A CONCEPTUAL MODEL OF THE WEEKLY HOUSEHOLD ACTIVITY-TRAVEL SCHEDULING PROCESS

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Paper to appear in *Travel Behaviour: Patterns, Implications and Modelling*, eds. E. Stern, I. Salomon, and P. Bovy. Previously presented at the *Network on European Communications and Transport Activities Research Euroconference*, Israel, April 19-25.

ABSTRACT

The goal of this paper is to describe a conceptual model of the household activity scheduling process, based partially on empirical evidence gathered using a Computerized Household Activity Scheduling Elicitor (CHASE) survey. The paper begins with a review of activity scheduling and travel behaviour, with a focus on past frameworks, behavioural assumptions, and how activity priority is depicted and related to the scheduling process. A brief description of the CHASE survey methodology is then given, followed by the presentation of the conceptual model. Empirical evidence derived from the survey is used to support its development. Analysis focuses on the basic process of activity scheduling as it occurs over time, including an examination of how far in advance decisions are made and how they are subsequently modified during their execution. The various modelling structures and decision rules incorporated in the conceptual framework are outlined and discussed.

KEYWORDS

Activities, travel, scheduling, travel behaviour, computerized surveys, conceptual model.

INTRODUCTION

Over the past several decades a strong argument has been made for the use of an activity-based approach to further our understanding of travel behaviour, to improve travel demand forecasting, and to better assess the impacts of emerging transportation policies. The rational for an activity-based approach has been well documented (e.g. Ettema and Timmermans 1997). One of the key questions of this approach is how individuals and households make and adapt their activity-travel decisions. These include the interdependent decisions about which activities to perform, where, at what time, for what duration, with whom, coupled with mode and route choice. When these decisions are coupled with their planning and execution over time, they define an "activity scheduling" process. This series of dependencies can be viewed as follows:

Scheduling process

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Activity-Travel Pattern (or Schedule)

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Activities

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Trips

As one moves up in this framework, a greater understanding of trips and travel patterns is achieved, especially of the more complex trip chaining, off-peak, and discretionary trips. The trade-off in understanding comes at a price in terms of the complexity of the phenomenon and of the observation task.

Regardless of the added complexities, travel behaviour researchers are increasingly recognizing the need for in-depth research into the household activity scheduling process. Early on, Pas (1985, 461) noted that existing theories and methodologies dealt almost exclusively with travel and related behaviour at particular points in time, but that "understanding travel and related behavior requires the development of models of the process by which travel and related behavior change". Jones et al. (1990, 41) noted that "household responses to changes in transport and land use supply characteristics may be varied and complex. They include reorganization of trips into tours, reassignment of trip/tasks among household members and complex rescheduling of activities and travel. Conventional models of travel demand consider only simple adjustments in the daily travel pattern." Axhausen and Gärling (1992) emphasize in general, that the re-scheduling of activities is at the core of many of the changes in travel behaviour brought on by recent policy initiatives related to information technology and transportation demand management. Thus, it is becoming ever more important that the development of travel forecasting models capable of assessing these types of emerging policies need to explicitly account for how people would temporally and spatially adjust their travel behaviour, which is dependent on an underlying process of activity scheduling.

Despite this realization, previous modelling efforts have relied mainly on the traditional utility-maximization framework to replicate specific aspects of the scheduling process in isolation or in limited combinations. Other models have attempted to capture the choice of an entire daily activity pattern. However, the behavioural validity of the utility-maximization framework as a description of how people actually make decisions has continuously been questioned (e.g. Gärling 1998) and insights from cognitive psychology about how people perform complex scheduling tasks suggests that people apply a large range of heuristics and strategies when faced with such tasks (Payne et al 1993). Gärling et al (1994, 356) argues that an even more serious issue relates to the tendency of these models to be confined to specifying what factors affect the final choice of *pattern* whereas the *process* resulting in the choice "is largely left unspecified".

In response to these criticisms, recent modelling efforts have attempted to more explicitly replicate the sequencing of decisions made during the scheduling process, under alternative behavioural structures. These include those that involve production systems (e.g. Gärling et al 1994), a mixture of utility-maximization and heuristic rules (e.g. Ettema et al 1993), as well as those involving a micro-simulation approach (e.g. RDC 1995). Far more extensive reviews can be found in Axhausen and Gärling (1992), Ettema and Timmermans (1997), and Bowman and Ben-Akiva (1997). What is important in this context is that these approaches, to varying degrees, attempt to limit the assumptions made about the underlying scheduling behaviour of individuals and households so that models can be used to assess the impact of policy initiatives that previous models were simple incapable of doing. However, as pointed out in the review by Bowman and Ben-Akiva (1997, 31), even these models "can be challenged as to the validity of its decision protocol", noting that in each model reviewed, "specific assumptions about how the decisionmaker goes about the search and decision are structured into the simulation. These assumptions may be wrong in enough cases to invalidate the model's parameter estimates and predictions."

The challenge of activity scheduling is thus threefold: (a) the details of the process are largely unknown, particularly in terms of how schedules are formed within a household over time; (b) its complexity makes the observation task very challenging and; (c) even with full information, the resulting modelling tasks requires the piecing together of at least the basic dimensions of the activity scheduling decisions that account for how they are formed and potentially modified. What seems clear is that existing activity diary techniques can provide only a limited amount of information on the underlying process, and without further empirical work, activity schedule modelling will continue with strong unsupported behavioural assumptions that limit their potential.

DATA COLLECTION METHODOLOGY

The week-long Computerized Household Activity Scheduling Elicitor (CHASE) survey addresses the problems of collecting data on the underlying household activity scheduling process. Considerable amounts of testing were devoted to the development of the CHASE survey, and a previous paper has been devoted to a description and assessment of the design based on a sample of households (Doherty and Miller, forthcoming). Only a brief summary of its design is given here in order to provide a basis for the empirical results presented.

CHASE goes beyond previous methodologies (Hayes-Roth and Hayes-Roth 1979; Ettema et al 1994) by providing a means to observe the scheduling process as it occurs in reality in a household setting over a multi-day period (as opposed to an individual in a laboratory setting over one day). In this way it is able to capture both routine and complex scheduling processes as well as observe those scheduling decisions made during the actual execution of the schedule that come as a result of unexpected and impulsive events, continuing changes in planning decisions, and interaction with the environment and other people with whom activities take place jointly.

The CHASE program is designed to track the sequence of steps whereby activities from a household "agenda" are added, deleted, and subsequently modified during their execution to form household weekly activity schedules. An upfront interview is used to establish a household's activity agenda which consists of a full list of activities potentially performed by household members, along with their attributes. This information is entered by an interviewer into computerized "forms" linked to a database file that the CHASE program can access in order to display the information back to the user in choice situations.

Adult household members are shown how to use the CHASE software program on a laptop computer, which is subsequently left in the household for a week long period (users begin recording their schedule decisions on a Sunday evening for activities that cover the following Monday to Sunday). Parents complete their children's schedule. Users are basically instructed to login daily to the program, and continuously add, modify, and delete activities to an ongoing display of their weekly schedule. A household member's weekly schedule is displayed as a series of columns depicting the days of the week from Monday to Sunday, and a series of rows depicting 15 minute time blocks starting at midnight, not unlike a typical dayplanner. Scrollbars allow the user to adjust the view. For parents, tabs along the left side of the screen allow them quick access to their children's schedules. Each activity on the schedule appears as a series of 15 minute coloured blocks, with the first of these boxes normally displaying the activity type and location. Multiple short activities in the same time block will scroll horizontally.

The main menu for the CHASE program includes the options to Add, Modify, or Delete an activity. To add a new activity, the user first selects a series of time blocks using the mouse, then selects the add command. This brings up a dialog box that prompts the user for the activity type, location, mode, travel time, and involved persons. For the most part, the user simply points and clicks his/her choices using pull-down lists and option boxes. To modify an existing activity, the user simply selects it on screen and chooses the modify menu command. This brings up the same dialog box within which the user can modify any of the previously entered attributes. Aside from these basic scheduling options, the program automatically prompts the user for all additional information. This includes prompts necessary to track the scheduling process accurately (e.g. when and why they made certain choices), prompts for other information of interest (e.g. costs of activities) and prompts designed to encourage accurate and timely completion of the schedule.

A total of 41 households (66 adults, 14 children) completed the survey during the months of April-June 1997. Households were recruited via advertisements on the McMaster University campus in Hamilton, Ontario, and were offered $50 to participate. Fourteen of these households were married couples, 13 were married couples with young children aged between 2 and 10 (six with two children, seven with one), and 14 were single person households. Adults were either working full-time (35) or part-time (4), conducting post-graduate research full-time (19) or part-time in conjunction with other part-time work (4), or were undergraduate students (4; 3 of which had part-time jobs). The majority of households were located within two kilometres of the McMaster University campus, which is situated at the very tip of the western end of Lake Ontario (Hamilton

Region population: ~600,000). A sub-sample of 55 adults were used for the analysis presented in this paper.

