Activity-based travel forecasting models in the United States: Progress since 1995 and Prospects for the Future

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ABSTRACT

Since the 1995 EIRASS conference the authors have been involved extensively in the design and implementation of new travel forecasting model systems for planning agencies in many metropolitan areas of the United States, with implementations in Portland, San Francisco, New York, and Columbus, and work in various stages of progress in Atlanta, Houston, Sacramento and Denver. To a great extent, these efforts represent the cutting edge of activity-based model implementation in the United States. In each case, serious attempts have been made to incorporate activity-based modeling principles and improve on earlier results. This paper describes these model systems, explains how they have attempted to incorporate behavioral realism, discusses issues that interfere with their acceptance in practice, and suggests a research agenda relevant to implementation of practical activity-based models.

The paper discusses the practical aspects of application of the new generation of models for metropolitan planning. Some of the issues that arise and must be addressed include concerns about micro-simulation variability, extra complexity of equilibrating the demand model system with the network model, calibration by matching base year model results with traffic counts, and validation by comparing model backcasts with known estimates of past travel. Another major issue is risk that planning agencies have of losing government funding of transportation projects if they implement a new model system that generates—in conjunction with emissions models—forecasts with higher air emissions than the old models. One way of dealing with this is to continue enhancing trip-based model systems while the new model systems are developed, and run old and new systems in parallel.

1. Introduction

The focus of our paper is very specific—the use of activity-based models in practice for urban and regional planning in the United States. While our focus is on projects that have been carried out for metropolitan planning agencies for immediate application in the U.S., we recognize that much other research is being done in other research settings, both inside and outside the U.S., that will help determine the types of activity-based models that are used in practice in the future.

We have chosen to focus our topic because regional planning in the US is at a critical stage where the adoption of activity-based models is accelerating, with the potential for much more acceleration in the future. This paper provides an opportunity to step back and look at what types of modeling developments have been successfully implemented since the previous EIRASS conference in 1995. An overview is provided in section 2. In section 3, we discuss the conceptual areas of the applied models that we feel need the most work, and introduce some work in progress for addressing those areas. In section 4, we discuss factors that remain as hindrances to the acceptance of activity-based models for planning by government agencies in the U.S.

2. A Brief History of Applied Activity-Based Models for Regional Planning in the U.S.

Transportation and land use planning in the United States is done primarily at the regional level, typically for an area that includes a large city and the surrounding suburbs and satellite cities. Each county or city within a region may also do its own planning, but it will typically use a version of the same planning model used by the regional metropolitan planning organization (MPO). The large majority of MPO’s use the aggregate 4-step modeling approach first introduced in the 1960’s. The 4 steps are:

(1) trip generation, done using cross-classification tables or simple regression models of trip production and attraction rates;
(2) trip distribution, done using “gravity” models based on impedance measures (which are often based only on auto travel times);
(3) trip mode choice, done using multinomial or nested logit choice models (often omitting non-motorized modes); and
(4) trip route assignment, done using equilibrium network assignment for car trips, and sometimes done for transit trips as well.

Although a great deal of marginal refinement to the 4-step approach has been done since the 1960’s, the basic drawbacks of the approach still remain. These include:

- Person-trips as the unit of analysis: The models do not capture
    - the interactions between trips made in the same trip chain,
    - the interactions between trip chains made during the same day, or
    - the interactions between the trips made by people in the same household.

- Spatial aggregation: All trip origins and destinations within a given zone are modeled as if they are located at the same point in space.

- Demographic aggregation: All households within a given zone are treated as identical, or, at best, segmented along a few dimensions such as income, household size and car ownership.

- Temporal aggregation: Typically, only two or three periods of the day are considered (e.g. AM peak hour, PM peak hour, off-peak), and the proportion of trips made in each period is treated as constant and not sensitive to changes in traffic congestion or other factors.

By the time of the previous EIRASS conference on activity-based methods in 1995, a number of tour-based models had already been implemented in order to replace trips with tours as the primary unit of analysis. Early applications were carried out in both the US and Europe:

- San Francisco Bay Area [*Ruiter and Ben-Akiva, 1978*]
- The Netherlands [*Daly, et al., 1983; Gunn, et al., 1987*]
- Boise, Idaho [*Shiftan, 1995*]
- Stockholm [*Algers, et al., 1995*]
- New Hampshire [*Rossi and Shiftan, 1997*]
- Italy [*Cascetta and Biggiero, 1997*]

These early tour-based applications were successful in eliminating the most glaring weakness of the 4-step approach, the poor ability to deal with non-home-based trips made in the middle of home-based trip chains. They did not, however, deal with any of the other weaknesses listed above. They did not consider interactions between tours made at different times in the same day, or by different people in the same household. Perhaps just as importantly, they did not offer any large improvements to deal with the issues of spatial, demographic and temporal aggregation. All three types of aggregation not only cause aggregation error, but they also can cause significant aggregation bias due to the fact that logit models and gravity models are non-linear—i.e the logit probability at the average value is not necessarily equal to the average of the logit probabilities across all individual values. This fact is often overlooked.

Since 1995, a number of activity-based travel demand model systems have been implemented in the United States that address the issues mentioned above. These include model systems developed for the following MPOs:

- Portland [*Bowman et al., 1998; Bradley, et al., 1998; Bradley, et al. 1999*]
- San Francisco County [*Bradley, et al., 2001; Jonnalaggada, et al., 2001*]
- New York City [*Vovsha, et al., 2002; Peterson, et al., 2002*]
- Columbus [*Vovsha, et al., 2004a, 2004b; Vovsha and Bradley, 2004*]
- Atlanta [*PBConsult, 2004*]

We will describe these projects not city by city, but in terms of five major changes that were introduced relative to the 4-step trip-based and tour-based models described above:

1. Consistent generation of all tours and trips made during a person-day.
2. The shift to a stochastic microsimulation model application framework.

3. Explicit modeling of interactions between activity patterns of household members.
4. Introduction of greater spatial detail for land use and walk and transit accessibility.
5. Introduction of greater temporal detail for activity and travel scheduling.

As a summary, Table 1 indicates which of these developments are included in the separate model systems. Each of the developments is discussed in some detail below.

