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Computational-Process Modelling of Household Activity Scheduling

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Computational-Process Modelling of Household Activity Scheduling

Abstract

Models of households' travel choices are an important focus of research. For some time it has been realized that such models need to incorporate how travel depends on activity choices. It is argued that production system models constitute an alternative or necessary complementary approach if the goal is to develop models of interdependent activity and travel choices, or activity scheduling, which are based on behavioral-science theories of higher cognitive processes. Several computational-process models (CPMs) which implement production systems as computer programs are reviewed. Currently, no encompassing CPM exists but some may be possible to integrate in a descriptive model of activity scheduling.

Computational-Process Modelling of Household Activity Scheduling

Introduction

Although daily travel by households is to a large extent routine (Burnett and Hanson 1982), individual household members occasionally make deliberate choices with consequences for their travel behavior. A basic question for research to address is how such choices are made.

In geography destination and route choices have been major foci of modelling because of their consequences for the spatial characteristics of travel patterns (Pipkin 1986). Some of the strong interest in the original modelling procedures based on gravity and entropy formulations has in recent years shifted to disaggregate discrete-choice modelling (Timmermans and Golledge 1990), although entropy based dynamic traffic assignment models are still being pursued (Janson and Southworth 1992). Discrete-choice modelling techniques have also been used in transport research for the modelling of choices of mode, departure times, or vehicle type (Ben-Akiva and Lerman 1985; Bunch et al. 1993). Despite some successful applications of discrete choice models, one shortcoming persists that they are limited to the modelling of how single trip choices are related to properties of the choice alternatives and characteristics of the group to which individuals making the choices belong.

It has become increasingly evident that travel choices are importantly dependent on choices to participate in activities (Jones et al. 1990). Thus, there is a mutual dependency between travel choices and a household's agenda of activities. As argued by Root and Recker (1983) in a seminal paper, choices of destinations, departure times, and frequency and duration of activity participation should therefore be treated in a single conceptual framework which entails behavioral assumptions accounting for the process of making these interdependent choices. Following Root and Recker, we term this process *activity scheduling*.

A primary aim of travel-choice modelling has been to forecast travel. In systems of disaggregate choice models which are used with this aim (e.g. Kitamura and Goulias 1989), the interdependency of travel and activity choices is not specified. An obstacle to further developments in this direction is however that activity scheduling is difficult to model with the mathematical-statistical techniques available for use in discrete-choice modelling (Axhausen and Gärling 1991; Kitamura 1988; Root and Recker 1983).

Our concern in the present paper is how activity scheduling can be modelled. In the next section we argue that computational-process modelling is a valuable alternative or complementary tool to mathematical-statistical techniques of discrete-choice modelling. Several existing computational-process models (CPMs) are then reviewed. The paper closes with a discussion of the directions future research on computational-process modelling of travel choices may take.

The Value of Computational-Process Modelling

Awareness of the limitation of discrete-choice models to focus on single trip choices has led to the development of tools suitable to model interdependent or joint choices, for instance, nested logit (Ben-Akiva and Lerman 1985; McFadden

1979) or structural equations (Golob and Meurs 1988). Following these developments, there are several attempts at estimating discrete-choice models in which activities are important components (see Axhausen and Gärling 1991; Jones et al. 1990; Kitamura 1988; Thill and Thomas 1987, for reviews). Examples include trip chaining (Damm and Lerman 1981; Kitamura et al. 1990), choice of activity participation and duration (Kitamura 1984), and choice of activity pattern (Adler and Ben-Akiva 1979; Recker et al. 1986a, 1986b). Some econometric research on time allocation (Winston 1982, 1987) may also be mentioned in this connection. Furthermore, related research has been carried out with the aim of describing activity patterns taking into account spatial, temporal, and interpersonal constraints (Hanson and Huff 1986, 1988; Pas 1988; Pas and Koppelman 1987).

Travel-choice modelling with the logit model seems invariably to rest on the utility-maximization framework of microeconomic theory (Ben-Akiva and Lerman 1985). Although its validity as a description of how people actually make decisions is constantly being questioned by behavioral scientists (e.g. Edwards 1954; Kahneman and Tversky 1979; Simon 1955, 1990; Tversky and Kahneman 1991, 1993) and occasionally by transport researchers (e.g. Supernak 1992), relying on a utility-maximization framework appears to be less serious than the fact that the approach fails to elucidate in much detail *how* utility maximization is accomplished. Thus models tend to be confined to specifying what factors affect the final choice, whereas the process resulting in this choice is largely left unspecified. It may be argued that nothing more needs to be known if the purpose is the practical one of forecasting choices. However, if a longer-term goal is to develop theory like in any other area of research (Pas 1990), further specification of the choice process is one direction which the research needs to take. In basic research on decision making (see, e.g., Abelson and Levy 1985, or Payne, et al. 1992, for recent reviews), process descriptions have been a focus of interest for a long time (Einhorn et al. 1979; Montgomery 1990; Svenson 1979).