The results presented in Doherty and Miller (forthcoming) showed that the pre-definition of a household agenda, coupled with a familiar and graphical computer-based survey design, proved to be a practical approach to gathering a wealth of information on the underlying process, while minimizing the burden on respondents. In summary, it was found that adults spent an average of 16 minutes per day to complete their own schedules, and 9 minutes per day for their children. The login durations were found to remain at a consistent length after the initial period of scheduling. Only about 10% of the survey days were skipped, mostly on or near weekends when respondents were out of town. During the week, adults made an average of 12.1 add, 2.4 modify, and 0.6 deletion steps per day to schedule 12.4 activities and 4.9 trips per adult per day. Taken together, the sum total number of activities and trips reported per adult per day from Monday to Thursday were very stable at 17.9, 18.0, 17.9, and 18.1 respectively. Friday and Saturday were comparable at 16.8 and 16.9, followed by 15.7 on Sunday. Thus, in addition to a low respondent burden, the survey appears to have minimized the potential of multi-day surveys to provide less information on subsequent days.
This approach goes a long way towards solving the data collection problem highlighted by Bowman and Ben-Akiva (1997) that simulation models of activity scheduling (citing Ettema et al 1993) require “very complex surveys for model estimation” wherein “respondents must step through the entire schedule building process”.

CONCEPTUAL MODEL DEVELOPMENT

The Weekly Household Activity Scheduling Process model presented below is supported by empirical analysis and by various flow diagrams that provide a visual means to connect the various components of the model (see Figure 1-Figure 3). Although the ultimate goal is to implement the model as a computer algorithm, this is not necessarily a binding restriction on the design. Note that *italicized* terms in the text refer directly to components of the model in the figures.

Foremost, it should be stressed that activity scheduling is a behaviourally complex process that spans across many time horizons and individuals. This has not only required innovative observational tools, but also complex modelling structures. However, the trade-off comes in an improved understanding of and ability to forecast complex travel behaviour that would not be possible without a knowledge of the underlying scheduling process that gives rise to this complexity.

Basic structure

To assist with an understanding of the overall model design, a summary of its basic structure is provided here. In general, the model attempts to dynamically replicate the scheduling process as it occurs over time through the use of various modelling constructs and decisions rules run in sequence. It begins by taking a household’s *weekly agenda* of activities, and establishes a set of *routine activities* and a *skeleton schedule* for the week. This is followed by scheduling decisions (additions, modifications, deletions) made during execution of the schedule. These include pre-planned decisions, decisions made the day-of, impulsive decisions, and decisions that result from random events. A *Planning Mode Executive* controls the flow of decisions, which inherently involves the movement through time. Decisions about what activities to schedule at any given moment are determined by the priority of activities on the agenda. Priority is determined as a function of static activity attributes from the agenda and dynamic aspects of the schedule at the particular moment. Once an activity is chosen for scheduling, a feasible window of time is chosen, and refinements in the activity made before it is placed on the schedule for a particular household member(s). Refinements include any needed duration, timing, location, or mode choices. In many cases, these refinements will be highly constrained given the relative fixitivity of the activity in time and space and/or the constrained nature of the circumstances, making these choices rather straightforward.

Conflicts that arise due to random events or time pressures, or cases where activities may be extended to fill time, are handled by the *Modify and Conflict Resolver*. This procedure takes the previously scheduled activities and determines those most likely to be modified. A set of possible modifications is determined, and a choice is made as to which ones to implement and to what extent. If the (set of) modification(s) does not meet the requirements of solving a conflict, then the *deletion of an activity* is considered. The procedure for deletion is similar to modification, except that the activity attempting to be scheduled is compared directly to the revised priority of the activity chosen for potential deletion. If none of the deletions is justifiable, then the model reverts back to the beginning, and the originating activity is left unscheduled. If an activity is deleted, control reverts back to scheduling to assess the new window feasibility.

The following sections describe the model components in more detail.

The household activity agenda

On a fundamental level, activity scheduling reflects personal and household related basic human needs constrained in time, capability, and in space by the urban environment. These needs can be viewed as manifested in a household's activity *agenda* which represents the initial input to the main model as shown in Figure 1. A simplified example weekly agenda is provided in Table 1. The agenda consists of a list of uniquely defined activities that a household could potentially perform, including highly infrequent activities that are only occasionally performed to fill up free time. Each activity on the agenda is viewed as having a unique set of (perceived) attributes that affect their scheduling, including duration (min, max, mean), frequency, time limits, involved persons, costs, perceived locations, etc. If an activity constitutes several unique subtypes that differ substantially in their attributes then they should be defined separately (e.g. work at the office, work-at-home; minor grocery shopping, major grocery shopping, clothing shopping). What is key to the success of the scheduling model is not the activity types as defined by traditional means (e.g. work, school, shopping, mandatory, discretionary etc.), but rather their salient attributes that serve to explain how they are scheduled in the context of an on-going process. This gives the model the ability to address any number of individuals/household types, regardless of their employment status or preferences.

[Figure 1 about here]
[Table 1 about here]

Although the derivation of household activity agendas are of considerable interest on their own, they are taken as exogenous to the process of scheduling in the short term. It is assumed that household agendas in a given urban area can be separately simulated or otherwise derived at regular time intervals as required by the scheduling model. The process by which these agendas are derived is an important component of the overall model, but is beyond the scope of this paper. Our suggestion at the moment is that the agendas need to be based on key socio-demographic characteristics of the household, household resources and constraints, and environmental factors. Attributes such as duration and frequency could be based on existing activity diary data, whereas the set of perceived locations would need to be simulated with a cognitive model using inputs such as the location and length of stay at current residences and employment locations. Incorporating the learning of new locations, new activity types, and the modification of activity attributes over time would be an important aspect of this model. An argument for linkages between the agenda and scheduling via learning processes in the long term is an important future consideration (e.g. as you execute your schedule you become aware of new locations for activities that should be added to the agenda).

Routine weekly activity skeleton

Empirical evidence derived from the CHASE survey shows that households begin the week with a firmly established set of *routine weekly activities*. From Figure 4 (looking only at the "additions" made on the "first Sunday") it can be seen that about 45% of the activities that take place on weekdays, and about 20% of those that take place on the weekend are pre-planned before the week starts on or before the first Sunday (totalling approximately 34 activity additions on the first Sunday). The remainder of activities are planned as the weekly schedule is executed (discussed in the next section). Of the decisions made on the first Sunday, a full 70% were part of multi-day entries (the activity was added on 2 or more days simultaneously), with 80% of these consisting of entries across 4+ days. Comparatively, on Monday, only 21% additions were part of multi-day entries, followed by 2%, 6% and no more than 1% on remaining days of the week. Such entries are indicative of highly frequent and routine activities, as suggested.

[Figure 4 about here]

Further evidence suggests that other key factors differentiate the activities pre-planned on the first Sunday besides their routine nature. First, they tend to be of a longer duration then subsequent days averaging 208 minutes long for adults in the sample. This was significantly higher than activity durations that were pre-planned one or more days in advance during the week (110 minutes), planned the day of (79 minutes) and planned impulsively (72 minutes), as confirmed by two tailed t-tests ($p<<0.0001$ in all three cases).

A rough examination of the activity types scheduled on the first Sundays also suggests that more highly fixed activities in space and/or time tend to be pre-planned before the weeks starts (e.g. work, chauffeuring, sleeping, sports events). Further empirical analysis using an appropriate discriminant analysis technique will be performed to further differentiate these types of activities from other activities on their agenda based on their key attributes, including duration, frequency, and indicator variables of temporal and spatial fixitivity (see also Table 2 for further details on these variables).

It is plausible to assume that these routinized activities pre-planned before the week starts are the result of a long-term deliberate planning and adaptation process controlled by negative feedback.

Thus, they may represent an optimized activity pattern around which other scheduling decisions are made during the week. Given this, it is reasonable to assume that an *optimization model* would be appropriate to derive the *weekly skeleton schedules*. This model would use the discriminated activities as input, which represent a much more limited choice set of activities that more closely match the assumptions to which these models are based (i.e. that activities are scheduled in an optimal way). Potential modelling techniques include those that start by generating all possible feasible combinations of skeleton structures and choosing the most optimal of the set (e.g. Recker 1995), or the more recently developed neural network models that offer a more behaviourally realistic modelling technique (e.g. Kitamura and Fujii, 1998). The details of this model form, and how it would deal with a weekly optimization problem, are however left as a long term research goal.

Weekly scheduling process

The remainder of this paper focuses on the more deliberate scheduling decisions made during the week as the schedule is executed. After the first Sunday, adults consistently made about 8 additions, 2 modifications, and 1 deletion per day during the execution of their schedule over the course of the week. These steps were taken to complete their schedules, which include an average of 12.4 activities and 4.9 trips per adult per day.

