UC Berkeley
Earlier Faculty Research

Title

Computational-Process Modelling of Travel Decisions: Review and Conceptual Analysis

Permalink
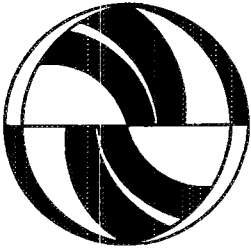
https://escholarship.org/uc/item/6mk0h2s2

Authors

Garling, Tommy
Kwan, Mei-Po
Golledge, Reginald G.

Publication Date

1991-09-01

Computational-Process Modelling
of Travel Decisions:
Review and Conceptual Analysis

Tommy Gärling
Mei-Po Kwan
Reginald G. Golledge

The University of California Transportation Center

The University of California Transportation Center (UCTC) is one of ten regional units mandated by Congress and established in Fall 1988 to support research, education, and training in surface transportation. The UC Center serves federal Region IX and is supported by matching grants from the U.S. Department of Transportation, the California Department of Transportation (Caltrans), and the University.

Based on the Berkeley Campus, UCTC draws upon existing capabilities and resources of the Institutes of Transportation Studies at Berkeley, Davis, Irvine, and Los Angeles; the Institute of Urban and Regional Development at Berkeley; and several academic departments at the Berkeley, Davis, Irvine, and Los Angeles campuses. Faculty and students on other University of California campuses may participate in

Center activities. Researchers at other universities within the region also have opportunities to collaborate with UC faculty on selected studies.

UCTC's educational and research programs are focused on strategic planning for improving metropolitan accessibility, with emphasis on the special conditions in Region IX. Particular attention is directed to strategies for using transportation as an instrument of economic development, while also accommodating to the region's persistent expansion and while maintaining and enhancing the quality of life there.

The Center distributes reports on its research in working papers, monographs, and in reprints of published articles. It also publishes *Access,* a magazine presenting summaries of selected studies. For a list of publications in print, write to the address below.

University of California
Transportation Center

108 Naval Architecture Building
Berkeley, California 94720
Tel: 510/643-7378
FAX: 510/643-5456

Computational-Process Modelling of Travel Decisions: Review and Conceptual Analysis

Tommy Gärling

Transportation Research Unit
University of Umeå
Sweden

Mei-Po Kwan
Reginald G. Golledge

Department of Geography
University of California at Santa Barbara
Santa Barbara, CA 93106

UCTC No. 209

The University of California Transportation Center
University of California at Berkeley

.Abstract

Travel behavior entails several interrelated decisions made by people, as well as the execution of routines not preceded by deliberate decisions. Furthermore, travel decisions are dependent on choices to participate in activities. After a brief review of research aiming at describing activity/travel patterns and approaches in which activity/travel decisions are modelled by means of discrete-choice modelling techniques, a conceptual framework is proposed as a background to an evaluation of several computational-process models. Further needed developments of these models are discussed, as well as the use of geographical information systems in their operationalization and application to traffic planning.

Introduction

Travel behavior entails several interrelated decisions made by people, as well as the execution of routines not preceded by deliberate decisions (Burnett & Hanson 1982). Destination choice is one of those decisions which is particularly important in a geographical context because of its consequences for the spatial characteristics of travel patterns. However, various modelling procedures developed in geography based on gravity and entropy formulations are inadequate. Disaggregate discrete-choice modelling does a better job (Timmermans & Golledge 1990). Still, as frequently applied in the past, this approach has shortcomings due to its narrow focus on the modelling of single travel decisions as a function of properties of the decision alternatives (Pas 1990). In particular, it fails to take into account that many decisions are dependent on other decisions.

It has become increasingly evident that travel decisions are not only interdependent but also dependent on choices to participate in activities (Jones, Koppelman & Orfeuil, 1990). Thus, an activity analysis may often be essential for the modelling of travel decisions. Such an analysis is however difficult to perform with available mathematical-statistical techniques used for discrete-choice modelling (Axhausen & Gärling 1991; Kitamura 1988). In the present paper we will review a few of the more promising attempts, followed by a discussion of an alternative approach using computational-process models.

