AGENT-BASED DYNAMIC ACTIVITY PLANNING AND TRAVEL SCHEDULING MODEL: MODEL FRAMEWORK

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Paper Submitted for Presentation at the 88th Annual Meeting of the Transportation Research Board

Submission Date: August 1, 2008

Word Count: 5,965 + 1,250 = 7,215 words
(Text) (1 Table and 4 Figures)

ABSTRACT

This paper describes a new framework for dynamically simulating activity planning and scheduling within an activity-based modeling framework. The dynamic activity planning framework is a process model which attempts to replicate time-dependent activity scheduling. By modeling the actual underlying activity and travel planning and scheduling processes rather than revealed activity-travel patterns, the model can represent a much wider range of travel demand management policies, especially policies which are expected to impact the planning process of individuals. In contrast with previous activity scheduling models, the proposed model considers activity scheduling steps as discrete events within the overall activity-travel simulation, and furthermore considers each attribute decision as a separate event. The paper develops a framework for modeling each activity and its attributes, and allows for a non-fixed attribute planning order, so that there is no pre-determined planning order assumed in the model. In addition, some initial data results from a pilot test of a new GPS-based prompted recall survey used to capture the underlying activity attribute planning process are presented and discussed in the context of the overall model framework. The initial data tend to support the hypothesis that significant variation exists in the manner in which activities are actually planned.

1. INTRODUCTION

Activity-based analysis has provided new and innovative ways to model travel demand and allowed for significant improvements in the understanding and forecasting of travel behavior. The realism and explanatory power of activity based modeling, especially when developed into a full microsimulation modeling system continue to improve. However, it has been recognized that significant issues still exist in all activity-based microsimulation systems and that there are areas where theoretical and practical developments still need to be made (Litwin and Miller 2004), including in modeling the underlying decision processes behind activity scheduling, improving the representation of time and representing the interdependence between the various decisions underlying the activity scheduling process (Miller 2005).

However, probably the most significant issue which has often been observed is that most models that are developed so far are designed to estimate executed patterns of activities, with no consideration for modeling the underlying process of how those activity patterns were actually arrived at (Garling et al. 1996, Litwin and Miller 2004, Lee and McNally 2006). Thus, activity based models are designed to fit existing revealed activity patterns and most work well for this purpose. Since the models do not represent the actual underlying scheduling processes, they are not sensitive to potential changes in these processes. However, changing the activity scheduling behavior of individuals is a growing area for travel demand management policy, and in fact many other transportation policies may induce changes to the actual planning and scheduling processes themselves. Therefore it is important that activity based travel demand models can represent these types of policies. For these reasons, a new framework for activity scheduling is proposed which is referred to as the Agent-based Dynamic Activity Planning and Travel Scheduling (ADAPTS) model.

This paper presents a framework for developing a fully dynamic activity planning and scheduling model for use in an activity-based microsimulation modeling system. A fully dynamic scheduling model treats activity planning steps as discrete events within the simulation, meaning that activity planning, modification, and execution are simulated along the same timeline. This system allows activities to be planned in a manner more closely approximating actual scheduling behavior, with activity scheduling decisions intertwined with actual activity execution, and therefore able to respond to changes and new opportunities which may occur during the simulation. The underlying fundamental concept of this framework is the extension of the activity planning horizon, which had previously been applied to the activity itself (Doherty and Mohammadian 2003), to the planning of the individual activity attributes. Therefore, in addition to an activity planning horizon models (Mohammadian and Doherty 2006), there will also be a timing planning horizon, a location choice planning horizon, mode choice planning horizon, etc. Each of the planning horizons will define a specific time within the overall simulation timeline when the attribute selection decision is made, allowing for much more complex interdependencies between attribute decisions. For example, in a model of this type, the location decision could depend on a previous mode decision, or vice versa, and both decisions could depend on many other scheduling decisions made in the intervening time between the general activity plan (activity planning horizon) and the individual attribute activity horizons. The rest of the paper is organized as follows. First a review of previous work in activity scheduling and planning horizon estimate is undertaken. Next, the general framework of the activity scheduling simulation is described. Afterwards, some initial exploratory data analysis from a small pilot study of attribute planning behavior is undertaken. Finally initial conclusions and recommendations for future work are made.