Figure 4 shows that the scheduling decisions applicable to each day are made on various time horizons. Outside of the routine activity additions made on the first Sunday (38% overall), a substantial proportion of additions are scheduled impulsively just before execution (28% overall), on the same day (20% overall), or are planned one or more days in advance (15% overall). The amount of pre-planning differs by day of the week. Most notably, more impulsive additions decisions occur on Saturdays, whereas more “day of” decisions are made on Sundays.

Modification decisions exhibit a significantly different pattern from additions. The vast majority tend to be made impulsively (62% overall), compared to on the same day (24% overall) and planned more than a day in advance (14% overall). This pattern is fairly consistent across the days of the week, as shown in Figure 4. Compared to modifications, more advanced thought appears to be put into deletions as a higher proportion are made on the same day (38% overall) and a lower proportion made impulsively (41% overall).

Figure 5 shows in three dimensions the distribution of activity additions planned on one day, by the activity day they are planning for (exclusive the first Sunday, which is shown in Figure 4). It clearly shows that in addition to pre-planning for the next day (62% overall) people also reach out and make additions on future days as the week progresses (38% overall), in an opportunistic fashion.

[Figure 5 about here]

This evidence strongly suggests that activity scheduling is a dynamic process reflecting continued addition and revisions to a schedule over time. Scheduling represents a mix of routine followed by continued pre-planning and impulsive decisions made over the course of the week. This differs substantially from the notion that activities are planned and carried out in sequence all at once.

Thus, if the goal is to develop a behaviourally sound model, then a dynamic model is needed - one that can simulate the fundamentally different types of decisions that occur over time.

The conceptual model presented in Figure 1 to Figure 3 attempts to account for the complexities of the scheduling process with a mix of empirically derived functions and a series of decision rules that serve to sequentially simulate the construction of activity schedules over time. Activity scheduling decisions including additions, modifications and deletions to each household members schedule, simultaneously implemented as a series of pre-planned and impulsive decisions. At the heart of the conceptual model is a "momentaneous scheduling priority" function that drives that selection and inherent sequencing of activity choices at each stage in the process.

Momentaneous priority

Activity "priority" has been suggested in the past as an important dimension in the construction of sequential scheduling models, particularly as a determinant for the sequencing and choice of activities. Past researchers have suggested that activity "priority" has a dynamic quality, wherein activities of different types have priorities that change over time in response to different situations (Axhausen and Gärling 1992; Gärling et al. 1989, 1998). It has also been suggested that activity priority in scheduling is related to the relative flexibility and fixity of activities, wherein inflexible and highly fixed activities are chosen first for scheduling, followed by more flexibly and less fixed activities (Cullen and Godson 1975; Kitamura 1983). The current model proposes that much of the complexity of the scheduling decision process is related to the changing level of priority associated with activities that household members have on their agenda at any one moment in space and time. Estimating a function describing how priority varies with different factors over time is therefore at the heart of the conceptual model.

Although activity "priority" has been proposed as the determining factor in the choice of activities to schedule in previous models (e.g. Gärling et al. 1989, 1998), it has remained a difficult attribute to operationalize because of its highly subjective and dynamic nature. Asking people to assess the priority of a list of activities is difficult not only because of a definition problem (how the researcher defines/explains what constitutes high versus low priority will largely effect the results), but because the priority of an activity depends on the situation. Any static assessment of the priority of activities will be inadequate to deal with all possible situations that arise during the scheduling process. This stresses the importance of differentiating between an activity's "general/overall" level of priority (all things being equal) versus its "scheduling" priority (which depends on the situation). For instance, a person may tell you that being at home with their children is generally a higher priority than being at the pub with friends. However, under the right circumstances (e.g. just spent the whole day with your children, they are now sleeping, and the person hasn't been to the pub in a while), you may find this person at the pub. Any measure of priority must be able to account for these observed differences.

If "scheduling priority" determines the choice of activities in a given situation, then any measure of it requires observations of activity scheduling choices under a range of situations - precisely what the CHASE survey is designed to accomplish. The following modelling function of momentaneous scheduling "priority" is thus proposed for development:

$$P_i^{m,s} = f(X_i,\ S_i^t,\ M_i^l, H, E) \qquad [1]$$

Where:

- P_i : "Priority" of activity *i* at scheduling mode *m* for scheduling operation *s*.
- m: Scheduling mode - pre-plan, day-of, and impulsive planning
- s: Scheduling operation - *add*, *mod*ify, *del*ete
- X_i: Attributes of activity *i* on household agenda
- S_i^t: Scheduling state characteristics of activity *i* at time *t*.
- M_i^l: Spatial possibilities for activity *i* at location *l*
- H: Household characteristics
- E: Environmental characteristics

At any moment in the scheduling process over the course of a week, the priority of activities in the household agenda can be evaluated in terms of their relative priority, given values for the attributes in the model. Separate models would be constructed for the priority of activities for *add*ition, *mod*ification or *del*etion to the schedule (represented by the subscript *s*). The form of the model is also proposed to depend on the mode (*m*) of scheduling (pre-planning, day-of planning, impulsive decisions). The exact form of the priority model and its estimation would require considerable exploration.

The explanatory variables in the priority model ($P_i^{m,s}$) include a range of static variables (A_i, H, E), and dynamic scheduling state variables (S_i^t, M_i^l) that continuously change over time (*t*) and space (*l*). The scheduling state variables are what makes this model unique so far, and give it the power to explain the apparent behavioural complexities of observed activity-travel patterns. The range of potential explanatory variables are outlined in Table 2. Of particular note are the history and future dependent variables that account for the likelihood that activities that have taken place recently or been planned for a future time, would be associated with lower priorities. Also, the temporal and spatial fixity of activities is captured by a combination of activity and scheduling attributes. The attributes of other household members schedules, such as the relative flexibility of their schedule at a particular moment, is also proposed a determining factor in activity priority. Many other variables are proposed in the table to account for the role of habits, travel times, and joint activities.

[Table 2 about here]

The behavioural power of the priority ($P_i^{m,s}$) model is threefold. First, because the model is sequential in nature, the scheduling state variables can be reassessed at each time step in the model after each decision. Certain activities will have a tendency to jump up in priority depending on the circumstances. This allows infrequent, discretionary, or otherwise unusual activities to emerge depending on the situation, contributing to complex activity-travel patterns. For instance, although a person may have a high priority job to get to at 9:00 a.m. and possibly some high priority shopping that needs to get done before the end of the day, s/he may be sitting in a coffee shop at 8:30 located on the way to work. This may be because the person was faced with a short window of opportunity for the activity after having already dropped the children off to school at 8:15 and a close location, allowing for an apparent flexible activity to emerge (coffee) as high priority.

Shopping was assigned a low priority at that moment because of the short time window and because few perceived locations were available in the vicinity to shop at.

Second, it simplifies the activity scheduling decisions - empirical evidence suggests that those decisions made before the week commences (on the first Sunday) tend to be highly routine, making the decision about their exact timing and location a relatively straightforward task. Those activities that are more flexible tend to be scheduled within an already constrained spatio-temporal environment limiting the specific choices of location, start-end times, duration, household members involved, and mode choices.

Third, the momentaneous priority model ($P_i^{m,s}$) indirectly contributes to the sequencing of activities in terms of the order in which decisions are made (pre-planned vs. impulsive), and the order in execution. This sequencing is not an explicit aspect of the model, but rather reflects the fact that impulsive decisions and, to a lesser extent, day-of and pre-planned decisions, are made in light of the open time slots in the skeleton schedule established on the first Sunday. This implies a certain order among existing activities on a weekly, daily or time window scale.

Sequential decision structure

Once the mode of scheduling is set by the *Planning Mode Executive* (described in more detail in the section to follow), the model uses the same basic set of sequential decisions to handle random events, add high priority activities to the schedule depending on the scheduling mode, and invoke modifications and deletions where necessary.

Ignoring for the moment random events, the choice of activity to add (*Choose Ai to Add)* is based on the momentaneous scheduling priority of all applicable activities on the agenda ($P_i^{m,s}$) for that particular mode of scheduling (s). Some logical rules may also be used to limit the choice set in certain circumstances due to constraints - or increase the priority of certain activities directly. The exact method would depend upon the extent to which the priority model ($P_i^{m,s}$) accounts for the constraints via the inclusion of appropriate variables. For instance, the maximum size of any feasible time window (max W_n) on a schedule relative to the minimum duration of an activity (min d_i) should presumably influence its priority for scheduling. An appropriate variable for investigation might be:

$$\frac{\min\ d_i}{\max W_n}$$

The smaller this is, the higher the priority should be. An example of a rule for excluding certain activities is:

$$\text{IF } \frac{\min\ d_i + \min\ t_i}{\max W_n} > [\beta] \text{ THEN } [\,P_i^{m,add} = 0]$$

This rule operates by assigning a zero priority to activities that are simply too long to fit in a given time window, considering any travel time to it (t_i). The threshold value of β should be larger than 1 and could be determined empirically, or simply set to a pre-specified value.

