Microsimulation and the Activity Scheduling Process: Views from the STELLA workshop

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1. Introduction

Information and communication technologies (ICT) will inherently invoke activity (re)scheduling responses by individuals and households. These responses, in turn, trigger short-term changes in activity-travel patterns, and longer-term changes in car ownership and residential location. For example, the use of ICT for telework will mean fewer people drive to work, but this will also open up vehicles to be rescheduled for use by other family members, and opens possibilities for altered daily activity schedules across the day or days. Indirectly, a teleworker may need fewer cars, or could be induced to relocate. While one hopes that these changes effect reductions in travel demand (and hence relieve congestion) we could in fact end up with relaxed connection to actual places of work and commute from a further distance but with lower frequency, resulting in the same amount of system load as before.

This position paper will argue that one method that can address these complex changes is based on modeling the activity scheduling process of each traveling individual directly. Three sections shed light at the issue: Sec. 2 looks at how to model the activity scheduling process of humans, and what data needs to be obtained. Sec. 3 looks at the status and caveats of the use of activity-based demand generation models in current practice. Sec. 4 then lays out a proposal for a multi-agent based traffic simulation which integrates activity-based demand generation with a microscopic, dynamic simulation of the traffic consequences of this, and is meant as a complete replacement of the 4-stage process. Sec. 5 discusses some of the topical questions which result from using these new methods, in particular in conjunction with ICT.

An interesting aspect of this paper is that our methods both *are* ICT (in the sense that they rely heavily on the use of data and computers) and they are suitable to *analyze* ICT.

2. Modeling the activity scheduling process

To better understand these complex first and second-order effects, Doherty et al. (2002) argues for a focus on underlying behavioral processes – especially the activity (re)scheduling process. Prior literature (Hayes-Roth & Hayes-Roth 1979; Hayes-Roth et al. 1979) attempted to formalize these decision rules as an AI production system that converts scheduling behavioral rules into action planning models. Recent attempts focus on the use of microsimulation of the sequence of decisions involved in the scheduling process using object-oriented or event-oriented simulations (e.g. Arentze and Timmermans 2000; Miller and Roorda 2002).

Despite these efforts, very little empirical evidence exists as a basis for understanding the activity scheduling process and for applied simulation model development. The desire to forecast the short and long-term impacts of ICTs makes this an even more pressing need. To meet this need in the short term, supplemental surveys that go beyond traditional activity/trip diaries are needed, such as the computerized activity scheduling surveys developed by Ettema et al. (1994) and Doherty and Miller (2000), as well as other creative in-depth surveys/experiments that explicitly focus on underlying processes, decision rules, adaptation processes and the like. Observed trip making patterns derived from diary surveys are not necessarily the best way to help with the understanding of the processes; for example it is difficult to see how a revealed preference pattern could possibly model the responsiveness to completely new or previously untested modal arrangements.

The immediate analytical goal of the new survey designs should be to explore the dynamic behavioral mechanisms that underlie observed activity-travel patterns (typically captured by diaries). This should include examination of the planned order of activities, how they get modified during execution, the dynamics of adaptation of plans (e.g. reaction to new situations through unexpected consequences), and the effects of learning and habit formation. Examination of activities and their most salient attributes that affect the scheduling process (e.g. spatial and temporal fixity) should also be a priority. A primary concern in this analysis should be the identification of decisions rules, and determination of whether they are stable, extremely simplistic and/or indeed already noted in the literature.

Equally important in the short term is the establishment of a clear dialog with members of the modeling community in order to: 1) identify key assumptions of existing models that require validation; 2) suggestions for fine-tuning existing models; 3) identification of new decisions rules or models that could be plugged into existing models; 4) alternative frameworks and/or wholesale changes in modeling forms. The long term-goal of such efforts could include the development of a fully functional household activity scheduling model that replaces the past 4-stage urban transportation modeling system, and its incorporation into integrated land-use and transportation simulation models.

