Computational-Process Modelling of Household Travel Decisions Using a Geographical Information System

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The University of California Transportation Center

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Computational-Process Modelling of Household Travel Decisions Using a Geographical Information System

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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 modelling 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.

1. INTRODUCTION

Household travel behavior entails interdependent deliberate decisions made by household members, as well as the execution of routines not preceded by deliberate decisions (Burnett and Hanson 1982). Furthermore, it has become increasingly evident that travel decisions are also dependent on the specific choices a person makes to participate in activities (Jones, Dix, Clarke and Heggie 1983). An activity analysis is often essential for the successful modelling of travel decisions.

Thus, there is a mutual dependency between household travel decisions and a household's agenda of activities for a particular time period. Our contention is that choices of destinations, departure times, and frequency and duration of activity participation, making up the spatiotemporal pattern of activities, need to be treated in a single coherent conceptual framework which specifies the process of making these interrelated sets of decision. Like Recker, McNally and Root (1986a) we refer to the decision making process as *activity scheduling*.

In the past disaggregate discrete-choice modelling has frequently been applied in transportation research (see, e.g., Timmermans and Golledge 1990 for a general overview), specifically with the aim of modelling single travel decisions (Pas 1990). In addition, there are some successful attempts at discrete-choice modelling of interrelated travel decisions using the nested logit (McFadden 1979) or structural-equation modelling approaches (Golob and Meurs 1988). As reviewed more selectively in Axhausen and Gärling (1992), in several of these attempts the dependency of travel decisions on choices of activity participation has also been modelled.

Interrelated decisions may be represented by discrete-choice models, although such a procedure seems invariably to rely on a utility-maximizing framework despite frequent questioning of its appropriateness for describing how people actually make decisions (e.g., Edwards 1954; Kahneman & Tversky 1979; Simon 1990). In attempts to replace the utility-maximizing framework with behavioral principles of information acquisition, information representation, information processing, and decision making, computational-process models (CPMs) have been developed. Such models offer more flexibility, as well as the ability to examine interdependencies of decisions - a characteristic not easily captured by other means. Thus, the strength of CPMs is that they make possible the modelling of the kind of interdependent decisions in which we are interested, i.e. activity scheduling, at the same as they are a means of articulating theory which incorporates behavioral principles (Smith, Pellegrino and Golledge 1982). In contrast to traditional discrete-choice models, validation requires a case study approach (Dukes, 1976; see Golledge, Smith, Pellegrino, Doherty, and Marshall 1985; Hayes-Roth and Hayes-Roth 1979 for examples). Such an approach is capable of capturing dependencies between decisions at an individual level not captured by other modelling approaches. CPMs are not usually thought of as predictive models in the same way as mathematical (e.g. discrete-choice) models are considered. A major problem inhibiting this view is that appropriate statistical techniques for estimating and calibrating CPMs are yet to be defined.

Although CPMs are promising means for reaching our long-term goal of developing a single coherent conceptual framework of activity scheduling, we need both to work out the set of behavioral assumptions entailed by such a conceptual framework and to develop means to operationalize the framework. In the present paper we build on the conceptual framework proposed by Gärling, Brännäs, Garvill, Golledge, Gopal, Holm and Lindberg (1989). The aim is to demonstrate how a CPM interfaced with a geographical information system (GIS) may be used to operationalize the conceptual framework. The GIS we chose to use is called ARC/INFO (ESRI, 1990) although we recognize that this is but one example of a variety of GIS that could be used in this type of problem. Very few CPMs have been successfully operationalized. Most have used hypothetical data for testing purposes because it is unusual to have data as detailed as the model needs. Like Miller (1991) we saw the opportunity to use GIS to break away from a hypothetical situation. However, whereas Miller focused solely on the objective restrictions on travel which the environment imposes, an additional concern we have is the implementation of behavioral principles of activity scheduling into the CPM using real world data. In this respect, we were able to evaluate the role that the ARC/INFO GIS may play in achieving our objective.

The paper is organized as follows. First, we briefly describe the conceptual framework. Second, we build a CPM based on the conceptual framework and discuss how it can be interfaced with ARC/INFO. By way of illustration, we then model data for a single household drawn from a sample of households participating in a study of telecommuting (Kitamura, Nilles, Conroy, and Fleming 1990). Finally, we discuss problems which need to be addressed by future research aimed at building workable GIS-interfaced CPMs.

2. CONCEPTUAL FRAMEWORK

As illustrated in Table 1, several CPMs (reviewed in Gärling, Kwan and Golledge 1993) exist which model different aspects of individuals' travel decisions. Some models which target navigation and route choice also tend to model acquisition and representation of information about the environment. Other models do not seem to pursue this goal in as much detail. The latter models are often more complete in modelling activity/travel decisions. A few models in each category appear more realistic descriptions of how people process information and make decisions. The remaining models make at least some assumptions which are unrealistic.