In addition to the modelling difficulties entailed by an activity-based approach, the possibility of applying it has sometimes been questioned (Kitamura 1988). In a final section we will discuss how geographical information systems (GIS) may be instrumental both in operationalizing computational-process models and in their application.

Description of Activity/Travel Patterns

A large amount of research on travel behavior has never been concerned with individuals' actual decision making but has focused on the description of activities, travel, and their interrelationships. Even though this approach apparently makes it difficult to draw conclusions about the decision-making process, it has provided indirectly relevant information about factors affecting activity/travel patterns. It has furthermore contributed to the development of methods for classifying such patterns which may be useful when calibrating models of decision making. We will therefore give a brief review as a background.

In the descriptive approach a salient issue is to what extent activity/travel patterns are invariant. Empirical results are rather discouraging. For a long time one-day diary data was the only source of information about activity/travel patterns. These patterns differ considerably between households with different sociodemographic characteristics. At the same time there are some successful early attempts at identifying relatively homogenous types (e.g. Jones et al., 1983).

During the '80s longitudinal data sets have more frequently been collected and analyzed. This has made possible to assess the degree of invariance of activity/travel patterns from day to day. Somewhat surprisingly, not even across weekdays do daily activity/travel patterns appear to be particularly stable (Hanson and Huff 1986 Kitamura, 1990). Researchers therefore face the problem not only of identifying households types but also of identifying a typical activity/travel pattern for each household. Several attempts have been made. For instance,

Hanson and Huff (1986) constructed a measure of similarity between activity/travel patterns based on some of their salient attributes. On the basis of this measure "typical daily patterns" were defined, often more than one for each household. This result may seem inconsistent with other findings indicating that many activities are repetitive. However, if different activities are repeated according to differing cycle lengths, then daily activity/travel patterns may not be stable.

Pas (1988) analyzed weekly activity/travel patterns. Going beyond the descriptive information, these patterns may be viewed as the outcome of a two-stage selection process. A weekly activity/travel pattern is first "selected," then a daily pattern. The former differs depending on households' sociodemographic characteristics. However, the daily patterns are much more influenced by situation factors such as weather conditions, breakdown of the car, etc. Thus, by focusing on patterns over longer time intervals it may still be possible to identify household types. This clearly speaks to the value of collecting longitudinal data, extending the traditional one-day activity/travel diaries to several days.

Analysis of Activity/Travel Decisions: Discrete Choice Modelling

Awareness of the limitation of discrete-choice models, noted in the introduction, to focus on single travel decisions has led many to use tools suitable to model several interrelated decisions, such as, for instance, the nested logit (McFadden 1979), or structural-equation modeling techniques (Golob & Meurs, 1988). However, Timmermans (1991) recently questioned whether these tools are adequate. Nevertheless, there are several attempts at

calibrating discrete-choice models in which activities are important components (see Axhausen & Gärling 1991; Thill & Thomas 1987, for a more extensive review). Despite uncertainty about its appropriateness as a description of how people actually make decisions (Edwards 1954; Kahneman & Tversky 1979; Simon 1990), these attempts invariably draw on a utility-maximization framework.

Approaches which more explicitly aim at modeling decisions utilize the same kind of activity/travel diary data as were referred to in the preceding section. Most data sets which have been used for calibrating models are furthermore of the one-day type. A few studies have used the superior technique of directly collecting data on how people make decisions (e.g. Levin et al. 1983; Louviere, 1988).

One application of discrete-choice modelling has been to the modelling of choices among alternative activity/travel patterns. For instance, as part of a computational-process model to be described below, Recker et al. (1986a, 1986b) calibrated a discrete-choice model of activity-schedule choice. A similar model was calibrated by Adler and Ben-Akiva (1979) who found a preference for home-based single-purpose journeys to destinations close to home.

Choice of activity participation (and/or duration) has also been modelled. Taking as their point of departure that choices to participate in activities during a specified time period are made sequentially, Kitamura and Kermanshah (1983) calibrated a model in which choice of activity type depended on sociodemographic household characteristics, number of cars available, time of day, and the degree to which the activity had been performed in the past. A

similar approach was taken by, among others, Damm and Lerman(1981) and Kitamura (1984a).

