicle guidance systems that aid in pre-trip planning and en-route decision making. Information obtained in advance about current traffic conditions on routes that have been selected as part of travel planning assists the potential traveler in making important decisions such as at what time to begin a trip. Research on individual differences makes us aware that drivers will respond in different ways to the same set of information. For example, advance information on the congested state of a particular route segment may encourage some drivers to delay departure times, others to choose different routes, and yet others not to change their travel plans on the assumption that the congestion will have cleared by the time they have reached the critical spot. Thus, reactions will range from ignoring

the advance information to accepting it and changing part of a travel plan. In this way, the ATIS acts as a decision support system—an integrated set of tangible and intangible information that is designed to supplement personal knowledge during problem activities (Densham & Rushton, 1988).

A decision support system does not replace individual decision making but, rather, acts as an additional source of information that must be evaluated and integrated into the regular decision making process. Much of the research in psychology and cognitive science on conflict resolution and decision-making has emphasized the importance of offering more than a single solution to a problem. Advance information serves a similar purpose by giving an early warning of potential impediments to travel, allowing a potential traveler to develop a set of alternate strategies that could be implemented in order to achieve the original goal (Adler et al., 1993a, 1993b).

While the nature of travel information has been explored extensively over the last decade and a half, much less research has been undertaken on the most appropriate way for people to receive this information (e.g., by visual signals or graphic map displays in-car, by special radio broadcasts, by voice command interfaces with in-car computers, by dynamic highway traffic signs, and so on). Behavioral research tells us that the probability of ignoring or accepting information provided may vary significantly between sexes and among age groups. Behavioral researchers at this point have therefore generally adopted a multi-modal approach in order to reach the greatest number of people in these different response groups. Perhaps the most significant factor emerging from this research, however, is that advance information will only be acted on if it is provided to potential travelers in a realistic time frame (Jayakrishnan et al., 1993, 1994).

One common scenario involves a potential traveler receiving information before the trip is actually initiated. We have already seen that trips for different purposes require different amounts of pre-planning. Trips to work, for example, often become more or less habitual, encouraging stereotyped behavior and repetitive travel over a well-defined route. Trips for other purposes may be more variable, both in terms of the times of departure, the times of travel (often varying considerably during the day), and whether the proposed trip will be part of a trip chain. Axhausen (1992) emphasized the importance of access to information in the pre-trip planning phase. Jou & Mahmassani (1998) and Mahmassani & Jou (1998) undertook diary surveys of commuters in two different environments—the north central expressway corridor in Dallas and the northwest corridor in Austin—to examine dynamics of commuter decisions. In particular, they focused on departure times and selection of the routes to be followed for both the morning and the evening commuters. They modeled pre-travel decision-making concerning route selection, departure time, and route switching patterns to other factors such as the time of day of travel, the normal time of departure, trip length, path selection criteria, the nature of the route to be followed, and expectations as to the likelihood that pre-trip planning would have to be changed. Significant results included evidence of greater route switching activity in the evening commute and a later frequency of time switching in the morning commute. Mahmassani & Herman (1990) previously reviewed the evolution of approaches focused on traveler information from models that were microeconomics-based analyses of idealized situations to elaborate simulation studies and critical observation work in laboratory and real world conditions.

Certainly, manipulation of departure times appears to be a first-order response to advance traveler information that specifies congestion or other problems along pre-selected routes.

En-route decisions require additional information other than personal evaluations of traffic conditions. For example, if information is given en-route to a driver about congestion or other impediments to travel, along with the time or distance along the route to the location of these barriers, the travelers must evaluate in situ the potential impact of the warnings on their travel plans. They must integrate at the same time the perception of the current speed of traffic, traffic volume, time lapses associated with completing designated sections of the route, familiarity with the network on which they are traveling, and familiarity with adjacent neighborhoods through which they may have to travel if they depart from a pre-set route, while at the same time re-evaluating their travel goals and expectations associated with the specific trip. They may also have to review their knowledge of landmarks and other important reference nodes on and off an alternative route and evaluated conditions of safety and uncertainty that may go along with a change in travel plans.

While en route, a traveler has a number of alternative strategies that are available in response to the receipt of negative information about the route being followed. Recent studies focusing on the nature of these choice alternatives have been undertaken by Bonsall & Perry (1991), Allen, Stein, et al. (1991), Ayland & Bright (1991), Ben Akiva, De Palma, & Kaysi (1991), Khattak, Schofer, & Koppelman (1993), and others. This early research examined the en route travel behavior change pattern in both laboratory experiments and in real world conditions. Adler, Recker, & McNally (1993) characterize en route driver behavior as an integrative process through which they assess the current state of a system and adapt travel behavior in response to the severity of their perceptions. They suggest that possible strategies would include route diversion; new information acquisition; revision of travel objectives; delay of travel; substitution of routes; substitution of destinations; and reordering of scheduled priorities. Factors that influence which of these are likely to be chosen include estimates of delay; estimates of travel time involved in waiting or clearance or by taking new routes; perception of the ease of travel and safety of alternative routes; the amount of prior experience with congesting conditions on the original route; the risk taking propensity of individual drivers; their tolerance thresholds with respect to delay; expectations of meeting the original travel goals, objectives, mode of travel, focus of trip, time of day of the trip; and the potential for rescheduling an activity.