Table 1: Activity-Based Model Systems Developed for U.S. Metropolitan Planning Agencies

	Portland (METRO)	**San Francisco (SFCTA)**	**New York (NYMTC)**	**Columbus (MORPC)**	**Atlanta (ARC)**
Consistent generation of all tours and trips made during a person-day?	Yes	Yes	Yes	Yes	Yes
A full population stochastic micro-simulation framework?	No in 1st version, Yes in later versions	Yes	Yes	Yes	Yes
Explicit modeling of interactions between activity patterns of household members?	No	No	No	Yes	Yes
Greater spatial detail than the TAZ level for land use and walk/transit access?	No in 1st version, Yes in later versions	No	Yes	No	Yes
Greater temporal detail for activity and travel scheduling?	Somewhat (5 time periods)	Somewhat (5 time periods)	Somewhat (4 time periods)	Yes (1 hour periods)	Yes (1 hour periods)

2.1. Consistent generation of all tours and trips made during a person-day

The full day activity schedule approach [*Bowman, 1998; Bowman and Ben-Akiva, 1999*] was the first operational discrete choice framework for simultaneously modeling the key aspects of an individual's day-long activity pattern:

- The purpose and location type of the primary activity of the day (subsistence, maintenance or discretionary; in-home or out-of-home);
- The number of intermediate stops made on the way to and from the primary activity (for out-of-home patterns only);
- The number of work-based tours made during the day (for work patterns only);
- The number and purpose of additional home-based tours made during the day.

The first application of this approach was for the Portland TROS model system, developed for the purpose at looking at the response to peak-hour congestion pricing, a type of policy that their

4-step model was not fully responsive to because trip generation and time-of-day distributions were not sensitive to travel times or costs.

Shortly afterwards, this same approach was adopted for the San Francisco County model system. Because of relatively limited data and budget to create this system, the full day pattern approach used for the Portland models was simplified in the following ways:

- Maintenance and discretionary tours were grouped as “Other”
- Instead of using detailed person-based mode/destination/time-of-day choice logsums in the day pattern generation model, as had been done in Portland, more simple zone-based accessibility measures were used to approximate the logsums, greatly reducing the run time for the entire system. (A variation on this same approach is also used in the New York, Columbus and Atlanta models.)

Another change made for the San Francisco models was to treat the location of work activities as a longer term choice. So, the generation of the activities in the person-day was directly conditional on both the home and work locations, rather than just the home location.

The New York and Columbus models use more of a “cascading” model approach – first generating mandatory tours, then maintenance tours, then discretionary tours, then intermediate stops on all tours. The residual time window remaining after higher priority tours and activities are generated and scheduled can be used in the generation of subsequent tours and activities. The advantage of this approach is that it is simpler and more flexible, particularly when dealing with interactions between household members, as discussed below. A disadvantage is that it does not directly capture substitution between trip chaining versus making multiple tours, as is captured in the approach used in Portland and San Francisco. In the Atlanta project and future projects, we are working toward combining the most valuable aspects of both approaches.

2.2. The shift to a stochastic microsimulation model application framework

Stochastic microsimulation of travel choices is not a new concept. Iit has been used before in both the US and Europe, although it virtually disappeared from the models used for planning in the US once the aggregate 4-step approach was adopted. Compared to aggregate methods which continually apportion groups of “identical” individuals based on choice probabilities, the stochastic approach simulates one specific sequence of choices for each individual. The relieves the modeler from having to keep track of huge multidimensional matrices of choice probabilities, and thus allows more components of choice and more segments of the population to be modeled separately. While the aggregate approach tends to force a quite simple overall model structure, the stochastic microsimulation approach allows model structures to be changed to more closely reflect theories of the way choice are made.

The first implementation of the Portland TROS model used microsimulation, but it was not stochastic. It used the technique commonly known as “sample enumeration”, simulating a specified fraction of the full population (typically about 10%), keeping track of all choice probabilities, and expanding up the results to match the full population. Stochastic microsimulation of the full population was first implemented in Portland in order to provide forecasts of activity sets for the early development of the TRANSIMS model system. Although simulating about 10 times as many individuals, the model run time was actually reduced because it was no longer necessary to multiple cascades of probabilities from one model to another. For tour-based models, this issue is especially important because the locations of intermediate stops are conditional on the locations of both the tour origin and the tour primary destination. In a probability-based framework, this requires applying a stop location choice model for every possible combination of tour origins and destinations, while in a stochastic framework it is only applied for a single O-D pair.

Similarly, a stochastic microsimulation approach was adopted in New York largely because the aggregate 4-step approach proved infeasible. With so many zones, modes and population segments to consider, the sheer size and number of aggregate O-D matrices that would need to be calculated was impractical. Microsimulation, however, proved to be feasible and practical, as well as providing the freedom to implement a more advanced activity-based model approach.

Stochastic microsimulation was also adopted for the other model systems listed—San Francisco, Columbus and Atlanta. It is interesting that each region has used a slightly different method and variables for generating synthetic populations from the National Census PUMS 5% sample. Each region has used a slightly different set of control variables for sampling, based primarily on which variables are available as forecasts from land use models or other regional planning agencies. In all cases, the control variables have included some combination of:

- Household income
- Household size
- Number of workers in household
- Age of the head of household
- Household type in terms of presence of children and senior citizens

The different population synthesis approaches have never been compared to determine which set control variables appear to be most necessary and which non-controlled variables are still matched reliably enough to include in the models that produce forecasts. We are currently carrying out such tests and comparisons for the Atlanta region, including an attempt to backcast to match 1990 Census distributions.

2.3. Explicit interactions between activity patterns of household members

While all of the model systems above capture interactions between various activities and tours made by a single person, interactions between household members were captured only implicitly, be including variables related to household type and structure in the various person-level models. The Columbus system represents a major advance for applied activity-based models in that it captures intra-household interactions in three separate ways:

- The type of activity pattern of each individual is directly conditional on the type of activity pattern made by other household members. So, if a child stays home all day because of illness, this also increases the chance that at least one parent will stay home also.
- Home-based tours that are made by more than one person from the household are generated at the household level rather than the person level.

- Maintenance activities are generated at the household level and then allocated to individuals, rather than generating them separately for each individual.

The Atlanta system, described in more detail in Section 3, also follows the Columbus approach. Some ideas for refining this approach further include:

- Explicit modeling and linking of activities to pick-up or drop-off household members with the activity schedule of the person who is picked up or dropped off.
- Predicting the activity pattern type of all household members simultaneously, obviating the need to assume a fixed hierarchy of interdependence across person types.

2.4. Greater spatial detail for land use and walk and transit accessibility

With modern GIS systems, data on land use and the location of residences and business is typically available at a much finer level than is used for transportation analysis zones (TAZ's). Although shifting to finer spatial detail is not strictly part of "activity-based modeling", it has made possible by the introduction of the stochastic microsimulation approach. Because residences and trips are simulated one at a time, there is no need to store huge O-D matrices that include every possible location. Any inputs and outputs that still require storage as O-D matrices, such as travel times and costs for car and transit and output trip tables for assignment, can still be used at the TAZ-to-TAZ level. The stochastic microsimulation framework is flexible enough to use two different levels of geographic detail for different types of data.