Another focus of discrete-choice modelling has been how travel decisions are related to activity choice (or travel purpose). For instance, Kitamura (1984b) modelled the dependency of destination choices on activity choice. Hirsh et al. (1986) developed a nested-logit model of timing of shopping and choice of shopping destinations.

Analysis of Activity/Travel Decisions: Computational-Process Modelling

An approach which has been used in forecasting travel demand is the building of a system of disaggregate discrete-choice models, for instance of choice of destination, transportation mode, and travel frequency (Bradley et al. 1991; Kitamura and Goulias 1989). In order to make actual forecasts, microsimulation techniques are used. Obviously, this approach is no better than the discrete-choice models it is based on. Furthermore, the assumption of a linear sequence of decisions may not be tenable. Our contention is therefore that such a microsimulation approach to forecasting must rely on more adequate disaggregate models. In the present context, it seems essential that the interrelationships between different decisions are modelled at the disaggregate level.

Interrelated decisions may be modelled by discrete-choice models, although, as we have noted, there are several limitations. In attempts to replace the utility-maximizing framework with cognitive principles of information acquisition, information representation, and decision

making, computational-process models (CPMs) have been preferred. Such models offer a much greater flexibility. Furthermore, even though deterministic, interdependencies are not easily modelled by other means. CPMs are however not without problems. A most salient problem is how to calibrate such models (Smith et al. 1982). Appropriate statistical estimation techniques are yet to be defined.

After a presentation and discussion of the conceptual framework proposed in Gärling et al. (1989), several CPMs will be briefly reviewed in this section. Finally, drawing on the conceptual framework, these CPMs will be evaluated with the aim of suggesting what further developments are desirable.

Conceptual Framework

In our conceptual framework (Axhausen & Gärling 1991; Gärling et al. 1984; Gärling et al. 1989) the environment offers individuals opportunities to perform various activities, such as work, shopping, and relaxation, by means of which their needs are satisfied. The individual informs himself or herself about these opportunities, identifies spatiotemporal constraints, forms shorter-term as well as longer-term plans taking these constraints into account, executes the formed plans, and evaluates the resulting outcomes. According to this view, travel decisions constitute an integral part of the plan formation.

Figure 1 depicts an individual's cognitive processes responsible for plan formation. The individual has a memory representation of the objective environment which has been acquired by different means. Another memory representation (termed the Long-Term
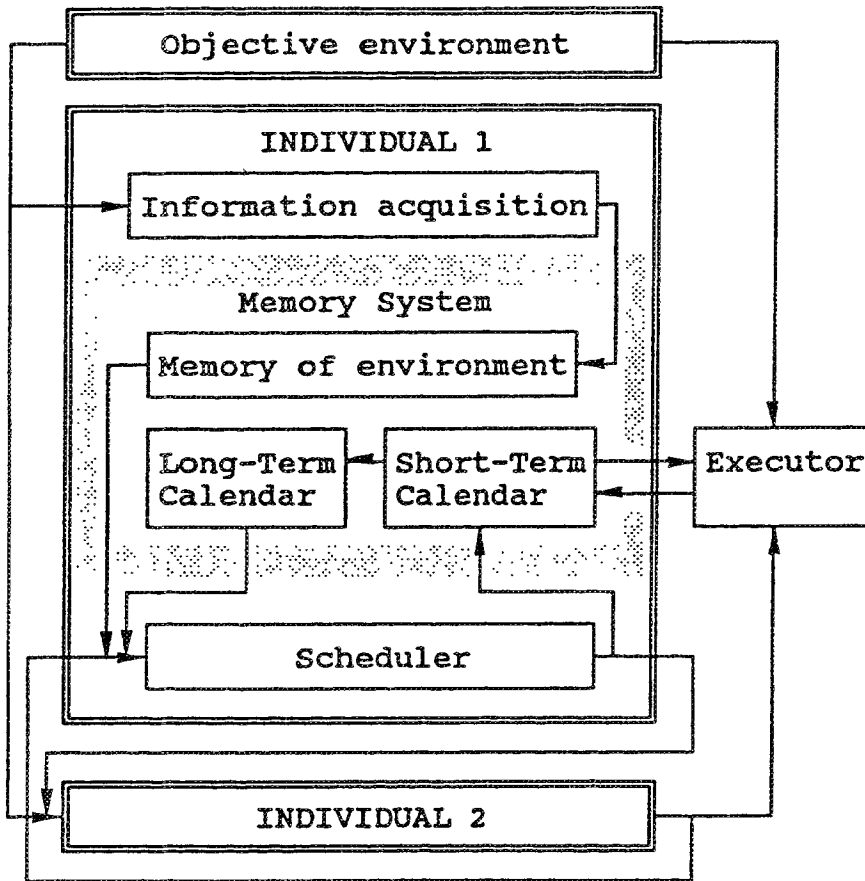
Figure 1. Conceptual framework.