Adler, Recker, & McNally (1993a, 1993b) devised a simulation method (FASTCARS) that allowed participants to make choices resulting in road changing, lane changing, and information acquisition while traveling between a given origin and destination. Information was provided through highway advisory radio (HAR) and in-vehicle navigation systems (IVNS). The HAR system provided real time traffic incident and congestion information for the freeways in the network. The IVNS calculated the shortest time path from the driver's current position to the destination of choice. Both these types of information were fed to participants, and the consequent activities and choices were evaluated after relating behavior profiles to trial event data. The results thus incorporated current traffic conditions with behavioral profiles to examine the role of spatial behavior in travel choice. Most studies assume that drivers' responses reflect their perceptual and cognitive processing ability, both of which are temporally and spatially dependent. The recording of physiological or psychological changes in driver behavior in real

time, however, is still lacking. It is likely, because of safety conditions associated with these types of studies, that microsimulation, virtual immersive, or virtual desktop environments are likely to be the most effective way of examining driver responses to changing traffic conditions.

Path Selection Criteria

Human wayfinding can thus be regarded as a purposive, directed, and motivated activity that may be observed and recorded as a trace through an environment. The trace is usually called the route or course. A route results from implementing a travel plan (Gärling, Böök, & Lindberg, 1984; Gärling & Golledge, 1989) which consists of predetermined choices defining the sequence of segments and turn angles that comprise the course to be followed or the general sector or corridor within which movement should be concentrated.

The criteria used in path selection vary significantly with trip purpose. Traditionally, the major types of path selection criteria include shortest path, shortest time, shortest distance, least cost, turn minimization, longest leg first, fewest obstacles (such as traffic lights or stop signs), congestion avoidance, minimizing the number of route segments, restriction to a known corridor, maximizing aesthetics, minimizing intermodal transfers, optimizing freeway use, avoidance of known hazardous areas, least likely to be patrolled by authorities, and minimizing exposure to truck or heavy freight traffic.

Most studies of travel behavior have adopted the assumption that travelers desire to minimize time, cost, or distance. Such assumptions facilitate the development of tractable, mathematical models that can use simple network structures to provide optimal route selection solutions to different types of movement problems. This has been the strength of traditional microeconomic models. Over the past decade, however, psychological and behavioral geographic studies have indicated that rational optimizing behavior is not widespread among individual travelers (Pas & Koppelman, 1986, 1987; Gärling and Golledge, 2000). So what criteria are used? Golledge (1997a) conducted a variety of laboratory experiments in regular and irregular networks. For about half the population, shortest path trips were chosen regularly. However, that same path was often not chosen when individuals were asked to retrace the route from the destination to the origin (e.g., 60% retraced it in a simple grid network environment, but only 20% retraced it in a more complex irregular network). Thus, depending on the nature of travel and the traveler's location at which to start a trip, different path selection criteria might be used. Criteria that have been found in both empirical and laboratory studies include: fastest time; minimizing left turns; minimizing total turns; driving the longest leg first; driving the shortest leg first; trying to approximate a straight line shortcut route between an origin and a destination; always heading in the direction of the destination; and defining a travel corridor beyond whose boundaries travel would not take place (Golledge, 1997a).

Apparently, people use different criteria for different purposes. Since much of the research has focused on the dominant home-work-home trip (usually without intermediate stops), the tendency has been to accept an assumption that drivers will minimize time, distance, or cost. An analysis of travel behavior, however, has shown that the trip home is not always a simple reversal of the trip to work. This is partly because of the increased probability of a trip chain

being undertaken on the way home, partly because of the perceptions of the ease or difficulty of retracing the route (Mahmassani, Hatcher, & Kaplice, 1997). Thus, as trip purpose changes from shopping, to recreational, to health and professional related needs or purposes, to education, or for religious purposes, the reasons for choosing a particular route may also change. At times, maximizing the aesthetic value of a particular route (e.g., on a recreational trip) may be more important than minimizing travel. Suddenly one cannot assume that all the people, say, traveling on a freeway at 5:15 pm on a weekday, are going directly home. Thus, while it may be expected that the bulk of them may be doing this, it is not necessarily a good assumption to build into a planning strategy for travel behavior at that time of day. Usually there are a number of “feasible route selection criteria” that are imbedded in daily activity patterns.

Behavioral Models for Forecasting Travel Demand

In the preceding sections we have reviewed research on human spatial behavior. How can the findings of this research be used in transport modeling and planning? In this section we briefly review some modeling approaches that build on behavioral assumptions and whose purpose is to forecast travel demand in such a way that it can be used in transportation planning.