The second version of the Portland model system used 9400 link faces to locate individual trip origins and destinations, rather than the 1250 TAZ's in the METRO zone system. This change was made to accommodate requirements of TRANSIMS as it existed at that time. It was found that using this level of detail allows the modeler to use much more detailed estimates of walk access and egress times for transit, as well as non-motorized travel times for short trips. These changes greatly improved the estimation of certain mode choice model parameters.

The same improvement in mode choice models was found in the current Atlanta project, where land use is being treated at the level of grid cells of 200 meters square. An attraction of the grid cell approach is that the land use data becomes independent of the definition of the networks and the zone system. One can adjust the networks and zone system over time without having to redefine the land use variables each time. Furthermore, each time the zone system and networks are made more detailed, the model system will already be capable of locating the trip ends in the more detailed system.

2.5. Greater temporal detail for activity and travel scheduling

The Portland and San Francisco model systems both introduced models of time of day choice in the form of a joint model of the time a person leaves the home to begin a tour and the time they return home to end a tour. In both system, the day is broken down into 5 separate periods:

- Early (before AM peak)
- AM peak
- Midday
- PM peak
- Late (after PM peak)

The AM and PM peak periods were defined to be periods of up to 3 hours, specific to the traffic patterns in each region. The New York models used a similar approach, but with only 4 periods—combining the Early and Late periods into a single Off-peak period.

While those model systems provided a great improvement over most existing trip-based and tour-based model systems that had no time-of-day choice model, their time-of-day choice models can still be viewed as their weakest area. The reasons are:

- Most departure time changes due to traffic congestion, pricing, etc. tend to involve shifts within the greater 3 hour peak, e.g. from the "peak of the peak" to one of the shoulder periods. These shifts are not captured when the day is only broken into 4 or 5 periods.
- Using such long periods does not allow one to model shifts in activity scheduling or the interrelationships between activity scheduling and activity generation in a very meaningful way.

The Columbus model system provided two major advances over the other model systems discussed above:

- The day is broken down into 1 hour time periods.
- Tours for various purposes are generated and scheduled in a consistent way. Work and school tours are generated first, those tours are scheduled, and then the amount of time remaining is used to model the generation of remaining non-mandatory tours. Each time a tour is scheduled, the hours of the day that that tour uses are made unavailable for subsequent tours.

For the Atlanta model system, we are testing further enhancements to this approach. We introduce various types of "time pressure" variables to ensure that the activity scheduling and activity generation models are as consistent as possible—i.e those that participate in more activities will tend to participate in each activity for a shorter duration, and vice versa. We may also test reducing the time period from 1 hour down to, say, ½ hour. (Because our discrete choice time-of-day/duration models mimic continuous duration models in using mostly pseudo-continuous independent variables, one can change the duration of the periods without substantially changing the specification of the model.)

3. Further Conceptual Evolution of the Modeling Structures

As described above, several new features and enhancements were incorporated in the recently completed Columbus (MORPC) model as well as in the Atlanta (ARC) model currently being developed. They reflect the growing body of research on activity-based modeling and micro-simulation for the last years. Two important and inter-related aspects have been frequently in the focus of research – intra-household interactions and time-use framework that proved to be of critical importance for describing and modeling individual activity and travel behavior. In particular, works of *Borgers et al, 2002; Ettema et al, 2004; Fujii et al, 1999; Gliebe & Koppelman, 2002; Golob & MacNally, 1997; Meka at al, 2002; Simma & Axhausen, 2001; Scott & Kanaroglou, 2002; Srinivasan & Bhat, 2004; Zhang et al, 2002; Zhang et al, 2004; and Zhang & Fujiwara, 2004* give examples of models for time allocation and activity episode generation between various type of activities and household members that provide valuable insights into the intra-household decision-making mechanism.

Comparing to the previous model design, the new structures of MORPC and ARC represent two significant steps further in a better and more realistic description of travel behavior along these two lines:

- Explicit modeling of <u>intra-household interactions and joint travel</u> that is of crucial importance for realistic modeling of the individual decisions made in the household framework and in particular for choice of the high occupancy vehicle (HOV) as travel mode. The original concept of a “full individual daily pattern” that constituted a core of the previously proposed activity-based model systems [*Bowman & Ben-Akiva, 1999; Bowman & Ben-Akiva, 2001; Bhat & Singh, 2000*] has been extended in the MORPC and ARC systems to incorporate various intra-household impacts of different household members on each other, joint participation in activities and travel, and intra-household allocation mechanisms for maintenance activities [*Vovsha et al, 2003b, 2004a, 2004b*].

- Enhanced <u>temporal resolution of 1 hour with explicit tracking of available time windows</u> for generation and scheduling of tours instead of the 4-5 broad time-of-day periods applied in most of the conventional and also activity-based models previously developed. The time-of-day choice model adopted for MORPC and ARC with further enhancements is essentially a continuous duration model [*Vovsha & Bradley, 2004*] transformed into a discrete choice form. The enhanced temporal resolution opens a way to explicitly control the person time windows left after scheduling of each tour and use the residual time window as an important explanatory variable for generation and scheduling of the subsequent tours.

The proposed enhancements are not just technical. They represent reflections on the natural and logical “evolution” of the model system structures in certain conceptual directions some of which are already quite formed into operational structures while some other ones will be explored in future.

3.1. Conceptual directions

In the most general way these conceptual directions can be classified as the following “lines of integrity” in modeling various travel-related multidimensional choices:

- "Vertical integrity" of each modeled individual daily activity and travel pattern in a sense that all modeled activity episodes, their durations, locations, and travel tours associated with visiting out-of-home activities are consistent and feasible within the person time-space constraints.
- "Horizontal integrity" that means that daily patterns of different household members are properly coordinated in view of participation in joint activities, joint travel arrangements as well as intra-household mechanism for allocation of maintenance activities, allocation of cars to the household members, etc.

