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Simulation Model of Activity Scheduling Behavior

DICK ETTEMA, ALOYS BORGERS, AND HARRY TIMMERMANS

The simulation model of activity scheduling behavior presented is influenced by recent theories of activity scheduling and production system modeling. The basic assumption underlying the model is that activity scheduling is a sequential process in which consecutive steps lead to the final schedule. Every step in this respect is modeled as a choice of an action to perform on a preliminary schedule. The behavior of the model was tested using simulations in different hypothetical spatio-temporal settings. The simulations were conducted repeatedly, varying the values of the parameters of the model systematically. In general, the simulations resulted in realistic schedules. The proposed approach therefore offers possibilities to model activity scheduling realistically. The next step, however, should be to develop calibration methods so that parameter values can be derived from observed behavior. Interactive simulations may be a promising technique in this respect.

Over the past few decades, travel has been increasingly regarded as a derivative of activities, implying that knowledge about the way people choose activities to perform and schedule these in space and time is crucial for understanding and predicting travel behavior (*1*). As a result of changing roles and lifestyles of individuals, activity patterns and travel behavior become increasingly more complex, making it difficult to forecast the impact of policy measures affecting travel behavior. The goal of travel behavior research therefore has moved from predicting single travel decisions to understanding how many of the mutually related decisions that lead to activity patterns and their associated travel behavior are made. Consequently, activity scheduling behavior has become a topic of interest. Activity scheduling can be regarded as the planning process preceding travel that determines what activities to perform and in which sequence the locations, the starting and ending hours of activities, and the route and travel modes are chosen.

Certain aspects of activity scheduling behavior have been addressed by such approaches as trip chaining models, activity choice models, time allocation models, and descriptive studies using activity diaries. [A discussion of these efforts is beyond the scope of this paper, refer to Kitamura (*2*) for a review.] To date, however, the only comprehensive model of activity scheduling is the STARCHILD model (*3,4*), which can be regarded as an extension of constraint-based approaches such as CARLA (*1*) and PESASP (*5*). Both CARLA and PESASP are based on Hägerstrand's space-time prism concept (*6*). STARCHILD uses a combinatorial algorithm to create all feasible patterns in a given situation and then selects the most attractive pattern. The approach assumes optimal choice behavior and the ability to select the best pattern out of a very large set.

This paper presents an alternate approach inspired by the theories of Root and Recker (*7*) and Gärling et al. (*8*) and production system modeling. The model assumes a heuristic, suboptimal way of problem solving. In addition to activity schedule characteristics, the model also incorporates the cost of scheduling effort, implying that the expected utility of the schedule is weighted against the efforts needed to find a better schedule.

The remainder of this paper discusses the following:

- Theoretical considerations concerning activity scheduling. The two most comprehensive theories of activity scheduling, the SCHEDULER framework (*8*) and the theory developed by Root and Recker (*7*), are briefly described.
- A model based on the theoretical insights to activity scheduling. This model will also be compared with the existing scheduling model STARCHILD.
- Testing the activity scheduling model using simulations in different hypothetical spatio-temporal settings and the results of these simulations.
- The results and possibilities of the modeling technique and some directions for future research are addressed.

THEORIES OF SCHEDULING BEHAVIOR

As activity pattern research has focused primarily on descriptive studies of revealed patterns, little documentation on the process underlying activity scheduling is available. The two most comprehensive frameworks to date have been developed by Root and Recker (*7*) and Gärling et al. (*8*).

Root and Recker state that individuals will generate activity patterns that give them maximum utility, subject to constraints such as opening hours of facilities and performance of the transportation system. That is, the utility gained from participation in activities is weighted against the disutility of travel needed for participation. Regarding the choice process preceding the formulation of an activity pattern, some remarks are made. First, the disutility of the scheduling effort needed for complex trip chains may be greater than the utility of combining multiple sojourns in a single trip. Thus, the cost of scheduling will influence the outcome of the scheduling process. This is an important conclusion because it implies that activity scheduling cannot be regarded as an optimizing problem in the sense that travel is minimized or utility is maximized per se. Rather a satisficing process will take place

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in which an acceptable schedule is created with acceptable effort.

Second, Root and Recker (*7*) distinguish a pretravel and a travel phase in the generation of activity patterns. In the pretravel phase, an activity program that maximizes the expected utility is constructed based on expected activity durations and travel times. However, during execution, activities or trips may require more or less time than expected. Depending on the pattern being "ahead" or "behind" schedule, the schedule may be adjusted by adding or removing activities or by changing the sequence or locations.

Finally, Root and Recker (*7*) point to the fact that the process of activity scheduling consists of several stages at which travel/activity decisions are taken. They assume that at each stage a utility is maximized, which consists of the utility of the travel decision itself and the expected utilities in later stages. The relation between the consecutive travel decisions can vary from completely independent, implying a suboptimal final result, to fully integrated, implying an optimal final result. Thus, a stepwise decision process in which an optimization occurs per step will lead to a more or less optimal solution.

The SCHEDULER theory [Gärling et al. (*8*)] focuses specifically on the scheduling process itself. The SCHEDULER framework assumes that some heuristic search is followed in the scheduling process. An individual is supposed to select a set of activities to be performed from the so-called long-term calendar (LTC). Also information is sought about when and where activities can be performed. On the basis of temporal constraints, the activities are first partially sequenced. The sequence is then optimized using a nearest-neighbor heuristic (*9*).