The standard travel demand forecasting procedure consists of a household base, a cross classification model for trip production, a regression based model for trip attraction, a gravity model for trip distribution, a multinomial logit model for mode choice (often focused largely on home/work trips only), and a network assignment procedure for highway or transit travel. Only the multinomial logit model amongst these has been based on behavioral principles, although it is usually made operational at an aggregate rather than a disaggregate level.

Ben-Akiva, Ramming & Golledge (2000) suggest that it is possible to identify a model with limited latent variables using only observed choices. To use maximum likelihood estimation, we need the distribution of the utilities, $f(U|X, X^*; \mathbf{b})$. An additive utility is a common assumption in the transportation literature:

$$U = V(X, X^*; \mathbf{b}) + \mathbf{e} \quad (1)$$

That is, the random utility is decomposed into the sum of a systematic utility $V(\bullet)$ and a random disturbance, \mathbf{e} . The systematic utility is a function of both observable and latent variables. \mathbf{e} are utility coefficients to be estimated.

Choice can then be expressed as a function of the utilities. For example, assuming utility maximization:

$$y_i = \begin{cases} 1, & \text{if } U_i = \max_j \{U_j\} \\ 0, & \text{otherwise} \end{cases} \quad (2)$$

where i and j index alternatives. From equations (1) and (2) and an assumption about the distribution of \mathbf{e} , we derive $P(y|X, X^*; \mathbf{b})$, the choice probability conditional on both observable and latent explanatory variables.

$$\begin{aligned} P(y_i = 1|X, X^*; \mathbf{b}) &= P(U_i \geq U_j, \forall j \in C) \\ &= P(V_i + \mathbf{e}_i \geq V_j + \mathbf{e}_j, \forall j \in C) \end{aligned}$$

$$U_i = V_i + \mathbf{e}_i \text{ and } V_i = V_i(X, X^*; \mathbf{b}), \quad i \in C,$$

where C is the choice set. The most common distributional assumptions result in logit or probit choice models. For example, if the disturbances, \mathbf{e} , are i.i.d. standard Gumbel, then

$$P(y_i = 1 | X, X^*, \mathbf{b}) = \frac{e^{V_i}}{\sum_{j \in C} e^{V_j}} \quad [\text{Logit Model}]$$

or, in a binary choice situation with normally distributed disturbances:

$$P(y_i = 1 | X, X^*, \mathbf{b}) = \Phi(V_i - V_j) \quad [\text{Binary Probit Model}]$$

where Φ is the standard normal cumulative distribution function.

Choice indicators could also be ordered categorically, in which case the choice model may take on either ordered probit or ordered logistic form. Finally, to construct the likelihood function, an assumption about the distribution of X^* is needed. Assuming X^* is independent of $\mathbf{?}$, and its distribution can be described by a vector of parameters $\mathbf{?}$, the result is:

$$f(y | X; \mathbf{b}, \mathbf{g}) = \int_{X^*} P(y | X, X^*; \mathbf{b}) f(X^*; \mathbf{g}) dX^*$$

Ben-Akiva, et al. (2000) further argue that, although the likelihood of a choice model with latent explanatory variables is easily derived, it is quite likely that the information content from the choice indicators will not be sufficient to empirically identify the effects of individual-specific latent variables. Therefore, indicators of the latent variables are used for identification, which leads to more elaborate model systems that combine choice models with latent variable models. When the complexity increases even further, other approaches are needed.

The fact that many trips are routine or repetitive (usually representing more than 50% of the total trips made on any given weekday in particular) has provided the basis for successful modeling and planning using structural models (McFadden, 2002). However, to forecast demand for more variable types of travel (e.g., weekend or leisure travel), it may be necessary to more completely understand the decision making *process* than is possible purely on the basis of building a successful structural model. At the same time, predictive validity of behavioral process models is not likely to be equally good (Gärling, Gillholm, and A. Gärling, 1998).

It may be questioned whether an increased understanding of the underlying travel-choice process parallels the progress that has been made with respect to the development of applications. The term *activity scheduling* is used to refer to the choice process resulting in a travel plan that eventually is implemented in an activity/travel pattern. Limits on human information-processing capacity render optimal activity scheduling generally infeasible unless the task is very simple (Gärling, 2001). An important goal of research is, therefore, to specify the kinds of simplification people are likely to make. To this end, behavioral process models have used a formalism called production systems which are sets of conditional rules that can be encoded in computer programs (Smith et al., 1982; Gärling, Kwan, & Golledge, 1994).

