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Computer simulation of household activity scheduling

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Abstract. An operational model of household activity scheduling is proposed. The model is based on a theory entailing behavioral principles of how persons acquire, represent, and use information from and about the environment. Choices of destinations and departure times are consequences of the scheduling of a set of activities to be executed in a given time cycle. Illustrative computer simulations of the operational model show realistic effects of work hours, living in or outside the center, and travel speed. Several necessary improvements of the theory and operational model are discussed, such as incorporating learning effects and choice of travel mode for home-based trip chains. Strategies outlined for empirical tests include comparisons with existing models, psychological experiments illuminating basic assumptions, and the use of geographical information systems to process travel-diary data for single cases.

Introduction

A substantial amount of research has been devoted to the disaggregate modelling of households' travel choices (Pas, 1990). In this research, models of choices of, for instance, travel mode, departure time, and destination have been estimated from travel-diary data (Pipkin, 1986; Timmermans and Golledge, 1990). Almost invariably the logit model has been used (Ben-Akiva and Lerman, 1985; McFadden, 1979).

It has become increasingly obvious that travel choices should be viewed as the outcome of a process of *scheduling activities* (Jones et al, 1990; Root and Recker, 1983). At times modelling single independent travel choices may therefore be futile, particularly in view of the impact that changing values, life-styles, and roles appear to have on travel in contemporary societies (Jones et al, 1983). An important problem is thus how to model dependencies between choices and activities.

Some approaches to travel-choice modelling have attempted to take activities into account (see reviews by Axhausen and Gärling, 1992; Kitamura, 1988; Thill and Thomas, 1987). 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).

Although many of the approaches followed to date perhaps are useful, they seem to lack a substantive theoretical underpinning. Thus, there is no guarantee that they are descriptive of how people actually make choices. Axhausen (1997) and Gärling (1994a) therefore argued for approaches which are more firmly based on behavioral theories,

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in particular such theories of decisionmaking. Behavioral decision theories are reviewed in many recent sources, for instance, Abelson and Levy (1985) and Payne et al (1992). Their empirical underpinnings in a voluminous number of psychological experiments are also described.

In a similar vein as Root and Recker (1983) in their seminal paper, Gärling et al (1989a) proposed a theory of how households schedule a set of activities during a time cycle. The theoretical assumptions drew in part on behavioral principles of decision-making (see Payne et al, 1993 for a recent statement), in part on the cognitive model of planning proposed by Hayes-Roth and Hayes-Roth (1979). Golledge et al (1994) demonstrated by means of case data how a tentative operational model (SCHEDULER) based on the theory could be interfaced with a geographical information system.

Other similar computer-based operational models are reviewed in Gärling et al (1994). Therefore, it may suffice to mention here that the work by Gärling et al (1989a) was recently carried further by Ettema et al (1994) who developed an operational model of how individuals schedule activities. A computer program is also available for simulating the activity schedule. In the model called SMASH, choices to include, delete, or substitute activities depend on the scheduling process, the schedule, and the activities to be scheduled.

In contrast to SMASH which is not connected to a consistent theory, in the present paper we report a refined operational model developed on the basis of the theory of activity scheduling presented in Gärling et al (1989a). After a description of the theory in the next section⁽¹⁾, the new operational model is presented. In the section thereafter some computer simulations are reported with the aim of demonstrating that the operational model does not produce unrealistic results. The paper ends with a discussion of improvements to the theory and operational model which are still needed. Strategies for empirical tests are also discussed.

A theory of activity scheduling

Overview of assumptions

In the present theory it is assumed that people engage in activities because they are basic means of satisfying needs⁽²⁾. Several activities may satisfy the same or, possibly, other substitutable needs. Furthermore, it may be possible to perform a particular activity in different locations at different costs. As a consequence, no direct and simple relationship exists between a need and the observable performance of an activity. Over time individuals therefore engage in many activities at different locations.

Activities may be classified with respect to content (for example, relationship to needs or goals), spatiotemporal characteristics, how they are performed (for example, routinely or nonroutinely), who performs them (whether a single individual or a group), and whether they are required or optional. A more thorough discussion of the problem of classifying activities can be found in Gärling and Garvill (1993) primarily from a psychological perspective, and Chapin (1974) and Cullen (1976) from a sociological and time-geographical perspective, respectively.

⁽¹⁾ This description is the most recent statement of the theory and entails some changes of assumptions since its original presentation in 1989.

⁽²⁾ Needs are here defined broadly to include physiological needs, social needs, desires, instrumental needs, requirements, and obligations. That activities are means to attain goals [such as, for instance, values (see Gärling et al, 1989b)] is an equivalent expression. A further discussion of the motivational structure underlying the performance of activities is, however, beyond our present scope. The reader is referred to reviews of relevant research in motivational psychology (for example, Gärling and Garvill, 1993).