Vertical integrity is associated with a proper conditioning in sequence of choices related to each individual from the top-level choice related to the daily activity pattern type to the lower-level choice related to details of each activity episode. Vertical integrity was in the core of the original concept of the daily activity pattern choice model [*Bowman & Ben-Akiva, 1999; Bowman & Ben-Akiva, 2001; Bhat & Singh, 2000*]. The major breakthrough that made this approach operational was the integrative formulation of the daily pattern in terms of a number and structure of travel tours rather than elemental episodes that provides the necessary input to the subsequent set of travel models. The number of observed individual daily activity patterns and structural complexity of the choice model in combination with a huge number of possible activity location alternatives make it impossible to model all dimensions in one choice structure. Thus, various hierarchical structures were proposed that resulted in a cascade of conditional choice models. This inevitable decomposition leads to two different structural lines within the vertical integrity framework:

- "Downward vertical integrity" that means that all lower-level decisions in the choice hierarchy should be properly conditional upon the upper-level decisions and take into account a gradually narrowed scope of lower-level choice alternatives as the upper-level choices progress.
- "Upward vertical integrity" that means that when modeling upper-level choices the composite measure of quality of the lower-level choices associated with each upper-level alternative should be properly taken into account

Downward vertical integrity is not an automatic property of hierarchical cascades of choice models, especially if different activity dimensions such number of tours/activities, their location, and timing are considered. For example, first activity-based models for Portland METRO, SFCTA, and NYMTC had independent-by-tours mode, destination, and TOD choice models that could produce conflicting choices for different tours made by the same person. Downward vertical integrity is ensured by a proper sequencing of models and tracking all important variables from choice to choice that accurately describe the feasible scope left for each subsequent choice and prevent conflicting choices for the same individual. It has recently been recognized that time-use approach provides an operational framework for downward vertical integrity because time serves as an ultimate and constrained resource for any type of activity. From this point of view, it proved to be more convenient to generate tours/activities and schedule them according to a certain hierarchy using residual time windows left after scheduling previously generated tours as variables explaining generation of the subsequent tours. Further research is needed to better understanding the interrelationship between activity generation and scheduling stages and their positioning in the model system hierarchy. Similar relationships should be further explored between such dimensions as activity locations/durations and tour configuration in terms of a distribution of activity episodes by tours. Also possible substitution between in-home and out-of-home (travel) activities can be considered as a part of the downward vertical integrity issue.

Upward vertical integrity is important to prevent illogically bad choices made at the upper levels of the choice hierarchy that may result in impasse at the lower level (for example, if a worker who has three non-work tours in addition to the work tour has been assigned a work schedule from 7:00AM to 22:00 PM) as well as it is crucial for the model system sensitivity to travel environment from the upper-level activity generation choices. Conventional fractional-probability models use the log-sum (expected maximum utility over the lower-level choices) technique to “inform” the upper-level choices about what can happen down the hierarchy. This technique can be used in the micro-simulation framework as well, however it is extremely intensive computationally when it comes to calculation of tour mode choice log-sums for destination choice (takes more than 60% of running time of the model system) and is not realistic at all when full destination choice log-sums (across all destinations and TOD periods) are considered as variables for daily activity pattern model. One possible solution that is currently explored is to exploit the overall iterative framework of the model application and use generated lower-level outcomes from the previous iteration as variables in the upper-level choices at the next iteration. This approach can be interpreted as “learning process”. Time-use framework also can be affectively used in this iterative procedure. Instead of feeding-back computationally intensive but actually quite abstract log-sums contracted over multiple choice dimensions a simple variable representing total travel time spent by individual to realize the activity pattern in time and space, can be fed-back and considered at the next iteration for a choice of the new daily pattern. To make the upper-level choice sensitive to the total expected travel time a continuous time allocation model (with travel budget as input variable) can be applied first and then daily pattern type and the subsequent chain of choices can be made conditional upon the expected time allocation. With this actually very simple technically approach, the whole model chain will be sensitive to network improvements since these improvements are finally expressed in time savings.

Horizontal integrity principle includes numerous ways to incorporate intra-household interactions in a travel demand model, either explicitly or implicitly:

- Using household composition variables (frequently presence of children of particular age categories) as explanatory variables in trip/tour generation or DAP models for workers and other adults. This approach can be classified as implicit.
- Explicit joint or at least coordinated modeling of daily activity pattern types (or related activity-travel characteristics) for several household members. Most frequently, time allocation units are used for modeling and the Structural Equation System is employed [*Golob & McNally, 1997; Fujii et al, 1999; Meka eat al, 2002; Simma & Axhausen, 2001;*]. The proposed approach, used in the MORPC and ARC system, however, is based on a linked set of discrete choice models [*Vovsha et al, 2004a*]
- Explicit modeling of joint activity and travel. This component has been modeled in terms of either episode generation or time allocation between individual and joint activities [*Ettema et al, 2004; Gliebe & Koppelman, 2002; Scott & Kanaroglou, 2002*]. Explicit

modeling of joint tours has been incorporated into the MORPC and ARC regional travel demand models [*Vovsha et al, 2003*].

- Explicit modeling of within-household allocation of maintenance activities to household members [*Borgers et al, 2002; Srinivasan & Bhat, 2004*]. The corresponding component has also been included and successfully tried in the MORPC modeling system [*Vovsha et al, 2004b*].
- Explicit allocation of cars to household members that accounts for actual availability of a car for a particular person's travel tour [*Wen & Koppelman, 1999; 2000*]. This model component is reserved for future model development.

3.2. Outline of the Core Model Structure

The current generation of activity-based regional travel demand models of which the MORPC and ARC model systems is the most advanced representatives, is based on a sequence of discrete choice models applied in a micro-simulation fashion. In the model system design, there always has been a question, what is the better behavioral unit that represents a decision maker for trip (or tour) generation stage – household or person. Conventional travel demand models are mostly household-based (i.e. applied at the entire-household level though any person-related characteristics can be incorporated) while the contemporary activity-based models tend to be person-based (i.e. applied at the individual person level though any household characteristics can be incorporated).

The choice of the decision-making unit (household or person) is less crucial if simple statistical models are applied that link person/household characteristics to the number of generated trips/tours (like conventional regression models for trip production). Conventional trip production models based on limited market segmentation produce very similar results for both strategies (household-based and person-based), being aggregated at the zonal level, while the model outcomes at the individual level are not analyzed. Micro-simulation modeling implies more detailed segmentation by household and person types, and is much more sensitive to the choice of the decision-making unit. Additionally, since ensuring consistency at the individual level is one of the main challenges of micro-simulation modeling, it is important to find a right balance and linkage between household and person dimensions. The micro-simulation technique allows this to be resolved by using the household for some choice dimensions and person for other dimensions.

Micro-simulation also allows for explicit incorporation of intra-household interactions of various types. Many travel-related decisions are made within the complicated framework of the entire-household decision-making process, where each person's preferences are intertwined and consolidated with those of all household members. As a result some activities are shared among several household members; some other ones are generated at the entire-household level but allocated to particular members to implement; while other activities have a purely individual character.

In the design and development of the MORPC and ARC modeling system, the following three-part segmentation of household and person activities is used:

- Individual activities. Corresponding tours are generated and scheduled at the person level (with possible inclusion of the household variables, but without direct coordination of choices). The frequency of these activities is modeled for each person either as a part of the daily activity/travel pattern (as currently proposed), or by means of the frequency choice model.