Next, starting with the first activity, the schedule is mentally executed. This means that a more detailed schedule is formed in which mode choice, activity durations, travel times, and waiting times are determined. In the stage of mental execution, the first sequence formed may be altered if conflicts between activities (e.g., overlapping starting and finishing times) occur. Other possibilities are the replacement of an activity with an activity of lower priority or the adding of activities from the LTC when open time slots are present in the schedule. When the mental execution is finished, the first activity is carried out. It is important to note that the scheduling process continues during the execution of the schedule. The schedule can then be revised if it cannot be executed as was initially expected.

It should be noted that the stepwise, suboptimal planning process of activity scheduling of the above theories is analogous to problem-solving strategies that are studied in the field of cognitive science and artificial intelligence. It is assumed that individuals, when faced with complex problems, will use heuristic rules to find a solution path through the state space, mostly resulting in a satisfactory but not optimal solution (*10*). Such heuristic search procedures are typically modeled by production systems, which are based on the way individuals store and process information. The application of production systems to activity scheduling has been suggested by Hayes-Roth and Hayes-Roth (*11*) and Golledge et al. (*12*). A problem with production systems, however, is that to date no calibration methods have been developed to match observed scheduling behavior and production systems. This is mostly due to the fact that the heuristics are defined in very specific IF . . . THEN . . . rules, making it difficult to generalize the behavior of the model.

The model presented in this paper incorporates several elements of the above frameworks: the stepwise construction and adaptation of the schedule, the suboptimal planning strategy, the use of heuristics avoiding the creation of all feasible patterns, and the incorporation of scheduling costs in the model. However, heuristics are defined in a more general way than is the case with production systems to make it easier to link the model to observed behavior.

SPECIFICATION OF MODEL

The task of the production system described in this section is to create a schedule for a 1-day period (7:00 a.m. to 12:00 p.m.). To complete this task, the following data are provided. An agenda containing activities to perform is assumed. The duration and the priorities of these activities are specified. Second, data are available on the opening times of facilities to perform activities, travel times between all pairs of locations (so far no distinctions have been made among transport modes, and travel times are measured "as the crow flies"), and the attractiveness of the locations.

The scheduling process is assumed to be a sequential process consisting of a number of consecutive steps. In every step, the schedule, which is empty at the beginning of the process, can be adjusted by one of the following basic actions:

- Adding an activity from the agenda to the schedule. The activity can be inserted on every place in the sequence.
- Deleting an activity from the schedule. In this case, the deleted activity is placed on the agenda again.
- Substituting an activity from the schedule with an activity from the agenda. The new activity can be inserted on every place in the sequence.
- Stopping the scheduling process. In this case, the schedule created will be the final schedule.

Thus by repeatedly applying one of these basic actions, the schedule is constructed and adapted, until a satisfactory schedule is created. In the schedule, only the locations and the sequence of the activities are stored. It is believed that the exact starting and finishing times are determined by the actual duration of previous activities for temporally nonfixed activities and are inherent to temporally fixed activities.

In every planning step, the production system creates all possibilities to perform the basic actions. For instance, in the case of substitution, all activities in the schedule can be replaced by all activities on the agenda, which can be inserted on every place in the sequence. Of all possible variants, the action that gives the highest utility is performed. The utility of the stop action is zero by definition. This implies that the process is aborted if the utilities of all variants of the add, delete, and substitute actions are less than zero. The utilities of these actions are defined as follows:

$$V_j = \alpha_j + \beta_{j1}\,\mathrm{TIMES}_j + \beta_{j2}\,\mathrm{SINCE}_j + \beta_{j3}\,\mathrm{COUNT}_j + \sum_{l=1}^{9} \gamma_l Y_l \qquad (1)$$

where

V_j = utility of action of type j (the action types will be denoted by subscripts add, del, and sub);
α_j = an alternative specific constant for action type j;
TIMES_j = number of actions of specific type j that has been taken so far;
SINCE_j = number of scheduling steps since last performance of action of type j;
COUNT_j = number of scheduling steps applied so far in scheduling process, (this is an alternative specific variable for every action type);
COUNT_j, TIMES_j, and SINCE_j = state-dependent variables of model;
β_{jk} = a parameter indicating importance of state-dependent variable;
Y_l = generic variables, namely, attributes of schedule resulting from action; and
γ_l = parameter indicating importance of attribute Y_l.

Nine attributes of Y_1 have been selected for the simulation experiment based on a literature search.

Attribute 1—The spatial configuration of the schedule. It is supposed that an individual tries to minimize distance within certain limits by spatially clustering activities. This clustering was observed in a "think aloud" protocol by Hayes-Roth and Hayes-Roth (*11*). The impact of the spatial configuration was also found by Gärling et al. (*9*). The following measure of the degree of clustering (CONFIG) was developed:

$$\text{CONFIG} = \begin{cases} \sqrt[N]{\prod_p \prod_q \exp\left(\frac{|d_{pq} - \bar{d}|}{\bar{d}}\right)}\,\bar{d} & (p \neq q) \quad \text{if } N \geq 2 \\ 0 & \text{if } N \leq 1 \end{cases} \tag{2}$$

where

p, q = subscripts denoting locations visited in schedule,
d_{pq} = travel time between location p and location q,
$\bar{d}$ = average travel time between all location pairs, and
N = number of locations visited.

In the case of $N \geq 2$, the first term is a measure of the deviation around the average mutual distance between all location pairs. The value will be 1 in the case of equal distances between all location pairs. In the case of outliers, this value and CONFIG will increase. The second part, being the average distance between all location pairs, implies that the value of CONFIG increases as the locations are more scattered about the area. Consequently, if the locations are situated very close to each other, $\bar{d}$ and therefore CONFIG will be almost zero. The value of CONFIG for situations with one location logically is determined at zero. Thus, the minimum value of CONFIG is zero in the case of optimal spatial concentration. In the case of more dispersed configurations or outliers, CONFIG increases.