A distinction is made between routine and nonroutine activities. A routine activity is in contrast to a nonroutine activity not a consequence of immediate deliberate decisionmaking (compare Ronis et al, 1989)⁽³⁾. Routine activities are thus regarded as predetermined and fixed in space and time. In contrast nonroutine activities are more flexible because their performance depends on choices among available opportunities. In general, in daily life routine activities take precedence over nonroutine ones. Only when a nonroutine activity becomes very important may it override a routine activity.

The performances of nonroutine activities are preceded by choices of location, start time, duration, and travel mode. The proposed theory attempts to explain how these choices are made when they form part of an activity sequence. This is the problem of *activity scheduling*. Routines or habits are only considered in this context to the extent that their performance constitutes constraints for the scheduling of nonroutine activities.

Figure 1 illustrates that activity scheduling entails acquisition of information from and about the environment, retrieval of information from a 'cognitive map' of that environment, retrieval of information about activities from a 'long-term calendar', and scheduling of this information in a process consisting of several stages. The activity schedule to be executed is stored in a 'short-term calendar'. Sometimes, when the circumstances change, scheduled activities are postponed for scheduling at a later occasion.

In the following, specific assumptions about the different components and the processes they support are discussed.

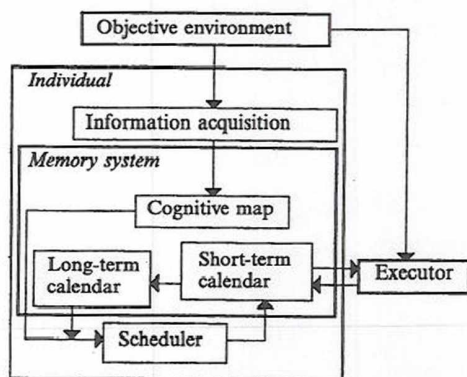


Figure 1. Stages of information processing assumed in the theory.

Cognitive map

According to the principle of bounded rationality (Simon, 1982), people make decisions on the basis of available information. Such information is retrieved from external sources or from a long-term memory of high capacity (for example, Anderson, 1983). Information about particular environments stored in long-term memory is termed a cognitive map (CMAP) (Gärling et al, 1984). The CMAP is acquired, maintained, and updated according to certain principles (Gärling and Golledge, 1989; Gärling et al, 1984)⁽⁴⁾: (1) with repeated exposure to the environment, information about an increasing number of locations and routes will be available; (2) at the same time inaccuracies of the representation of locations, routes, and distances will decrease; and (3) information which has not been encountered for some time will be more difficult to retrieve.

⁽³⁾ A routine activity may be a consequence of *long-range* deliberate decisions.

⁽⁴⁾ Here and subsequently the principles drawn on are only enumerated. For a more thorough discussion, the reader is referred to the cited references.

The CMAP also contains approximate information about opening hours. Travel speeds between locations at different times of the day are furthermore likely to be represented. Additional information that is available in the CMAP includes aversion for locations.

Long-term calendar

Another long-term memory structure is termed the long-term calendar (LTC). It contains information about activities. Such information consists of optional locations where an activity can be performed. A minimal duration required for its performance is also stored for each activity. Information about when it is suitable to perform the activities at different locations is also available.

Only a subset of activities is stored in the LTC. The selection of the activities in this subset depends on how important they currently are for the individual to perform. Because importance varies over time, different subsets of activities are stored at different times.

Short-term calendar

Before its execution, the activity schedule is represented temporarily in a short-term calendar (STC). Part of the content of the STC is stored in a limited-capacity short-term or working memory (Anderson, 1983; Newell and Simon, 1972). Information needed to execute an activity, such as location, travel mode, departure time, start and end times may or may not be stored depending on the degree of detail of the activity schedule. If information required for the execution of the schedule is missing, this information must be acquired before its execution.

Activity scheduling

After the different representations of information assumed in the theory have been described, in this subsection the focus is on the processes operating on these representations, that is, the activity scheduling.

At several stages information is retrieved from long-term memory. One such process activates a set of activities in the LTC to be scheduled. In this case retrieval is assumed to depend on degree of importance or utility of performing the activities at the particular time.

For the activities to be scheduled, information is retrieved about utility, duration, location, and opening hours. A subset of all available such information is activated in the CMAP. Some of the information may be missing. Retrieval therefore also entails consulting externally accessible information, for example, street maps, telephone directories, and the like (Gärling et al, 1984).