TABLE 1. Computational Process Models

Modelling focus	Model
Information acquisition and representation	TOUR (Kuipers 1978) NAVIGATOR (Gopal, Klatzky, and Smith 1989; Gopal and Smith 1990) TRAVELLER (Leiser and Zilberschatz 1989) ELMER (McCalla, Reid, and Schneider 1982)
Interrelated activity/travel decisions	CARLA (Jones, Dix, Clarke, and Heggie 1983) STARCHILD (Recker, McNally, and Root 1986a, 1986b) Lundberg (1988) Hayes-Roth and Hayes-Roth (1979)
Navigation/ route choice	TOUR (Kuipers 1978) NAVIGATOR (Gopal, Klatzky, and Smith 1989; Gopal and Smith 1990) TRAVELLER (Leiser and Zilberschatz 1989) ELMER (McCalla, Reid, and Schneider 1982)

Our previous review of existing CPMs points to the possibility of developing a model that integrates parts of other models. The models proposed by Hayes-Roth and Hayes-Roth (1979) and the STARCHILD model of Recker, McNally and Root (1986a, 1986b) are perhaps the most promising to use as points of departure. Yet, there are a few things that these models fail to accomplish which our conceptual framework attempts: (1) They fail to explicitly represent the fact that travel 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 during a day or week (Axhausen and Gärling 1992). Furthermore, temporal revisions of such decisions are not modelled. (2) They fail to model changes over time as a function of repeated experience of the environment. Such changes may be observed both in terms of which decisions are made and how they are made. The representation of the decision alternatives may also change. (3) They only consider one decision maker. Even though most decisions are made individually, it may still be necessary to simultaneously model other decision makers (e.g., other household members) to be able to validly represent the constraints under which decisions are made.

In the conceptual framework (Gärling, Böök, and Lindberg 1984; Gärling, Brännäs, Garvill, Golledge, Gopal, Holm and Lindberg 1989) it is assumed that the environment offers an individual opportunities to perform various activities, such as work, shopping, and recreation, by means of which needs are satisfied. The individual informs himself or herself about these opportunities, identifies spatiotemporal and other constraints, makes shorter-term as well as longer-term plans entailing many decisions which take these constraints into account, executes the decisions, and evaluates the resulting outcomes. According to this view, travel decisions constitute an integral part of the formation of an activity schedule.

Figure 1 depicts the cognitive processes responsible for activity scheduling. The individual has a memory representation of the objective environment which has been acquired by different means. Another memory representation (termed the Long-Term Calendar) contains information about an agenda of activities with different priorities. The activities with highest priorities are scheduled (by the SCHEDULER) taking opportunities and constraints into account. The resulting schedule is stored in memory (as the Short-Term Calendar) before being executed (by the Executor).

The set of feasible locations where an activity can take place is perceived by an individual on the basis of his or her memory representation (cognitive map) of the environment. First, only destinations that are remembered will enter into the choice set. Secondly, 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. Constraints include distance, cost, and time. As suggested in Figure 1, constraints also arise because of the frequent need to coordinate the schedule with other people, such as additional household members. Whatever causes the constraints, they result from a process of identification and judgment. Thus, it is possible that some apparent objective constraints are never identified, or that constraints are subjectively identified although they do not exist objectively (e.g., fear of crime, fear of congestion, or uncertainty regarding adequacy of parking).

Activity scheduling is highly dynamic and flexible. It is supposed to start with a set of prioritized activities. However, if constraints are perceived to make it impossible to perform the initially selected activities, less prioritized activities may be chosen. Activities with higher priority may have to await identification of feasible opportunities on subsequent occasions. This is also the case when the priorities assigned to activities change over time, both over a day or over a longer time span.