2. LITERATURE REVIEW

In response to demands for more realistic travel demand models which are more capable of analyzing a wider range of transportation policies, the activity-based modeling framework was originally proposed and further developed. These models often tend to specify the full daily pattern of activity and travel at a disaggregate level for modeled regions, and in general have a more behavioral basis than preceding travel demand models. However, many activity-based models make unrealistic assumptions about the scheduling behavior of individuals and in general are better at replicating observed outcomes than they are at replicating how those outcomes where arrived at. This has the tendency to make the models unresponsive to changes in the process of activity scheduling amongst individuals. A modeling framework that had initially been advanced as an alternative to correct some of these deficiencies is the rule-based or computational process model (Garling et al. 1994). Computational process models tend to use either heuristics (Roorda et al. 2005) or some other rule structure to represent the decision making process itself, rather than modeling only the outcomes of the decision process as in most econometric models. Much of the theory of the computational process model is based on work by Newell and Simon (1972) in the development of the production system. The production system is a model of cognitive behavior which states that "individuals' choices are based on their cognition of their environment" (Ettema and

Timmermans 1997). This means that a cognitive process can be represented by a model which contains an individual's memory, including knowledge of their environment and the results of their interactions with it, rules which operate on that memory and some currently known information about the environment.

Several models using rule-based frameworks or computational process models have been developed. One of the first models to be developed using the CPM framework was created by Hayes-Roth and Hayes-Roth (1979). The Hayes-Roth model was in fact the first to apply the principles to activity scheduling. More recent models include SCHEDULER (Golledge et al. 1994), ALBATROSS (Arentze et al. 2000) and TASHA (Roorda et al. 2005b). These models all attempt, in some way, to specify the process of activity scheduling, and are therefore potentially more theoretically satisfying as well as more policy sensitive, since this type of model is the only one which would represent policy scenarios which actually represent changes in the scheduling process itself. However, the scheduling process has rarely captured short-term scheduling dynamics as proposed in several conceptual models (Litwin and Miller 2004, Miller 2005). However, empirical observations of some of the dynamic aspects of activity scheduling have been conducted (Lee and McNally 2004, Joh et al. 2005, Roorda and Miller 2005, Clark and Doherty 2008, Ruiz and Roorda 2008) and aspects of dynamic activity scheduling such as planning horizons and conflict resolution have been modeled (Mohammadian and Doherty 2005, Lee and McNally 2006, Ruiz and Timmermans 2006, Auld et al. 2008a). Recently, models have even begun to account for short-term adjustment and rescheduling processes, such as the AURORA model (Joh et al. 2002, Joh 2004) and the related FEATHERS model (Arentze et al. 2006). These developments have all been aided greatly through new sources of data describing the scheduling process such as CHASE (Doherty et al. 2004), REACT (Lee and McNally 2001) and others (Ruiz and Timmermans 2006, Zhou and Golledge 2007, Clark and Doherty 2008)

All currently operational process models necessarily make many simplifying assumptions about the scheduling process itself. These simplifications include using an assumed priority order of activities to sequence the addition of new activities to the schedule as in TASHA (Roorda et al. 2005) and others, as well as using a fixed sequence for planning attributes as in most econometric models, the CEMDAP system (Bhat et al. 2004) and ALBATROSS (Arentze and Timmermans 2000) among many others. In fact, to the best of the authors' knowledge, all activity-based modeling systems assume some a priori planning order for specifying the activity attributes. Recent data collection efforts including CHASE (Doherty et al. 2004) and others have shown that priority assumptions are unrealistic. It is likely too that the planning order assumptions typically made also do not reflect the reality of activity scheduling. Analysis of planning time horizons from scheduling process data shows that many activities are opportunistically planned (Mohammadian and Doherty 2005), during execution of a tour which could not be handled by scheduling models where the activities are selected first, then formed into tours.

3. PROPOSED DYNAMIC SCHEDULING MODEL FRAMEWORK

The fundamental concept underlying the framework of the dynamic activity scheduling and planning model is to treat activity planning events as individual discrete events within the overall simulation framework, so that an activity schedule is created and modified over time, and that attributes of each activity are not necessarily planned in any given order, which contrasts with the assumptions usually made about the sequential planning process, as in ALBATROSS (Arentze et al. 2000), TASHA (Miller and Roorda 2004), and others. Furthermore, there are separate events for the planning of each attribute of each activity, so that party composition, location choice, time-of-day decisions and mode choice decisions are all represented by separate planning events. The execution of these planning events occurs along with the execution of activities and travel.

The scheduling model itself is a submodel in a larger overall activity-based modeling framework, a proposed outline of which is shown in Figure 1, where long-term decisions, such as housing choices, job choices, vehicle ownership, household composition, etc, are estimated in a long-term simulation which feeds in to the short term simulation of the activity-travel pattern, the results of which are then fed back to the long term simulation. The combination of the long term land use simulation with the short term activity-travel simulation defines an integrated land-use transportation microsimulation model. However, the present focus of this paper is on the development of the new activity-travel model formulation alone.