Another process assumption is whether people schedule one activity at a time, or schedule several activities simultaneously. If a satisficing principle (Simon, 1982) is followed, scheduling decisions are likely to be incremental. However, in the model proposed by Hayes-Roth and Hayes-Roth (1979), scheduling or planning is defined as the *predetermination* of a sequence of activities. A plausible assumption is that the planning horizon depends on the circumstances. For instance, if it is important that the plan succeed, people may plan more activities than they would otherwise. On the other hand, scheduling then requires more effort. Thus an accuracy-effort tradeoff is involved (Payne, 1982; Payne et al, 1993). A related question also entailing such a trade-off concerns how detailed scheduling is of each activity.

In which order and how the different choices entailed by scheduling are made remains to be addressed. It is assumed that the most important activity will always be the candidate for being scheduled first. However, the activity is not scheduled unless the psychological cost of its performance is acceptable. That the scheduling person

feels active, that he or she has time, and that the activity can be performed in a suitable location are additional factors affecting the scheduling.

The satisficing principle (Simon, 1982) also implies that choices are made according to rules which do not lead to overall optimization. In this vein, research has revealed that people use choice rules which are contingent on the circumstances (Payne et al, 1988; Svenson, 1979). Furthermore, Huber (1990), Montgomery (1989), and Tversky (1972) have conceived of choice as a process which at different stages entails the application of different rules. Choice rules are characterized as compensatory or non-compensatory. The latter tend to be more frequently applied when there are many complex alternatives (Ford et al, 1989).

An important aspect of scheduling is that sets of dependent choices are made simultaneously. Drawing on the notion of Louviere (1984) and Louviere and Timmermans (1992) of hierarchical information integration, we assume that a choice entails several subordinate judgments or choices. At the highest level a person weighs the utility of performing an activity against cost of performing it. He or she also takes into account an inclination to perform *any* activity. At lower levels different information is retrieved to make a judgment of the cost, including time pressure and travel cost. Travel cost entails time, aversions for locations, and the risk of being late.

Learning

Information available in the LTC and CMAP changes as a function of learning. In the CMAP, information about routes, travel times, and locations becomes more complete and accurate. In the LTC is stored additional information acquired about where and when activities can be performed. All stored information becomes more easily accessible the more recently it has been accessed in scheduling.

New information is acquired when activities are scheduled as well as when they are performed. In both cases new locations may be discovered. Each time an old location is included in the schedule, random errors in its coordinates relative to some reference system are reduced until an upper limit on precision is reached. Similarly, when pairs of old locations are encountered, more accurate information about the length of the route between them is acquired. In this way straight-line distances originally stored in the CMAP are eventually replaced by travel distances (Säisä et al, 1986). Aversion for locations changes with actual encounters with the locations.

Operational model

Simplifying assumptions

When we were contemplating an operational model, we decided on a strategy to overlook some of the complexities of the theory. By doing so we hoped that the operational model would be more tractable and open to empirical estimation. A logical first step was then to center on the scheduling decisions (performed by Scheduler, see figure 1). In addition the operational model currently rests on the following simplifying assumptions as compared with the theory: (a) a subset of activities is assumed to be available for an individual to schedule in a given time cycle (a day); (b) scheduling consists of sets of incremental choices of an activity, a location, and a start time⁽⁵⁾;

⁽⁵⁾ Only one activity at a time is thus assumed to be scheduled. In this way scheduling is reduced to the simplest case when decisions are incremental. The reason is that it is not clear how simultaneous choices of many activities should be modelled considering the existence of human capacity limits. Empirical studies of this issue has only begun (Gärling, 1994b). By specifying travel speeds between pairs of locations, choice of travel mode (for example, between automobile and public transport) will become a consequence of activity scheduling. No choice of duration is assumed to be made. This appears realistic if it is assumed that a minimal duration is specified. If the time available is less than that, an activity will not be chosen. If the time is longer, either there will be wait time or another activity will be squeezed into the time slot.

(c) choices are made according to a rule in which a set of hierarchically organized factors are combined linearly⁽⁶⁾; (d) the variation of utilities of the activities over time is given; (e) routine activities are defined as fixed in time and space and their utilities are high when they are scheduled to be performed, at other times they are low; (f) no learning takes place.

Choice rules

The choice rules are described in the following. In setting them up, computational ease was an important criterion as they are otherwise unlikely to mimic how people make choices.