The development of process models has focused travel choice research on important issues (Gärling, Laitila, and Westin, 1998). With reference to Table 1, it has been a shift of focus from time-invariant determinants of single choices with no learning (upper left corner) to the *process*

of making multiple choices (concerning multipurpose multistop trips) in which learning takes place (lower right corner). At the same time, the tractability of mathematical-statistical models decrease. Yet, behavioral process models allow modeling of more complex activity/travel choice. For instance, it is now realized that utility maximization is an unrealistic assumption. In response to this, process models based on bounded rationality assumptions and employing noncompensatory decision rules have been developed (e.g., Arentze and Timmermans, 2000). This development may influence structural models in the future. To this end, Ben-Akiva et al. (1999) have extended a conceptual framework as a basis for (travel) choice modeling which includes affective factors. In addition, it is also essential to model how information is searched, perceived, and remembered.

Table 1. Different foci of past and current research on travel choice.

	Structure	Process
Single choice	No learning	No learning
Multiple choice	Learning	Learning
	No learning	No learning
	Learning	Learning

If encoded in computer programs, it may be possible to make exact predictions from production-system models, for instance, in simulating the outcome of policies on individuals or households (e.g., Gärling, Kalén, Romanus, Selart, & Vilhelmson, 1998; Pendyala, Kitamura, Chen, & Pas, 1997; Pendyala, Kitamura, & Reddy, 1998). In contrast to statistical-mathematical structural models, estimating free parameters of process models is nevertheless considerably more difficult. With some success (Ettema, 1996), structural and process models have been combined to this end. In fact, both types of models should be compatible. Still, the validity of process assumptions is not easily judged from estimates of the parameters of structural models. Thus, there are problems to be solved concerning data and methods of data collection with reference to process models. Some such solutions appear to be forthcoming (Doherty, 1998).

Three systems of models of activity/travel scheduling (Ben-Akiva and Bowman, 1997; Kitamura and Fujii, 1998; Arentze and Timmermans, 2000) have recently been proposed. These models are operational, so they can forecast activity/travel patterns. They also aspire to make realistic behavioral assumptions.

In Ben-Akiva & Bowman (1997), a system of nested discrete-choice models for travel demand forecasting is described. It is assumed that decisions with different time frames are hierarchically organized. Mobility and life-style decisions (e.g., choosing to purchase an automobile, residential choice) condition longer-term activity and travel scheduling which, in turn, conditions daily activity and travel *rescheduling*. The latter is the major focus of the model. A primary daily activity pattern is assumed to exist. Interrelated choices are then assumed to be made for tours, including a primary activity (out of or in the home), the type of tour for the primary activity (the number, purposes, and sequence of activity stops), and the number and purposes of secondary

tours. Timing and mode are chosen for tours. A hierarchy of choices is again postulated, this time on the basis of priority. Choices are assumed to maximize utility at each level. A hierarchical organization of interrelated choices seems reasonable to assume, because it restricts the size of the choice sets. Still, the empirical examples indicate that, from a behavioral point of view, the choice sets may be unrealistically large. It would therefore be reasonable to make the additional assumption that people, instead of maximizing utility, use some simplifying choice heuristics. Furthermore, it is also assumed that the choices are made sequentially (not taking into account subsequent choices). A drawback is that the basis for the hierarchical organization (priority) is not defined. For instance, it may not be realistic to assume that priority does not change over time (Doherty, Axhausen, Gärling, & Miller, 2000).

A similar system of discrete/continuous-choice models is reported in Kitamura and Fujii (1998). It is labeled the Prism-Constrained Activity-Travel Simulator or PCATS because it takes as a starting point the time-geographical concept of a prism that defines the maximal range of possible travel within a certain time period (Hägerstrand, 1970). Thus, it is assumed that the choice sets are restricted, but that each choice maximizes utility. In an “open period” (no activities chosen), a two-stage choice of an activity (out-of-home vs. in-home followed by type) conditions choice of location, which, in turn, conditions choice of mode. At the lowest level activity, duration is chosen. In summary, the model system is similar to that proposed by Ben-Akiva & Bowman (1997) in that it may realistically describe activity-travel rescheduling that forms part of a routine activity-travel pattern.

ALBATROSS (Arentze and Timmermans, 2000) is a third model system. Like that proposed by Ben-Akiva & Bowman (1997), several time horizons are assumed. The detailed model concerns short-term activity-travel scheduling/rescheduling. In this respect, the model is similar to PCATS in assuming relatively fixed sets of constraints on choices. An important difference is that, using a decision-table formalism, choices are modeled as the application of rules selected from hierarchies of condition-action pairs. This is clearly in line with approaches in cognitive psychology (Payne, Bettman, and Johnson, 1993). Furthermore, although activity-trip related choices are assumed to be made sequentially in a fixed order, they are strongly interconnected by means of the condition-action rules. Thus, not only prior choices but also *subsequent* choices or *expectations* influence a particular choice. The model specifies the constraint rules and a base of preference rules. The actual preference rules that people use are determined by fitting the model to diary data on actual activity travel patterns. In this way the model is adjusted to the data.