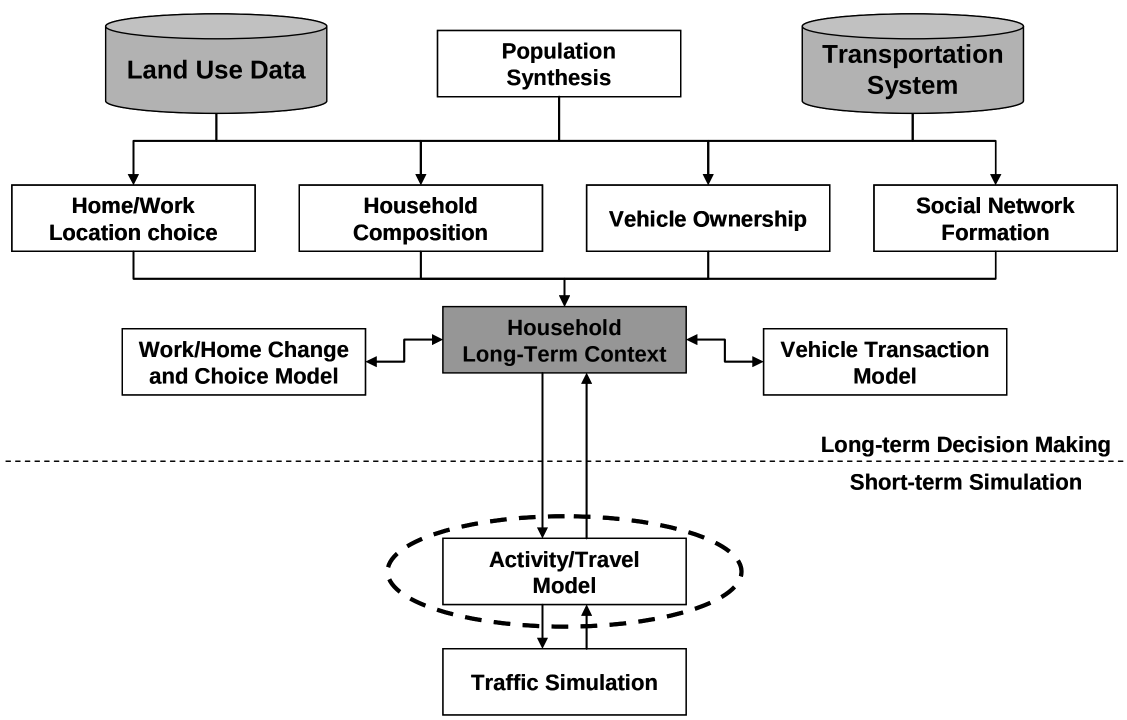


Figure 1. Integrated Land-Use Transportation Framework

The Dynamic Activity Planning and Scheduling Model framework simulates the dynamic process of schedule formation with potentially more realism, since it accounts for the varying interdependencies and potential differences in planning times, between the various attributes. For example, an activity can be added and a location chosen at the same time, but the timing for the activity may be left open. If the timing is decided later, it will therefore depend on the location choice. However, the timing may not depend on the location choice at all, i.e. it could be planned first or even at the same time. It is felt that there could be fundamental differences between, for example, location choice decision processes when timing is known, versus when timing is unknown. This framework attempts to capture those effects. Detailed descriptions of each decision or model are given below.

At the conceptual level, the model can be thought of to split the activity scheduling process into three distinct phases. The first phase is activity generation. In this framework, activity generation refers only to the highest level decision of whether or not to add an activity of a certain type, i.e. all other activity attributes are left unspecified. This current framework focuses mostly on the planning and scheduling of activities, so for the current formulation details of the potential activity generation stage are omitted. The second phase of the model framework is activity planning. In this phase, the actual values of the various activity attributes are specified. Again, unlike in previous models, however, this framework is set up so that the attributes can be determined in any order, with attributes planned later dependent on the already planned attributes. Finally, the last phase of the framework would be activity scheduling, where the activities would be added to the planned schedule and conflicts would be resolved.

The detailed framework for the ADAPTS activity scheduling model is presented in Figure 2. This framework presents activity scheduling as a dynamic process, completed over time with the final executed schedule resulting from a series of decisions. The high level decisions represented in the framework include: whether to add a new activity, whether to update (or initialize) attribute values for an existing activity, whether to resolve conflicts between planned activities (either when one of the activities is attempted to be executed or beforehand), and finally, whether a planned activity can be executed. As shown in the figure, each high-level decision can contain a number of models which can represent how aspects of the decision are made. For example, if the individual decides to add a new activity, this decision will encompass several subsequent decisions, which are captured in the *planning order* model as well as the *planning horizon* models.