The priority, $PRI_{ij}(\text{ACTTYPE}_j)$, at time t that a scheduling person includes an activity type j in the schedule is

$$PRI_{ij}(\text{ACTTYPE}_j) = \beta_1 \text{ACTIVATION}_t + \beta_2 \text{ACTUTILITY}_{t'j} - \left(1 - \sum \beta_i\right) \text{COST}_{ij}, \quad \beta_i > 0, \quad \sum \beta_i \leq 1. \quad (1)$$

$\text{ACTUTILITY}_{t'j}$ denotes the anticipated utility of performing the activity at time t' (when scheduled to be performed). ACTIVATION_t refers to the state of readiness to perform any activity. It decreases according to an exponential function, $\exp(-N\text{RACT})$, with the number of activities ($N\text{RACT}$) already scheduled during the time cycle. COST_{ij} is related to two independent factors as follows:

$$\text{COST}_{ij} = \beta_3 \text{TIMEPRESS}_{ij} + (1 - \beta_3) \text{TRAVAVER}_{tok}, \quad 0 \leq \beta_3 \leq 1. \quad (2)$$

TIMEPRESS_{ij} denotes a judgment of whether there is sufficient time. It is obtained from

$$\text{TIMEPRESS}_{ij} = \text{HOUR}_t + \text{ACTDURATION}_j - \text{TIMEHORIZON}_t, \quad (3)$$

where HOUR_t is current time, ACTDURATION_j is the duration of activity j , and TIMEHORIZON_t is the time when the next activity is scheduled (or if no activity is scheduled, when the time cycle ends).

TRAVAVER_{tok} in Equation (2) denotes a judgment of the cost to travel from the current location o to location(s) k where the activity can be performed. If there are several locations, the location with the lowest value is chosen. The following factors are taken into account by the scheduling person:

$$\text{TRAVAVER}_{tok} = \beta_4 \text{LOCAVER}_{tk} + \beta_5 \text{TRAVTIME}_{tok} + \beta_6 \text{WAITTIME}_{tk} - \left(1 - \sum \beta_i\right) \text{TIMELEFT}_{tjk}, \quad \beta_i > 0, \quad \sum \beta_i \leq 1. \quad (4)$$

LOCAVER_{tk} indicates how aversive the location k is at time t . TRAVTIME_{tok} is travel time at time t obtained as⁽⁷⁾

$$\text{TRAVTIME}_{tok} = (\text{TRAVSPEED}_{tok}^{-1}) [(\text{LOCX}_o - \text{LOCX}_k)^\alpha + (\text{LOCY}_o - \text{LOCY}_k)^\alpha]^{1/\alpha}, \quad 0 < \alpha \leq 2, \quad (5)$$

⁽⁶⁾ An additive linear rule is chosen although empirical evidence indicates that people select from a set of different choice rules depending on an accuracy-effort tradeoff (Payne et al, 1988). As such a tradeoff is likely to reflect a deliberate decision or *metadecision*, it would require that the latter is incorporated in the operational model (compare Hayes-Roth and Hayes-Roth, 1979). This was however beyond the scope of the present paper.

⁽⁷⁾ A scheduling person is unlikely to calculate travel time according to this expression. It is instead assumed to reflect how the information is stored in memory.

where $TRAVSPEED_{tok}$ is travel speed, $(LOCX_o, LOCY_o)$ and $(LOCX_k, LOCY_k)$ are the x-y-coordinates of o and k , respectively, and α is a constant which specifies route length.

$WAITTIME_{ik}$ in equation (4) denotes waiting time before the activity can be performed in location k at time t . It is assumed to be calculated by the scheduling person as the difference between the time remaining until the activity can be performed (current time $HOUR_t$, subtracted from opening hour $OPENHOUR_k$) and travel time to location k , that is

$$WAITTIME_{ik} = OPENHOUR_k - HOUR_t - TRAVTIME_{tok} (\geq 0). \quad (6)$$

If $WAITTIME$ is negative, it is set to 0. On the basis of this judgment, $ACTSTART_{ij}$ is computed as $HOUR_t + TRAVTIME_{tok} + WAITTIME_{ik}$, and $ACTEND_{ij}$ as $ACTSTART_{ij} + ACTDURATION_j$.

$TIMELEFT_{ijk}$ in equation (4) denotes a judgment of how much time is available in each location until it closes ($CLOSEHOUR_k$). It is obtained from

$$TIMELEFT_{ijk} = CLOSEHOUR_k - HOUR_t - ACTDURATION_j - TRAVTIME_{tok} (\geq 0). \quad (7)$$

If negative, $TIMELEFT_{ijk}$ is set to 0.

Figure 2 shows how the different judgments entailed by equations (1)–(7) are hierarchically organized. Thus, as assumed in the theory, choice of an activity depends on activation, the utility of performing the activity, and the cost of performing it. The cost in turn depends on judged time pressure related to activity duration and travel impediment dependent on both choice of departure time and location.