Attribute 2—The time spent on activities. It is assumed that individuals try to maximize the amount of time spent on activities. The measure TIMEUSED is calculated as the sum of the durations of the scheduled activities, excluding travel time.

Attribute 3—The percentage of scheduled activities. As mentioned before, individuals try to include as many activities as possible from the agenda in the schedule, especially those with a high priority. The measure PERSCHED therefore is defined as the percentage of the activities on the agenda that are scheduled, in which the priority of every activity is used as a weighting factor:

$$\text{PERSCHED} = \frac{\sum_{i \in S} Pr_i}{\sum_{i \in T} Pr_i} \cdot 100 \tag{3}$$

where

Pr_i = priority of activity i, defined on a 0–10 scale,
S = set of scheduled activities, and
T = set of activities, both scheduled and not, on agenda.

Attribute 4—The location of activities in the schedule in relation to the locations of activities not yet scheduled. This measure accounts for the propensity of individuals to incorporate future activities in their scheduling decisions. It is assumed that one prefers to perform an activity on such a location that other activities can be performed in its vicinity. For instance, one might choose to do one's shopping at a particular mall because it offers the possibility to combine the trip with visits to the library, the post office, etc. A location is more attractive when other important activities can be included. This factor was also described in the experiment by Hayes-Roth and Hayes-Roth (*11*). Other empirical support comes from Kitamura (*13*), who found that the choice of a destination was influenced by the possibility to reach other locations afterward. The measure NEAROTH therefore can be defined as:

$$\text{NEAROTH} = \frac{\sum_{i \in S} \sum_{j \in R} d_{ij}^{\min} Pr_j}{N_S N_R} \tag{4}$$

where

$d_{ij}^{\min}$ = travel time between location where i is performed and closest location where j can be performed,
Pr_i = priority of activity i and is measured on a 0–10 scale,
N_S = number of elements in S,
N_R = number of elements in R,
S = set of scheduled activities, and
R = set of activities on agenda that have not yet been scheduled.

Attribute 5—The attractiveness of the locations visited. It seems plausible that individuals try to optimize the utility of the schedule by visiting the locations with the highest utilities. For instance, Borgers and Timmermans (*14,15*) demonstrate the influence of the floorspace of shops on the destination choice of pedestrians in shopping areas. To capture this effect, the measure UTILLOC (utility of locations) is given by:

$$\text{UTILLOC} = \frac{\sum_{i \in S} U_i}{N_S} \tag{5}$$

where

S = set of scheduled activities,
U_i = utility of the location at which activity i is performed, and
N_S = number of activities scheduled.

Attribute 6—The total travel time implied by the schedule. It is recognized that individuals try to minimize the travel time and distance of their schedules within certain limits [see van der Hagen et al. (*16*)]. The measure TRAVTIME (travel time) accounting for this is simply the sum of the travel times between all consecutive pairs of locations in the schedule:

$$\text{TRAVTIME} = \sum D_i \tag{6}$$

where D_i is the travel time for the ith trip.

Attribute 7—The latest possible finishing times of the scheduled activities. It is supposed that individuals prefer to schedule first those activities for which the least time is left. Lundberg (*17*) also uses this factor in his simulation model. To operationalize this measure, the latest possible finishing time (LASTEND) of the last activity in the schedule is taken.

Attribute 8—The length of open slots in the schedule. Recker et al. (*3*) mention the disutility derived from waiting times at locations out of home. It can therefore be assumed that people try to minimize waiting times implied by the schedule. To calculate a measure for this effect, all the waiting times implied by the sequence of activities, travel times, and opening hours of facilities are summed. The measure WAITTIME is given by:

$$\text{WAITTIME} = \sum W_i \tag{7}$$

where W_i is the duration of the ith waiting time.

Attribute 9—The chance of completing the schedule. In this stage of model development, it is checked whether the schedule can be executed given durations, travel times, and availability times. If a schedule can be performed, the measure CHANCE (chance of completing) is assigned the value 1, if it cannot be performed it is assigned the value 0. In a later phase, however, when durations and travel times are considered to follow some statistical distribution, probabilities could be calculated more accurately.

The general behavior of the model will basically be determined by the parameters α and β of Equation 1. Specifically, α and β_{j2} will have positive values, and β_{j1} and β_{j3} will have negative values. This will lead to the execution of several ADD, DEL, and SUB actions before their utility decreases below zero due to the COUNT and TIMES variables. In that case, the STOP option is selected. By manipulating the exact parameter values, higher propensities to revise the schedule or to invest more effort in the scheduling process itself can be simulated. The values Y_1 determine which specific variant of an action type is selected. The values of the parameters γ in this respect indicate the importance of the attributes in every separate scheduling step. The parameters γ and the attribute values Y_1 determine which variant of every action type is the most favorable. Finally, the action that has the highest utility implied by both the state-dependent and the other variables will be selected.

When compared with STARCHILD, the above model clearly adopts a different principle. According to the STARCHILD mechanism, an individual would be able to optimize his or her activity pattern by creating a large number of alternative patterns and select the most favorable. In reality, however, as mentioned by Root and Recker (*7*) and Gärling et al. (*8*) individuals will use heuristic search procedures leading to suboptimal solutions.

The model presented here includes heuristic search procedures by assuming a stepwise, sequential planning process. Analogous to the nearest neighbor heuristic, the best "following step" is selected repeatedly, implying that suboptimal solutions will in principle be reached. In this process, the cost of scheduling is also accounted for. The heuristics used in the model are defined in a very general way, so that by manipulating the parameters of the model, the effect of the heuristics can be modified. In this regard, the model differs from production system models where heuristics are defined by very specific IF . . . THEN . . . rules. Therefore it will be easier to generalize the results of this model compared with production system models.