As a description of an activity-scheduling process consisting of interdependent choices where each involve acquisition and storage of information, memory retrieval, accuracy-effort tradeoffs, and conflict resolution (Gärling et al. 1989; Hayes-Roth and Hayes-Roth 1979), a production system model is an alternative, or necessary complement, to a discrete-choice model. Originally developed by Newell and Simon (1972) for modelling how people think when they solve problems, production systems have been widely used in theories of higher cognitive processes (e.g. Anderson 1983, 1990; Newell 1992). A production system is a set of rules in the form of condition-action pairs which specify how a task is solved. For instance, if the task is to choose one alternative in a choice set, production system rules may specify what information is searched under different conditions, how the information is evaluated, and how the evaluations or judgments are integrated. A production system is also conceived of as being realized in a cognitive architecture featuring a perceptual parser, a limited-capacity working memory, a permanent long-term memory, and an effector system. Recent examples of production system models of decision making include Engemann et al. (1988), Huber (1990), Payne et al. (1988), and Smith et al. (1982).

An operational CPM is a production system model implemented as a computer program. As pointed out by Engeman et al. (1988), the virtue of such an operationalization is that it is instrumental in the development of theory (1) by contributing to its rigorous specification, (2) by offering the possibility to assess its sufficiency, (3) by facilitating the derivation of testable hypotheses, and (4) by making it possible to compare consequences of alternative assumptions (e.g. sensitivity analysis). If a *validated* theory is simulated, a CPM also offers a testbed for assessing the consequences of different policy measures.

A CPM is capable of providing, without loss of rigor, a more detailed description of the individual choice processes than can discrete-choice models. A drawback is that typical travel-diary data may not be sufficient for such modelling, for it records only the spatio-temporal actions or behaviors and rarely considers the cognitive processes underlying decision making and choice behavior. In part this difficulty is shared with discrete-choice modelling where the need for stated-preference experiments that complement traditional data collection is now recognized (Bunch et al. 1993; Louviere, 1988;). An illustration of how travel-diary data can be used to test the validity of a CPM is given in Golledge et al. (1993). Nevertheless, new techniques of data collection which trace the *cognitive* processes preceding overt choices need to be developed (Axhausen 1993; Ettema and Timmermans 1993; Jones 1985), something which has already occurred in areas where CPMs are being used (Ericson and Simon 1984; Ericson and Oliver 1988; Svenson 1979).

Even though a CPM provides a detailed description of individual choice processes, the aim is nevertheless to reveal principles which apply generally. Still, the difficulty of aggregating detailed descriptions of individual choice processes may appear to be a remaining serious drawback (Smith et al. 1982), in particular if the aim is to use a CPM for forecasting consequences of policy measures. Microsimulation is now being used for forecasting from systems of disaggregate discrete-choice models (e.g., Kitamura and Goulias 1989), and it may be possible to use this technique with CPMs. Another possibility is to treat CPMs and discrete-choice models as complementary (Ettema et al. 1993): A CPM developed on the basis of stated-preference experiments may suggest variables to include in a discrete-choice model which is then estimated from travel-diary data and used in forecasting. The value of the CPM (i.e., the production system model) is to provide the theoretical basis for the discrete-choice model.

If the goal is to test theory, a disaggregate approach is in principle preferable because it is more sensitive to possible violations of assumptions. In general, a CPM should prove better than a discrete-choice model such as the logit which requires for its estimation a substantial sample of observations. It is true that appropriate statistical estimation techniques are yet to be defined. However, as demonstrated by Golledge et al. (1985, 1993) among others, in a case study approach it will nevertheless be possible to find out which assumptions are violated and the nature of such violations. Collecting data for many cases will also make possible the compilation of various summary statistics. Such an approach is consistent with the more realistic goal of research on human behavior to search for qualitative rather than quantitative laws (Simon 1990).

Existing Computational-Process Models

Review

Several attempts have been made to implement a conceptualization of travel choices in a computer program aimed at emulating how people make such choices. However, in varying degrees all of them are incomplete, limiting themselves as they do to isolated aspects. This is probably to be expected at this stage of development. Nevertheless, a virtue of production system models is their capacity to provide complete descriptions. An important goal for us is therefore to outline how a more encompassing CPM can be built on those which already exist.