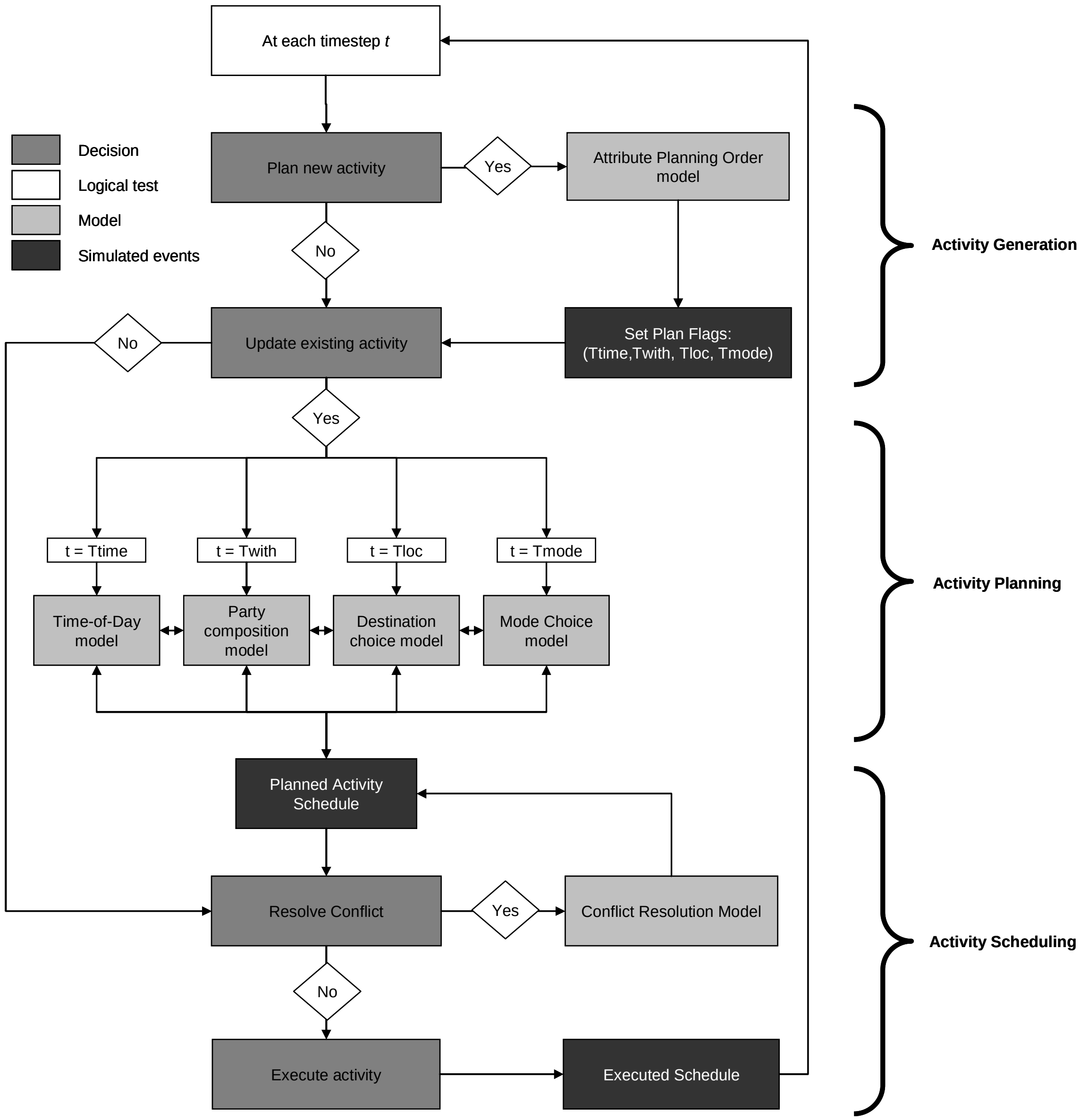


Figure 2. Scheduling Process Model Framework

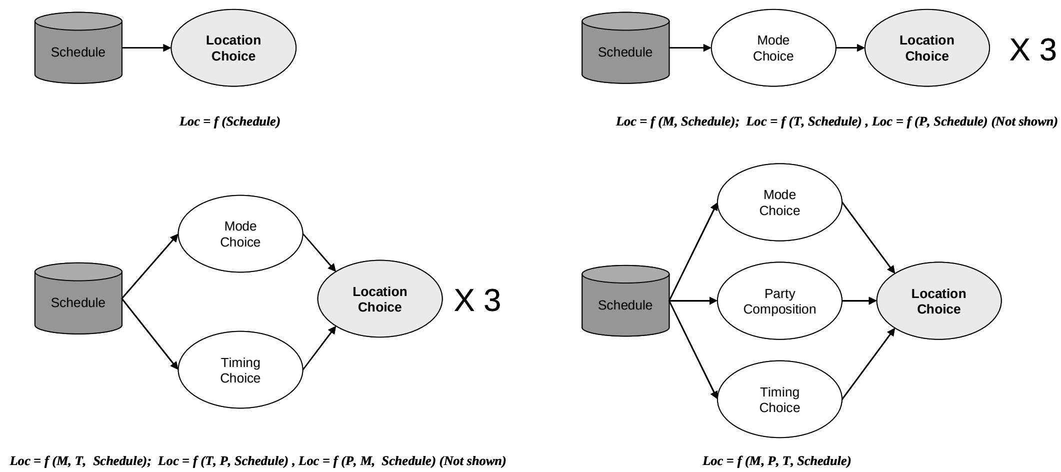
As is shown in Figure 2 the framework consists of a series of four top-level decisions ('Plan new activity', 'Update existing activity', 'Resolve Conflict' and 'Execute Activity') which are evaluated in order for each time step to determine if further action is required. Under each top level decision are further sub-models which refine or change the planned activity schedule or execute and activity as needed. The following subsections describe each top-level decision and related sub-models.