Finally, it is important to note that the mechanism of the model allows for the adjustment of the schedule during the travel phase. After completing an activity or a trip, the schedule for the rest of the planning period can be adjusted by the basic actions described earlier in this section. If and how the schedule is adjusted will depend on the utilities of possible adaptations and the utility of the existing schedule. The utilities may be affected by congestion resulting in delayed travel times or unexpected durations of activities so that the chance of completing the schedule decreases. The impact of information on expected travel times in a congested area can be described in a similar way. Also, the priorities of activities may change during the course of day, affecting the utility of the schedule through the attributes PERSCHED and NEAROTH. In this way, activities with a short planning horizon can be added to the schedule.

SIMULATIONS

The model described above was used to complete a simulation experiment that produced activity schedules in eight hypothetical spatio-temporal settings. Of these settings the following data were specified (see Table 1):

1. A travel time matrix containing travel times between every pair of locations.

TABLE 1 Description Scheduling Tasks

	SITUATIONS 1,3 AND 4					SITUATION 2				
activity	utility location	earliest start time*	latest end time	priority (0-10 scale)	duration (0.01 hours)	utility location	earliest start time	latest end time	priority (0-10 scale)	duration
breakfast	10	700	800	10	25	10	700	800	10	25
work	5	800	1800	10	800	5	800	1800	10	800
going to grocery	1	900	1800	5	25	1	900	1900	5	25
	5	900	1800			5	900	1900		
preparing and having supper	10	1800	2000	10	150	10	1800	2000	10	150
sports	10	1900	2300	2	150	10	1900	2300	2	150
visiting friends	2	1900	2300	2	100	2	1900	2300	2	100
going to postoffice	1	900	1750	5	15	1	900	1900	5	15
	5	900	1750			5	900	1900		
going to bakery	5	900	1800	5	10	5	900	1900	5	10
going to library	8	900	2100	2	25	8	900	2100	2	25
deliver a parcel	2	900	2100	2	5	2	900	2100	2	5

	SITUATIONS 5,7 AND 8					SITUATION 6				
	utility location	earliest start time	latest end time	priority (0-10 scale)	duration (0.01 hours)	utility location	earliest start time	latest end time	priority (0-10 scale)	duration
breakfast	10	700	800	10	100	10	700	800	10	100
bring children to school	5	825	850	10	5	5	825	875	10	5
get children from school	5	1250	1300	10	5	5	1225	1300	10	5
lunch	10	1300	1400	10	75	10	1300	1400	10	75
work	5	800	1300	10	300	5	800	1900	10	300
going to grocery	5	900	1800	2	15	5	900	1900	2	15
	1	900	1800			1	900	1900		
preparing and having supper	10	1600	1900	10	150	10	1600	1900	10	150
bring children to sports club	1	1900	1905	10	5	1	1900	1905	10	5
get children from sports club	1	2050	2055	10	5	1	2050	2055	10	5
go shopping	9	900	1800	2	40	9	900	1900	2	40
sports	3	1900	2300	2	100	3	1900	2300	2	100
visiting friends	8	1900	2300	2	100	8	1900	2300	2	100

* for computational ease, an hour is determined to have 100 'minutes'

2. A list of activities to perform, with their priority and expected duration.
3. A specification of the utilities of all possible locations.
4. Information concerning where and when activities can take place. For every activity, the locations and the opening hours of facilities are specified.

The eight situations relate to a hypothesized single working person and a hypothesized working parent, combining child care and work. The reason for this is that both groups are recognized to have problems executing their activity schedules under current spatio-temporal circumstances. In the first four situations, relating to a single working person, the same list of activities to perform is specified. The spatio-temporal settings however differ. Situations 1 and 2 relate to an urban setting, whereas situations 3 and 4 represent a suburban setting. In situation 2, shop hours are extended relative to situation 1, and some facilities are located in the direct surroundings of the work location. Situations 3 and 4 are identical, except for the travel times, which are significantly shorter in situation 4. Because of the short travel time, either a bicycle or a car could be the transportation mode.

In situations 5 through 8, relating to a working parent combining child care and work, the same list of activities to perform is specified. Situations 5 and 6 represent an urban setting, while situations 7 and 8 relate to a suburban/rural setting. Situations 5 and 6 differ in that situation 6 offers the more flexible work and shopping hours. In situation 7, most of the facilities are located in the city, but the residence is located in an adjacent village. In situation 8, all facilities are scattered about several municipalities.

The simulation was conducted repeatedly with different settings of the parameter values to examine how this affects the model's behavior. As there are 3 alternative specific constants, 9 state-dependent variables, and 9 attributes, 21 parameters were manipulated by a 3^{21} orthogonal fractional design using 54 treatments. The design values are displayed in Table 2. The values were determined by trial and error so that, in general, schedules were created containing about half of the activities on the agenda. The signs of the parameters α and β are chosen according to the hypothesized control mechanism described in the previous section. In addition, the attribute measures Y_1 were rescaled such that their values lie within a range of 1 to 10 and the relative importance of the attributes can be examined properly.