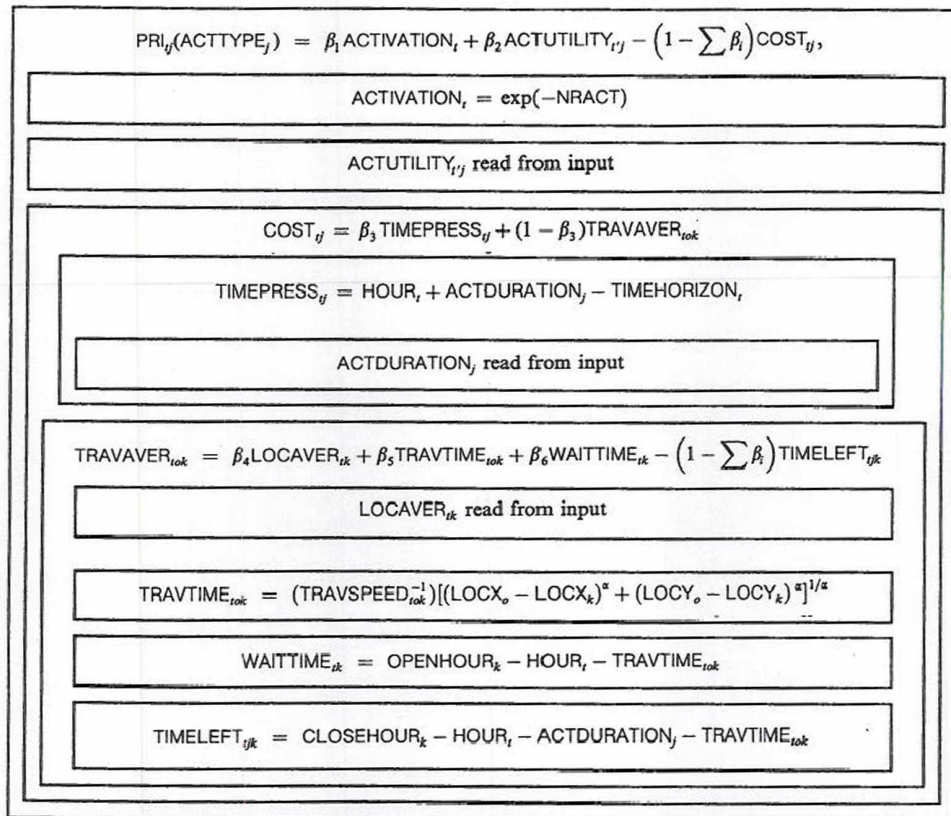


Figure 2. Hierarchical organization of choice rules. (For explanations of terms, see text.)

Computer simulation

If activity scheduling is conceived of as a sequence of choices of activities (see footnote 4), then it would be possible to estimate several separate models by means of conventional disaggregate-choice-modelling techniques (Ettema et al, 1994). The current operational model would be possible to estimate in this way. Yet there are several distinct advantages with simulating the model on a computer. As Engemann et al (1988) note, a computer simulation is instrumental in the development of a 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 (that is, sensitivity analysis). In addition a computer simulation of a *validated* theory offers a testbed for assessing the consequences of different policy measures. On the negative side, the difficulty of aggregating may appear to be a serious drawback. However, in the present case when theory testing is a primary aim, a disaggregate approach should be very sensitive to possible violations of assumptions.

In the following a description is given of the program (SCHEDULER2) (written in TurboPascal6.0 by the second author assisted by William Montgomery) which is being used for simulating the model. As figure 3 shows, there are three input files. The LTC is defined as one of the input files (LTC.INP) containing a list of activities (ACTTYPE) with specified durations (ACTDURATION). In this file the utilities of the activities (ACTUTILITY) are specified for each hour of the time cycle. The information in the CMAP is contained in a second input file (CMAP.INP). In this file activities (ACTTYPE) which can be performed at each location are specified. For each location (LOCTYPE) the x-y-coordinates LOCX and LOCY are given. The earliest time (OPENHOUR) and the latest time (CLOSEHOUR) when an activity can be performed are specified. Information is provided about aversion towards the locations (LOCAVER). The third input file (CONFIG.PAR) consists of the parameters needed in equations (1)–(7) to perform the computations (α , TRAVSPEED_{tok}, and β_i).

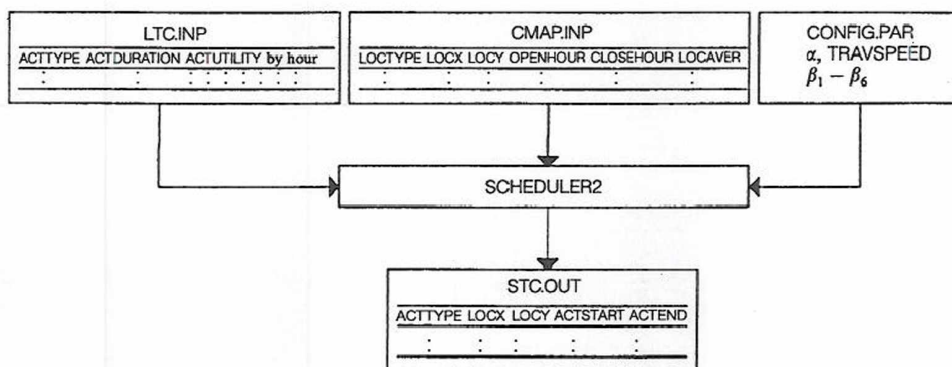


Figure 3. Input and outpile files to SCHEDULER2 (for explanation of terms see text).