Still further rules could be incorporated before the final choice to artificially increase the priority of certain activities (A_i) when dependent/related activities (A_j) have already been scheduled. For example, an out-of-home recreation activity for parents may first depend on a chauffeuring activity for the children (to a babysitter), or a socializing activity (going to the pub) may habitually follow the playing of a sporting event. These would, of course, depend on a well-defined agenda that establishes these dependencies.

Once the momentaneous priority is determined and constraints met, the choice of activity to schedule is made based on an appropriate decision rule (*Choose A_i to Add*). The simplest rule would be to select the activity with the highest priority. Alternatively, the choice could possibly be made randomly, for instance if there is time pressure. Selection of activities to schedule in this fashion proceeds until a threshold level of priority for the given mode m is reached. The decision rule used at this stage could be of the form:

$$\text{IF } P_i^{m,add} > (\alpha_m) \text{ THEN } [\textit{continue}] \qquad [2]$$

where the α_m threshold value is determined empirically for the given mode of scheduling (α_m would be relatively higher during pre-planning compared to impulsive planning, reflecting the notion that only high priority activities are pre-planned). This rule implies that only the priority of the current activity in question is considered in the decision. An alternative would be to base the decision on the sum of priorities of activities on the agenda, replacing the left side of the above equation with $\sum^{i} P_i^{m,add}$. This would reflect the aggregate amount of pressure the particular person is under to continue scheduling activities. If many of the activities that are typically pre-planned are not yet placed on the schedule, then the sum of activity would be high, invoking further scheduling until the threshold level is reached.

More precise decisions about scheduling are not made until an activity is chosen (A'_i) and a decision to continue is reached. First, *Feasible Windows of Opportunity* (W_n) must be identified. These are defined as open time periods of length at least equal to the minimum duration of the given activity that fall within the feasible hours for the given activity. Feasible hours are defined by the opening hours of any required facilities (if applicable) and any preferences of the individual reflected in the agenda (e.g. a preference for shopping only on weekends).

In the event more than one window is feasible, another rule is needed to *Choose the Feasible Window*. Given that it has already been established that the activity is of high priority, it may suffice to use a satisficing rule that the first available window in time be chosen. However, in some cases, other attributes of the windows may be considered, such as their length, or the attributes of activities that bound the window. It may be appropriate to develop a feasible window choice model, using attributes of the windows and the activity as determining factors.

Having chosen a high priority activity (*A'*$_i$) and identified a window of opportunity (*W'*$_n$) greatly constrains the remaining choices to a specific spatial-temporal setting. These include the planned choices of activity duration, location, start and end times, mode of travel and involved persons (*Refine A'*$_i$ *Choice*). In many cases, these choices are already constrained enough that only one is feasible. This would be the case for many pre-planned activities that are highly fixed in time and space and involved persons, and for activities impulsively planned within highly constrained situations already.

For those activities where a choice on one or more dimensions exists, more definitive rules would be needed to make the refinement choices. Rules would be needed to identify what the alternatives are for each dimension, and second, how the choice is made among alternatives. The scheduling model would provide a means to do the former - i.e. providing a means to limit the range of feasible alternatives to a manageable level, given the spatial-temporal setting of the decision and attributes of other activities in the vicinity. In the case of activity duration, it would naturally be constrained by the length of the time window available less any necessary travel time, and the maximum and minimum duration for the activity. An aggregate measure of the number and magnitude of other high priority activities that may need to be scheduled as of yet may also be used to constrain the upper bound on duration. The location will already be constrained by the perceived location choice set in the agenda and travel time relative to where they are in space and where they may have planned to be at the end of the activity. Constraints on location related to the household (e.g. at least one parent at home with children in the evening) could also be formed. The modes available would be limited to what is currently available and the implications for travel time. The start time would likely be given from the end time of the preceding activity, whereas the end time would be governed by the duration and opening hours. Who would be involved, if a choice exists, would depend on the scheduling state of various household members. Operationalizing these constraints would require a series of "if … then" rules to establish the choice set of alternatives. The actual rules then used to make the choice amongst the alternatives would need to be arrived at through more in-depth cognitive analysis of decisions making, which is beyond the scope of the current paper.

Once refinements in the activity are made, the activity is added to the schedule for the applicable household members (*ADD A'*$_i$). Control is then returned to the momentaneous priority model, which re-evaluates all activities on the agenda after each addition. Subsequent additions (and possible modifications/deletions) are then continued until a decision is made to halt scheduling in any particular mode (via *Continue Scheduling?*).

At specified times during the scheduling process, modifications and deletions may occur in response to *random events*, scheduling *time pressure*, or convenience (*open time*). In all cases, this leads to the "*Modify and Conflict Resolver*" sub-model, although upon return, it may proceed in different directions, as shown in Figure 1. Each of these processes are described in the following sections.

Random Event Simulator (RES)

In the impulsive planning mode, the RES serves to randomly generate "unexpected" events that require immediate attention for scheduling. Two main types of events may be generated. The first are unexpected changes in the duration of planned activities, generated each time the model moves to the beginning of an activity (A_j) in the impulsive scheduling mode (as determined by the *Planning Mode Executive* - see section below for more detail). These events represent the distribution/flexibility of the activities duration, as well as changes in travel as a result of unexpected congestion, route changes, or mode changes. The extent of any duration changes would be constrained by some rules related to the fixitivity of activities that follow the given activity - for instance, if a highly fixed activity follows a given activity, then an upper bound on any unexpected changes in duration may be set (e.g. if a recreational event precedes a fixed commitment to chauffeur one's children follows, then random duration changes should have an upper bound).

In cases where the unexpected change leads to a decrease in duration or an increase that does not cause any conflicts with other planned activities, the changes are made to the schedule. In cases where a conflict arises, the *Modify and Conflict Resolver* is evoked. The behavioural response to such a situation is similar to that when faced with time pressure - one must now squeeze a high priority activity into a time slot that is no longer adequate. To operationalize this behaviour in the model, the activity can be temporally removed from the schedule, while at the same time assigning a high priority to the activity along with fixed start and end times and duration. In this way, scheduling would proceed with the choice of this activity, to the identification of the window, to time pressure, and to the *Modify and Conflict Resolver*, where the conflict would eventually be resolved due to its high priority. After any unexpected changes in duration are implemented, the activity is executed with no further changes.

The second type of random event concerns the simulation of urgent, emergency, or surprise activities that are mostly outside the control of the person. These would be handled by directly assigning a very high priority to the activity item and having scheduling proceed. For immediate urgent activities (e.g. seek medical care), scheduling proceeds as is, in impulsive scheduling mode. For surprise activities that will occur at a later time (e.g. news of surprise visitors coming to your home the next day), the *Planning Mode Executive* would be called upon to switch immediately to pre-planing mode to make the scheduling changes, then switches back to impulsive planning.

Time pressure

Compared to random or unexpected events, *Time Pressure* is the result of a more purposeful choice process wherein the scheduling of an activity meets with insufficient time windows to conduct it. A decision rule is needed at this point to decide if the given activity priority is still high enough yet to warrant potential modification or even deletion of previously scheduled activities to accommodate its scheduling. Such a rule may be of the form:

$$\text{IF } [\, P_i^{m,add} >> \alpha_m] \text{ THEN } [\textit{Modify Conflict Resolver}]$$

Other more complex rules may be necessary that replace the right hand side of this rule with an aggregate measure of the priority of existing activities (A_j) in the vicinity of the new activity (A'_i) that may need to be modified. These latter priorities would be re-evaluated for the given moment, as opposed to using their priority level when originally scheduled. The end result is that either the *Modify and Conflict Resolver* searches for a means to increase the size of the window, or scheduling returns to the *Planning Mode Executive* and no further additions are attempted.

Open time

Modifications may also be due to convenience, in a sense that a person has *open time* slots and the freedom to extend the duration of previously planned activities or choose a different location/mode in light of the opportunity. This type of modification would occur during impulsive scheduling in the event that none of the activities on the agenda evaluate to a high enough priority for addition to the free time slot (i.e. *Continue Scheduling* A'_i*?* No). The *Modify and Conflict Resolver* is called upon to fill up the *open time.* This serves to maintain the continuity of time in the schedule (i.e. a person must always be doing something).

Planning mode executive

The result of the momentaneous scheduling priority model is used to choose activities for addition, modification, and deletion to household member's schedules in a sequential fashion. The sequential movement through time is simulated by the *Planning Mode Executive* by controlling movement from one planning mode to the next. During the course of the week, people alternate between pre-planning activities for future days, pre-planning activities for the same day, and impulsive decision making. Weekly pre-planning mode is defined as those scheduling decisions made one or more days in advance of the event. Daily planning mode involves decisions made the same day as the event occurs. Impulsive decisions are made just before or during the activity.