3.1 Plan New Activity Decision and Sub-Models

The *Plan New Activity* decision of the scheduling framework corresponds to the activity generation of the model. If the individual at time *t* decides to plan a new activity, the type of the activity is first selected. Although all of the other attributes can be selected in any order, the activity type is fixed to be selected first, as it is fundamental to the concept of activity, i.e. one can say "I'm going *shoppin*g today" without any of the other attributes being determined, but it is unlikely that one would decide "I'm doing *something* today at 12:00", etc. After the activity type is determined, the *Attribute Planning Order* model is run to determine what order the attributes are planned, i.e. location first, timing second, who with third, etc. This sets the basic order for the dependencies in the attribute planning and choice models. After the planning order is determined, the planning horizon models are run for each attribute in that order, with each result constraining the subsequent attribute planning horizon. One potential outcome of the *Planning Horizon* models is that the attribute is planned at the current time, in which case the attribute choice models contained in the *Update Existing Activity* decision are run for those attributes. Otherwise, the planning time horizons for each attribute are set according to the model. The time horizons for each activity determined in this stage are used to set the *Attribute planning events* for the current activity. When the attribute planning events are reached in the simulation, the planning for that attribute can then occur. The incomplete (or completely) defined activity is then added to the *Planned Schedule* for later updating or execution. Therefore the *Plan New Activity* decision, and the *Planning Order* and *Planning Horizon* sub-models have the effect of generating a new activity and its related planning events as defined by the various planning horizons.

3.2 Update Existing Activity Decision

After the *Plan New Activity* decision is run, the model then checks the *Update Existing Activity* decision. This portion of the model framework corresponds to activity planning, which determines the various activity attributes. This model scans the schedule to see if any *Attribute Planning Events* are to occur within the current timestep. If so, then the required *Attribute Planning* model is called. The various *Attribute Planning* models all take as input the current state of the planned schedule and the current state of the activity to be planned. Therefore there is a complicated set of conditional models which determine each activity attribute. For example, if the location of one activity is planned first, it will be conditioned only by the attributes of the individual and the current schedule. However, if the timing is known the location will also be conditioned by this information and if the mode choice is also known this will further condition the location choice model, and so on. This same process holds true for all of the *Attribute Planning* models. Additionally, it is likely that various attributes may often be made simultaneously, i.e. "I will go shopping at the *store* at *5pm*." Therefore a set of models for each attribute will be needed to describe all conditional dependencies as well as all possible simultaneous decisions for each attribute choice. Figure 3 shows an example of some of the possible conditional models for the location choice. In fact, assuming only four activity attributes are planned (location, timing, mode, party) there are a total of 65 different models required to fully describe all of the possible dependencies; 32 modeling individual attribute choices as shown in the figure and 33 models describing simultaneous choices where two or more attributes are planned at one time.



Note: M = mode choice, T=timing choice, P=party composition

Figure 3 Conditional Non-Simultaneous Location Choice Models

As each activity attribute decision is made, the activity itself is updated. The activity is added to the planned schedule after the timing decision is undertaken. After all required activity planning decisions are completed for the current time step, the model then shifts to the activity scheduling routines.

3.3 Resolve Conflict Decision

After an activity has been planned, it is necessary to schedule the activity for execution. This involves placing the activity into the planned activity schedule. However, as activities are generated it is possible that there may be incompatibilities between the activity and those previously scheduled, which are referred to as activity scheduling conflicts. When the activity is added to the planned schedule the model will then check to see if any new scheduling conflicts have been created. If so the conflict resolution model, described in Auld et al. (2008a), is called to determine what sort of changes to the existing schedule are required to resolve the conflict. The possibilities include changing the newly planned activity, changing the preplanned activity with which it is in conflict, changing both activities or deleting one or the other. After the desired resolution strategy is selected a set of heuristics is used to evaluate whether a feasible resolution can be implemented. If there is a feasible conflict resolution it is then run to make the planned schedule consistent again, while if there is no feasible resolution, the later planned activity is removed from the schedule entirely.