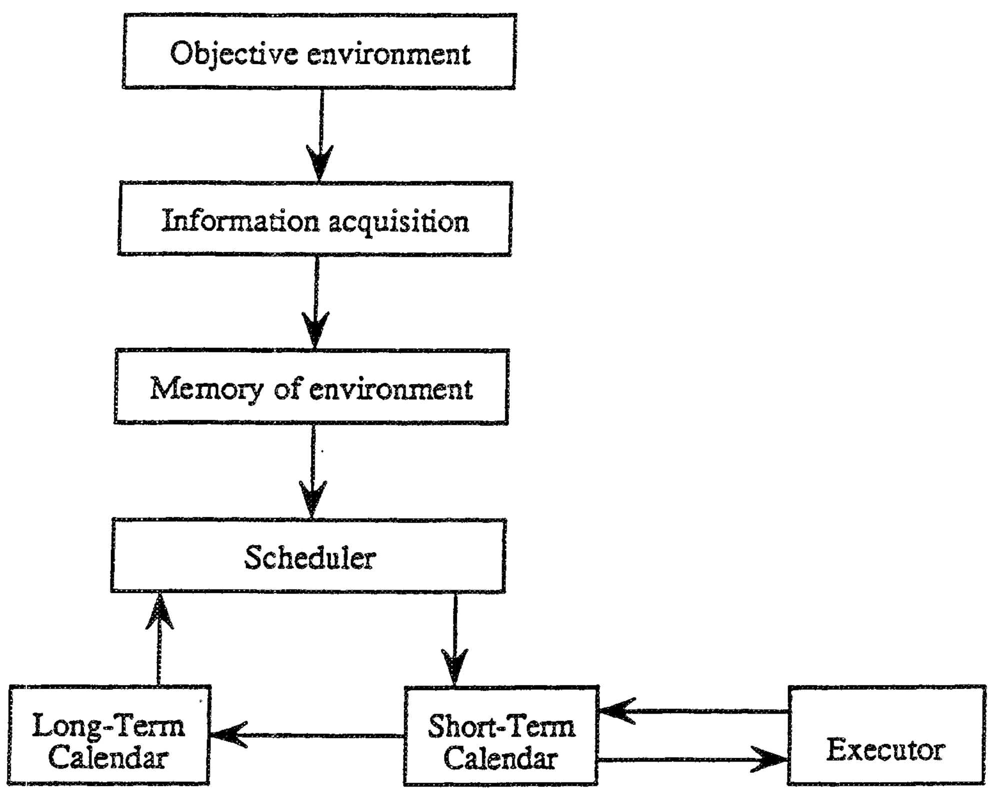

FIGURE 1. Schema of SCHEDULER

How scheduling is accomplished differs depending on tactical decisions. One such important decision is the trade-off between scheduling in detail and executing the schedule. In general, scheduling may proceed in a top-down fashion. A schematic schedule entailing choice of the sequence in which to perform a set of activities in different places is first formed, then through a process of "mental execution," a more detailed schedule is formed entailing choice of travel modes and departure times. Conflicts encountered in this detailed scheduling 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 scheduling stage. He or she may also need to do that because information is not available. Execution thus starts before a complete schedule is formed. As execution proceeds, the schedule is made complete in subsequent stages of scheduling. Not only additions to but also revisions of the schedule depending on changes in the environment may then be accomplished. An example would be that the activities to be performed during a day are first prioritized and sequenced, then a detailed schedule is made for the morning. However, because of unforeseen delays or other constraints, the schedule 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 rescheduling.

As mentioned above, constraints may arise because the schedule needs to be coordinated with those of other people. This will occur for activities that can only be performed mutually, or for activities that can be performed optionally by any of the involved people. Such interdependencies arise perhaps most frequently within a household, although they are not confined to household members. Even though decisions are made singly, they are thus influenced by other people's agendas as communicated to the individual engaged in forming his or her schedule. The communication may be untimed, incomplete, or distorted, thus giving rise to another source of suboptimality of schedules. Furthermore, one individual often dominates the other(s); that is, one household member may be more unwilling to change his or her schedule, on the basis of temporal precedence, the relative priorities of activities, household gender roles, or perhaps personal characteristics.

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

3. A GIS-INTERFACED CPM OF ACTIVITY SCHEDULING

The problem we pose in this section is how to operationalize the conceptual framework using a GIS. GIS have many uses in a transportation context, for example in vehicle routing and scheduling where GIS may provide both the environmental map and the path selection algorithm. ARC/INFO is one powerful system, although the capability of SPANS (Intera Tydac Technologies, Inc., 1991) to subdivide areas and perform disaggregate analysis may prove to be of even more interest. Other GIS such as the revised TRANSCAD (which integrates the path selection algorithms of the original TRANSCAD with GIS-PLUS to give a base system) may also prove useful (Wong, 1992; Caliper Corp., 1990). However, as Miller (1991) points out, the basic data handling and network operations required are normally present in the generic procedure of ARC/INFO. For our purposes, ARC/INFO appears at present sufficiently versatile. It has the basic set of functions we require (e.g., shortest path selection, buffering, overlaying, address matching, estimation of centroids, and so on).

An approximation of the street network on which individuals travel in US cities is provided by available TIGER files. These also give a base on which to locate trip origins when exact addresses are known. Specific destinations can also be tied into these databases. Other information, such as landuse and sociodemographic characteristics (which often come in areal units such as landuse, traffic zones, or census tracts), may be superimposed on the network. For example, our data from Sacramento County, California, to be discussed below have landuses differentiated by census tract which can be overlaid on the street network to help select feasible destinations for many trip purposes (e.g., shopping, recreation). Business hours, attributes of origins/destinations, and availability and speed of different transport modes are still other information that can be stored in the GIS in the form of attribute tables associated with specific origins and destinations, or more generally for selected traffic zones or census tracts.

In our CPM, the SCHEDULER schedules a set of activities selected from the Long-Term Calendar. Limiting ourselves to this part, Figure 2 shows how SCHEDULER is interfaced with the ARC/INFO GIS. In the absence of an accurate memory representation of the environment, ARC/INFO provides as factual a physical environment as possible for us to work with. Buffering, path-selection, and overlaying operations are then used to select environmental information to include in the SCHEDULER's representation of the environment. The figure also illustrates how the SCHEDULER processes this information. A set of activities with the highest priority is selected from the Long-Term Calendar. For these activities, information about where and when they can be performed is then retrieved from the representation of the environment. The activities are first sequenced on the basis of the temporal constraints. Choices of locations are then made for each activity taking into account the temporal sequence. If there are no temporal constraints, the location choices are based on the nearest neighbor heuristic although this is only one of several that people may use (Hirtle and Gärling 1992). A detailed schedule is finally formed using all the information in the memory representation of the environment and the Long-Term Calendar. At this stage conflicts may be noted. Such conflicts are resolved by changes of the original sequence of those activities which are in conflict. If this does not solve the conflict, the activities with the lowest priorities are postponed. Finally, the schedule is stored in the Short-Term Calendar which guides execution of activities.

4. AN EMPIRICAL EXAMPLE

In a study by Kitamura, Nilles, Conroy, and Fleming (1990), 3-day travel diaries were collected from households before and after they volunteered to participate in a telecommuting program organized among state employees in Sacramento County, California. As reported in Pendyala, Goulias, and Kitamura (1991a, 1991b), analyses of the travel diary data revealed that telecommuters chose non-work destinations closer to home so that their action spaces contracted after the introduction of telecommuting. This contraction took place on all days. The telecommuters cut peak-period travel on telecommuting days by 60 percent, vehicle miles traveled were reduced by 80 percent, and freeway use contracted by 40 percent. Other driving-age household members also exhibited smaller action spaces after the introduction of telecommuting.