Probably the first attempt at developing a CPM of travel choices was launched by Kuipers (1978) in TOUR which models an individual's memory representation of the environment, or cognitive map, its acquisition, and its use for route choices. 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 and Golledge 1989; Golledge 1987). A more recent, similar model called the NAVIGATOR (Gopal et al. 1989; Gopal and Smith 1990) is based on empirical results reported in Golledge et al. (1985). Of particular interest with NAVIGATOR is that route planning is modelled by means of various choice heuristics. If information for making a route choice is lacking, "moving in the same general heading" or "make a random turn at an intersection" are examples implemented in the model.

Route planning in a static environment is also modelled by TRAVELLER (Leiser and Zilberschatz 1989), 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 the execution of the plan.

None of the models reviewed so far include the dependencies between different travel choices and between travel and activity choices. A few other CPMs aim at doing that, such as CARLA (Jones et al. 1983) and STARCHILD (Recker et al. 1986a, 1986b). Still another similar model is reported in Lundberg (1988). Of these models, CARLA is the least elaborated in terms of behavioral assumptions. Taking as its point of departure the work by time geographers (e.g. Lenntorp 1978), CARLA identifies objective constraints. The output from CARLA consists of the feasible activity schedules or patterns. STARCHILD goes a step further by modelling the choice between such activity schedules. In the actual implementation a conventional discrete-choice model is used to this end, although other choice models would be possible to implement. 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 the process of activity scheduling since they fail to take into account people's limited capacity to consider alternatives (Newell 1992; Simon 1955, 1990). In contrast to CARLA which employs an "objective" criterion, STARCHILD implements a psychologically more plausible noncompensatory decision rule (e.g. Montgomery 1990; Svenson 1979; Tversky 1972) in selecting the generated alternative schedules. The notion that all feasible activity schedules are generated in order to select this maximum utility alternative is still unrealistic. We are attempting to overcome this problem by adding human limitations for selection of feasible opportunities in our work.

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 linguistic. 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 Hayes-Roth and Hayes-Roth's (1979) model of planning which is the most complete of those reviewed in modelling cognitive processes. This 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.

Gärling et al. (1989) outlined a conceptual framework which since then has been implemented in SCHEDULER (Golledge et al. 1993). SCHEDULER is confined to an individual's choice of activities, destinations, and departure times which form his or her agenda for a certain time period. The model works as follows (see Figure 1). Activities are available in the Long-Term Calendar (stored in long-term memory). Each activity has a priority and duration. A subset is retrieved for scheduling on the basis of priority and duration. Information about spatiotemporal constraints (feasible locations, open hours) is retrieved from a memory representation of the environment called the Cognitive Map (also stored in long-term memory). Choices of location and departure times are then made by the SCHEDULER. The resulting activity schedule is stored in the Short-Term Calendar (short-term memory) for later execution. Drawing on empirical observations indicating that people often use a nearest-neighbor heuristic in choosing sequences of locations (Gärling et al. 1986; Gärling and Gärling 1988; Hirtle and Gärling 1992), location choices are modelled accordingly. However, data are lacking on how temporal constraints are taken into account. In the SCHEDULER such constraints (open hours) are imposed before choices of location are made. If activities in the sequence of activities cannot be "mentally" executed because they overlap, the conflict is resolved by first changing the sequence of the activities in conflict and, if this does not work, by replacing the activity with lower priority. Although SCHEDULER takes into account human limitations to a greater extent than, for instance, STARCHILD, it still makes several unrealistic assumptions. For instance, that activity scheduling and execution are separated is one such unrealistic assumption. Another is that the Cognitive Map is a veridical representation of the objective environment. Furthermore, how spatial and temporal constraints are traded off is an unresolved issue which is presently being addressed in empirical research (Gärling 1993).

In a recent paper by Ettema et al. (1993), the authors report their work on SMASH which in certain respects is a development of SCHEDULER. SMASH emulates the scheduling process by computing utilities for choices to include, delete, or substitute activities. *Disutility* accrues as the number of choices increases, and the process terminates when no choice results in a positive utility. Utilities of activity choices are related to several factors including the number of prioritized activities in the schedule, travel distance or time, attractiveness of locations, time pressure, and wait time. Like in SCHEDULER the resulting schedule's realism is evaluated. The model is more complete than SCHEDULER in including factors which are known to, or could be assumed to, affect activity scheduling. In this respect it is similar to STARCHILD but differs importantly in that the schedule is successively constructed by maximizing utility in each scheduling step (inclusion, deletion, or substitution of an activity) rather than for the schedule as a whole. However, the model still appears to make unrealistic