Calendar) contains information about an agenda of activities with different priorities. The activities with highest priorities are planned (by the Scheduler) taking opportunities and constraints into account. The resulting plan is stored in memory (as tbe Short-Term Calendar) before being executed (by the Executor).

Figure 1 about here

The opportunities are perceived by individuals on the basis of their memory representations of the environment. For instance, only destinations which are remembered will enter into the opportunity set. Furthermore, their properties may be incomplete or distorted depending on imperfect memory. This is also true of other components of the environment, such as paths and travel modes. Identified constraints delimit the set of opportunities. Some constraints are simply distance, cost, and time per se. As suggested in Figure 1, others have to do with the frequent need to coordinate the plan with other people such as additional household members. Whatever the constraints are, it is important to note that they result from a process of identification and judgment. Thus, it is possible that some objective constraints are never identified, or that constraints are identified although they do not exist objectively.

Plan formation is highly dynamic and flexible. Some precedence is given to activities since plan formation is supposed to start with a set of prioritized activities. However, if there are no opportunities to perform the initially selected activities, the identification of other opportunities may lead to less prioritized activities being chosen. Activities with higher priority will then remain to be selected on subsequent occasions. The priorities assigned to activities also change over time, both over a day and over a longer time span.

How planning is acomplished differs depending on tactical decisions. One important such decision is the trade-off between planning in detail and starting to execute a plan. In general planning may proceed in a top-down fashion. A schematic plan entailing choice of the sequence in which to perform the set of activities in different places is first formed, then through a process of mental execution a more detailed plan is formed entailing choice of travel modes and departure times. Conflicts encountered in this detailed planning stage are solved by changing the sequence, compressing and/or deleting activities, or postponing departure times. At any point in time the individual may decide to postpone the detailed planning stage. He or she may also need to do that because information is not available. Plan execution thus starts before a complete plan is formed. As execution proceeds, the plan is made complete in subsequent stages of planning. Not only additions to but also revisions of the plan depending on changes in the environment may then be accomplished. An example would be that the activities to be performed during a day is first sequenced, then a detailed plan is made for the morning. However, because of unforeseen delays, the plan may have to be changed during its execution in the morning. This in turn may affect the agenda of activities to be performed in the afternoon, thus making necessary another sequencing of activities, and so forth.

Constraints may arise because the plan needs to be coordinated with other people's plans. This will occur for activities which can only be performed mutually, or for activities which can be performed optionally by any of the involved people. Such interdependencies arise perhaps most frequently within a household, although it is certainly not confined to household members. Even though decisions are made singly, they are influenced by other people's agendas as communicated to the individual forming his or her plan. The communication may

be untimed, incomplete, or distorted, thus giving rise to another source of suboptimality of plans. Furthermore, in general one individual is dominating the other(s), that is, is more unwilling to change his or her plan, on the basis of temporal precedence, the relative priorities of activities, or perhaps individual characteristics.

Over time planning becomes less deliberate. Although incomplete and distorted, an individual has a memory representation of his or her evaluations of the outcome of the execution of previous plans. This record has the potential of affecting subsequent planning. When repeatedly facing the same or similar situations, some decisions entailed by planning are never deliberated or, if deliberated, another decison rule entailing less information search is employed. The share number of repetitions is however only one factor causing planning to become less deliberate. Some assessment of how important the plan is for the attainment of salient, current goals is another factor. Thus, even plans executed every day may become deliberate if their execution is currently important for the attainment of salient goals.