As already pointed out, validation of a CPM based on the conceptual framework proposed by Gärling, Brännäs, Garvill, Golledge, Gopal, Holm and Lindberg (1989) must rely on data on how decisions are dependent at an individual level. A case study approach is therefore the most appropriate. Here we will attempt to demonstrate how the CPM can be

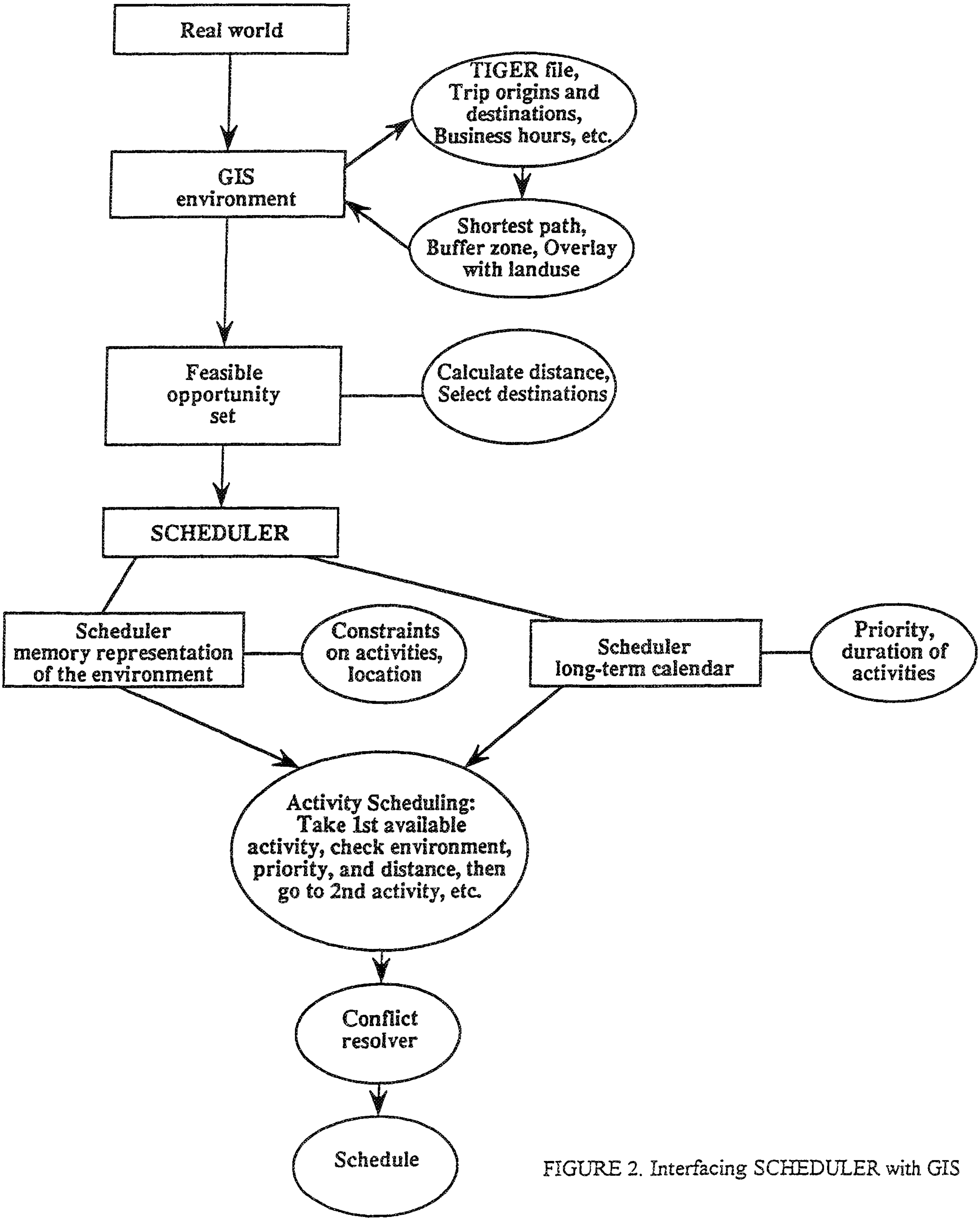

FIGURE 2. Interfacing SCHEDULER with GIS

TABLE 2. Travel Diaries Before and After Telecommuting for the Telecommuting Household

Condition	Activity	Start	Stop	Activity duration (Mins.)	Travel time* (Mins.)
Telecommuter, non-telecommuting day	Home-based	0:00	8:10	8:10	N/A
	Meal	8:22	8:28	0:06	0:12
	Work	8:37	11:50	3:13	0:09
	Meal	12:10	13:12	1:02	0:20
	Work	13:30	18:30	5:00	0:18
	Recreation	19:20	19:45	0:20	0:50
	Home-based	20:25	24:00	3:35	0:40
Non-telecommuter, non-telecommuting day	Home-based	0:00	8:10	8:10	N/A
	Child-transport	8:16	8:19	0:03	0:06
	Campus	8:34	12:59	4:25	0:15
	Home-based	13:03	16:30	3:27	0:04
	Child-transport	16:40	16:41	0:01	0:10
	Home-based	16:51	19:15	2:24	0:10
	Recreation	19:22	23:10	3:48	0:07
	Home-based	23:17	24:00	0:43	0:07
Telecommuter, telecommuting day	Home-based	0:00	8:10	8:10	N/A
	Child-transport	8:24	8:25	0:01	0:14
	Home-based	8:42	16:29	7:47	0:17
	Child-transport	16:45	16:46	0:01	0:16
	Home-based	17:02	24:00	6:58	0:16
Non-telecommuter, telecommuting day	Home-based	0:00	8:45	8:45	N/A
	Campus	9:05	15:38	6:33	0:20
	Meal	15:42	15:47	0:05	0:04
	Home-based	16:08	17:42	1:34	0:21
	Work	18:00	21:30	3:30	0:18
	Home-based	21:51	22:16	0:25	0:21
	Recreation	22:20	23:10	0:50	0:04
	Home-based	23:17	24:00	0:43	0:07