Thus in the simulation, 54 activity schedules were created for every hypothetical setting. A program written in Turbo PASCAL 6.0 conducted the simulations. The program encompasses the control mechanism described previously and a combinatorial algorithm to create all possible adaptations of the schedule. The data describing the spatio-temporal settings were provided in data files as was the design. The program

TABLE 2 Attribute Values Design and Examples

parameter	attached to variable	value level 1	value level 2	value level 3	example 1	example 2
α_1	constant add	32	34	36	36	34
α_2	constant delete	-6	-4	-2	-6	-6
α_3	constant substitute	1	3	5	3	5
$\beta_{add,1}$	$\text{TIMES}_{\text{ADD}}$	-2	-4	-6	-2	-4
$\beta_{add,2}$	$\text{SINCE}_{\text{ADD}}$	1	2	3	1	2
$\beta_{add,3}$	$\text{COUNT}_{\text{ADD}}$	-3	-4	-5	-3	-5
$\beta_{del,1}$	$\text{TIMES}_{\text{DEL}}$	-4	-5	-6	-5	-5
$\beta_{del,2}$	$\text{SINCE}_{\text{DEL}}$	1	2	3	2	3
$\beta_{del,3}$	$\text{COUNT}_{\text{DEL}}$	-5	-6	-7	-7	-5
$\beta_{sub,1}$	$\text{TIMES}_{\text{SUB}}$	-3	-4	-5	-5	-3
$\beta_{sub,2}$	$\text{SINCE}_{\text{SUB}}$	1	2	3	2	1
$\beta_{sub,3}$	$\text{COUNT}_{\text{SUB}}$	-4	-5	-6	-6	-6
γ_1	CONFIG	-1	-2	-3	-1	-2
γ_2	PERSCHED	1	2	3	1	3
γ_3	NEAROTH	-1	-2	-3	-1	-1
γ_4	UTILLOC	1	2	3	2	2
γ_5	TRAVTIME	-1	-2	-3	-2	-3
γ_6	WAITTIME	-1	-2	-3	-3	-1
γ_7	LASTEND	-1	-2	-3	-2	-3
γ_8	CHANCE	1	2	3	3	1
γ_9	TIMEUSED	1	2	3	2	1

recorded the following data concerning the scheduling process and its outcome:

- The schedules created, that is, a list of activities that will be performed of which the sequence and location are determined;
- For every schedule, the attribute values (CONFIG, PERSCHED, NEAROTH, UTILLOC, TRAVTIME, WAITTIME, LASTEND, CHANCE, and TIMEUSED) of the schedule;
- For every schedule, the number of times every action type was applied (NRADD, NRDEL, and NRSUB); and
- For every schedule, the number of steps needed to create the schedule (NRSTEPS).

ANALYSIS

One of the main objectives of the simulation experiment was to find out if the proposed modeling approach generates realistic activity schedules. In this respect, it was examined what activities were included in the schedules and whether the characteristics of the schedules were affected logically by different hypothetical situations and different parameter sets.

First, two examples of schedules that were created are described. The schedules were created for situation 1 based on the parameter sets displayed in Table 2 (Examples 1 and 2). In the first example, there is a higher propensity to include activities in the schedule as indicated by α_{add}, $\beta_{add,1}$ and $\beta_{add,3}$. Moreover, the disutility of travel time (γ_5) and late finishing times (γ_7) is less important in the first example, while the maximization of time spent on activities is more important (γ_9). These characteristics are reflected by the schedules that were created (see Figure 1 and Table 3). In the first example,

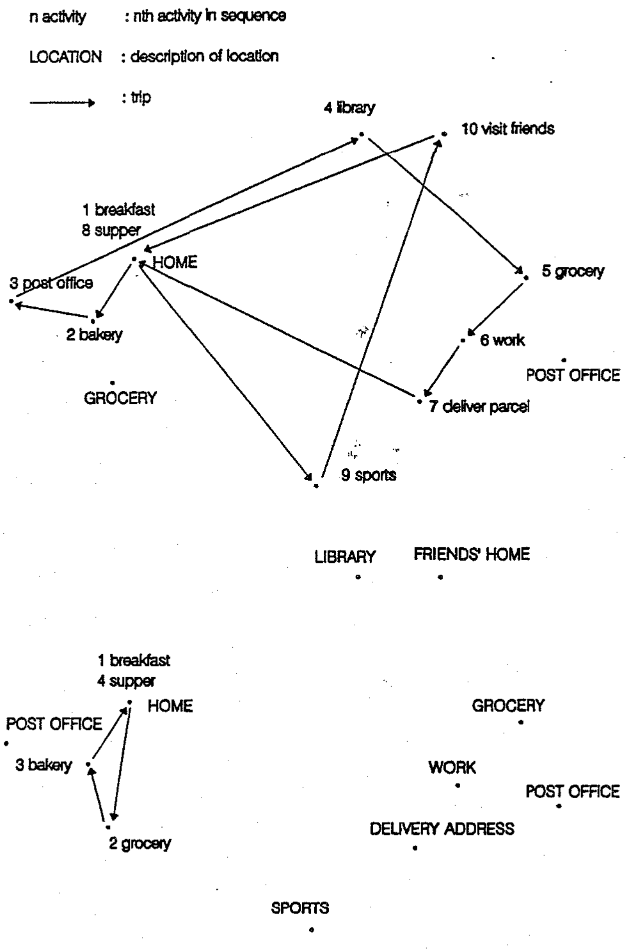

FIGURE 1 Examples, Activity Pattern 1 (*top*) and Activity Pattern 2 (*bottom*).