Computational-Process Models

Several attempts have been made to implement a conceptualization of travel decisions in a computer program aiming at emulating how people make such decisions. However, in varying degrees all of them are incomplete, limiting themselves as they do to isolated aspects. Probably the first attempt was launched by Kuipers (1978) in his TOUR model. TOUR models an individual's memory representation of the environment, or cognitive map, its acquisition, and its use in wayfinding. Although successful in many respects, TOUR is not based on the rather extensive empirical research on people's cognitive maps, spatial

orientation, and wayfinding (as reviewed in, for instance, Gärling et al. 1984; Gärling & Golledge 1989). A more recent similar model called the NAVIGATOR (Gopal et al. 1989; Gopal & Smith 1990) is based on empirical results reported in Golledge et al. (1985). Of particular interest here is that route planning is modelled by means of various choice heuristics. If information to base route choices is lacking, "moving in the same general heading" or "make a random turn at an intersection" are examples of decision rules implemented in the model.

Route planning in a static environment is also modelled by TRAVELLER (Leiser & Zilberschatz 1988), and, in a dynamic environment, by ELMER (McCalla et al. 1982). TRAVELLER makes the assumption that the relative locations of origin and destination are known. An unknown route from origin to destination is then constructed through a process of search starting both from the origin and the destination. In ELMER routes are, in contrast, conceived of as sequences of instructions for how to travel. When navigating an environment, routes are retrieved when a need arises. Thus planning is interwoven with execution of the plan.

None of the models reviewed so far include the interrelationship between different travel decisions and between travel decisions and activity choices. A few other CPMs attempt to do that, such as CARLA (Jones et al. 1983) and STARCHILD (Recker et al. 1986a, 1986b). Still another similar model is reported in Lundberg (1988). The least elaborated model is CARLA which does no more than identify constraints. The output from CARLA consists of the feasible plans or activity schedules. STARCHILD goes a step further in modelling the choice between these schedules by means of a conventional discrete-choice model. The choice of activity schedule is based on the sum of the activities' utilities and the disutilities of waiting

and travel times. STARCHILD, and CARLA as far as it goes, are unlikely to be valid descriptions of people's actual decision making. In contrast to CARLA which employs an "objective" criterion, STARCHILD implements a psychologically more plausible noncompensatory decision rule in selecting the generated alternatives (e.g. Montgomery 1990; Svenson 1979; Tversky 1972). The notion that all feasible activity schedules are generated is still not realistic given the cognitive limitations people are known to have (Simon 1990). Furthermore, the particular form of utility maximization assumed in STARCHILD's choice model does not seem to have independent empirical support.

Lundberg (1988) does not state as his aim to mimic actual activity scheduling. Nevertheless, the model has several realistic features worth mentioning. Constraints are modelled as fuzzy-set representations to capture their imprecise nature. Furthermore, rather than being quantitative, the variables are linquistic. Each activity has an activation or arousal level which at a particular stage in the planning process determines whether or not it is chosen. The activation/arousal level of an activity is in turn affected by the degree to which the activity is related to goals. However, there is also, through a bottom-up process, an effect of updated information about opportunities and constraints.

The model by Lundberg (1988) has many similarities with the model of planning reported in Hayes-Roth and Hayes-Roth (1979) which is the most complete of those reviewed in modelling underlying cognitive processes. This latter model also differs from the others in being directly based on data on how people plan. A critical assumption is that people are opportunistic in their planning, rather than proceeding hierarchically from a global, schematic plan to a more refined plan. The planning process is assumed to comprise the independent action of many "cognitive specialists" who make tentative decisions to be incorporated in the

plan. The different decisions concern the plan itself, what data are useful to acquire, desirable attributes of plan decisions, and how to formulate and approach the planning problem (meta-plan decisions). An executive controls the planning process by making decisions about how to allocate cognitive resources, what types of decisions to make at certain points in time, and resolving conflicts if there are competing decisions.