The exact sequencing of pre-planning and impulsive decisions is unknown and remains as a difficult phenomenon to disentangle even with more repeated observation periods. For modelling purposes, one simplifying assumption would be to make all pre-planning decisions before the start of each day, wherein activities are planned for the same day or for a future day depending on the windows of opportunity. This would then be followed by impulsive decisions made at the start and end of each scheduled activity, starting with the first activity for the day. However, it may be argued that pre-planning is revisited during the day, perhaps as needed depending on the state of the schedule.

To briefly review, the model begins with a skeleton schedule for the week, followed by pre-planning during execution of the schedule, followed by an impulsive decisions that occur in between each activity. Thus, once pre-planning halts for the day, the model proceeds in time via the *Planning Mode Executive* to the starting point of the first activity, invoking the impulsive mode of planning. This mode is subsequently invoked at the beginning of each scheduled activity until a pre-planning mode is invoked by the planning mode executive. The model inherently moves through time after impulsive decisions conclude at the beginning of an activity, and the model moves to the end of the activity.

Specifically, in the impulsive mode, the model proceeds to the beginning of the first scheduled activity for the day and first determines the actual duration of the activity via the *Random Event Simulator* (see below for additional detail). This may result in changing the actual duration from the planned activity. Following this, the model proceeds in time to the end of the activity. At this time point, an empty time slot may or may not exist, and a decision is made to impulsively add an activity before the start of the next activity. The choice of activities to add during impulsive planning follows the same procedure as in pre-planning (including the possibility of the generation of a random new activity), except in the handling of empty time windows - whereas empty time windows are permissible during pre-planning, any *Open Time* windows must be filled during impulsive scheduling. In the case where none of the activities on the agenda meet the threshold for scheduling set for impulsive planning (*Continue scheduling?* No) then a situation arises in which *Open Time* exists. The *Modify and Conflict Resolver* is then invoked to revisit existing activities (A_j) to choose for modifying in order to fill up the time (see below for details), potentially resulting in a longer duration or new location/mode choices. In either event, the open time slots must be filled before the scheduler moves in time again to the start of the next activity (which may be an activity that was just added), and the procedure repeats itself. In this way, the final executed schedule is formed.

A graphical example of the above process is provided in Figure 6. The example shows how a persons schedule for a particular period of time would be sequentially pieced together by the model, from weekly skeleton to final executed schedule. Each time step is controlled by the Planning Mode executive. First, the skeleton schedule for the given time period starts with just two activities - work (A_1), and a routine household obligation (A_2). Next, a meeting is pre-planned a day in advance (A_3). This pre-planning is followed by a procession of impulsive decisions and random/unexpected events that occur in between each activity in time times steps of t_n. Each of these decisions serves to define the end state of the schedule and resulting activity-travel pattern.

[Figure 6 about here]

Modifications

As described in previous sections, random events, time pressure, and open time could potentially lead to the *Modify and Conflict Resolver (MCR)*, a flow diagram of which is presented in Figure 2. Except in the case of open time, the inputs are the list of scheduled activities (A_j), the new activity (A'_i), and the attributes of the chosen time window (W'_n) in which the new activity does not currently fit. The minimum time necessary can be taken as the difference between the minimum duration for the activity (including travel time to the closest possible location) and length of the chosen time window. The option to bypass the MCR and proceed directly to the *Activity Deletion* sub-model for highly *Urgent Activities* is provided - this decision would be based on the level of priority associated with A'_i (in most cases, this would result from high priorities being assigned by the random event simulator). Otherwise, the role of the MCR is to identify activities and specific modification types that could be made to make room for the new activity. In the case of open time, no A'_i exists, and instead the MCR identifies activities that can be lengthened via a set of modifications to fill the empty time.

[Figure 2 about here]

In either case, the MCR does this by defining a function similar to [1] that determines the "priority" ($P_j^{m,\mathrm{mod}}$) of scheduled activities A_j for modification (the subscript i is replaced by a j in all cases, and X_j refers to the attributes of activity j on the schedule). Such a model would be estimated using data on observed modifications, such as that provided by the CHASE survey. In particular, variables that indicate the flexibility of each activity for potential modification should be included in the model. For instance, the differences between a scheduled activities duration (d_j) and the activities minimum duration (min d_j from the agenda) would be a strong indicator of its potential for modification. The proximity of A_j to the window of opportunity, in terms of the number of activities that separate the two, may also be an important determinant, as closer activities are more likely to satisfy the modification need. The number of locations and possible modes available to the user may also signify more flexibility for modification.

Similarly to the addition of activities, once the priority for modification is established, a choice must made of which A_j to modify (*Choose* A_j *to Modify*), similarly to the choice of activities to add in the main model in Figure 1 (*Choose* A_i *to Add*). The next step is to *Determine the Modification Types for* A_j and the their potential to free up time in order to increase the size of W'_n (in the case of open time, the goal would be the opposite - to fill up time in order to decrease the W'_n). These include just moving the activity in time, decreasing the duration in relation to its minimum, and changing the location or mode to decrease travel time. The maximum possible savings should be identified (e.g. the difference between duration of A_j and its minimum possible duration; the difference between the travel time to current location and the travel time to the nearest perceived alternative location).

Once these modifications and their potential are identified, a decision must be made to *Choose Another Activity to Modify.* This choice would be based on the increase in the amount of time savings that has accrued from the preceding step compared to the amount of time necessary. Thus, if the ratio of the potential time savings to the time necessary is below a threshold value, then the procedure should stop, similar in structure to the rule in [2]. This would halt the search for modifications at a point where no significant gains are being made.

At this point in the sub-model, the range of potential modifications must be evaluated in terms of their ability to meet the minimum time needed or, in the case of open time, fill up the time (*Evaluate Impact of Modifications*). This would constitute a simple rule wherein the sum effect of the modifications must be greater than the minimum time necessary. If not, then more drastic measures may be considered in the form of *activity deletions*. If they are adequate, then the magnitude of the modifications must be refined such that any potential savings in time is distributed fairly amongst the new activity (A'_i) and the modified ones. For example, suppose a new activity requires 30 extra minutes in order to be scheduled at its minimum duration, and that another activity could potentially be shortened by as much as one hour in order to make room for the new activity. The decision is then how the residual 30 minutes of activity time is distributed between the two activities. A simple approach would be to split the amount of time savings equally after both activities are scheduled at their minimum. In this case, 30 minutes of the modified activity are traded to the new activity to get it to a minimum, and the residual 30 minutes is distributed equally to both, providing an additional 15 minutes of duration. A more complex rule could distribute any residual times saving in proportion to the durations of the activities, or in proportion to their priority. The complexity of this decision increases as the number of alternative modifications increases. Further analysis of the observed modifications, and more in-depth analysis of the underlying decision process is necessary before more refined rules can be suggested.

Once the refinements are made, the modifications are implemented (*Modify Activities*) and control reverts back to the main model, where the final refinement choices for the new activity are made given the new time window.

Deletions

In the event that no set of modifications are adequate to resolve a conflict or schedule an urgent activity, then the deletion of an activity is considered. A flow diagram of this procedure is presented in Figure 3. The procedure is similar to the MCR in the inputs, the priority model ($P_j^{m,del}$), and the choice of activity to delete. Following this, a decision then needs to be made of whether the new activity is indeed of much higher priority to warrant deletion of the chosen activity (*Delete* A_j*?*). One way to handle this would be to re-evaluate the priority of the chosen activity for addition (i.e. $P_j^{m,add}$ *)* given the new state of the schedule (this would differ from when it was originally made) and compare it directly to the priority of the new activity. If the discrepancy is large enough (i.e. $P_i^{m,add}$ >> $newP_j^{m,add}$ *)*, then the deletion should proceed, and control revert back to the main model where the resulting time window is then reassessed (note that further modifications or deletions may follow to accommodate the new activity). If not, then other activities may be considered for possible deletion (*Choose Next Activity to Delete?*). In the event that no deletion is feasible, then control reverts back to the MCR and subsequently back to the main model, and the activity is no longer considered for addition. At this point, it can be assumed that a rescheduling responses was simply not adequate to accommodate the scheduling of the new activity, or that the activity was simply not important enough to justify changes to existing activities.

[Figure 3 about here]

Optimization in the scheduling process

Although the scheduling process proceeds in a sequential fashion, without directly involving the optimization of the schedule as a whole (apart from the optimization already achieved through scheduling high priority activities first), a further degree of optimization is achieved in the scheduling model by revisiting previous activities for modification in the event that *time pressure* accrues, or *open time* results. This leads in the first case to more optimized locations, durations, mode choices, etc. that minimize travel time or durations via the *Modify and Conflict Resolver*, and in the second case by allowing previously planned activities to be optimized in a sense that preferred locations or extended durations are realized. Thus, durations and travel times (via location choices) will only be optimized to the extent that other activities of high priority need also be scheduled in the same time window. Behaviourally, this reflects the notion that people consider optimizing their behaviour only when and where needed and/or possible.