Any process model is incomplete if it does not include statements about how travelers learn and adapt to the transportation environment. Gärling (2001) points out that the fact that people are able to solve complex scheduling problems is in large part due to their eminent ability to learn how to simplify information processing, for instance, by chunking information or retrieving ready-made action plans called scripts. A promising development in this respect is the model system proposed by Pendyala, Kitamura, Chen, & Pas (1997) focusing on behavioral adaptation. Furthermore, work is in progress (Arentze and Timmermans, 2001) to augment ALBATROSS with a model of how choice rules change as a function of the outcome of previous choices.

Summary and Conclusions

Because of individual differences in spatial abilities, differences in the content and structure of cognitive maps, different motivations or purposes for travel, and different preferences for optimizing or satisficing decision strategies, human travel behavior is difficult to understand or predict. If we add to that the unexpected barriers and obstacles to traffic flow that occur spontaneously and intermittently (e.g., from congestion, accidents, construction, or other obstacles that impede movement over a selected path or over a network), then problems of intelligently modeling travel behavior in the real world become substantial. Yet, some success has been achieved in doing this, using simplified assumptions about human behavior (e.g., assuming that, knowingly or unknowingly, travelers adopt shortest path optimizing practices). But models like this and the predictions they make can be very inadequate. The problem facing future research is that of combining travel demand (considering people's activities) with network supply (considering the tracks, corridors, or transport systems available) with an understanding of how humans decide on where they prefer (or have) to go and how they prefer (or have) to get there. A gap thus still exists between knowledge of spatial behavior and the practice of modeling travel choice with the aim of forecasting demand for travel. As argued by Simon (1990), it is unlikely that the behavioral sciences will ever be able to make exact quantitative predictions of behavior. The laws will most likely remain qualitative. However, practitioners should realize that this does not necessarily make the theories less useful. An example is the germ theory and its highly successful applications to fight infection and diseases. A challenge to practitioners is how they can use qualitative behavioral principles in transportation planning—for instance, in making quantitative predictions of travel demand.

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Selected Annotated References

Arentze, T., & Timmermans, H. P. J. (2000). *ALBATROSS: A learning based transportation oriented simulation system*. Eindhoven, The Netherlands: Technical University of Eindhoven, European Institute of Retailing and Services Studies.

Based on the findings of a workshop on changing modeling needs, the Ministry of Transportation, Public Works and Water Management commissioned EIRASS at the end of 1996 to develop a prototype of a rule-based system for predicting transportation demand. This project reflected a desire to explore the potential of a new generation of transport demand models that should circumvent some limitations of the existing models. The model should allow one to better assess the likely consequences of flexible work hours, longer opening hours of shops and similar trends. This book reports the development of this rule-based system, which was given the acronym *ALBATROSS*. Model development, data collection and performance of the model are described.

A team of researchers, all members of the Urban Planning Group of the Eindhoven University of Technology and associates of EIRASS, worked on different components of the model system.

Axhausen, K., & Gärling, T. (1992). Activity-based approaches to travel analysis: Conceptual frameworks, models, and research problems. *Transport Reviews*, 12, 323-341.

Abstract: The recent policy discussions about information technology in transport and traffic demand management have increased the interest in activity-based approaches to the analysis of travel behaviour, in particular in the modelling of household activity scheduling which is at the core of many of the required changes in travel behaviour. The paper is a state-of-the-art review of conceptualizations and models of activity scheduling with special regard to issues raised by the new policy instruments. In the course of the review, the validity of behavioral assumptions are critically examined and several needs for future research identified.

Ben-Akiva, M. E., & Bowman, J. L. (1997). Activity based disaggregate travel demand model system with daily activity schedules. *Transportation Research*.

Abstract: They present an integrated activity based discrete choice model system of an individual's daily activity and travel schedule, intended for use in forecasting urban passenger travel demand. The system is demonstrated using a 1991 Boston travel survey and level of service data.

The model system represents a person's choice of activities and associated travel as a daily activity pattern overarching a set of tours. The daily activity pattern includes (a) the primary activity of the day, with one alternative being to remain at home for all the day's activities; (b) the type of tour for the primary activity, including the number, purpose and sequence of activity stops; and (c) the number and purpose of secondary tours. Tour models include the choice of time, destination and mode of travel, and are conditioned by the choice of a daily activity pattern. The choice of daily activity pattern is influenced by the expected maximum utility derived from the available tour alternatives.

Bhat, C. R., & Koppelman, F. S. (2000). Activity-based travel demand analysis: History, results, and future directions. *Transportation Research Record*.

Abstract: Since the beginning of civilization, the viability and economic success of communities have been, to a major extent, determined by the efficiency of the transportation infrastructure. To make informed transportation infrastructure planning decisions, planners and engineers have to be able to forecast the response of transportation demand to changes in the attributes of the transportation system and changes in the attributes of the people using the transportation system. Travel demand models are used for this purpose; specifically, travel demand models are used to predict travel characteristics and usage of transport services under alternative socio-economic scenarios, and for alternative transport service and land-use configurations.