TABLE 3 Percentage of Schedules in Which Activities Are Included

	breakfast	bring child to school	get child from school	lunch	work	going to grocery	having supper	bring child to sport	get child from sport	shopping	sports	visit friends	going to post-office	going to bakery	going to library	deliver parcel
situation 1	94				74	69	100				59	46	80	80	63	65
situation 2	96				72	76	100				65	52	81	85	67	57
situation 3	96				15	48	100				15	15	61	65	15	28
situation 4	93				76	78	100				67	54	100	98	61	70
situation 5	100	35	46	94	61	80	100	35	35	61	52	52				
situation 6	100	31	37	96	63	76	100	39	41	59	54	59				
situation 7	100	15	24	94	24	46	94	20	24	24	15	24				
situation 8	100	30	26	98	43	30	98	30	39	31	28	37				

situation 1 : single worker, urban situation
situation 2 : as situation 1, but with facilities concentrated at the work spot and extended opening hours shops
situation 3 : single worker, suburban situation, transportation mode bicycle
situation 4 : single worker, suburban situation, transportation mode car
situation 5 : working mother, urban situation
situation 6 : as situation 5, but with extended opening hours shops
situation 7 : working mother, suburban situation
situation 8 : working mother, rural situation

all activities are included. In the second example, only four activities are scheduled, of which only two are out of home. Consequently, more time is spent on travel (TRAVTIME) and activities (TIMEUSED) in the first example. The planning horizon is also longer in this case (LASTEND), and more effort is invested in the planning process (NRSTEPS). As more locations are visited, the degree of clustering is less in the first case (CONFIG). The waiting time out of home in both cases is zero. When looking at routing and sequencing, it can be concluded that distance is minimized and space is used efficiently. However, the sequence in which activities take place is somewhat unusual (shopping before work), as in this stage preferences for particular sequences are not yet incorporated in the model. It should be noted that the above examples represent two extreme situations based on extreme parameter sets, of which the second is especially unrealistic (e.g., work is excluded in the schedule). In most cases, however, a considerable number of activities is included in an efficient schedule.

Another way to view the results is to compare the characteristics of the schedules created in different hypothetical situations. These values, which are the average of the attributes over the 54 parameter sets, are displayed in Table 4.

The average number of activities included in the schedules ranges from three to nine in the different hypothetical situations. Within the situations, this figure is rather stable, as can be concluded from the standard deviations. When looking at the activities that are included in the schedule, it appears that obligatory activities, such as breakfast (93–100 percent), lunch (94–98 percent), dinner (94–100 percent), are included in almost all schedules. Other activities are included less frequently, although work (15–76 percent) and shopping (24–98 percent) are also scheduled relatively often. The average travel time in the different situations ranges from 18 to 31 min, while the finishing times vary from 7:22 p.m. to 9:40 p.m. Waiting time is negligible in the single worker case, but it is considerable in the working parent case. Finally, the time spent on activities varies from 2.91 to 5.99 hr on average in the different situations.

Examining the differences between the hypothetical situations, some conclusions can be drawn. First, the degree of clustering (CONFIG) is smaller in the urban situation than in the suburban situation. This is probably due to the fact that in suburban situations, two clusters naturally occur: one of facilities in the home village and one of facilities in town. This will lead to an increase in the deviation around the average distance between all location pairs and therefore of CONFIG. Another finding is that the attribute PERSCHED is higher in urban settings than in suburban settings. The same holds for TIMEUSED. This indicates that in urban settings it is easier to create schedules including many activities. The greater scheduling possibilities are also indicated by the more favorable values of NEAROTH. Travel time (TRAVTIME) in general is higher in the urban areas as the result of inclusion of more activities and locations. Further, finishing times (LASTEND) in suburban areas are earlier, indicating that it is harder to include evening activities. Finally, the creation of a schedule in the urban situation requires more planning steps of every kind. This may be caused by the fact that there are fewer constraints and more possibilities to adjust the schedule.

Looking at the reaction to changes in the spatio-temporal settings as simulated, some conclusions can be drawn. The changing of shopping times and spatial concentration of facilities in situation 2 relative to situation 1 leads to schedules with less travel time. Apparently, more effective schedules can be found. PERSCHED, however, indicating the number of activities included, increases very little. With respect to car

TABLE 4 Characteristics of Final Schedules

	number of activities	config	persched	nearoth	utilloc	travtime	waittime	lastend	chance	timeused	nradd	nrdel	nrsub	nrsteps
situation 1	9 (0.06)	7.78 (0.06)	0.79 (0.00)	28.51 (0.50)	6.24 (0.03)	30.57 (0.35)	1.07 (0.10)	2137 (3.64)	1 (0.00)	531 (4.23)	10.0 (0.06)	1.7 (0.01)	1.9 (0.02)	12.6 (0.08)
situation 2	9 (0.06)	7.58 (0.06)	0.81 (0.00)	25.84 (0.51)	6.32 (0.02)	25.50 (0.28)	0.69 (0.09)	2146 (3.41)	1 (0.00)	549 (4.27)	10.2 (0.06)	1.7 (0.01)	2.0 (0.02)	12.9 (0.08)
situation 3	6 (0.05)	6.89 (0.16)	0.57 (0.00)	142.53 (1.28)	6.84 (0.04)	18.35 (0.52)	0.00 (0.00)	1959 (2.63)	1 (0.00)	291 (3.59)	6.8 (0.05)	1.2 (0.01)	1.3 (0.01)	8.2 (0.06)
situation 4	9 (0.04)	7.16 (0.06)	0.85 (0.00)	24.92 (0.53)	5.54 (0.01)	19.74 (0.18)	0.00 (0.00)	2166 (3.49)	1 (0.00)	581 (3.42)	10.7 (0.05)	1.7 (0.02)	2.0 (0.02)	13.4 (0.07)
situation 5	4 (0.10)	7.04 (0.07)	0.62 (0.01)	80.26 (1.04)	6.51 (0.03)	30.65 (0.50)	74.83 (1.64)	2072 (4.41)	1 (0.00)	585 (4.87)	9.2 (0.07)	1.6 (0.01)	2.0 (0.02)	11.7 (0.09)
situation 6	4 (0.10)	7.24 (0.08)	0.63 (0.01)	80.04 (1.03)	6.67 (0.03)	31.39 (0.49)	155.15 (4.04)	2128 (3.60)	1 (0.00)	599 (4.86)	9.2 (0.07)	1.6 (0.01)	2.0 (0.02)	11.8 (0.09)
situation 7	3 (0.07)	5.43 (0.13)	0.44 (0.01)	184.86 (1.47)	8.02 (0.04)	19.98 (0.66)	65.91 (2.66)	1938 (4.40)	1 (0.00)	378 (4.29)	6.4 (0.07)	1.3 (0.01)	1.4 (0.02)	8.1 (0.09)
situation 8	3 (0.09)	7.29 (0.15)	0.51 (0.01)	111.96 (1.14)	8.22 (0.04)	28.15 (0.64)	36.69 (1.15)	2016 (3.87)	1 (0.00)	470 (4.82)	7.4 (0.07)	1.5 (0.01)	1.5 (0.02)	9.4 (0.09)
example 1	10	9.71	1.00	0.00	5.78	47.00	0.00	2300	1	720	11	1	1	13
example 2	4	3.51	0.53	61.65	5.67	5.00	0.00	1900	1	200	5	1	1	7