*Travel time is inferred from the time difference between two consecutive activities operationalized in such an approach. To do this we selected one illustrative single household among those participating in the telecommuting study. Slightly modified and cleaned travel diary data obtained from that household, consisting of a male adult with two teenage children, are shown in Table 2 for one telecommuting and one non-telecommuting day. All trips were made by automobile. The male adult is the telecommuter; the oldest, driving child is the non-telecommuter. This example thus represents the data we will use. It may be noted that telecommuting changed both individuals' trip patterns in the following way:

1. Before telecommuting started, the male telecommuter had a stable activity pattern - a daily trip to and from work, eating meals on the way to work and at lunch time. Also, he made a recreation trip directly after work. When telecommuting commenced the telecommuter suppressed the trips to eat meals but took over from the other household member transport of the child to and from school. Telecommuting thus changed the allocation of duties among household members. The telecommuter decreased driving.
2. The non-telecommuting household member started work while still going to school after telecommuting started. On the telecommuting day, he made trips to school, to eat a meal, to return home in the middle of the day, to work and to recreation. In contrast to the telecommuter, the non-telecommuter increased driving after telecommuting started.

Applying SCHEDULER

We now use the travel diary data in Table 2 to demonstrate how the SCHEDULER can be interfaced with the ARC/INFO GIS in modelling the telecommuting household's activity scheduling. In doing this, we first estimated activity durations, activity priorities, and locations of feasible alternatives for when and where to carry out the activities of eating meals and recreation. The work place, campus, and the child's school were not considered as choices from among different opportunities.

Below we describe the steps taken using the data for the telecommuter on the non-telecommuting day. We proceeded as follows:

Step 1. We constructed from the TIGER file of Sacramento County, California, a realistic environment consisting of possible origins, destinations, routes, and census tracts.

Step 2. We identified in the TIGER file home and work place between which the telecommuter travelled.

Step 3. We defined the shortest path between home and work. This was done by using an ARC/INFO NETWORK operation. (For the non-telecommuter before telecommuting, the path was between home and campus. After telecommuting, this person began work and the new home-work path was defined as the base.)

Step 4. We selected the set of feasible destinations for work and nonwork trips. This was done by using the BUFFER operation to find zones of 10 mile radius in which to search for feasible destinations for eating meals and recreation. (Before telecommuting buffering was done around the home-work path. After telecommuting it was done only around the home location.) The buffer zones were overlaid on a composite map of TIGER files and Land Use Zones. Original Land Use Zones were obtained from the Sacramento Council of Governments. To ensure compatibility with the TIGER files, zones were transformed to census tracts, a level of aggregation deemed suitable for our purposes. Of course, buffers of any selected radius can be defined. Unlike Miller (1991) who only used travel times, we used travel times to select the closest opportunities and travel distances to define the activity space.

Step 5. We inputted the feasible destinations for different activities to the SCHEDULER's representation of the environment. This was done in ARC/INFO by (i) matching and when necessary aggregating land use zones into census tracts, (ii) developing land use attribute tables for each census tract, and (iii) matching the data on land use attributes with the proper census tract in the TIGER file. Since our data consisted of the percentage of each type of landuse in each tract, we selected only from among tracts that had more than 10 percent of their land in a given use (e.g., commercial, recreational). From these we defined for each activity the census tracts in which feasible destinations occurred. Those census tracts containing specified destinations that lie within the buffer zones were considered feasible opportunities. In the absence of accurate geo-referenced information on specific landuse features, the centroid of the census tract (calculated by using the LABEL and TRANSFORM functions of ARC/INFO) was used to indicate possible destinations (see Figure 3). Each destination is differentiated by the centroid of a census tract. The centroids were transformed into SCHEDULER's X,Y coordinates (see Table 3). Travel times between X,Y coordinates were calculated by dividing the Euclidean distance with an estimate of travel speed obtained from the travel diaries. For any two locations within the same census tract, we assumed that travel time was 5 minutes each way. The operating hours of the different businesses were either obtained from general information or inferred from the travel diary data.