The need for realistic representations of behavior in travel demand modeling is well acknowledged in the literature. This need is particularly acute today as emphasis shifts from evaluating long-term investment-based capital improvement strategies to understanding travel behavior responses to shorter-term congestion management policies such as alternate work schedules, telecommuting, and congestion-pricing. The result has been an increasing realization in the field that the traditional statistically-oriented trip-based modeling approach to travel demand analysis needs to be replaced by a more behaviorally-oriented activity-based modeling approach.

Downs, R. M. and D. Stea (1973a). *Image and Environment: Cognitive Mapping and Spatial Behavior*. Chicago, Aldine.

A concern with the relationship between human behavior and environment has always been at least an implicit claim of social scientists and planners, in theory as well as practice. But never has this concern been manifested so vocally and forcibly as in the very recent past.

Image and Environment addresses itself to this concern by considering how people acquire, amalgamate, and remember all the bits of information necessary to form a comprehensive picture of their environment, and how they then formulate a strategy that enables them to overcome two central behavioral problems: where things are, and how to get from there from here. The book introduces and gives coherence to the many approaches to this new field of study, and provides an understanding of cognitive mapping as a crucial aspect of the more general process whereby individuals cope with information from and about their total environments.

The approach of the editors—one trained as a psychologist, the other as a geographer—is necessarily interdisciplinary. Two dozen authors from such diverse disciplines as psychology, geography, sociology, neurophysiology, anthropology, biology, and urban design and planning bring an extraordinary richness of viewpoint to this innovative book. An introduction by the editors provides the first genuine attempt to integrate a comprehensive array of papers, which deal with such topics as cognitive representations, spatial preference, developmental sequences, spatial orientation, and cognitive distance. Several of the papers are classics in the field, but three-quarters of them have never before appeared in print, and more than half were especially

commissioned for this volume. The book also includes the first exhaustive bibliography of work in the field, as well as comprehensive author and subject indexes.

Image and Environment is a major effort to set forth and illustrate a conceptual framework that will unify the contributions of such diverse research areas as cognitive and developmental psychology, human and animal learning, urban sociology, behavioral geography, psychophysics, education, and neurophysiology, as well as the spatial decision-making techniques of architects, designers, and planners. For teachers, students, researchers, and practitioners in all these fields and more, the book will serve as a benchmark of what has been achieved to date and will open up broad new vistas of thought.

Ettema, D. and H. P. J. Timmermans (1997). *Activity-Based Approaches to Travel Analysis*. New York, Elsevier.

Societal trends have made the need for better travel demand forecasts more urgent, at the same time as making people's travel and activity patterns far more complex. Traditional traffic flow models are no longer sophisticated enough to cope.

Activity analysis is seen by many as the solution. It has had a short but intense history in geography, urban planning, time use research and, more recently, transportation. Pioneering activity-based models have now been developed to the point where, some argue, it is time to abandon the traditional four-step model for transportation demand forecasting, and to adopt activity-based approaches instead. Others claim that the complexity of such approaches, and their tremendous data requirements, prevent them from having a significant impact.

This book explores these claims and the issues associated with them. An introductory section outlines the debate. The body of the work is organized in four sections: modeling developments; theories and empirical analyses; data needs and data representation; and policy analysis. The final section discusses future research directions.

The work presented here will be of value to researchers, lecturers and students of transportation, geography, and urban planning; legislative and public policy analysts; and transport planners and consultants.

Gärling, T., Kalén, T., Romanus, J., Selart, M., & Vilhelmson, B. (1998). Computer simulation of a theory of household activity scheduling. *Environment and Planning A*, 30, 665-679.

Abstract: An operational model of household activity scheduling is proposed. The model is based on a theory entailing behavioral principles of how persons acquire, represent, and use information from and about the environment. Choices of destinations and departure times are consequences of the scheduling of a set of activities to be executed in a given time cycle. Illustrative computer simulations of the operational model show realistic effects of work hours, central/decentral living, and travel speed. Several needed improvements of the theory and operational model are discussed, such as incorporating learning effects and choice of travel mode

for home-based trip chains. Strategies outlined for empirical tests include comparisons with existing models, psychological experiments illuminating basic assumptions, and using geographical information systems to process travel diary data for single cases.

Gärling, T., Laitila, T., & Westin, K. (1998). *Theoretical Foundations of Travel Choice Modeling*. Oxford: Pergamon.

This volume fulfils a long-felt need for a single text which documents the theoretical foundations of travel choice modeling. With contributions from a good cross-section of the leading researchers in the field, the work provides a valuable reference which will be of lasting interest and value.

Divided into three parts, Microeconomic Theory, Behavioral Decision Theory, and Statistical Theory, the book extends approaches to travel choice modeling beyond the consumer theory developed in economics by applying theories from the fields of geography, psychology, and statistics and in doing so addresses two fundamental questions: What are the theoretical foundations of travel choice modeling and what should they be?