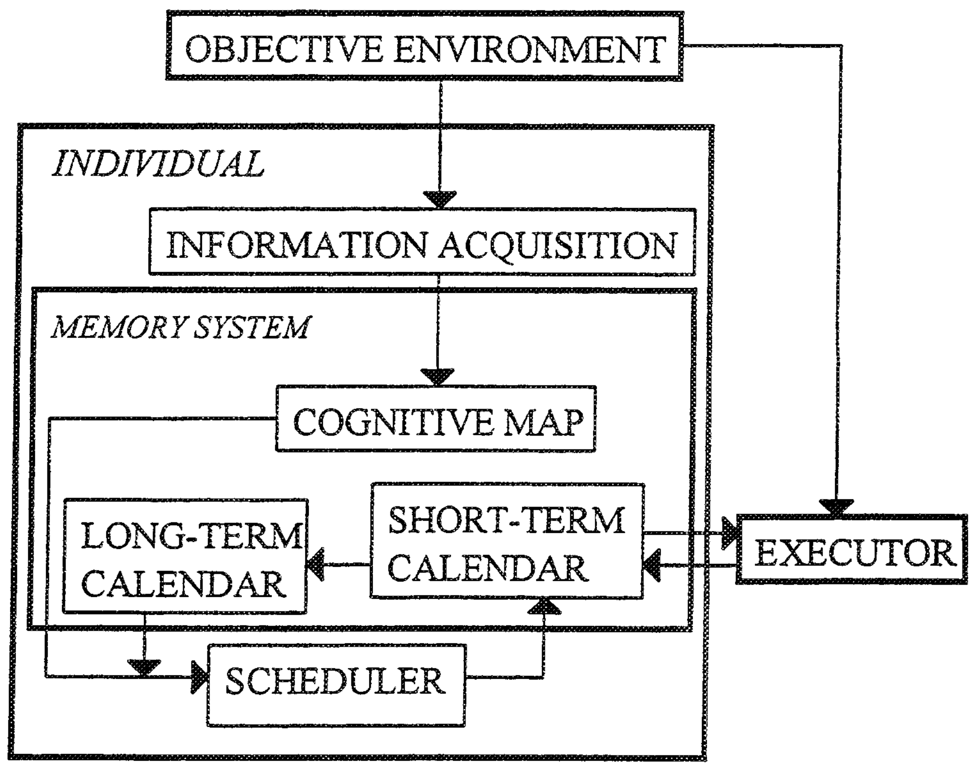

Figure 1. Flow diagram of SCHEDULER.

claims on human computational capacity since in each scheduling step all possible choices are evaluated. Furthermore, the actual computations involved are unlikely to emulate what a scheduling person does even though he or she, in some way, takes into account the factors which the model specifies. Of particular interest to note here is that Ettema et al. (1993) and Ettema and Timmermans (1993) have envisaged a way of empirically testing SMASH by means of mathematical-statistical modelling. In such empirical tests each choice of including, deleting, or substituting activities are predicted from variables describing the current state of the scheduling process (e.g. the number of activities already scheduled) and attributes of the activities to be scheduled. Of course, individual difference factors may also be included although they are at present unspecified in the model. As Ettema and Timmermans (1993) accurately point out, data on the *scheduling process*, rather than travel-diary data, are needed. Interactive experiments will provide such data.

Evaluation

The models reviewed seem to do an excellent job in modelling different aspects of travel choices. As shown in Figure 2, these aspects differ among the different models. Whereas models targeting route choice also tend to model acquisition and representation of information about the environment, the models focusing on interdependent activity/travel choices do not do that in as much detail. On the other hand, these models are more complete in modelling the dependency of travel and activity choices. Although all models either make at least some assumptions which are untested or make unrealistic claims on human capacity, as already pointed out a few models in each category appear more realistic descriptions of how people process information and make choices than others.

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 for further theoretical development. It should be possible to augment this model with assumptions about how information about the environment is acquired/represented and about how route choices are made. In this process the further *empirical* development of SMASH (Ettema et al. 1993: Ettema and Timmermans 1993) may be most useful. Further integration with more comprehensive models like STARCHILD will make it possible to predict activity patterns and choices.

There are a few, important things which the models reviewed do not accomplish. For one thing, the models of interrelated activity/travel choices fail to explicitly represent that such decisions may in varying degrees 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 and Gärling 1992; Gärling et al. 1989). Furthermore, that activity schedules are frequently revised during execution is not modelled (Gärling et al. 1989; Root and Recker 1983).