The program computes the priority [PRI(ACTTYPE)] of activities remaining in LTC in order of their utilities. Computations are interrupted at any point if PRI(ACTTYPE) is not a positive number. If more than one activity has a positive priority, the activity with the highest value is chosen (or in case of a tie, the activity with the highest ACTUTILITY is chosen).

An output file (STC.OUT) corresponds to the STC. In this file is stored the activity (ACTTYPE), location (LOCX, LOCY), and times (ACTSTART, ACTEND) which were chosen.

Illustrations

Illustrations of the overall performance of SCHEDULER2 are provided by simulating the activity schedule of a fictitious person under various conditions. The environment (CMAP.INP) described in table 1 entails a centrally located department store for grocery shopping, a bank, and a post office. There are two other centrally located banks and post offices with shorter opening hours. As figure 4 shows, the fictitious person is assumed to live either in downtown or far out from downtown. The workplace, a daycare center, and a local grocery store are located in the vicinity of the home. The department store is more attractive than the other locations.

Table 1. Cognitive map (CMAP.INP) used in the simulations of a fictitious person's activity schedule when living centrally or outside the center. (For explanations of terms in this and following related tables, see text.)

LOCTYPE	ACTTYPE	LOCX ^{a,b}	LOCY	OPENHOUR	CLOSEHOUR	LOCAVER
home	home activity	8/2	8	12 am	12 am	1
workplace	work	7/1	9	8 am	6 pm	1
daycare center	leave or pick up child	8/2	9	7 am	7 pm	1
department store	grocery shopping, bank errand, post errand	9	7	10 am	8 pm	1
grocery store	grocery shopping	7/1	8	8 am	8 pm	5
bank office 1	bank errand	7	7	10 am	3 pm	5
bank office 2	bank errand	9	9	10 am	3 pm	9
post office 1	post errand	6	8	9 am	6 pm	5
post office 2	post errand	10	8	9 am	6 pm	9

^a Units in km.

^b 1 indicates an activity which takes place downtown and 2 indicates one which takes place far from downtown.

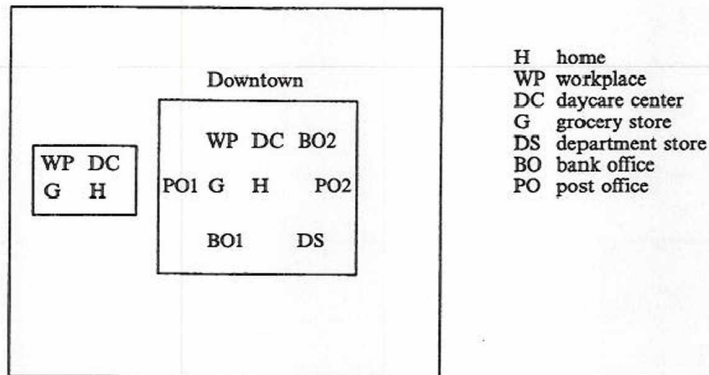


Figure 4. Graphic representation of the environment input (CMAP.INP) in the simulations.

As table 2 (see over) shows, the agenda (LTC.INP) is varied so that the fictitious person works either 4 or 8 hours. Work hours are flexible between 8 am and 6 pm. However, a child must be left and picked up between 7 am and 7 pm. This is expected to take 15 minutes each time. Grocery shopping is the most important additional activity. It takes 1 hour to perform. Bank and post errands are less important items on the agenda. The fictitious person has preferences for when to perform the additional errands, either in the lunchbreak or after work.

Table 2. Activity agenda (LTC.INP) used in the simulations of a fictitious person's activity schedule when working short or long hours.

ACTTYPE	ACTDURATION	ACTUTILITY (7 am to 10 pm) ^a
work am	4 hours	0 9 9 9 9 0 0 0 0 0 0 0 0 0 0
(work pm)	4 hours	0 0 0 0 0 1 9 9 9 9 1 1 1 1 1
leave child	15 minutes	9 1 1 1 1 1 0 0 0 0 0 0 0 0 0
pick up child	15 minutes	0 0 0 0 0 0 1 1 1 1 9 1 1 1 1
grocery shopping	1 hour	1 1 1 1 1 9 1 1 1 1 1 9 9 9 9
bank errand	30 minutes	1 1 1 1 1 5 1 1 1 1 1 5 5 5 5
post errand	30 minutes	1 1 1 1 1 1 1 1 1 1 1 1 1 1 1

^a A 0 means that the activity cannot be performed. It is here used to guarantee that a certain activity is not performed before another one.