The models described so far seem to do a good job in modelling different aspects of individuals' interrelated travel decisions. As illustrated in Table 1, these aspects differ between the different models. Whereas those models which target navigation and route choice also tend to model acquisition and representation of information about the environment, the other models, focusing on planning, do not seem to do that in as much detail. These models are, on the other hand, much more complete in modelling interrelated activity/travel decisions. A few models in each category appear more realistic descriptions of how people process information and make decisions, whereas the remaining models make at least some assumptions which are clearly unrealistic. There is, however, a need for more extensive, comparative empirical tests.

Table 1 about here

The overview points to the possibility of developing a model which integrates parts of other models. The model proposed by Hayes-Roth and Hayes-Roth (1979) is perhaps the most promising to use as a point of departure. It may be possible to augment this model with a model of the acquisition and representation of information about the environment as well as of how route choices are made.

Table 1. Computational-process models.

Modelling foci	Model
Information acquisition and representation	TOUR (Kuipers 1978)
	NAVIGATOR (Gopal et al. 1989; Gopal & Smith 1990)
	TRAVELLER (Leiser & Zilberschatz 1989)
	ELMER (McCalla et al. 1982)
Interrelated activity/travel decisions	CARLA (Jones et al. 1983)
	STARCHILD (Recker et al. 1986a, 1986b)
	Lundberg (1988)
	Hayes-Roth & Hayes-Roth (1979)
Navigation/ route choice	TOUR (Kuipers 1978)
	NAVIGATOR (Gopal et al. 1989; Gopal & Smith 1990)
	TRAVELLER (Leiser & Zilberschatz 1989)
	ELMER (McCalla et al. 1982)

There are a few things which none of the present models accomplish. The models of interrelated activity/travel decisions fail to explicitly represent the fact that such decisions may in varying degree be interwoven with their execution. In this way they do not adequately take into account that individuals' time horizons may differ at different points in time (Axhausen & Gärling 1991). Furthermore, revisions of plans are not modelled.

Another shortcoming of the current models is that they fail to model changes over time as a function of repeated experience of the environment and changes in saliency of goals. Such changes may be observed both in which decisions are made and in how they are made. The representation of the decision alternatives may also change. The current models thus need to be turned into dynamic models, something which is, in fact, pleaded for within the area (Goodwin, Kitamura & Meurs 1990).

A final shortcoming is that the models reviewed only consider one decision maker. Even though most decisions are made individually, it may still be necessary to simultaneously model other decision makers to be able to validly represent constraints. Furthermore, an important future task should be to model how social interaction with others affects the information acquired about opportunities and constraints.

Computational-Process Modelling of Activity/Travel Decisions and Geographical Information Systems

Geographical information systems (GIS) have many uses in a transportation context, for instance vehicle routing and scheduling. A salient problem is to determine the relationship between these uses and traditional network analysis with aggregated data. However, most GIS are developed not only for aggregated data sets, but also for the scale of operations involving complete networks. Activity-based discrete-choice or computational-process modelling requires the possibility to work with such disaggregated data, in small traffic zones or unique origin/destination locations. Otherwise it would not be feasible to examine in real time the impact of changing household decisions on the patterns of flow and the selection of route segments in specific networks. Thus, the evaluation and application of these models would be seriously impaired.

GIS can provide a host for a comprehensive database and analytical procedures to operationalize our conceptual framework presented in the preceding section. An approximation of the street network on which individuals travel may be provided, in US cities through available TIGER files. The same is true of origins/destinations when exact addresses are available. Other information is also accessible, such as landuse and sociodemographic characteristics which may be superimposed on the network. Business hours, attributes of origins/destinations, and availability and speed of different transport modes are still other information which can be stored with network information. By providing a factual physical environmemt in which to simulate this information, there are in the present context two potential uses. One is to provide a realistic initial input to a model concentrating on household travel decisions. The other use is to emulate the actual trips resulting from these

decisions, primarily with the purpose of modelling how decision may be revised during the course of a specified time cycle (planning horizon). If data are also collected on how households travel, then calibrating the model will be feasible.