3. Activity scheduling models in current practice

A convincing case has been made that microsimulation models allow much greater realism in the classification of travel demand, while avoiding the extremely sparse contingency tables that normally are associated with stratified models (Vovsha, Petersen and Donnelly, 2002). This approach also links together the travel allocation decisions of households in much more meaningful ways, and is able to represent the interactions between household members. Such models incorporate space and time budgets and recognize the necessity to treat the household travel planning problem over a horizon of multiple days and a wide variety of constraints. These ideas are becoming more widely known in the US though they have been considered for some time in European studies. The current practice is that there are active micro-simulation models in use for several US cities including San Francisco, New York, Columbus and Portland.

Microsimulation models <u>derive</u> detailed household records by seeding the data base with some key demographic parameters, <u>infer</u> their more detailed characteristics (from probability distributions) and then <u>extract</u> a matching household with these same characteristics from the micro-census [PUMS] data bases. A data base of responses to detailed travel activity surveys is used to derive parameters for many submodels, including destination and mode choice. Results of validation studies by Kitamura et al. (2000) show that individuals' daily travel patterns can be practically synthesized by micro-simulation. Further they state that "... properly representing rigidities in daily schedules is important in simulating daily travel patterns."

In practice these techniques depend on the ability to infer detailed household characteristics from broader descriptions. In forecasting mode, such models rely on predictable exogenous variables. This new approach is not without risks. For one thing, the conventional models produce output which is a required element of transit investment proposals (FTA), and so in some sense the newer models will have to be made backwardly compatible with less sophisticated outputs. Simulations produce results that are derived from particular seed values and averages over multiple runs may need to be synthesized into the equivalent of a deterministic forecast, even though many analysts would recognize the much greater value in a distribution with confidence limits. Second, there is a clear sense of time-sensitivity on the parameters of these models, and the phrase "shelf life" has been used to signify the fact that the models are now, more than ever, dependent on critical parameters.

The new model system relies on some key parameters and assumptions. Although micro-simulation is a novel technique, there are many overlaps and similarities between it and the empirical results found in the basic literature. For example, no one familiar with the trip generation literature would be surprised to find the importance of the role of children in the home on trip generation rates. The complex role of income in trip generation is also well known -- more income implies greater car ownership and initially higher expected trip making rates. But, in turn, higher incomes at the household level derive from multiple workers and hence more responsibilities, constraints and linkages required by the package of daily activity patterns. Microsimulation, given sufficient richness, goes some way towards accommodating the households' daily round of activities, which in aggregate produce the diurnal cycle of city traffic. It does this by making pragmatic rule-based decisions about the fixity of activities: whether mandatory journey to work, or discretionary serve passenger activity. Enhancing such rules to avoid static association of fixity by activity type (e.g. assuming work is fixed in space and time, which is clearly being challenged in light of ICTs) appears to be one key way where further exploration of activity-scheduling process may improve the behavioral validity and transferability of such models help. For instance, measuring an individuals perceived degree of relative spatial/temporal fixity associated with activities, followed by exploration of how such activities are scheduled and subsequently modified, would provide a basis for development of a more dynamic rule concerning the fixity of activities based on their relative attributes, not the static activity type label assigned to it.

For examples of current research on this topic see Esser and Nagel (2001), Jonnalagadda et a. (2001), Kitamura et al. (2000), Miller and Salvini (2002) and Vovsha Petersen and Donnelly (2002).

4. Towards integrated multi-agent simulation of travel behavior

Once the activity scheduling process is better understood, the question becomes how that knowledge can be used for regional transportation planning. As described in the introduction, it is plausible to expect higher order effects. Higher order effects means that not only do people react to ICT and other infrastructure changes, but these reactions affect the infrastructure again, leading to further reactions. The typical well-known example for this is congestion relief, which makes people schedule additional trips which they would not have scheduled at higher congestion levels. It is clear that such effects depend on the layout of the transportation system, and on complex interactions inside that layout.