Table 3 displays the activity schedules (STC.OUT) when the fictitious person for different home locations either only has access to public transport (travel speed set to 7.5 km per hour which is an average value in metropolitan areas of Sweden), or uses an automobile (travel speed set at the approximate average value of 15 km per hour). In the simulations, weights were chosen to be approximately inversely proportional to the maximum range of a variable. City-block distances were computed ($\alpha = 1$).

The simulation results showed that the model is sensitive both to agenda and to environmental differences. Only when work hours are short are all errands performed. For long work hours no errands are performed in the lunchbreak. After work, time allows only grocery shopping which is the most important errand. An exception is when the person lives far from the center. In this case the least important post errand is also performed. This is because a post office happens to be closer than the preferred grocery store.

The most preferred location (the department store) is always chosen for grocery shopping. However, even though a bank and post office are also available in the same location, only once is one of them chosen. This is because the bank and post errands are performed before grocery shopping at locations which are closer to the workplace. Similarly, the child is picked up immediately after work because of the closeness of the daycare center.

Living away from the center and the choice of public transport over automobile affect only total time away from home. The effect is, however, substantial, in particular for living away from the center with long travel times.

In conclusion, it may be noted that an important aspect of the results is whether they indicate that the different conditions made it possible for the simulated person to perform all activities at preferred times and locations. This criterion is similar to utility maximization. As one should expect, in particular long work hours but also living away from the center and slow travel speed prevented maximization of preferences. Thus, in this respect the simulation results appear to be realistic. Still, a few exceptions should be noted. First, in all simulations the person arrives at work earlier. However, this is only because the model does not distinguish between waiting time being spent at the origin or at the destination. Second, travel times were longer than they needed to be because subjects did not perform several activities in the same location when they could. Basically, this reflects the fact that the model does not take into account subsequent choice alternatives. To do this generally would not be realistic because of the dramatic increase in demand on foresight. Third, the child was picked up earlier than was optimal. Because this result depended on closeness of the daycare center it again reflected lack of foresight.

Table 3. A fictitious person's simulated activity agendas (STC.OUT).

ACTTYPE	Slow travel speed ^a				Fast travel speed ^b			
	LOCX	LOCY	ACTSTART	ACTEND	LOCX	LOCY	ACTSTART	ACTEND
<i>Living in the center</i>								
Short work hours								
Start	8	8	7.00 am		8	8	7.00 am	
Leave child	8	9	7.08 am	7.23 am	8	9	7.04 am	7.19 am
Work	7	9	8.00 am	12.00 am	7	9	8.00 am	12.00 am
Bank errand	7	7	12.15 pm	12.45 pm	9	7	12.08 pm	12.38 pm
Grocery								
shopping	9	7	1.00 pm	2.00 pm	9	7	12.45 pm	1.45 pm
Post errand	9	7	2.00 pm	2.30 pm	9	7	1.45 pm	2.15 pm
Pick up child	8	9	2.54 pm	2.11 pm	8	9	2.27 pm	2.42 pm
End	8	8	3.19 pm		8	8	2.46 pm	
Long work hours								
Start	8	8	7.00 am		8	8	7.00 am	
Leave child	8	9	7.08 am	7.23 am	8	9	7.04 am	7.19 am
Work	7	9	8.00 am	4.00 am	7	9	8.00 am	4.00 am
Pick up child	8	9	4.08 pm	4.23 pm	8	9	4.04 pm	4.19 pm
Grocery								
shopping	9	7	4.45 pm	5.45 pm	9	7	4.31 pm	5.31 pm
End	8	8	6.01 pm		8	8	5.39 pm	
<i>Living outside the center</i>								
Short work hours								
Start	2	8	7.00 am		2	8	7.00 am	
Leave child	2	9	7.08 am	7.23 am	2	9	7.04 am	7.19 am
Work	1	9	8.00 am	12.00 pm	1	9	8.00 am	12.00 pm
Post errand	6	8	12.48 pm	1.18 pm	6	8	12.24 pm	12.54 pm
Bank errand	7	7	1.34 pm	2.04 pm	7	7	1.02 pm	1.32 pm
Grocery								
shopping	9	7	2.20 pm	3.20 pm	9	7	1.40 pm	2.40 pm
Pick up child	2	9	4.32 pm	4.47 pm	2	9	3.16 pm	3.31 pm
End	2	8	4.55 pm		2	8	3.35 pm	
Long work hours								
Start	2	8	7.00 am		2	8	7.00 am	
Leave child	2	9	7.08 am	7.23 am	2	9	7.04 am	7.19 am
Work	1	9	8.00 am	4.00 pm	1	9	8.00 am	4.00 pm
Pick up child	2	9	4.08 pm	4.22 pm	2	9	4.04 pm	4.19 pm
Post errand	6	8	5.02 pm	5.32 pm	6	8	4.39 pm	5.09 pm
Grocery								
shopping	9	7	5.48 pm	6.48 pm	9	7	5.25 pm	6.25 pm
End	2	8	8.02 pm		2	8	6.57 pm	

^a Public transport.^b Automobile.