CONCLUSIONS

This paper has sought to move closer to the solution of a complex problem in the field of travel behaviour that has hampered development of behaviourally sound forecasting models - namely to understand better how various activity/travel choices or scheduling decisions are interrelated over time. An attempt was made to provide a behaviourally realistic framework which brings in the important dynamic component of household activity/travel scheduling. This development is part of a continuing and long term project for the authors. One of the main goals is to support the development of an operational scheduling model to be used within integrated land-use, transportation and environmental emissions models currently being developed by a collaborative research team in Canada (Miller and Salvini, 1998).

Empirical evidence obtained by means of a newly developed survey methodology (CHASE, see Doherty and Miller, forthcoming) was used to support the development of the conceptual framework. Furthermore, the data make possible future development in the form of the specific estimation of several sub-models so that assumptions of the conceptual framework as a whole can be tested and validated. In the case of the momentaneous priority models for instance, they may be estimated using the existing CHASE survey data, with careful selection of variables from Table 2 and due consideration to the form of the model. Some of the decisions rules may also be investigated using the CHASE data. However, their exact form would benefit from further parallel investigation of underlying cognitive decision making processes.

The conceptual framework also places renewed focus on basic human needs, as manifested in the household activity agenda. Simulation of a detailed activity agenda is crucial to the scheduling model, and represents a significant research challenge. Such development may benefit from contemporary developments in motivational psychology (Gärling and Garvill 1993). The importance of the agenda is also highlighted by the fact that many changes in policy would first need to be implemented via changes in the attributes or distribution of activities on the agenda. This would then invoke a scheduling response and subsequent changes in activity and travel patterns. For instance, the implementation of flexible work hours would in the first instance lead to changes in the earliest start and latest end time for work activities in the agenda, which would then have clear implications for scheduling within the household.

The conceptual model also leaves room for a role to be played by existing optimization style models. It attempts to address past behavioural criticisms of these models, by providing a reduced choice set of activities that are amenable to optimization. Applying past successes with these models to a weekly scheduling setting is an important aspect of the success of the overall scheduling model.

Overall, the CHASE survey and results went a long way towards solving the data collection problems that have hampered the development of simulation models of activity scheduling, of which the current one is but one possibility. Continued focus on activity scheduling, with the support of a new techniques such as CHASE, could lead to fundamentally new advances in the future.

ACKNOWLEDGEMENTS

This study was financially supported in part by a doctoral fellowship awarded to Sean Doherty by the Social Science and Humanities Research Council of Canada, a collaborative research grant to Eric Miller from the Natural Science and Engineering Research Council of Canada, and a grant to Tommy Gärling from the Swedish Transport and Communications Research Board.

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Table 1 A simplified household weekly agenda example

Activity	**Applicable Household members**	**General location**	**Attributes**			
			Duration (mean)	Frequency (per week)	# Perceived locations	etc.
Work	Male head	home	2	2	1	
Work	Male head	out-of-home	8	5	1	
School	Child	out-of-home	8	5	1	
Grocery Shop	Female head	out-of-home	1	3	12	
Grocery Shop	Male and female	out-of-home	2	1	12	
Active Sport	Male head	out-of-home	1	1	2	
Activity Sport	Male or female	out-of-home	2	1	1	
Chauffeuring	Male or female	out-of-home	.5	5	1	
Socializing	Male or female	in or out-of-home	3	2	10	
Etc.						

Table 2 Potential explanatory variables in the momentaneous priority model ($P_i^{m,s}$)

Characteristics/ Attributes	**Indicator variable***
Attributes of Activities on agenda X_i	
Time window (feasible)	Earliest start - latest end time # Feasible days
Temporal flexibility	(Minimum duration)÷(Time window size) (Frequency per week) ÷ (# days occur on per week) (Days it occurs per week) ÷ (#Days it could occur on)
Duration	Minimum, maximum, mean
Frequency	Days between performance (observed or stated)
Activity direct costs	{Yes, No}
Joint scheduling	{joint mandatory, joint optional, individual}
Activity type by activity motivation/need	Categories: {physiological, institutional, social, psychological, household obligation, household task}
Scheduling State at time t, S_i^t	
Schedule flexibility/window	(Minimum A_i duration) ÷ (Maximum feasible window available)
Alternate household member flexibility	As above, for alternative household member
Activity history	(Days since last performance of A_i) ÷ (A_i frequency) (Duration of last performance) ÷ (Mean duration) Number of activities (of same basic type) performed recently
Activity future	{A_i not scheduled, scheduled} (Days to scheduled performance of A_i) ÷ (A_i frequency) Number of activities (of same basic type) scheduled for future
Activity habit history	Frequency of performance directly before/after given scheduled activity
Travel time	Total travel time for day
Spatial Attributes, M_i^l	
Spatial fixity	# of perceived locations {only at home, only one out-of-home; in or out of home}
Perceived distance	Distance to nearest perceived location for A_i
Travel time	Perceived travel time to nearest activity location by fastest available mode
Scheduled activity attributes	Perceived distance in space between nearest activity before/after desired activity
Environmental Attributes, *E*	
Opening hours	Opening hour restrictions for A_i
Location attributes	Attraction variables for locations for participating in A_i

* values in {} indicate categorical variables.