4.1 Multi Agent Simulation for travel behavior and land use

One method that promises to integrate all these complex interaction into one framework is multi-agent simulation (MASim). The idea of MASim is that each entity of the system, in particular each traveler, is represented individually, with its own set of behavioral rules. A typical MASim for travel behavior can look as follows (TRANSIMS, 2003; Raney et al, 2003):

(0) Synthetic population generation: From census data, a Monte-Carlo representation of the true population is generated. That is, one has individual households, with individual members, and with demographic characteristics such as gender, age, income, car ownership. This synthetic population is not the same as the real-world population and so privacy remains conserved, but the synthetic population mirrors the real population in all demographic characteristics as they are available from public data.

(1) Activity generation: For each member of the synthetic population, activity plans are generated. The methods here are currently rather rudimentary, but this is where the techniques from Sec. 2 come in.

(2) Mode and route choice: Activities at different locations trigger demand for transportation. This module selects how this transportation is done.

(3) Traffic micro-simulation: So far, everything is intentions or plans. In the traffic micro-simulation, all those plans are executed simultaneously, resulting in interaction, in particular congestion.

(4) Feedback: This is strictly speaking not a module but a method. As we all know, the above process is not linear from one module to the next, but there is backwards causality. In particular, congestion influences route choice, mode choice, activity timing, activity location choice, and activity patterns. Feedback methods distinguish between day-to-day replanning and within-day replanning. **Day-to-day replanning** means that first all agents make preliminary plans ((1) and (2)), then these plans are executed in (3), then some agents revise their plans, then all plans are executed again, etc., until some kind of stopping criterion is fulfilled. Clearly, this implies that agents do not change their plans *during* the day. A more realistic method is **within-day replanning**. Within-day replanning offers additional challenges over day-to-day replanning, both from the theoretical/conceptual side (evolutionary game theory does not apply in a straightforward way any more) and from the implementation side (more difficult to couple modules from different teams; more difficult to maintain parallel computing performance).

What is described above is a system for which implementations should become operational within the next ten years. In fact, systems which span (0)–(1) (activity-based demand generation; micro-simulation of travel behavior) or (2)–(4) (under the name of dynamic traffic assignment, DTA) exist already and are currently being moved into practice (Bowman, 1998; DYNAMIT, 2003; DYNASMART, 2003; Raney et al, 2003). The two remaining challenges are to integrate all levels (0)–(4), and to implement within-day replanning in these systems in a meaningful way.

Another issue, which was mentioned in the introduction, is the issue of land use and housing changes. Clearly, it is possible to also make module (0) from above adaptive, that is, have people change home locations. In addition, it is possible to have companies (including retail) change their own locations in reaction to market developments. Such models can be either agent-based or aggregated. There is more experience with aggregated models, but the agent-based ones would be much easier to integrate with the travel behavior MASim as outlined here.

Prominent project that are based on agent-oriented concepts of land use and housing are URBANSIM (Waddell et al, 2001) and ILUTE (Integrated Land Use, Transportation, Environment modelling system; see Salvini and Miller, 2003 or Miller and Roorda 2003). A similar European project is ILUMASS (Integrated Land-Use Modelling and Transportation System Simulation, see irpud.raumplanung.uni-dortmund.de). Again, an important long-term challenge will be to couple these models, as well as incorporate realistic activity (re)planning/scheduling modelling components that both accommodate the impacts of ICTs on short-term travel behavior, and serve as potential triggers for longer-term land-use, housing and vehicle ownership changes. In support of this, both the ILUTE and ILUMASS models as being supported by recently completed in-depth surveys, in the form of a laptop-based interactive activity scheduling panel survey of 270 households in Toronto (see Doherty 2003), and a hand-held activity scheduling survey in Dortmund with 300 individuals (Rindsfüser et al. 2003).