Summary and discussion

In this paper a theory of household activity scheduling was presented. This theory is still far from the goal of such a theory set out in Gärling et al (1989a; 1994). Although the goal has not yet been achieved, the current operational model which makes computer simulation feasible is a step forward. Illustrations of computer simulation were provided. Before we briefly comment on the results of these, some needed improvements to the theory and operational model will be highlighted (see also Golledge et al, 1994).

It may first be noted that the theory in one respect actually goes further than the operational model. Several definite statements are made of principles for how learning affects activity scheduling. It would not be too difficult to implement these principles in SCHEDULER2. Such implementation should clearly improve the realism of the computer simulation. However, as already noted, empirical estimation of the operational model may be made more difficult.

In other respects the theory is vague. The possibility of accuracy-effort trade-offs underlying, for instance, the choice of decision rule is noted. Unlike the model of Hayes-Roth and Hayes-Roth (1979), the theory does not specify how different decision rules, weights of evaluation criteria, and planning horizon depend on such trade-offs. To specify the theory in these respects is a most important future task.

There are also some important omissions. First, the theory does not specify how travel mode is chosen. Although it may appear to be a serious shortcoming because many other comparable discrete-choice models incorporate mode choice (see Axhausen and Gärling, 1992), the following line of reasoning leads to the conclusion that it may be possible to do this without changing the operational model. Travel mode choice is not likely to be made for single trips but for home-based trip chains. As was shown, such trip chains can be simulated for different travel speeds. Still, it would be valuable to include the actual choice. It may be necessary then to relate it to properties of the activity schedules for the different modes. Some such attempts have been reported (for example, Adler and Ben-Akiva, 1979; Recker et al, 1986a; 1986b). However, it is unrealistic to expect that people plan two activity schedules between which they then make a choice. Rather they are likely to start scheduling on the assumption that they can (cannot) use the automobile, then find out whether or not it is feasible according to some criteria. Apparently, this process of activity scheduling and mode choice would be of great interest to study. SCHEDULER2 should provide an appropriate frame of reference for such studies.

Second, as noted by Gärling et al (1989a; 1994), although activity scheduling is made individually most of the time, it may still be necessary to model the activity scheduling of others simultaneously (for example, other household members) to be able to represent constraints validly. Furthermore, an important future question to address would be how social interaction affects activity scheduling, in particular lack of or distortions of information transmitted from one individual to another. The presence of social obligations is another, possibly important, factor to take into account (Axhausen and Gärling, 1992).

The present computer simulations were provided only as illustrations. Still, the validity of the operational model and the theory itself may to some extent be judged from the degree of realism the simulation results exhibit. On the basis of such a crude criterion the results appear encouraging. However, more stringent tests using actual observations are of course needed. In such tests the relatively few free parameters of the model should be possible to determine to obtain the best fit to actual observations.

How then can the operational model be tested empirically? A first strategy is to perform comparative tests of existing similar models (for example, Ettema et al, 1994) to determine identifiability. If such tests include models estimated from data [for example, discrete-choice models (see Axhausen and Gärling 1992)], they will provide empirical evidence. In addition such tests need to be accompanied by thorough analyses pinpointing conceptual differences and similarities.

Another avenue of research is to subject to empirical tests explicit behavioral assumptions entailed by the theory. As an illustration of this approach, in a series of psychological experiments Gärling and associates (for example, Gärling, 1994b; Gärling et al, 1986; Hirtle and Gärling, 1993) have investigated assumptions about how spatial

and temporal information is processed in activity scheduling. But because these results have been used in building the operational model, further research is needed. A new and promising method for directly collecting data on activity scheduling is being developed by Ettema et al (1993) and would be most valuable to use in this research. This method consists of a computerized interactive interview procedure in which subjects schedule a specified set of activities (for example, those intended to be performed on the following day). In addition to details of the activity schedule, data are collected on how subjects proceed when scheduling the activities, how the activities are perceived (for example, how important they are, how routinely they are performed), where they are usually performed, typical durations, and typical travel modes.

Finally, activity and travel diary data should be collected to test the theory. As illustrated in Golledge et al (1994), a geographical information system can be used in a case-study approach. At present this research strategy may turn out to be more costly and difficult than the others. Before it is chosen, the operational model should therefore be thoroughly validated by the other means.

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