Model focus	Model
Acquisition/representation of information about the environment	TOUR (Kuipers 1978) NAVIGATOR (Gopal et al. 1989; Gopal and Smith 1990) TRAVELLER (Leiser and Zilberschatz 1989) ELMER (McCalla et al. 1982)
Interdependent activity/travel choices	CARLA (Jones et al. 1983) STARCHILD (Recker et al. 1986a, 1986b) Lundberg (1988) Hayes-Roth and Hayes-Roth (1979) SCHEDULER (Gärling et al. 1989; Golledge et al. 1993) SMASH (Ettema et al. 1993)
Route choices	TOUR (Kuipers 1978) NAVIGATOR (Gopal et al. 1989; Gopal and Smith 1990) TRAVELLER (Leiser and Zilberschatz 1989) ELMER (McCalla et al. 1982)

Figure 2. Computational-process models reviewed.

Another shortcoming is that the current models fail to model changes over time as a function of repeated experience with the environment. Such changes may be observed in the way decisions are made. The representation of the decision alternatives may also change. The current models thus need to be augmented with a dynamic component, something which, in fact, is generally pleaded for within the area (Goodwin et al. 1990).

A final shortcoming is that the models reviewed only consider one decision maker. Even though choices are made individually most of the time, it may still be necessary to simultaneously model other decision makers' (e.g. other household members) activity scheduling to be able to validly represent constraints (Gärling et al. 1989). Furthermore, an important future task would be to model how social interaction affects activity scheduling.

Discussion

In the present paper we reviewed and evaluated several computational-process models (CPMs) of interdependent activity/travel choices, or activity scheduling. The particular modelling approach promises to enhance the theoretical underpinning of travel-choice modelling by providing the means of importing behavioral principles of higher cognitive processes such as acquisition and representation of information, judgment, and decision making (e.g. Newell 1992). Furthermore, the approach facilitates modelling of the dependency between travel and activity choices. Although not directly contributing to the practical goal of travel analysis, applications will in the longer-term benefit from the development of substantial theories (Pas 1990) which the approach promotes. However, computational-process modelling of activity scheduling is only in its infancy. We therefore conclude by pointing out some directions for future research.

As the preceding discussion has implied, extensive, comparative empirical tests of existing CPMs would be most useful in an attempt to build a model which integrates elements of existing models. Such tests are however not easy to perform since they require a thorough analysis which pinpoints conceptual differences and similarities. Also, some of the models are complementary and cannot therefore be compared.

Another avenue of research is to subject to empirical test of explicit behavioral assumptions entailed by different CPMs. Such tests would then constitute an indirect comparison of models whether or not they have the same focus. As an illustration of this approach, in a series of psychological experiments Gärling and associates (e.g. Gärling 1993; Gärling et al. 1986; Hirtle and Gärling 1993) have investigated assumptions made in SCHEDULER (Gärling et al. 1989) about how spatial and temporal information is processed. Similar research is being planned by Ettema and Timmermans (1993), and Golledge (1992).

Whereas much transport research has been devoted to the modelling of travel choices, much less information is available about the determinants of activities. Some progress has been made in recent years through the theoretical analyses by Supernak (1992) and Winston (1982, 1987). However, a vast amount of empirical research exists in the behavioral sciences (see Gärling and Garvill 1993 for review) which awaits integration into such theoretical analyses.

Another research area that awaits integration into the transport research literature is that of Geographic Information Systems (GIS). As suggested in Golledge et al. (1993), research may also be directed towards applying GIS as one way to ground CPMs of activity/travel choices in real world situations. One example currently being pursued by Kwan (1993) is that of using GIS to calibrate a CPM of individual household travel behavior when the data is derived from travel diaries. A particularly promising area for using GIS would be as a host for descriptions of the cognitive maps people acquire of the environment. Since people frequently use cognitive maps when making choices, knowledge about what information they store and how it is stored (Gärling et al. 1984; Gärling and Golledge 1989; Golledge 1987) would have immense importance for the forecasting of choices. The work by Golledge et al. (1993) so far has been applied only to individual households. GIS is also flexible enough to provide process descriptions accounting for many cases. Work in progress has been concentrated on writing routines known as AML in a GIS named ARC/INFO to account for travel diary data for modeling activity scheduling. GIS functionalities are being used to model human limitations such as the inability to identify all the possible opportunities in the environment and to find the shortest path in a street network. Experiments are being undertaken to interactively estimate travel time during the scheduling process as each new situation arises, as in real world cases planning is interwoven with execution. This process would then be integrated into more comprehensive models like STARCHILD in an attempt to compensate for several of the traditional shortcomings of mathematical choice models.

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