4.2 Operational Challenges of Multi Agent Simulation

What are the challenges in the area of MASim for travel behavior and land use?

Moving them into practice. Sec. 3 of this text discussed issues related to moving activity-based demand modeling into practice. This concerns modules (0) and (1) as outlined above. This alone is a major political step which is not taken lightly by the decision-makers. In a similar way, modules (2) and (3) are currently moved into practice at several places, mostly in the context of Intelligent Traffic Systems (ITS). Moving all of (0) to (3) into practice is maybe still several years ahead, although first attempts are made with TRANSIMS.

Research oriented on case studies. Before moving the models into practice, it is important to go beyond the conceptual work and provide real-world case studies with the application of these methods. In fact, many projects go that path, e.g. at MIT (Ben-Akiva), at the University of Maryland (Mahmassani), and at ETH Zurich (Nagel/Axhausen). It is maybe worth noting that there is sometimes a shortage of publication outlets in the area of case studies, resulting in a lack of open and transparent discussion.

Implementation is too hard. Most of us make the experience that implementing MASim systems is hard work. Many of the concepts were already around ten years ago, yet we still do not have a fully functioning system in place (with, maybe, the exception of TRANSIMS). The experience is that computational and computer science methods support is still much weaker than one might hope for. For example, the area of object-oriented languages is split between java and C++, and between Microsoft and the rest of the world. The Standard Template Library (STL) in C++, urgently needed for standard implementations of the most basic data structures, still keeps changing from one release of a compiler to the next. XML (eXtensible Markup Language) formats, which are *very* useful for the file-based encoding of agent-based data, are only slowly becoming standard. This list could be made much longer. An open issue is thus if our implementations will ever catch up with the real world. At this point, with respect to activity-based travel modeling we are using the computational methods of the year 2000 to implement travel behavior of the 1950s (i.e. concentrating on day-to-day patterns and excluding radio broadcasts etc.). It is unclear if it will be possible to narrow this gap.

Dynamics of learning systems. It is completely unclear what the range of dynamical behavior of a simulation with co-evolving agents will be. From a theoretical perspective, anything from "convergence to a fixed point" to "chaos" is possible. Fortunately, weather and climate forecasting was and is confronted with the same issues, and is still capable to be useful. However, these issues need to be sorted out if researchers want to have confidence in MASim forecasting methods.

5. Inter-cultural issues and possible future projects

A root issue in our deliberations about urban traffic communications and land use interactions is recognition of the strong ties to patterns of housing development. The spatial layout of housing, and the inherent need to reach the place of work separated by increasing distance from the home base, is a fundamental process difference that leads to the levels of excess commuting that are prevalent in both the US and the EU. There are clear cross-system comparisons possible. The county-to-county travel to work data in the US gives some indication of the empirical realities, and there are interesting potential data analysis questions to be tested out as these levels of excess commuting are calculated.

Tolls and taxes and congestion mitigation efforts are factors in destination and mode choice that require a more integrated model of household activity schedule and trip-making coordination. Such models are now emerging as part of the discipline of microsimulation. Empirical research might address just how much more onerous the commuting situation is for the core London and Dublin areas as compared to similar sized cities in the US. What might we expect from the introduction of a center city entry tax in Columbus OH? What about a commuter tax in NYC (fiscal issue)?

The inherent characteristics of the demand for housing may have significant cross-cultural variations. (What is the norm for density? The Copenhagen model of high density is nice, but in reality the ideal of more space is deeply entrenched in other cultural systems notably the US and Canada.) The availability of space and the provision of affordable housing within reasonable commuting range of work place locations is a critical issue (as was related to us in the example of in the need for UCSB staff to commute from 50+ miles). The example replays itself in Ireland where there are extended commuting distances needed to reach the Dublin metro area where house prices have eliminated affordable entry-level accommodation for the young and growing population.