3.4 Execute Activity

After all of the generation and planning processes have been undertaken for the current time step, any activity or travel which is scheduled to occur during the timestep is begun. For a travel episode this involves setting the state of the current agent to traveling and outputting a new trip with the required characteristics (start time, mode, destination, etc.) to the travel simulation. For an activity episode, this involves ending the previously started trip, removing the agent from the travel simulation and setting the state of the agent to being at an activity. The details of the integration of the activity scheduling with travel simulation will be left for later work, however it is important to note that the model framework is envisioned to make use of the individual simulated travel times returned from a traffic simulation for future activity planning and scheduling.

4. CURRENT STATUS OF ADAPTS MODEL

Currently, various stages of the ADAPTS model are being implemented in an overall simulation framework. A population synthesizer has been implemented which uses Census and survey data to generate each household and individual for a modeled region (Auld et al. 2008b), which initializes the model. The model then cycles through each household randomly over a series of time-steps (currently set to 15 minutes) for the analysis period. At each time step, activities are generated randomly from a series of parameterized distributions developed from travel survey data to determine if an activity is to be scheduled. Since the activity planning order and attribute planning horizon models are contingent on future data collection efforts, these have not yet been implemented, so the model instead uses a previously developed activity planning time horizon model (Mohammadian and Doherty 2006) to determine a range of time when the activity will be scheduled (i.e. immediately, during the same day, or sometime later in the week) by the model. Currently, the choice models for the actual activity attributes, such as mode, party composition, timing, etc. are rather limited, and are merely replicated from survey distributions randomly. The location choice, however, is handled through the use of a learning algorithm which is based on a location utility measure estimated from survey data and allows the agents to store previous results at zones, search for new zones and exchange information about zones in order to make location choices. After the activity is planned it is scheduled using scheduling rules presented in Auld et al (Pending) based on a previous activity conflict resolution model (Auld et al 2008a). At the end of each time step, the model outputs a list of all agents who are currently undertaking a travel episode for use in a traffic microsimulation. Although the linkage with the traffic simulation is not completed, when it is done the model should then read back the travel results for each individual who was traveling to determine their experiences over the transportation network (i.e. is the trip complete, did the trip take longer or shorter than expected, etc.) for use in later time-steps. To complete the framework and create a truly dynamic model of activity planning, however, will require the completion of the planning order model, the attribute planning horizon models and the set of conditional attribute choice models, all of which require further data collection. Current efforts toward this goal are described in the next section.

4. INITIAL PLANNING PROCESS OBSERVATIONS FROM PILOT SURVEY[1]

In order to support the development of the ADAPTS model, and to create the conditional planning models as described in the previous section, a large amount of data on the

[1] More data will be available for the analysis in this section after the actual survey begins in August.

dynamic planning process is required. For this reason, a new internet-based prompted recall study was developed to specifically elicit information of this type of data from respondents. This survey utilizes GPS data loggers to collect activity-travel survey data from individuals, which is then uploaded to a website for analysis. The uploaded GPS trace data is then used to automatically generate a prompted recall survey which individuals complete, filling in the details such as the type of the activity, who was involved in the activity, reasons for location choice decisions, activity timing and flexibility decisions, as well as mode and route choice details and reasons for their selection. In addition, for all attributes planning horizon details were collected. For example, when a survey participant was asked about the location choice for the activity, an additional question such as “When did you make the decision to visit this location?” was asked. In this way, planning horizons for all activity attribute decisions were obtained. Full details of the design and implementation of the survey instrument can be found in Auld et al. (forthcoming-b). An initial small scale pilot survey was conducted using this prompted recall survey in order to make observations regarding the attribute planning order for activities to determine if the planning order differs significantly from common assumptions. The pilot survey collected data regarding activity-travel decisions for 10 volunteers for an average of one week each, which provided a total of more than 338 planned activities for this initial analysis. A more comprehensive survey with a larger sample size is being conducted to gather data for the proposed modeling framework.

In the following section, observations about the planning dynamics of the out-of-home activities reported in the pilot survey data are made. The attribute planning order distributions for each of the individual attribute planning decisions are shown in Figure 4 below. Note that for this analysis the party composition choice was not included. The figure shows the overall activity planning horizon as well as the individual timing, location and mode choice decision planning horizons. From the initial sample data, it is clear that mode choice tends to be a highly routine decision, with over 42% of mode choice decisions reported as routinely planned, indicating many activities occurring in the midst of routine tours to routine activities (i.e. to work/school, etc.) In fact, of the 88 activities with a routinely planned mode, only 28 of those activities are themselves routinely planned (mostly work, school and pickup/drop-off). This means that for all of the other activities, they are added to the schedule and the other attributes are planned with the mode already known. This could add additional constraints and dependencies for further attribute planning which are generally not captured in a system with a fixed attribute planning order. The timing decision is the least routine planning decision made, with the highest percentage of impulsive decisions at 42%, indicating a high degree of opportunistic planning in the time-of-day choices. The location choice falls somewhat in between these two decisions, less impulsive than timing choices and less routine than mode choices. However it is more instructive to look at the overall order of planning rather than at each individual planning horizon to get a sense of the dynamics involved in attribute planning.