- Allocated activities. Activities are generated at the entire-household level because they reflect the collective household needs. However, they are implemented and scheduled individually. Thus, an activity (or tour) frequency model is used for the household, followed by an intra-household allocation model that household members as alternatives.

- Joint activities. Corresponding tours are generated at the entire-household level and also implemented by several household members traveling together (and frequently sharing the same activity). A tour-frequency model is used for the household, followed by a person participation model that is applied for each generated tour and considers possible travel parties (subsets of the household members) as alternatives.

The activity types and trip purposes are grouped into three main segments:

- Mandatory activities (including going to work, university, or school).
- Maintenance activities (including shopping, banking, visiting doctor, etc).
- Discretionary activities (including social and recreational activities, eating out, etc).

Table 2 summarizes the main assumptions made regarding the possible combinations of activity types and settings. Only five out of the nine possible combinations are allowed, which greatly simplifies the modeling system, while preserving behavioral realism and covering most of the observed cases.

Table 2. Modeled Activity-Travel Segments

Activity Type / Travel Purpose	**Individual Setting**	**Allocation Setting**	**Joint Setting**
Mandatory	X		
Maintenance		X	X
Discretionary	X		X

Travel for mandatory activities is always assumed to have an individual character. Frequency of these activities, location, and scheduling are modeled for separately for each person. While household-composition variables are used in the utility functions for these individual activities, there is no explicit linkage across all choices made by different individuals with the notable exception of staying at home together or having a non-mandatory travel day together. This assumption is based on the fact that most of the mandatory activities have fixed frequencies and schedules defined exogenously to the household activity framework; however, a realistic activity-based model should be sensitive to the fact that unscheduled at-home activity (child at home sick) will negatively impact the frequency of other mandatory travel.

Maintenance activities may be either allocated or joint. It is assumed that the maintenance function is inherently household-based, even if it is implemented individually or related to a need of a particular household member, like visiting doctor. Even in these cases, maintenance activities are characterized by a significant degree of intra-household coordination, substitution, and possibly sharing.

Discretionary activities may be either individual or joint. It is assumed that these activities are not allocated to household members since they do not directly relate to household needs. Thus, these activities are either planned and implemented together by several household members or are planned and implemented individually.

It is assumed that all else being equal, there is a predetermined structure of preferences in the activity generation and scheduling procedure along both dimensions (activity type and setting). Mandatory activities take precedence over maintenance activities, while maintenance activities take precedence over discretionary activities. Joint activities are considered superior to allocated activities, while allocated activities are in turn considered superior to individual activities. Combination of these two preference principles yields the following order of generation and scheduling activities that serves as the main modeling skeleton for the model system design:

1. Individual mandatory activities,
2. Joint maintenance activities,
3. Joint discretionary activities,
4. Allocated maintenance activities,
5. Individual discretionary activities.

In the MORPC and ARC model system the stages 2, 3 and 4 are partially combined. The household generation of all joint tours may be done in one simultaneous choice structure and a further combination of joint and allocated tour generation stages is considered. The person participation models for joint and allocated tours, however, are still de-composed into stages 2-4 and implemented sequentially.

The intra-household interactions and enhanced time-of-day (TOD) resolution have lead to several important re-arrangements in the day-level hierarchy of choices stemming from:

- Daily activity pattern types for all household members are modeled in a coherent way by means of explicit linkages across household members. These linkages account for the most important features of the daily patterns that have principal impact on the entire-day level choice (go to work or school, stay at home, or have a day-off for a major out-of-home non-mandatory activity). This requires de-composition of the individual daily pattern into several parts and modeling the first part (pattern type) for all household members taking into account interactions between them before going into pattern details for each person.

- Various episodic intra-household interactions in a form of joint or allocated activities are modeled explicitly. Explicit modeling of joint and allocated activities requires an entire-household formulation of the tour-generation model. Then, participation in the generated joint tours is modeled for each person as well as allocated tours are assigned to persons. This structure requires a further de-composition of the individual daily pattern into several successive stages. Essentially, in this structure, important aspects of the individual daily pattern emerge as the result of the numerous intra-household participation and allocation mechanisms, and the individual incorporates them, along with their work activity (if applicable) and individual discretionary activities into a complete pattern.

- Enhanced resolution of the time-of-day (TOD) choice model allows for explicit tracking of time-use attributes (time windows available for implementing activities and travel tours) for each person at each stage of the tour generation and scheduling procedure. In particular, it has proven to be beneficial to model time-of-day choice for mandatory activities (that normally take the biggest share of the daily time budget) first and them condition the further generation and scheduling of non-mandatory activities on the size of the residual time windows left after the mandatory activities have been scheduled. This requires a certain re-arrangement of the choice hierarchy with modeling time-of-day choice for mandatory tours earlier in the model stream.

Figure 1 presents the latest modified model system hierarchy adopted for the ARC project.