Containing twenty specially commissioned chapters, this book represents the latest and best thinking in this rapidly expanding field. Activity-based and dynamic approaches are fast emerging as the state of the art in transport modeling and are replacing trip-based models. This book tackles the key theoretical foundation that underpin these new approaches by asking:

- Are there developments in traditional microeconomic theory which make it useable?
- Is behavioral decision theory a more appropriate theoretical foundation?
- Which are the statistical data analytical issues in each case and how can they be solved?

Golledge, R. G., Kwan, M.-P., & Gärling, T. (1994). Computational-process modelling of household travel decisions using a geographical information system. *Papers in Regional Science*, 73, 99-117.

Abstract: Household travel behavior entails interdependent deliberate decisions, as well as the execution of routines not preceded by deliberate decisions. Furthermore, travel decisions are dependent on choices to participate in activities. Because of the complexity of the decision making process in which individuals are engaged, computational process models (CPMs) are promising means of implementing behavioral principles, which, unlike other disaggregate modeling approaches do not rely on a utility maximizing framework. A conceptual framework is proposed as the basis of a CPM interfaced with the geographical information system *Arc/Info*. How to model households' travel behavior is illustrated in a case study of a single household in which one member started telecommuting.

Golledge, R. G., & Stimson, R. J. (1997). *Spatial Behavior: A Geographic Perspective*. New York: Guilford Press.

How do human beings negotiate the spaces in which they live, work, and play? How are firms and institutions, and their spatial behaviors, being affected by processes of economic and societal change? What decisions are made about the natural and built environment, and how are these decisions acted out? Updating and expanding concepts of decision making and choice behavior on different geographic scales, this major revision of the authors' acclaimed *Analytical Behavioral Geography* presents theoretical foundations, extensive case studies, and empirical evidence of human behavior in a comprehensive range of physical, social, and economic settings. Generously illustrated with maps, diagrams, and tables, the volume also covers issues of gender, discusses traditionally excluded groups such as the physically and mentally challenged, and addresses the pressing needs of our growing elderly population.

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

Abstract: Recent questioning of assumptions underlying current theory and practice in studies of urban travel behavior is continued. The focus here is on the assumption that the individual's day-to-day travel is habitual and that therefore a one-day record of behavior constitutes a sufficient data base for theory and for model building. A rationale for examining the day-to-day variation in an individual's travel is established; then some of the field procedures that can contribute to making longitudinal data suitable for studying this issue are discussed, by using the Uppsala Household Travel Survey data as an example, the efficacy of these procedures is tested. Next several techniques are described for measuring travel patterns so that day-to-day variability can be detected, and an approach to the measurement problem is outlined with illustrative examples from the Uppsala data, which consist of travel diaries collected over 35 consecutive days. The results of the empirical analysis are preliminary, but they indicate that (a) the quality of longitudinal travel-diary data need not deteriorate over the survey period. (b) both employed men and nonworking women exhibit a great deal of repetition in their daily travel-activity patterns, so that (c) days with similar travel patterns can be identified and grouped.

Kitamura, R. (1988). An evaluation of activity-based travel analysis. *Transportation*, 15, 9-34.

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

Kitchin, R. M. (1994). "Cognitive maps: What are they and why study them?" *Journal of Environmental Psychology* 14(1): 1-19.

Abstract: It is often implicitly assumed by researchers that their readers understand what cognitive map and cognitive mapping are, and their justification for study. This paper differs in this respect by explaining explicitly the 'what' and 'why' questions often asked, demonstrating cognitive mappings multidisciplinary research worth. First, it examines questions concerning what cognitive maps are, the confusion inherent from the use of the term 'map', and the usage and reasons for alternative expressions. Second, it examines the theoretical applications or conceptual research, concerning cognitive maps role in the influencing and explaining spatial behaviour; spatial choice and decision making; wayfinding and orientation; and the cognitive maps utility and role as a mnemonic and metaphorical devise; a shaper of world and local attitudes and perspectives; and for creating and coping with imaginary worlds. Third, it discusses cognitive mappings practical and applied worth, concerning the planning of suitable living environments; advertising; crime solving; search and rescue, geographical educational issues, cartography and remote sensing-, and in the designing and understanding computer interfaces and databases, especially Geographical Information Systems (GISs).

Kuipers, B. J. (1978). "Modelling spatial knowledge." *Cognitive Science* 2: 129-153.

Abstract: A person's cognitive map, or knowledge of large-scale space, is built up from observations gathered as he travels through the environment. It acts as a problem solver to find routes and relative positions, as well as describing the current location. The TOUR model captures the multiple representations that make up the cognitive map, the problem-solving strategies it uses, and the mechanisms for assimilating new information. The representations have rich collections of states of partial knowledge, which support many of the performance characteristics of common-sense knowledge.