If cities are sprawling and the land is developed to provide lower density development, it is still sensible to make sure that the location and allocation of activity is as efficient as possible. The older haphazard intense business core that grew organically is conducive to transit solutions focused on the city center (preferred bus lanes and high capacity and high frequency alternatives to car and high costs for parking etc). If the urban pattern is multi-nucleated with a new developing edge of city it is quite helpful NOT to have everyone trying to funnel to a central accessible location! If we are starting from scratch with a new developing edge of city, other solutions might be possible. Given the complexity of the problem, we find it impossible to predict how such solutions might look like; microscopic simulation offers once more a tool to investigate this situation in detail.

We believe that it would be useful to revisit the suggestion by Don Janelle to model the intrinsic locational utility with two offsetting components placing a 'natural' premium on certain locations and resulting in an obvious peak value. In order to better understand city organization and its relation to housing prices, models which put the whole activity scheduling into a spatial perspective are urgently needed. The concept is there that higher rents inside the city should be balanced by (monetary and disutility) costs of commuting, and the first models of this are emerging (e.g. Marchal, 2003). Balancing such costs against an extended set of activities in a persons schedule, not just commuting, may provide an even more realistic link to activity scheduling process (e.g. balance against the combined disutility costs associated with a persons routine/preplanned activity set, which may/may not include commuting). However, much more research both on the modeling and on the empirical side will be necessary to fully understand this issue.

Can ICT help? In many countries there are high levels of cell phone use but as yet low penetration of broadband; and in addition there are metered phone and telecomm rates. Even the emerging GPSR technology is to be billed on the amount of use and throughput, and this is not likely to make telecommuting any easier. Also the widely discussed Wi-Fi solution, integrated in places with GPSR (seamless handoff from Wi-Fi to cell phone based nets) is clearly some way from happening. Yet, the future seems to be the possibility of *everything* served over the infrastructure of the net (voice over IP); we will operate in a world where there are seamless access to corporate databases and the ability to query and post data from remote site. But will this help with respect to transportation issues, e.g. sustainability? It makes the situation more complicated, and once more we point to modeling to help resolve the issues. Clearly, as was discussed extensively in the meeting, telecommuting can make some trips unnecessary, and there is some hope that in a congested situation with high information (provided by ICT) these trips will not replaced by other ones. Beyond that, we find it hard to make predictions. Possibly, the overwhelming diversity and range of affordable housing in a more integrated urban system (the US) provides a much greater level of possibilities. Equally possible, the high densities of urbanized cores like London or New York City may allow solutions based on high-class mass transit, where one can for example work on the train.

We need further exploration of the demand responsive travel modes [that were mentioned by Andy Lake] and we see large potential for the STELLA cluster to assist in writing about and conceptualizing the translation of potentially useful models to a more realistic model of the choice of activity patterns.

Future projects that should involve cross-cultural comparisons, as well as cross-disciplinary involvement, concern the understanding and identification of the behavioral/decision rules that govern the activity (re)scheduling, re-planning, etc. in response to ICTs. The computer scientists, engineers, economists etc. that lead much of the operational model development need to be forthcoming and clear in outlining the underlying behavioral assumptions of their models, and in highlighting their immediate and longer-term desires for alternatives behavioral structures and rules. In this context, the above-mentioned scarcity of publication outlets for simulation work, in conjunction with a lack of publication standards in the area, becomes a serious issue. The social scientists, geographers, psychologists, etc. that lead much of the data collection and empirical analysis, need to pay more attention to these needs, and provide more definitive suggestion for alternative decisions rules and modeling structures as well as the provision of quantitative data for their estimation. We must go beyond separate publications on these two issues (which may or may not be considered by each party), and instead, team up at the earliest possible stage of project development in genuine collaboration. This should invariably lead to development of decision rules that are both behavioral realistic, and operationally possible. Cross-culturally, an important goal will be to identify and assess the "stability" of decisions rules that are identified, and thus the potential for transferability.

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