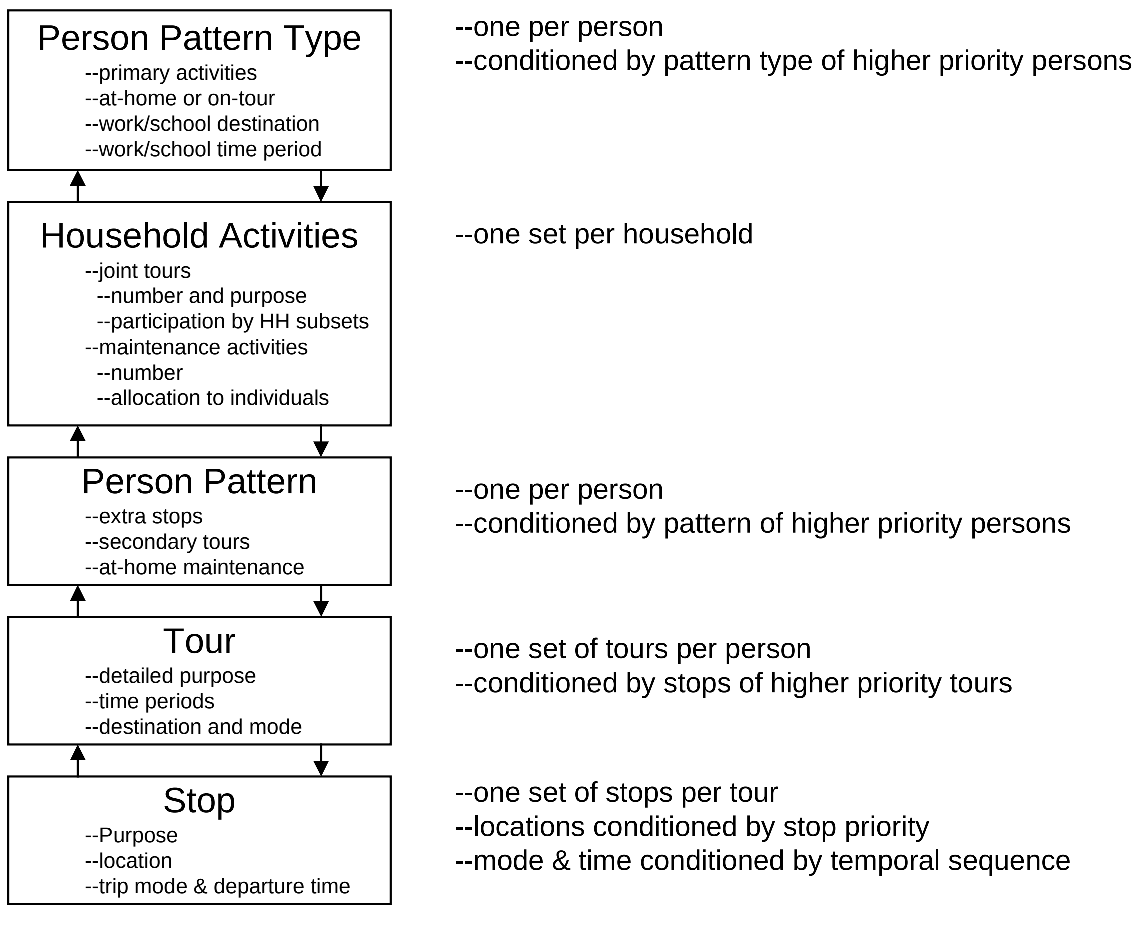

Figure 1. Current Proposed Household Activity and Travel Model System for ARC

4. Acceptance of Activity-Based Travel Demand Models in Practice

Along with the current successes of the new-generation models, and the general sense that this approach represents a major breakthrough in travel demand modeling, it is also important to recognize the problematic side of these models, especially in how practitioners, planners and final decision makers may view them. It should also be noted that, to date, the amount of money and effort spent to develop and maintain conventional 4-step models across MPOs in US is larger by an order of magnitude than the amount spent on the development of activity-based models. (The only exception is the TRANSIMS project, which is funded at the Federal level, and is focused much more on representing the spatial aspects of travel than on representing the formation of activity patterns.)

For modelers, the clear and strong advantages of the new generation of models are their behavioral realism and their ability to come closer to an understanding and modeling of individual behavior. These advantages will not be appreciated by planners, however, unless they see how it permits the travel demand models they use to better address their needs.

Transportation planning decisions are generally based on aggregate forecasts of demand for and performance of transport facilities. In order to see the relevance and importance of micro-simulating the decisions of individual travelers, practitioners need to first understand how this new approach leads to more realistic and more policy responsive forecasts – at the aggregate level. Once this is appreciated, there is then an opportunity for practitioners and transportation planners to also see the advantages that the disaggregate approach offers for a more detailed evaluation of transportation alternatives, such as augmented reporting and analysis capabilities for segmented user benefits and costs assessment.

The necessary pragmatism of practitioners in their assessment of travel demand models should be accommodated by modelers and researchers. To find a common language between the two communities and move activity-based models into practice, the advantages of the new models should be clearly translated into terms of realism of aggregate travel forecasts acceptable in transportation planning community rather than formulated in terms of “realism in understanding and modeling individual travel behavior”, as is common in the transportation research community. The key requirement to convince practitioners to adopt the new models is a demonstration of the “tangible” advantages of the new models over conventional ones in a practical context of particular types of projects or policy issues.

To summarize the current state of the acceptance in practice we will structure the subsequent discussion into four inter-related topics:

1. Objective theoretical advantages of activity/tour-based models that need to be better explained to practitioners,
2. “Tangible” practical advantages of activity/tour-based models that need to be communicated more actively,
3. Concerns that stem from misunderstanding and mistrust of model complexity by practitioners,
4. Valid concerns that need to be addressed in future research

4.1. Theoretical advantages that need to be better explained

One of the reasons why acceptance of the new generation of models is still very partial is that many practitioners believe that the conventional trip-based 4-step models are quite good and in general produce reasonable results. Thus, if the new models are even better, there is no urgency in switching to new models. It is important to realistically and critically re-estimate conventional models and help practitioners understand the limitations of conventional models. It should be noted that “dethronement” of the 4-step approach in many respects can be done based in its internal deficiencies even before any comparison of the outcomes produces by the 4-step model to those produced by new models. In particular two major deficiencies of the trip-based 4-step models should be demonstrated to practitioners – numerous internal inconsistencies across different model outcomes and inability of the model to replicate the base year statistics without strong mechanical adjustments of the model parameters.

Internal inconsistencies of the 4-step model include unavoidable and uncontrolled discrepancies between amount of home-based and non-home-based trips produced by and attracted to each zone, imbalanced mode shares for outbound and inbound trips to or form the same zone, and other numerous conflicting outputs that can be easily captured and demonstrated to practitioners. It is important to demonstrate that in many cases these discrepancies are comparable in magnitude with the marginal advantages and disadvantages of the compared transportation alternatives.

The 4-step modeling paradigm in reality proved to be inseparable from the culture of mechanical static adjustments that relate to almost all model components. It includes adjustment of trip generation rates to match the VMT targets, K-factors introduced to trip distribution models, adjustment of mode-specific constants to match aggregate modal shares, direct adjustments of trip tables to match traffic or transit counts, etc. It should be explained to practitioners that these adjustments only help pass a static validation of the model but may well be irrelevant in future. If the new models are able to replicate behavior without making so many post-modeling adjustments, this fact needs to be communicated as an indicator of their greater predictive validity.

It has been generally relatively easy to explain the advantages of the tour-based modeling technique in terms of the value of models that consistently account for mode, destination, and timing choices for all linked trips. It is more difficult to explain how the tour-based technique actually works, in part because the normal set of dimensions for tour modeling includes seven components (primary destination, entire-tour time of day, entire-tour mode combinations, stop frequency, stop location, trip time of day, and trip mode), while for trip-based modeling, only three components (destination, time of day, and mode) are considered. However, actual visualized examples that appeal to the practical intuition, rather than describing the mathematical structure are valuable. In general, practitioners respond with interest and understanding to examples of how conventional models that treat each trip separately are forced to function with less than full information and can produce conflicting and illogical choices.