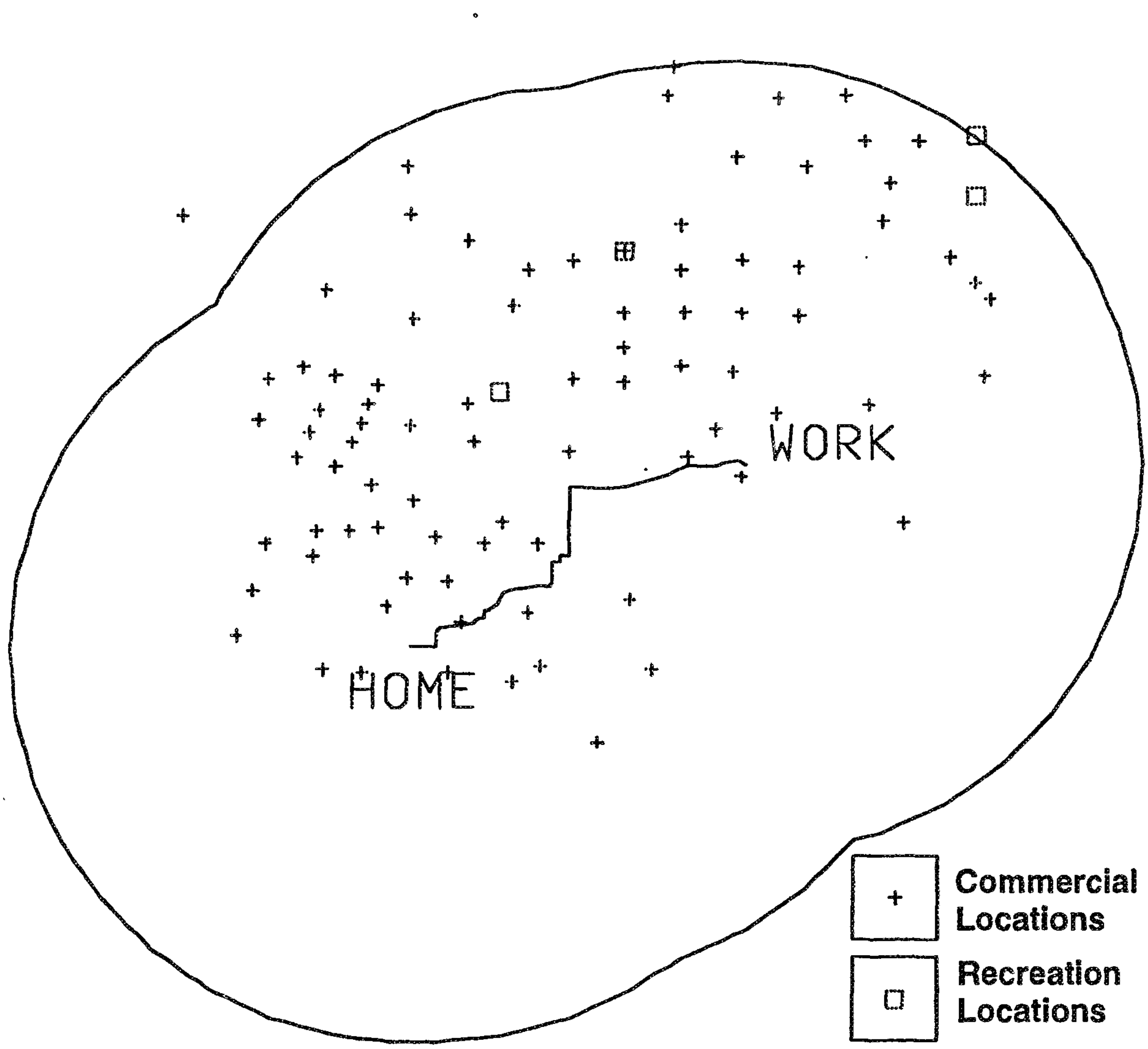

FIGURE 3. Buffer Zone Around Home-Work Path with Possible Destinations

(Note that one location is outside the buffer zone because the latter overlays only part of the census tract such that the tract's centroid is outside the buffer boundary)

TABLE 3. Environment Before and After Telecommuting for the Telecommuting Household

Condition	Location type	X,Y coordinates	Open from	Open to
Telecommuter, non-telecommuting day	Home	1,2	0:00	24:00
	Work place	2,1	8:00	20:00
	Restaurant 1	2,3	8:00	22:00
	Restaurant 2	2,2	8:00	22:00
	Restaurant 3	1,3	8:00	22:00
	Restaurant 4	1,2	8:00	22:00
	Restaurant 5	0,3	8:00	22:00
	Restaurant 6	0,2	8:00	22:00
	Restaurant 7	0,1	8:00	22:00
	Restaurant 8	1,1	8:00	22:00
	Recreation place 1	1,3	13:00	24:00
	Recreation place 2	0,2	13:00	24:00
	Recreation place 3	2,3	13:00	24:00
Non-telecommuter, non-telecommuting day	Home	1,2	0:00	24:00
	Campus	0,2	8:00	14:00
	Child's school	1,2	8:00	17:00
	Recreation place 1	1,3	17:00	24:00
	Recreation place 2	0,2	17:00	24:00
	Recreation place 3	2,3	17:00	24:00
Telecommuter, telecommuting day	Home	1,2	0:00	24:00
	Child's school	1,2	8:00	17:00
Non-telecommuter, telecommuting day	Home	1,2	0:00	24:00
	Work Place	0,1	17:30	22:00
	Campus	0,2	9:00	16:30
	Restaurant 1	2,3	12:00	22:00
	Restaurant 2	2,2	12:00	22:00
	Restaurant 3	1,3	12:00	22:00
	Restaurant 4	1,2	12:00	22:00
	Restaurant 5	0,3	12:00	22:00
	Restaurant 6	0,2	12:00	22:00
	Restaurant 7	0,1	12:00	22:00
	Restaurant 8	1,1	12:00	22:00
	Recreation place 1	1,3	22:00	24:00
	Recreation place 2	0,2	22:00	24:00
	Recreation place 3	2,3	22:00	24:00

TABLE 4. Long Term Calendar Before and After Telecommuting for the Telecommuting Household