Kwan, M.-P., Golledge, R. G., & Speigle, J. (1998). Information representation for driver decision support systems. In T. Gärling, T. Laitila, & K. Westin (Eds.), *Theoretical Foundations of Travel Choice Modeling* (pp. 281-303). Oxford: Pergamon.

Abstract: Intelligent Transportation Systems (ITS) utilize advanced communication and transportation technologies to achieve traffic efficiency and safety. There are different components of ITS, including Advanced Traveler Information Systems (ATIS), Automated Highway Systems (AHS), Advanced Traffic Management Systems (ATMS), Advanced Vehicle Control Systems (AVCS), and Advanced Public Transportation Systems (APTS). Development of a system for ITS depends on our ability to deal with a vast amount of information about the locations of places as well as with the complex representation of the transportation network linking those places, and to incorporate these into a geographic database. The system therefore needs to be constructed based upon the foundation of an integrated and comprehensive Geographic Information System (GIS). As compared to the simplified node-link graph theory

representations of transport networks used by current ITS, GIS are able to provide more realistic representations of elements of the complex environment.

Transportation science has an expressed goal of increasing accessibility for all groups of people with regard to the environments in which they live and interact. A significant component of these goals is to further develop Intelligent Transportation Systems (ITS) through multi-level and multi-modal research and testing. This includes contributing to research and transportation system architecture, technology development, policy formation, and operational tests of various systems including ATMS, ATIS, and APTS. In this paper we focus on ATIS.

McFadden, D. (2001). Disaggregate behavioral travel demand's RUM side: A 30-year retrospective. In D. A. Hensher (Eds.), *The Leading Edge in Travel Behavior Research*. Amsterdam: Elsevier.

Abstract: This resource paper is intended to give a historical account of the development of the methodology of disaggregate behavioral travel demand analysis and its connection to random utility maximization (RUM). It reviews the early development of the subject, and major methodological innovations over the past three decades in choice theory, data collection, and statistical tools. It concludes by identifying some topics and issues that deserve more work, and fearlessly forecasting the future course of research in the field.

Pas, E. I. and F. Koppelman (1986). "An examination of day-to-day variability in individuals' urban travel behavior." *Transportation* 14: 13-20.

Abstract: Day-to-day variability in individuals' travel behavior (intrapersonal variability) that been recognized in conceptual discussions, yet the analysis and modeling of urban travel are typically based on a single day record of each individual's travel. This paper develops and examines hypotheses regarding the determinants of intrapersonal variability in urban travel behavior.

Two general hypotheses are formulated to describe the effects of motivations for travel and related behavior and of travel and related constraints on intrapersonal variability in weekday urban travel behavior. Specific hypotheses concerning the effect of various sociodemographic characteristics on intrapersonal variability are derived from these general hypotheses. These specific hypotheses are tested empirically in the context of daily trip frequency using a five-day record of travel in Reading, England.

The empirical results support the two general hypotheses. First, individuals who have fewer economic and role-related constraints have higher levels of intrapersonal variability in their daily trip frequency. Second, individuals who fulfill personal and household needs that do not require daily participation in out-of-home activities have higher levels of intrapersonal variability in their daily trip frequency.

Pendyala, R. M., Kitamura, R., & Reddy, D. V. G. P. (1998). Application of an activity-based travel demand model incorporating a rule-based algorithm. *Environment and Planning B*, 25, 753 – 772.

Abstract: In this paper an activity-based travel demand model called AMOS is described. The model system is capable of simulating changes in individual activity and travel behavior that may be brought about by a change in the transportation system. These simulations may then be used to predict the impacts of various transportation policies on regionwide travel characteristics. A rule-based activity-scheduling algorithm is at the heart of AMOS. The algorithm simulates changes in activity and travel patterns while recognizing the presence of constraints under which travelers make decisions. Operationally, the algorithm reads the baseline activity and travel pattern of an individual and then determines the most probable adjustments that the individual may make in response to a transportation policy. In this paper, the scheduling algorithm is described in detail and sample results from a case study in the Washington, DC metropolitan area are provided.

Stopher, P. R., & Lee-Gosselin, M. (Eds.) (1997). *Understanding Travel Behaviour in an Era of Change*. New York: Elsevier Science Ltd.

Travel behavior research has a pivotal role to play in informing the current worldwide debate over the degree to which the growth in personal travel, notably by private motor vehicle, should be encouraged or controlled. At stake are complex public interests concerning air quality, energy, lifestyle, economic development, and the built environment.

This international collection of papers on current methodological and substantive findings from the analysis of personal travel is written by leading travel behavior researchers from the social and engineering sciences. It is organized in four sections: traveler activity and perception; Stated Preference methods; dynamic behavior; and improvement of behavioral travel models.

The work presented here will be of value to researchers, lecturers, and students of transport planning and engineering; legislative and public policy analysts; transport planners and consultants; and public interest groups.