4.2. Tangible practical advantages that need to be communicated more actively

One of the primary advantages of activity-based models is a full incorporation of the time-of-day dimension as an integral part of the model system. The conventional model structure is inherently incapable of comprehensive treatment of time-of-day choice. Actually, the placement of the trip distribution by time-of-day periods in the 4-step framework has never been well established theoretically and different modelers have followed different simplified conventions regarding time-of-day choice. In some cases 4-step models have been developed for different time-of-day periods with complete segmentation from the trip generation stage. This has an advantage of using time specific level-of-service variables in trip distribution and mode choice models. However, the problematic side of this approach is that it is very difficult to make the time-of-day choice component of trip generation reasonable sensitive to network improvements and policies. More conventional approach is to apply trip generation, trip distribution, and mode choice models in a daily fashion, while having time-of-day choice as the last model before assignment. This approach, however, is characterized by inherent problems in defining day-representative level-of-service variables for trip distribution and mode choice models that normally results in serious and actually unreasonable simplifications (like using exclusively peak-period level-of-service variables for work and school trips while using exclusively off-peak level-of-service for the other trip purposes).

In 4-step models, the time-of-day distribution model normally takes a form of flat peak factors, or in the best case is sensitive to the level-of-service variables for each particular trip. Also, in all cases, a simplified trip-based modeling framework does not take into account trip timing in combination with the duration of the underlying activity. Application of models of this type may result in naïve prediction of massive shifts of trip in some period (say trips to work in the AM peak period) as the result of growing congestion or police measures without subsequent analysis of inevitable shift of the return trips in the PM peak period and impacts on these shifts on the other trips made during the day. The following practical examples of important projects and policy measures that cannot be handled by conventional models because of the limited representation of the time-of-day dimension, but can be effectively handled by the new-generation models can be mentioned:

- Differential by time-of-day toll strategies / parking policies; a trip-based model will predict a modal or time shift within each period independently, thus, for example, reducing toll in the AM period would not make a difference for the PM period; a tour-based model will predict a full round-day effect when changing the toll in the AM period would results in additional toll users for both AM and PM periods.
- Shorter workday / changing opening and closing hours for offices or shops; a trip-based model would not be sensitive for most of this policies or in the base case would predict time shifts for trips in one of the periods directly affected by the policy. A tour/activity-based model incorporates activity duration as a part of the tour time-of-day choice and thus would be able to predict numerous derived effects like consistent change of departure and arrival hours and rescheduling of the whole daily pattern with the subsequent implications for congestion in the transportation network.

A constructive discussion normally arises around the common over-sensitivity of the conventional models (a long-standing criticism) that may be well attributed to ignoring linkages across trips within the same tour. In this regard, the argument that a tour-based model has the tendency to exhibit a reasonable conservatism, compared to a conventional model, is generally well accepted.

A favorable response is also shown to the incorporation of intra-household interactions in the model. This component also normally works in the same direction ensuring a more realistic conservatism of the model, limiting volatility with off-setting interactive components. High-Occupancy-Vehicle (HOV) facilities and differential-by-occupancy toll strategies facilities are commonly a major focus of transport planning in US, thus, the explicit modeling of joint travel that is believed to make forecasts for such projects more realistic, may be presented as a clear advantage of the activity-based models over conventional ones. There is a distinct discrepancy between the conventional planning approach, focused on inter-household work HOV travel, and the reality that upwards of 75% of HOV travel is intra-household based and carried out for non-mandatory purposes as reported by *Vovsha et al*., 2003. Conventional models treat HOV as "mode" making very crude assumptions regarding its availability to each individual traveler. As the result, forecasts for HOV facilities attributable exclusively to the level-of-service attributes as well as sensitivity to various toll strategies are often significantly over-predicted since they do not consider properly real intra-household constraints on carpooling. The new generation models can successfully capture the second type of HOV travel and, in doing so, may reorient the discussion of HOV travel and facilities in a more productive direction.

Another important practical advantage of activity-based models comparing to conventional models is a better sensitivity to structural demographic changes that can produce a significant difference for long-term forecasts as well as for short-term policies that are targeting particular population slices. Conventional models applied in a factional-probability fashion are very limited in terms of the population segmentation especially at the trip distribution and mode choice stages. Technically reasonable segmentation for trip distribution and mode choice models in the conventional model framework normally includes only 3-4 income groups and 3-4 car-ownership / car-sufficiency groups. Trip generation stage can also incorporate 5-6 household size categories and 2-3 number-of-workers categories. Activity-based models applied in a micro-simulation fashion are virtually unlimited in the number of population segments. In particular, they incorporate person type attributes (worker status, age, gender) and various household composition types (presence of workers in combination with children of different age groups) that can have significant impacts on travel behavior. The resent sensitivity analysis implemented with the NYMTC model has shown that changing proportion between full-time and part-time workers in favor of full-time workers can add up to 10% of traffic and transit ridership to the CBD area since full-time workers not only implement work trips more frequently but also have longer distances and travel to a different spatial cluster of jobs compared to part-time workers. However, changing proportion between fulltime workers, part-time workers, and non-workers is closely related to the household life-cycle and demographic forecasts. Also, workers with children and (especially) preschool children are characterized by significantly shorter trip distances for maintenance and discretionary purposes that can result in about 5% of the daily VMT corrections if properly accounted. Conventional models cannot incorporate these types of effects. As the result, impropriety of the conventional aggregate modeling technique for long-term forecasts has been long recognized and unfortunately attributed to all types of travel demand models. We believe that the issue of non-transferability in time and space pertinent to conventional models has been to a large extent derivative from the limited segmentation of these models and variables used to explain travel; this can be principally reconsidered for the new generation of models.

4.3. Concerns that stem from misunderstanding and mistrust of model complexity

Some practitioners have voiced a skepticism about the complexity of the model cascade, seeing in it more of an opportunity to introduce new errors, as well as the possibility of "compounding of errors", rather than yielding additional accuracy in the final results. As a part of the response to this concern, it is important to demonstrate the real magnitude of hidden aggregation biases pertinent to conventional models, and to explain how these biases can be eliminated in the new model framework, using real numerical examples. It is important to confront the widely spread belief that "simpler is better" or "less complex is more robust". As mentioned above, non-linear-in-response models can produce erroneous results when the input variables are aggregated. From this point of view, any plausible assumption about the (unknown) distribution of the input variables will work better than the average value. Examples of frequently applied aggregations in the conventional models that can produce huge aggregation biases include the following list:

- Using average zonal walk distance to transit in a mode choice model; in our experience a proper disaggregation of this variable solely can drastically change the mode choice results as well as change the model itself at the estimation stage. Transit share is extremely sensitive to walk accessibility with a very steep sensitivity within the range from 0 to 1 mile that is comparable with the traffic zone size. If there are two spatial clusters of population of the same size within the zone – one with transit access of 0.1 mile and the second one with transit access of 0.9 mile – averaging them at the level of 0.5 miles would reduce the transit share to approximately 50% of the share otherwise obtained for the first cluster only.