Figure 1 Weekly Household Activity Scheduling Process Main Model

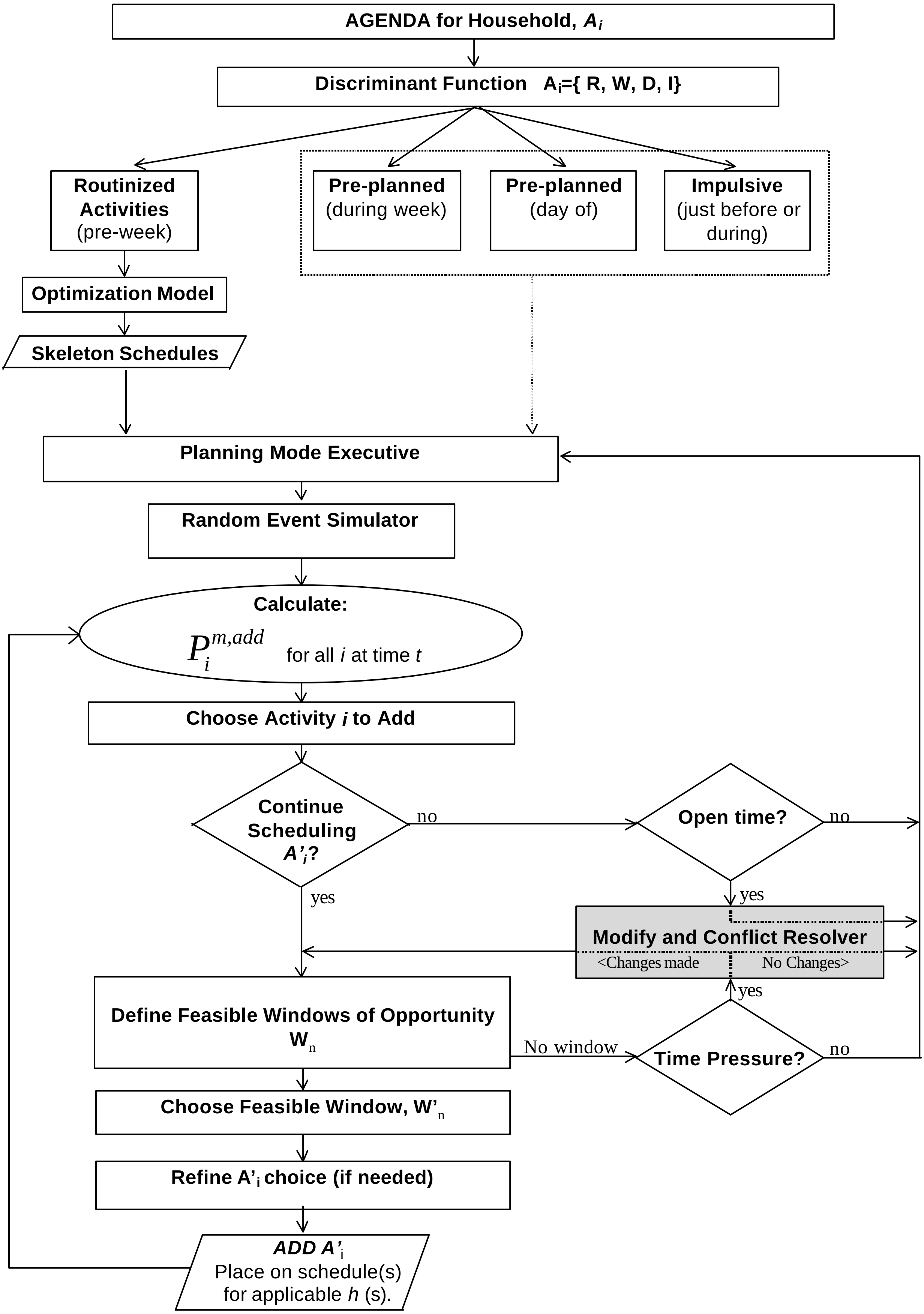


Figure 2 Modify and Conflict Resolver Sub-model

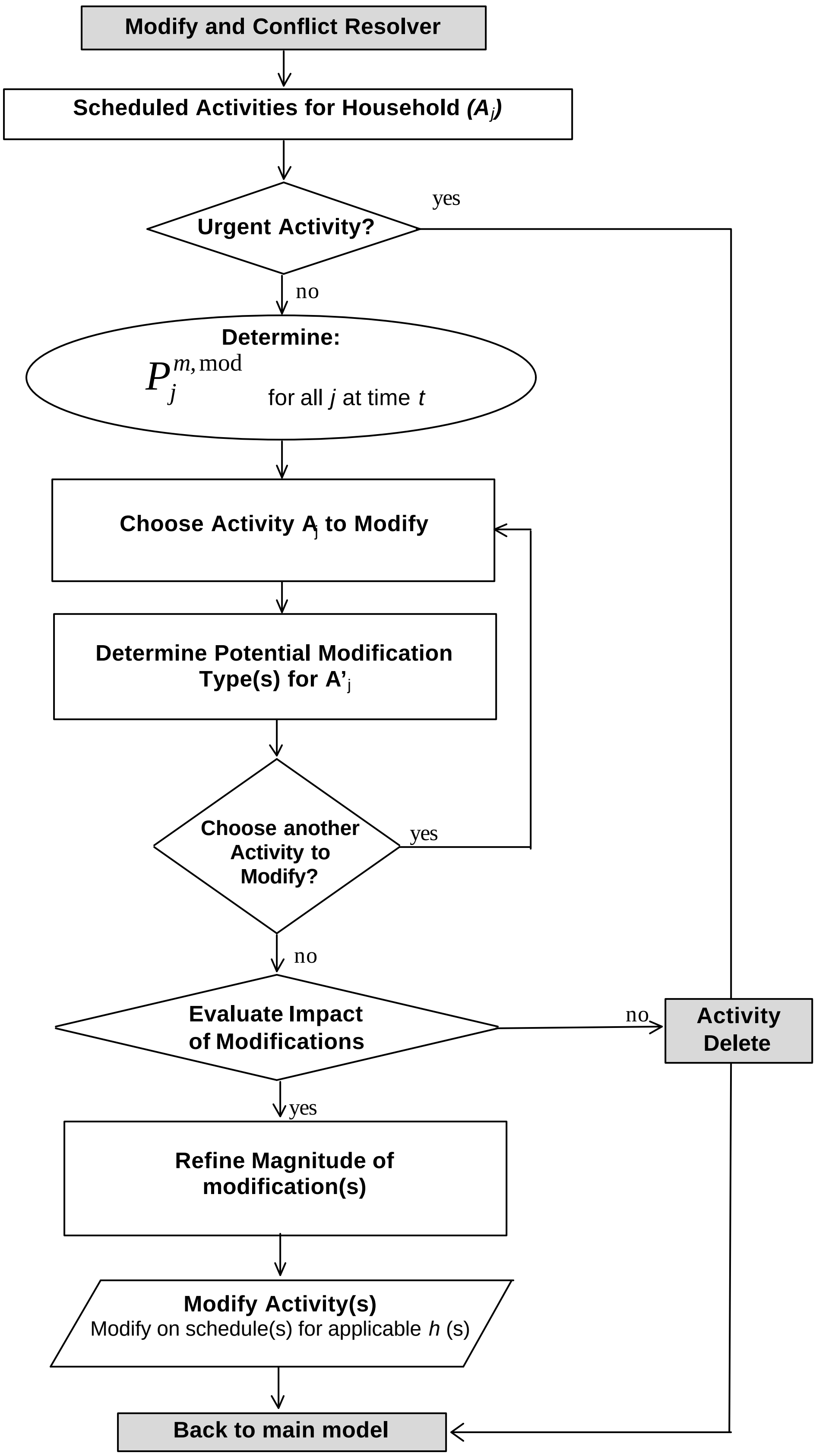


Figure 3 Delete Sub-model

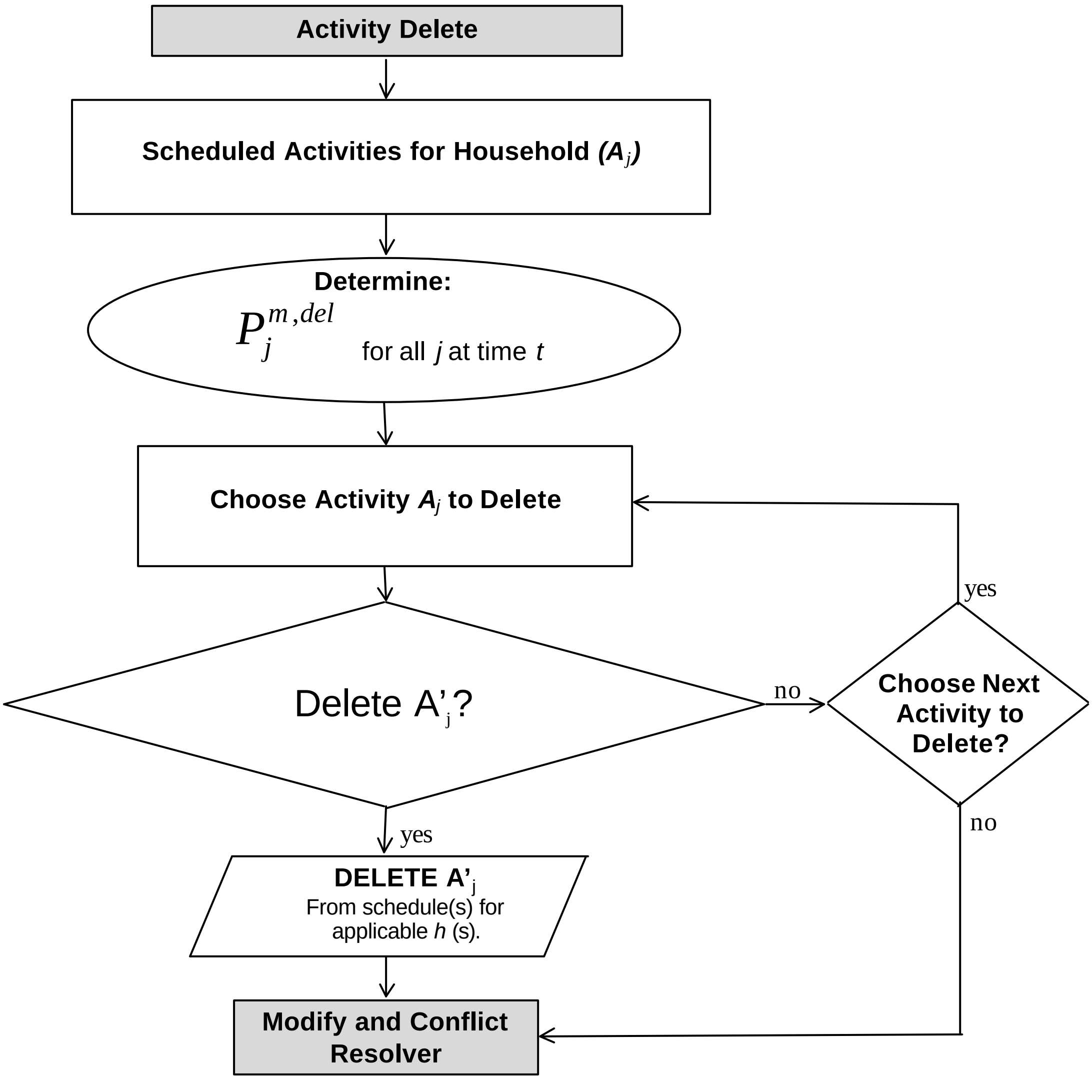


Figure 4 The proportion of additions, modifications, and deletions made for each day by when they were planned