Still another use of GIS is in the modelling of the decisions.-Transformations of the objective information may first be accomplished according to principles for how people distort such information in perception and memory. Secondly, a GIS data model could be selected to represent the process by which plans are formed. Several possibilities exist.

Finally, to be useful some possibility of aggregating data is needed. Again, GIS offer this. Therefore, GIS are not only instrumental for the development of realistic models but also render such models directly relevant for traffic planning.

Apparently, on all these points further research is needed aimed at developing GIS. Empirical tests of the feasibility of overlaying an activity-scheduling module on a GIS of a particular environment is a primary task. Work on this is in progress and will be reported in a later companion paper (Golledge, Kwan, & Gärling, in preparation).

References

Adler, T. J. & Ben-Akiva, M. E., (1979), A theoretical and empirical model of trip chaining behavior, *Transportation Research B, 13,* 243-257.

Axhausen, K. & Gärling, T., (1991), *Activity-based approches to travel analysis: Conceptual frameworks, models, and research problems,* Manuscript submitted for publication.

Bradley, M., et al., 1991, Paper presented at the 6th international conference on travel behavior organized by the International Association for Travel Behavior, Quebec City, Canada, May 22-24 1991

Burnett, K. P. & Hanson, S., (1982), Rationale for an alternative mathematical approach to movement as complex human behavior, *Transportation Research Record, 723,* 11-24.

Damm, D. & Lerman, S. R., (1981), A theory of activity scheduling behavior, *Environment and Planning A, 13,* 703-718.

Edwards, W., (1954), The theory of decision making, *Psychological Bulletin, 51,* 380-417.

Gärling, T., Böök, A., & Lindberg, E., (1984), Cognitive mapping of large-scale environments: The interrelationship of action plans, acquisition, and orientation, *Environment and Behavior, 16,* 3-34.

Gärling, Brännäs, K., Garvill, J., Golledge, R. G., Gopal, S., Holm, E. & Lindberg, E., (1989), Household activity scheduling, pp. 235-248 in *Transport policy, management & technology towards 2001: Selected proceedings of the fifth world conference on transport research,* Vol. IV, Western Periodicals, Ventura, CA.

Gärling, T., & Golledge, R. G., (1989), Environmental perception and cognition, pp. 203-236 in *Advances in environment, behavior, and design,* Vol. 2, (edited by E. H. Zube & G. T. Moore), Plenum Press, New York.

Golledge, R. G., Kwan, M.-P. & Gärling, T., (in preparation), Computational-process modelling of travel decisions: Empirical tests. Paper to be presented in R. G. Golledge (Chair), *Activity-based models of household travel bevavior,* Symposium accepted at the meeting of the North-American Regional Science Association, New Orleans, November 8-10, 1991

Golledge, R. G., Smith, T. R., Pellegrino, J. W., Doherty, S. & Marshall, S. P., (1985), A conceptual model and empirical analysis of children's acquisition of spatial knowledge, *Journal of Environmental Psychology, 5,* 125-152.

Golob, T. F. & Meurs, H., (1988), Development of structural equations models of the dynamics of passenger travel demand, *Environment and Planning A, 20,* 1197-1218.

Goodwin, P., Kitamura, R. & Meurs, H., (1990), Some principles of dynamic analysis of travel behaviour, pp. 56-72 in *Developments in dynamic and activity-based approaches to travel analysis* (edited by P. Jones), Gower, Aldershot.

Gopal, S. & Smith, T. R., (1990), Human wayfinding in an urban environment: Performance analysis using a computational process approach, *Environment and Planning A, 22,* 169-191.

Gopal, S., Klatzky, R. & Smith, T. R. (1989), *Journal of Environmental Psychology, 9,* 309-322.

Hanson, S. & Huff, J., (1986), Classification issues in the analysis of complex travel behavior, *Transportation, 13,* 271-293.

Hayes-Roth, B., & Hayes-Roth, F. (1979). A cognitive model of planning, *Cognitive Science, 3,* 275-310.

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

Jones, P., Dix, M. C., Clarke, M. I. & Heggie, I. G., (1983), *Understanding travel behavior,* Gower, Aldershot.