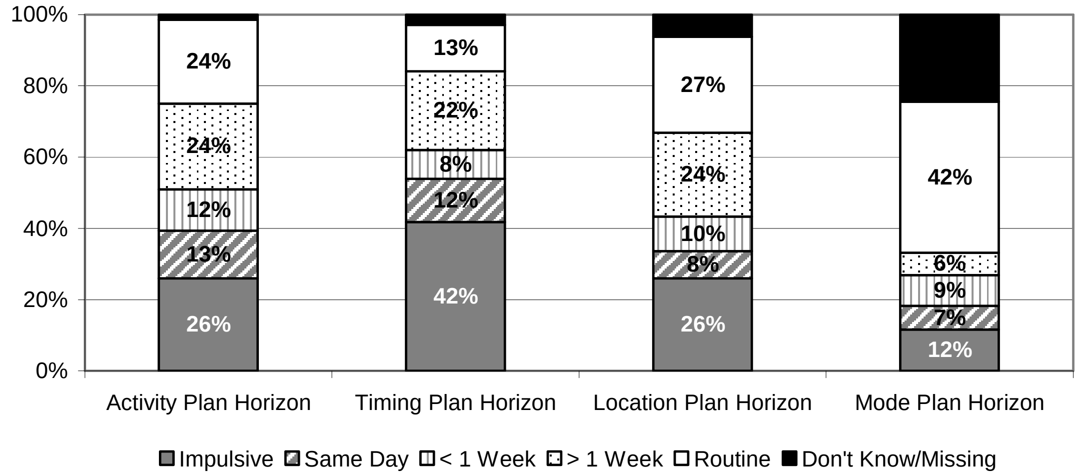
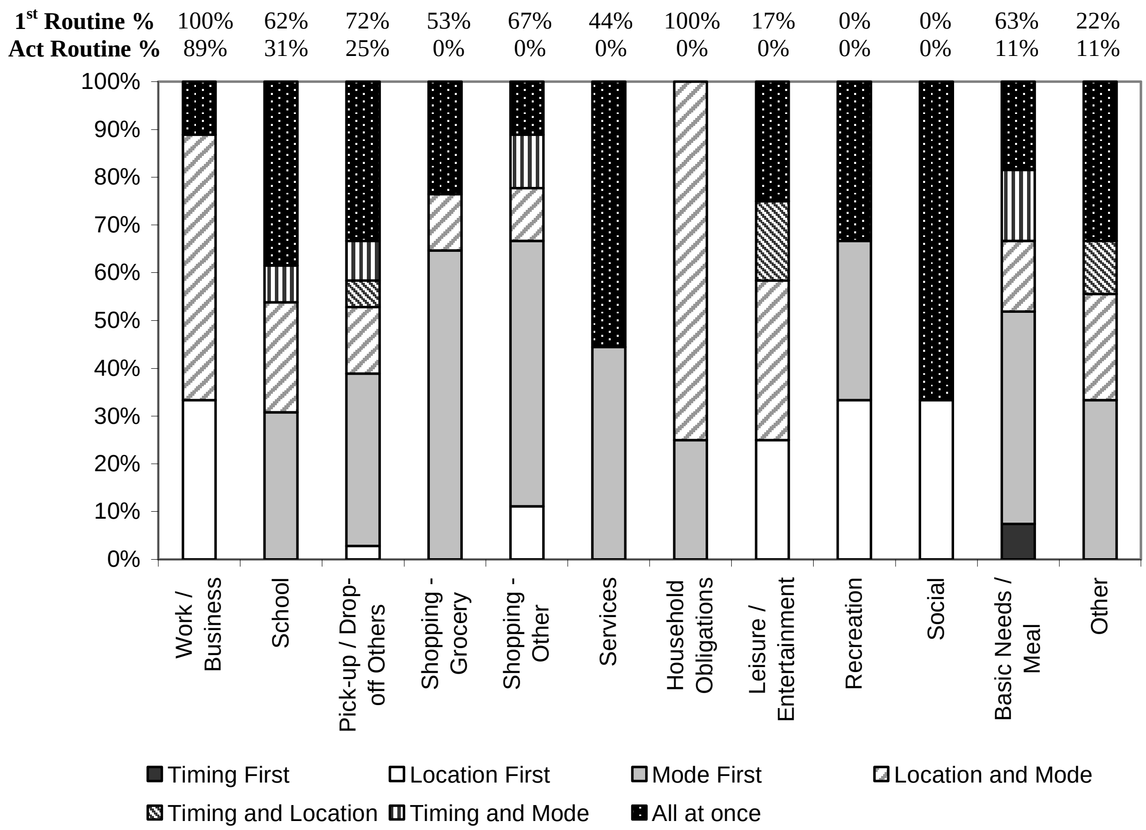