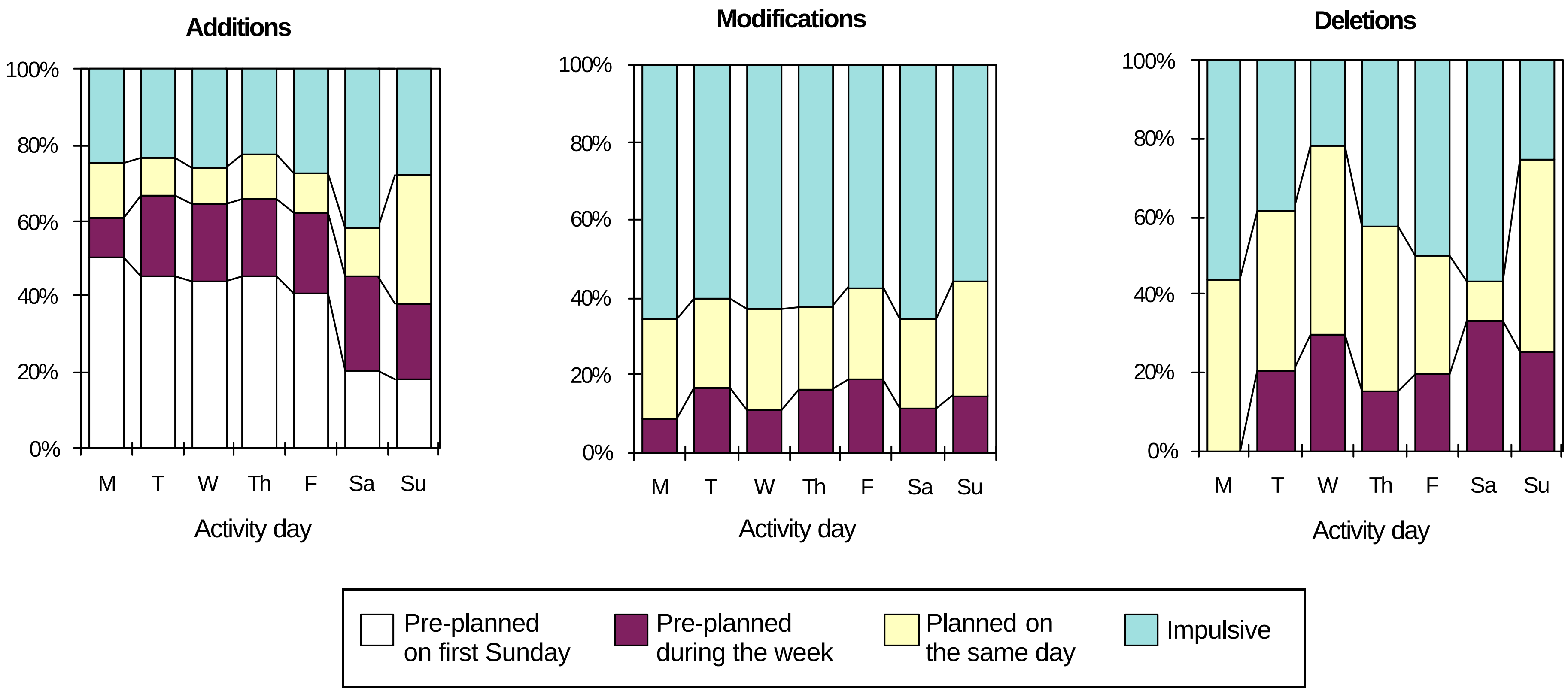
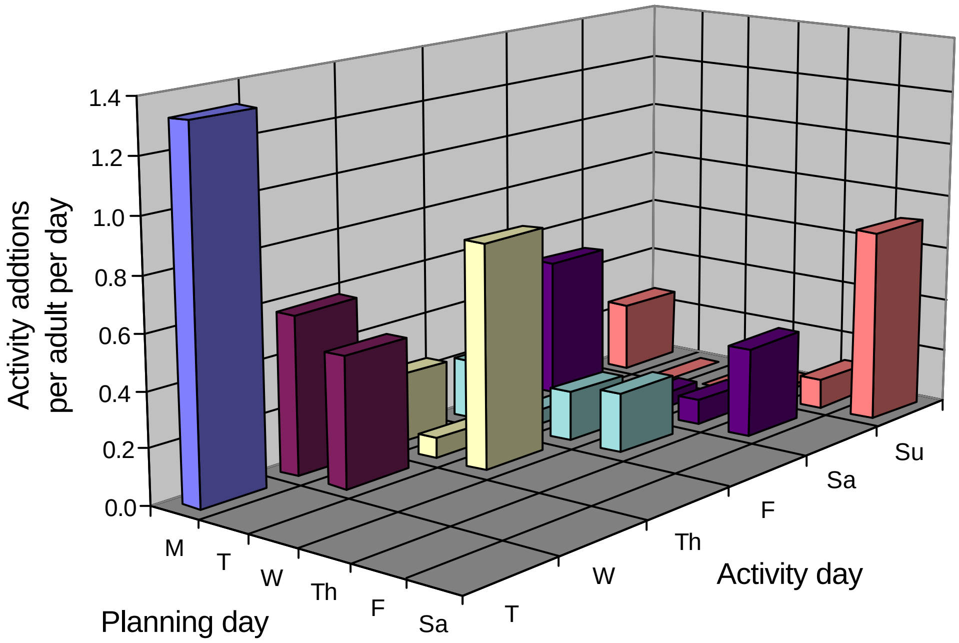


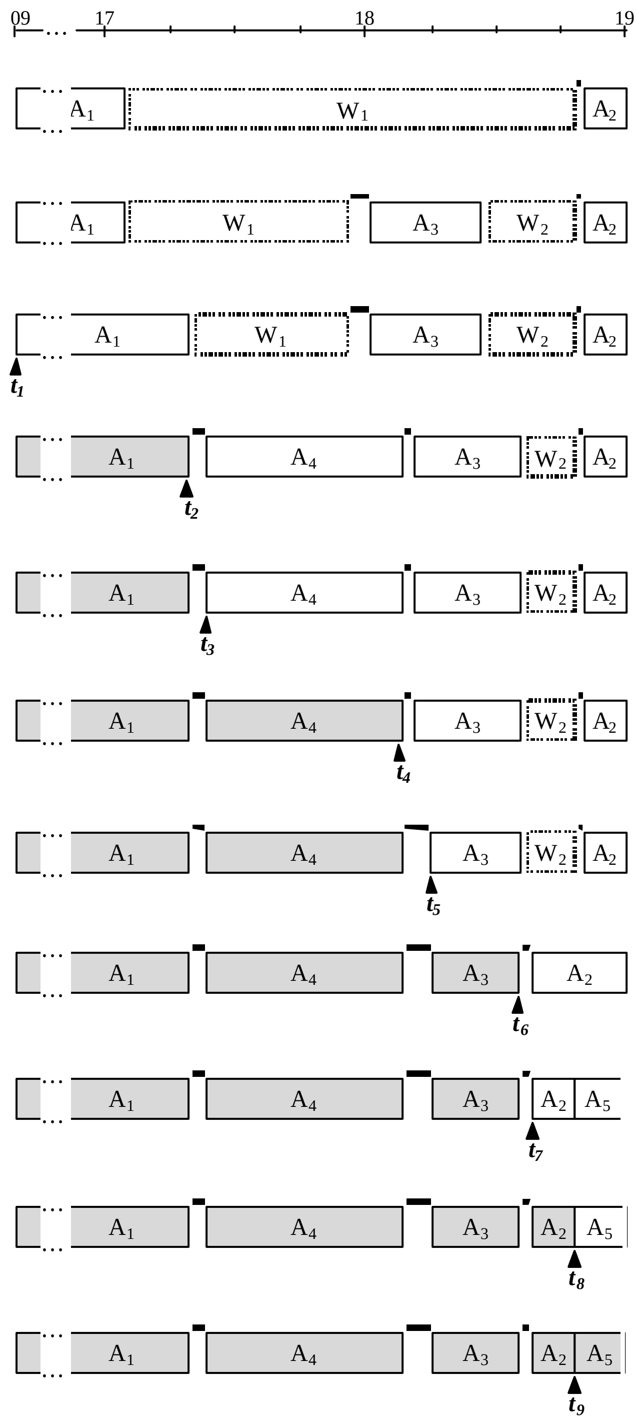
Figure 5 Pre-planned activities* by planning day and activity day



*Restricted to activities planned more than a day before the activity occurred, exclusive of the first Sunday.

Figure 6 Graphical example of the sequential steps simulated by the model

Scheduling Steps Over an Example Time Period	**Description** (at each time step)



Time Scale

t_0 ***Weekly Skeleton,:*** *A_1 and A_2 routine activities*

t_0 ***Pre-planned activity****: A_3 scheduled on previous day*

t_1 ***Random event****: extend duration of A_1*

t_2 ***Impulsive decision:*** *Add A_4 to empty time window W_1 requiring modification to A_3*

t_3 ***Random event:*** *no change in A_4 duration, no urgent activities*

t_4 ***Impulsive decision:*** *no additions between A_4 and A_3*

t_5 ***Random event:*** *A_3 randomly shortened (due to travel time extension), no urgent activities*

t_6 ***Impulsive decision:*** *Open time (nothing high priority enough to add) - extend A_2*

t_7 ***Random event:*** *no random change in A_2 duration, but urgent activity addition A_5, requiring modification to A_2*

t_8 ***Impulsive decision:*** *no additions between A_2 and A_5*

t_9 ***Random event:*** *no change in A_5 duration, no urgent activities*

Legend

Time Window, W_n | Planned Activity, A_j | Executed Activities, A_j | Travel

A_1: Work A_2: Home obligation A_3: Meeting A_4: Shopping A_5: Surprise visitors