Jones, P., Koppelman, F. & Orfeuil, J.-P., (1990), Activity analysis: State-of-the-art and future directions, pp. 34-55 in *Developments in dynamic and activity-based approaches to travel analysis* (edited by P. Jones), Gower, Aldershot.

Kahneman, D. & Tversky, A., (1979), Prospect theory, *Econometrika, 47,* 263-291.

Kitamura, R., (1984a), A model of daily time allocation to discretionary out-of-home activities and trips, *Transportation Research B, 18*, 255-266.

Kitamura, R., (1984b), Incorporating trip chaining into analysis of destination choice, *Transportation Research B, 18*, 67-81.

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

Kitamura, R. & Goulias, (1989), *MIDAS: A travel demand forecasting tool based on dynamic model system of household car ownership and mobility*, Unpublished manuscript.

Kitamura, R. & Kermanshah, M., (1983), Identifying time and history dependencies of activi choice, *Transportation Research Record, 944*, 22-29.

Kitamura, R., Nilles, J.M., Conroy, P. and Fleming, D.M., (1991), Telecommuting as a transportation planning measure: Initial results of the State of California Pilot Project, *Transportation Research Record* (in press).

Kuipers, B. (1978). Modeling spatial knowledge, *Cognitive Science, 2*, 129-153

Leiser, D. and Zilberschatz, A., (1989), The TRAVELLER: A computational model of spatial network learning, *Environment and Behavior, 21*, 435-463.

Levin, I. P., Louviere, J. J. and Schepanski, A. A., (1983), Validation test and applications of laboratory studies of information integration, *Organizational Behavior and Human Performance, 31*, 173-193.

Louviere, J. J., (1988), Conjoint analysis modelling of stated preferences, *Journal of Transport Economics and Policy, 22*, 93-119.

Lundberg, C. G., (1988), On the structuration of multiactivity task-environments, *Environment and Planning A, 20*, 1603-1621.

McCalla, G. I., Reid, L. & Schneider, P. K., (1982), Plan creation, plan execution and knowledge execution in a dynamic micro-world, *International Journal of Man-Machine Studies, 16*, 89-112.

McFadden, D., (1979), Quantitative models for analysing travel behavior of individuals, pp. XXX-XXX in *Behavioral travel demand modelling* (edited by D. Hensher & P. R. Stopher), Croom Helm, London.

Montgomery, H., (1990), From cognition to action: The search for dominance in decision making, pp. 23-49 in *Process and structure in human decision making* (edited by H. Montgomery & O. Svenson), Wiley, New York.

Pas, E., (1988), Weekly travel-activity behavior, *Transportation B, 15*, 89-109.

Pas, E., (1990), Is travel demand analysis in the doldrums?, pp. 3-27 in *Developments in dynamic and activity-based approaches to travel analysis* (edited by P. Jones), Gower, Aldershot.

Recker, W. W., McNally, M. G. & Roth, G. S., (1986a), A model of complex travel behavior: Theoretical development, *Transportation Research A, 20*, 307-318.

Recker, W. W., McNally, M. G. & Roth, G. S., (1986b), A model of complex travel behavior: An operational model, *Transportation Research A, 20*, 319-330.

Simon, H. A., (1990), Invariants of human behavior, *Annual Review of Psychology, 41*, 1-19.

Smith, T. R., Pellegrino, J. W. & Golledge, R. G., (1982), Computational process modelling of spatial cognition and behavior, *Geographical Analysis, 14*, 305-325.

Svenson, O., (1979), Process descriptions of decision making, *Organizational Behavior and Human Performance, 23*, 86-112.

Thill, J.-C. & Thomas, I., (1987), Towards conceptualizing trip-chaining behavior: A review, *Geographical Analysis, 20*, 140-156.

Timmermans, H., (1991), *Retail environments and spatial shopping behavior*, Unpublished manuscript.

Timmermans, H. and Golledge, R. G., (1990), Applications of behavioural research on spatial problems II: Preference and choice, *Progress in Human Geography, 14*, 311-354.

Tversky, A., (1972), Elimination by aspects: A theory of choice, *Psychological Review, 79*, 281-299.