Figure 4. Activity Attribute Planning Horizons

The planning order analysis conducted is shown in Figure 2 below. The figure shows the percentage of activities planned in each order shown. This figure shows for each activity type the percentage of activities which were planned as location, timing or mode first, planned with two attributes simultaneously or planned with all attributes simultaneously. In addition, the percentages of activities for which the first planned attribute was "routine" and the percentage of activities which had "routine" planning horizon are given for each activity type.

The most commonly observed planning order is the 'mode selected first' type, where the mode is known before any other attribute. According to the data, 34% of all of the activities fall into this category, mainly in the shopping, services, basic needs and similar categories, although a significant number of school and pickup/drop-off activities also had the mode planned first. Interestingly, only 8% of these activities are routine although in 84% of them the mode is routine, indicating a routine tour. A majority of these activities were preplanned, i.e. a stop location and time were selected in advance during a routine travel episode. An example planning step for activities of this type could sound like "I will be driving home from work next Tuesday so I can stop at the store at 4:00". Again this shows the degree to which activities are planned to fit within routinely conducted tours. In 27% of cases the three attributes are planned simultaneously and over 50% of these are non-routine activities. Activities planned in this fashion are mostly preplanned or routine, with only a small number spontaneously planned. This is likely due to the higher degree of planning and flexibility needed to select all three attributes simultaneously, although small activities such as "I need to run to the store right now" still occur. The final significant planning type observed in the data is 'location and mode planned first'. These activities again mostly have routinely planned mode and routine location choice, which could be something like "I will stop at the coffee shop on my way home from work." Other planning modes are also observed as seen in the figure, although at lower frequencies. For instance, the time is rarely planned first, and the location is planned first in only 8% of activities, although both are often planned first in combination with another attribute.



Note: 1st Routine % indicates the percentage of activities for each type for which the indicated first planned attribute(s) were routine.
Act Routine % indicates the percentage of activities of each type which had 'routine' activity plan horizon.

Figure 5. Attribute Planning Order by Activity Type

The planning order data clearly shows that the assumption of a fixed planning order for activity attributes is not realistic. Activities can be planned in a variety of ways, which should be represented in the planning model due to the very different scheduling conditions imposed. As mentioned previously selecting a location when the mode is known is very different than selecting a location when the mode is unknown and vice versa, so that assuming one or the other is likely to introduce some error into the planning model. This initial pilot survey goes some way towards demonstrating the various planning strategies that individuals' use, however much more data is needed in order to generate models of planning behavior.

5. CONCLUSIONS AND FUTURE WORK

This paper has presented a framework for incorporating dynamics into the activity planning process. Whereas most activity scheduling models treat activity planning as generally a step in the activity generation process, i.e. activities are generated and their attributes selected, followed by an activity scheduling step, this framework proposes to develop activity planning as a separate stage of the activity scheduling simulating. In addition, the activity generation, activity planning, and activity scheduling are all simulated as actual events within the microsimulation, so that planning happens at a given time for each attribute, rather than outside of the simulation in a fixed order. This allows the model to represent the activity scheduling process as a dynamic, event-driven system, where each planning model is dependent only on what happens before it and what is currently planned, and in addition allows the activity planning to react to unforeseen events and changes in the schedule.

However, much work remains to be accomplished before the modeling framework can be actualized within an activity-based microsimulation system. The activity attribute planning models require a complex set of conditional models dependent on all the other attributes, and will therefore need large amounts of data on the dynamic scheduling process. A GPS-based prompted recall survey is being conducted to gather data for this purpose. Additionally, the planning order model itself will need to be developed using this data. How to realistically model the activity attribute planning order, and incorporate the very basic planning horizon times into the detailed simulation time are also areas requiring further development.

Overall, the incorporation of dynamic planning into activity based modeling should help to not only increase the accuracy of the model output, but also increase the behavioral realism of the model. This would allow a wider range of policy scenarios, especially those which would be expected to impact the planning process itself, to be more realistically modeled.

ACKNOWLEDGEMENTS

The authors would like to acknowledge the financial support provided to this project from the National Science Foundation (NSF) Integrative Graduate Education and Research Traineeship (IGERT) program in Computational Transportation Science at UIC.

In addition, the authors are grateful to Eric Miller for providing valuable advice and comments on the development of this model.

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