Condition	Activity	Priority*	Activity duration** (Mins.)
Telecommuter, non-telecommuting day	Home-based	2	8:00
	Meal	1	0:06
	Work	2	3:13
	Meal	1	1:02
	Work	2	5:00
	Recreation	1	0:20
	Home-based	2	5:24
Non-telecommuter, non-telecommuting day	Home-based	2	8:00
	Child-transport	1	0:03
	Campus	2	4:25
	Home-based	2	3:27
	Child-transport	1	0:01
	Home-based	2	2:24
	Recreation	1	3:48
	Home-based	2	0:57
Telecommuter, telecommuting day	Home-based	1	7:30
	Child-transport	2	0:01
	Home-based	1	7:47
	Child-transport	2	0:01
	Home-based	1	8:21
Non-telecommuter, telecommuting day	Home-based	2	9:00
	Campus	2	6:33
	Meal	1	0:05
	Home-based	2	1:34
	Work	2	3:30
	Home-based	2	0:25
	Recreation	1	0:50
	Home-based	2	0:38

* 2 is higher, 1 is lower priority
** Excludes travel time

TABLE 5. Activity Schedules Before and After Telecommuting for the Telecommuting Household

Condition	Activity	X,Y coordinates	Start	Stop	Activity duration (Mins.)	Travel time (Mins.)
Telecommuter, non-telecommuting day	Home-based	1,2	0:00	8:00	8:00	N/A
	Meal	0,1	8:20	8:26	0:06	0:20
	Work	0,1	8:31	11:44	3:13	0:05
	Meal	0,1	11:49	12:51	1:02	0:05
	Work	0,1	12:56	17:56	5:00	0:05
	Recreation	0,2	18:06	18:26	0:20	0:10
	Home-based	1,2	18:36	24:00	5:24	0:10
Non-telecommuter, non-telecommuting day	Home-based	1,2	0:00	8:00	8:00	N/A
	Child-transport	1,2	8:05	8:08	0:03	0:05
	Campus	0,2	8:18	12:43	4:25	0:10
	Home-based	1,2	12:53	16:20	3:27	0:10
	Child-transport	1,2	16:25	16:26	0:01	0:05
	Home-based	1,2	16:31	18:55	2:24	0:05
	Recreation	1,3	19:05	22:53	3:48	0:10
	Home-based	1,2	23:03	24:00	0:57	0:10
Telecommuter, telecommuting day	Home-based	1,2	0:00	7:30	7:30	N/A
	Child-transport	1,2	7:35	7:36	0:01	0:05
	Home-based	1,2	7:41	15:28	7:47	0:05
	Child-transport	1,2	15:33	15:34	0:01	0:05
	Home-based	1,2	15:39	24:00	8:21	0:05
Non-telecommuter, telecommuting day	Home-based	1,2	0:00	9:00	9:00	N/A
	Campus	0,2	9:10	15:43	6:33	0:10
	Meal	1,2	15:53	15:58	0:05	0:10
	Home-based	1,2	16:03	17:37	1:34	0:05
	Work	0,1	17:57	21:27	3:30	0:20
	Home-based	1,2	21:47	22:12	0:25	0:20
	Recreation	0,2	22:22	23:12	0:50	0:10
	Home-based	1,2	23:22	24:00	0:38	0:10

Step 6. We inputted information about activities to the SCHEDULER's Long-Term Calendar. The activities to input and their durations were obtained from the telecommuter's travel diary. For example, Table 4 shows that the Long-Term Calendar included five out-of-home activities which is within the range of 3 to 5 trips that other studies claim are typical (Goddard 1983; Hanson and Huff 1988). Priorities were assigned to each activity depending on whether it was obligatory (home-based, work) or discretionary (recreation). (After telecommuting when the number of out-of-home activities was reduced to one, that activity was assigned a higher priority than the home-based activity.)

Having prepared the input to the SCHEDULER, the actual activity scheduling took place using a program written in Pascal. Table 5 shows the outcome of the telecommuter's and non-telecommuter's activity scheduling before and after telecommuting. As compared to the travel diary presented in Table 2, there are the following similarities and differences:

Telecommuter before telecommuting. The SCHEDULER selected the same order of the activities. The destination for the first meal on the way to work coincided with the actual location. However, SCHEDULER also chose the same location for the second meal whereas the location chosen by the telecommuter was farther away, requiring 20 minutes of travel. In the case of recreation, the scheduled destination was not the one chosen by the telecommuter. The telecommuter's actual chosen location was not even in the feasible opportunity set. The actual travel time before telecommuting was 149 minutes, as compared to the 55 minutes defined by the SCHEDULER.

Telecommuter after telecommuting. Again, the SCHEDULER selected the same order of activities. Since location is given for home and child's school, no selections of location were made. The actual travel time on that day was 63 minutes, whereas the SCHEDULER allocated 20 minutes to travel. The reason for the discrepancy is that we assumed an average of 5 minutes within-zone travel time; in actuality, the telecommuter made four within-zone trips of about 16 minutes each from home to school and back.

Non-telecommuter before telecommuting. The SCHEDULER first tried to schedule the trip to campus before transporting child in the morning. However, transporting child could not be scheduled under the constraint of the environment. The SCHEDULER then resolved this conflict by changing the order of the activities and putting the transport-child activity before going to school. The SCHEDULER thus selected the same order of the activities. The SCHEDULER selected from the feasible opportunity set the location closest to home. According to our 10 percent landuse criterion, there was no opportunity to perform recreation in the home zone (i.e., less than 10 percent landuse in the zone was recreational). However, the commuter actually performed the activity in the home zone. The travel time for the day was 55 minutes which was slightly higher than the actual travel time of 45 minutes.