availability (situation 4) relative to bicycle availability (situation 3), the simulations show an increase of PERSCHED and travel distance in case of car availability. In the case of the working parent in an urban situation, alleviating time constraints regarding work and shopping does not result in the inclusion of more activities and longer travel times. When the two suburban settings are compared, it can be concluded that PERSCHED in the city-oriented case (situation 7) is smaller and more time is needed for travel. The value of NEAROTH in the rural situation indicates that other activities can be included more easily.

The results described above indicate that the model reacts logically to different spatio-temporal settings resulting from concentration of facilities, changes in opening hours, and

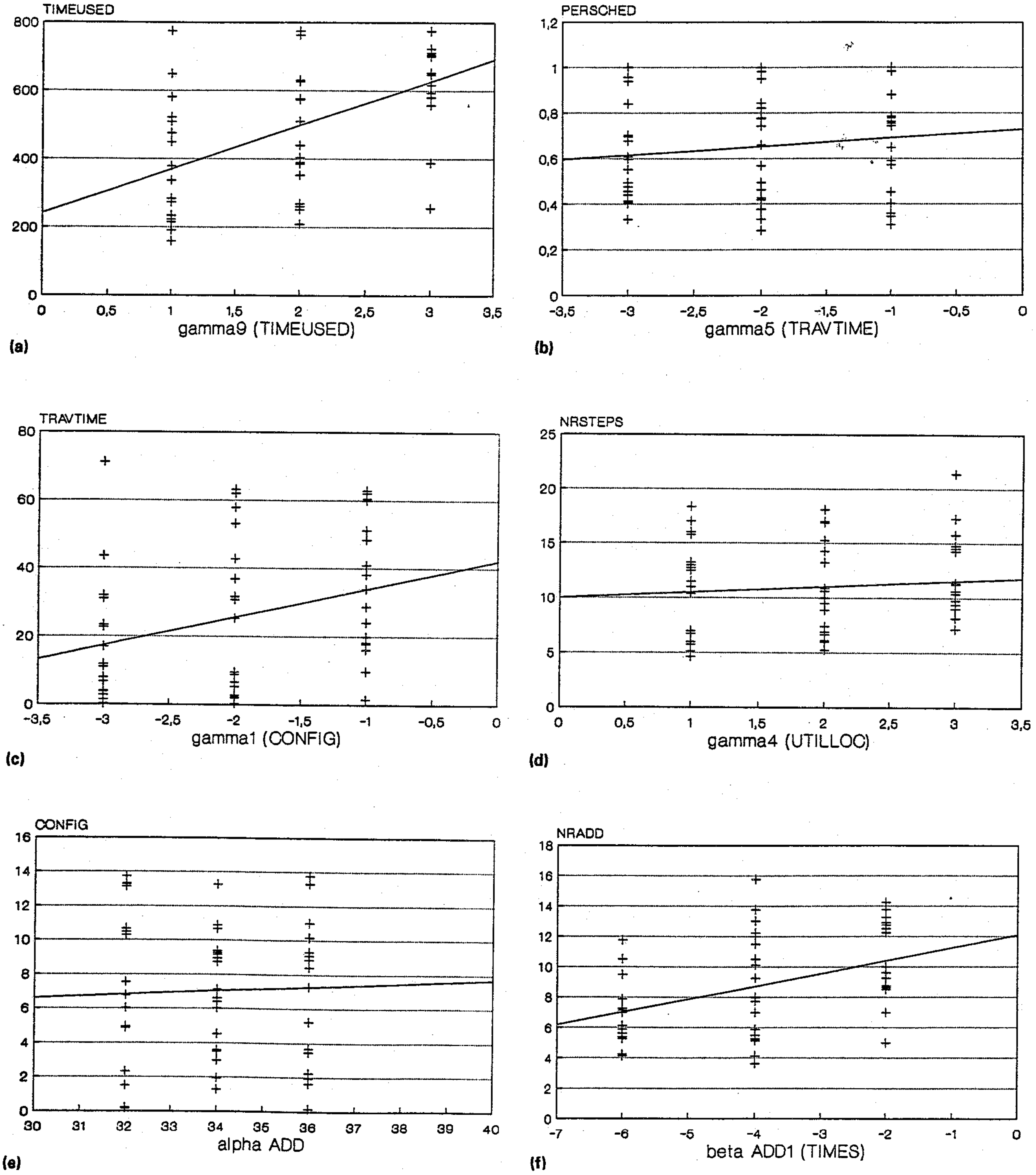

FIGURE 2 Relations Between Parameters and Attributes of Schedules, Scattergrams and Regression Lines: (*a*) TIMEUSED, (*b*) PERSCHED, (*c*) TRAVTIME, (*d*) NRSTEPS, (*e*) CONFIG, (*f*) NRADD.

changes in the transportation system. This is an important conclusion as the model should be used to evaluate policy measures as previously mentioned.

To gain insight in the mechanism of the model, the relationship among the parameter values, indicating the weight of factors in each planning step and the characteristics of the schedules created at the end of the process is investigated. It appears that the influence of the γ parameters strongly influences the *Y* attributes of the final schedules. For instance, a greater propensity to allocate time to activities during the scheduling process (γ_9) leads to more time allocated to activities in the final schedule (TIMEUSED). This is illustrated in Figure 2*a*. (To facilitate interpretation, the scattergram and the regression line are displayed.) The parameters can also influence other attributes of the final schedule. For instance, when travel time is less important (γ_5), more activities are included in the schedule (PERSCHED, Figure 2*b*). When the spatial configuration is less emphasized (γ_1), travel times increase (Figure 2*c*). The γ parameters may also influence the scheduling process itself. For instance, a greater importance of the utility of locations (γ_4) requires more steps to reach an acceptable schedule and causes higher values of NRSTEPS (Figure 2*d*).

However, the importance of the state-dependent variables also influences the outcome of the scheduling. For instance, a higher value of α_{add}, indicating a higher propensity to include activities, results in more dispersed locations (CONFIG) in the final schedule (Figure 2*e*). Logically, the α and β parameters will also determine the scheduling process itself. As can be seen from Figure 2*f*, for instance, less importance of the TIMES_{add} attribute (as indicated by $\beta_{add,1}$) leads to the execution of more add-actions in the process.

The above examples indicate that the model reacts logically to changes in the parameter values. All relations among parameters of the model and characteristics of the final schedules are summarized in Table 5 where each of these variables was used as the dependent variable in a regression analysis in which the parameter values α, β, and γ served as explanatory variables. Generally, it can be concluded that the relationships among parameter values and characteristics of the schedule have the expected sign.

CONCLUSION AND DISCUSSION OF RESULTS

This paper presented a simulation model of activity scheduling to test the behavior of such a model responding to different circumstances. The results indicate that the simulation model reacts logically to different parameter settings and differences in spatio-temporal settings. The schedules created also seem reasonable in the sense that a considerable number of activities are included in most schedules and that travel time is minimized to some extent. This implies an efficient use of time and space.

The above results give rise to the expectation that the proposed approach can realistically model activity scheduling behavior. Of course, improvements, such as the incorporation of mode choice, the planning of time spent home, and constraints in the sequence of activities (so that, for instance, shopping is not planned before work), remain to be made.

The next major step is to link the model to observed behavior so as to derive parameter values. In this respect, interactive simulations may be a promising technique. In such experiments, subjects are asked to complete a task consisting of several steps. After each step, subjects are given information on the results of that step. In the case of activity scheduling, these scheduling steps can be recorded in a standardized way by allowing the subjects to perform only the basic actions for the specification of the model. Because the explanatory variables can also be recorded, the relation between the action chosen and the explanatory variables can be examined. In this respect, every planning step could princi-

TABLE 5 Results Regression Analyses

parameter		γ_1	γ_2	γ_3	γ_4	γ_5	γ_6	γ_7	γ_8	γ_9	α_{add}	$\beta_{add,1}$	$\beta_{add,3}$	$\beta_{del,2}$	$\beta_{del,3}$	α_{sub}	$\beta_{sub,2}$	$\beta_{sub,3}$	R^2
variable		con fig	per sched	near oth	util loc	trav time	wait time	last end	chance	time used	const (add)	times (add)	count (add)	since (del)	count (del)	const (sub)	since (sub)	count (sub)	
dependent variables	config	2.19	1.64	0.94	0.65	0.69		1.14	1.49	1.83	0.25	0.75	0.68						0.98
	per sched	1.58	2.00	0.86	0.48	0.68		1.43	1.56	2.79	0.34	1.30	1.35		-0.79				0.99
	nearoth	-0.97	-0.97			-0.75		-0.49	-0.83	-1.41	0.17	-0.68							0.97
	utilloc	-0.41	-0.50	-0.57				-0.57	-0.33	-0.47		-0.32	-0.25						0.99
	travtime	1.99	1.98	1.12		1.16		1.54	1.96	3.21	0.17	1.46	1.60		-0.68				0.98
	waittime	0.15	0.13			0.15			0.18	0.32		0.15	0.24		-0.09	0.06			0.90
	lastend	0.29	0.36					0.29		0.76		0.19							1.00
	time used	3.63	3.20	1.48	0.89	1.25		2.39	2.81	5.28	0.59	1.84	1.72			-0.45			0.99
	nradd	0.95	1.46	0.67	0.44	0.50		2.00	1.23	2.08	0.24	0.81	0.90						0.99
	nrdel		0.25		0.16			0.28	0.24	0.33	0.04			0.18	0.30				0.98
	nrsub	0.28	0.38						0.34	0.48		-0.19	-0.26				0.35	0.36	0.93
	nrsteps	1.19	2.09	0.93	0.60	0.50	0.39	1.66	1.80	2.88	0.27	0.61	0.72				0.47		0.97

* only the coefficients significant at $\alpha = 0.05$ are displayed

pally be modeled as a choice between several actions resulting in different preliminary solutions. The authors plan to perform such an interactive experiment in early 1994. Further research therefore will have to focus on calibration methods for sequential choice models that can model the consecutive decisions in the scheduling process in their mutual coherence.

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