Non-telecommuter after telecommuting. The SCHEDULER selected the activities in the same order as the actual order. It also selected the location for the next activity (eating a meal after school) to be near the next destination, home. However, the actual location chosen for eating a meal was in the same zone as the school. The non-telecommuter also carried out recreation in the same zone as the home. Since no recreation opportunities in the home zone appeared in the feasible opportunity set, the SCHEDULER selected the closest available location to home. The actual travel time was 95 minutes, whereas the SCHEDULER allocated 85 minutes to travel.

5. DISCUSSION

In the present paper we showed how a CPM of a household's interdependent activity/travel decisions, or activity scheduling, can be interfaced with a particular GIS to describe the basic spatiotemporal pattern of household travel behavior and the changes in travel behavior due to telecommuting. As Langran (1989) points out, many of the functions needed in a spatiotemporal GIS have yet to be developed. They also need to be tested on a case-by-case basis. Our research is consistent with this suggestion. Following such research, more extensive empirical tests are clearly required to evaluate model performances according to traditional criteria. We have shown that GIS would be most helpful in such tests. However, at the same time several shortcomings of the conceptual framework proposed by Gärling, Brännäs, Garvill, Golledge, Gopal, Holm, and Lindberg (1989) are highlighted. At present these shortcomings constitute obstacles preventing a successful implementation of a GIS-interfaced CPM as a fully adequate operationalization of the conceptual framework. Below we discuss these obstacles and the needed improvements which future research should address. We also realize that improvements of the GIS are desirable. However, a discussion of such improvements are beyond the scope of the present paper.

The conceptual framework does not provide guidelines for how to assign priorities to activities. In our empirical example we assigned priorities on a common-sense basis. A solution may be to specify in the conceptual framework some general form of time dependency of priorities, then to collect data which make it possible to rank order activities with respect to their priorities. For instance, the frequency with which households in the full sample participate in different activities may be used as a crude index of the priority a single household member assigns to the activities performed by him or her. A better way may be to obtain from household members ratings or rank orders of their preferences for different activities (see Recker, McNally, and Root 1986b).

In the empirical example ARC/INFO provided a detailed representation of the individuals' environments in the SCHEDULER. However, in the absence of a specification in the conceptual framework of how individuals represent the environment, we used the factual environment as provided by the TIGER file and landuse data. The facilities in ARC/INFO which we used to select feasible opportunities (e.g., tract centroid, buffer) could only provide crude approximations. In fact, the differences between the SCHEDULER's selections of destinations and those chosen by the household members largely arose because of that, although some differences (e.g., travel times) appear related more to the violation of least effort or nearest neighbor principles by each of the travellers, a fact previously reported by Gärling and Gärling (1988). Principles for how people perceptually select features in the environment, how they remember such features, and how they form preferences for them need to be built into a GIS-interfaced CPM. In part these principles are known from previous research on cognitive mapping (see Gärling and Golledge, 1989, for a review). However, other means of data collection are also needed. Rather than making assumptions about the formation of choice sets which are difficult to test, methods are available which directly reveal people's cognitive representations, or cognitive maps, of environments. Unfortunately, such data were not available to us in the telecommuter study (Kitamura, Nilles, Conroy, and Fleming 1990).

The feasible opportunity sets were defined for both the telecommuter and the non-telecommuter on telecommuting and non-telecommuting days using the BUFFER operation in ARC/INFO. In each case we defined a 10 miles buffer zone because the telecommuter travelled long distances before starting telecommuting. However, the choice of size of buffer zone could be more adequately tuned to different conditions. One possible improvement would be to vary size of the buffer depending on type of activity. For example, it may be assumed that people would travel longer for the purpose of recreation than for eating meals. Like Miller (1991) did in defining "potential path areas," we could also define buffers of different size depending on individuals' characteristics. Instead of distance, we could furthermore use travel time for the buffer. Again, many options are available but a choice among them must be based on behavioral principles built into the conceptual framework.

Our definition of a feasible opportunity set relied on the selection of a shortest path. This may however not be the path actually travelled. As suggested by Miller (1991), path selection could be done using a time-constrained shortest path. Behavioral principles such as preference for freeways or local streets could be added to the path selection algorithm. Travel speed, turn penality, and time-dependent impedance are also possible to build into a GIS.

Although the principle of selecting the nearest opportunity implemented in the SCHEDULER may be valid, this principle can be operationalized in different ways in an actual environment. In SCHEDULER the choice is based on Euclidean distances. It seems plausible that travel times would be a better choice. However, it is not specified in the conceptual framework how distances are remembered. Different forms of distortions are commonly found in empirical studies (Gärling and Golledge 1989), although knowledge is still incomplete. Through operations such as rubbersheeting, ARC/INFO provides many options for transforming actual environments to better fit their cognitive representation.

Thus there are several needed improvements of the conceptual framework. Their discovery has been dependent on our exercise with the SCHEDULER reported in this paper. Our exercise furthermore indicated ways in which to proceed in operationalizing the conceptual framework as soon as the needed improvements have been accomplished.

Let us also finally note an additional use of GIS which we intend to work on. In the further development of the SCHEDULER, the dynamic decision making in which people engage will require modelling of the real-time execution of activities. Only in this way will it be possible to model how individuals over time develop and revise their schedules when receiving additional information. Clearly, GIS offer facilities which can be used to model the *actual* execution of activity schedules and thus provide a feasible mechanism to assist in further development and testing of transportation oriented CPMs.

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