- Using average zonal parking cost in a mode choice model; this factor alone can change the mode choice results by 50% or more. If (as frequently happens in reality) there are two groups of drivers parking in this zone – one having this parking for free or at reduced rate (say $2 per hour) and the second one paying a full price (say $12 per hour) applying of the average of $7 is completely meaningless. It would lead to a severe overestimation of the sensitivity to parking policy (say extra $2) because the average value fall on the steepest part of the choice curve while shifts from $2 to $4 and from $12 to $14 would result in a relatively low response.

- Using a single child category without segmenting by the age of the child in the trip generation and other models; in reality three different groups of children – preschool children under 6, school children of pre-driving age 6-15, and school children of the driving age 16-17 – are characterized by principally different travel behavior as well as have critical impact on the travel behavior of the household adult members. These effects relate to trip generation, trip length, mode choice, and percentage of joint travel and can easily produce deviations at the level of 50-100% for each dimension.

- Using a single home-based-work trip purpose without segmentation by income group; statistical analysis implemented for several regions has consistently shown that workers of different income groups are characterized by very different commute distance and spatial structure of jobs. Taking into account that different income groups also normally have different residential clusters, mixing different income groups in one aggregate trip distribution model produces unrealistic structure of spatial interaction, an outcome that is typically adjusted for in 4-step models by the introduction of K-factors in model adjustment.

The variability of micro-simulation is still perceived by many as a drawback that complicates the comparison and unambiguous ranking of transportation alternatives. It is important to introduce into the planning culture an acceptance of handling the probabilistic outcomes of the travel demand models (maximum and minimum values along with averages), and to provide guidance on how to constructively exploit variability of micro-simulation in order to support the decision-making procedures. It is also important to explore in additional research the magnitude of Monte-Carlo error, both theoretically and empirically in order to have reasonable strategies and application protocols for different types of projects and model applications. It is true that the current regulatory framework in the US is not supportive of variable model results, so strategies must be developed to manage variability, while at the same time proponents of the new generation of models should encourage regulators to rethink their current stance.

Many practitioners point out that the newer models may not have obvious advantages over conventional ones in terms of replication of traffic counts or other observed statistics for the base year. Moreover, in many respects it is easier to adjust a conventional travel demand model to fit base condition traffic counts exactly than activity-based micro-simulation model, because aggregate adjustments can be naturally incorporated into the aggregate model structure. In this regard, it is important to distinguish between static model accuracy in terms of the replication of the base-year observed data, and the responsive properties of the model that are related to the quality of the travel forecasts for future and changed conditions. These two properties of the model are not necessarily parallel. Static validation and adjustments have very weak relationship to the dynamic validation. The main reason of the fully-disaggregate modeling of individuals is not that we hope to predict exactly the behavior of each and every person. It is the desire to ensure realistic aggregate sensitivity of the model to changing transportation and land-use environment that we know cannot be adequately modeled directly at the aggregate level.

Conventional travel demand models have created a certain modeling culture generally accepted by the transportation planning community. In particular, the behavioral component of the travel demand models has been greatly simplified, sometimes to the point of utilizing trip rates per person and household, while the trip origin-destination distribution, mode choice, and network simulation procedures have received the most attention and staff resources. Traffic engineering has been considered as the best background for travel demand modeling, since it covers the most important issues for network processing, while the trip generation and distribution models have been simple enough to learn quickly. The new generation of travel demand models has changed the proportion between the behavioral aspects of travel modeling versus network processing. Although the last is still as important as ever, the behavioral aspect has also come to the foreground. Social science (in particular, understanding the demography, behavioral tendencies, structural shifts in household composition, evolution of activity/travel habits, etc.) needs to be added to the transportation planning culture in order to create a more productive dialogue between the model developers and users.

Gradual transition from conventional models with parallel development and comparison is possible. It has been recognized that it would be beneficial to develop a conventional model and a new activity-based model in parallel, for the same region (based on the same surveys and other data sources) in order to compare them in various applications. This type of comparison is planned in the framework of the Atlanta, Houston and Denver model improvement projects, where the existing conventional models are being maintained and enhanced for several years, along with the parallel development of new activity-based models. Contrary to the prevailing opinion that switching to a new-generation model would require the agency to “throw out” the existing conventional model and “jump” into a multi-year development process with a great deal of uncertainty, the new and conventional models can co-exist for a certain period of time with gradual replacement of the conventional model components by the new ones. In particular, the following two-stage transition can be recommended:

1. Replacement of the trip-generation and time-of-day models with a daily activity pattern model. At this stage the conventional trip distribution and trip mode choice models are still applied since replacement them with the tour-based modifications is technically more complicated than development of a daily activity generator. The daily activity generator is formulated in terms of tours and has almost all final features. However, tours are broken into elemental trips before the trip distribution and mode choice stages and also tour-based log-sums and accessibility measures are substituted with the trip-based surrogates.
2. Replacement of the trip distribution and mode choice models with tour-based models of mode and destination choice, as well as the corresponding adjustment of the network processing procedures.

Many practitioners think that activity-based models are characterized by specific estimation requirements and cannot be supported by travel surveys not specifically designed for the activity based approach. Actually, only two specific new aspects have been added to the survey format – explicit recording of joint activities and more systematic reporting of in-home activities. The core structure of the household travel surveys is equally suitable for estimation of conventional and activity-based models.

However, the scope of traditional household travel surveys requires reconsideration in view of the activity-based and tour-based dimensions. The sample size of the survey (typically, 4,000-5,000 households) can impose serious restrictions on the model structure and segmentation. Since, the micro-simulation technique essentially reduces any limitation on model segmentation (number of travel purposes/activity types as well as number of household and person types), it is the sample size of the travel survey used for model estimation that limits the further disaggregation of the model components and level of detail, not the difficulty of accommodating many segments in model application (as is the case of conventional models). It is important to substantiate the necessary sample size and scope of the new travel/activity surveys that are going to be used for the model development, as well as to consider the usefulness of combining standard surveys implemented in different regions.

In discussion with practitioners, much attention has always been paid to how to achieve reasonable running times, as well as how to deal with the complexity of the computerized model set-up in terms of managing input/output components and user friendly interface. These technical questions should be addressed and the associated problems successfully resolved by application of contemporary hardware (multi-processing) and software solutions.

The new models are more complicated than the conventional ones; they create new modeling dimensions, as intricate linkages across various models that are less easily understood by practitioners and users of the models. All this makes the model output and sensitivity to the network changes less obvious. With the new models, it is important to retain the production of aggregate reports and outputs across the traditional dimensions (zonal tour/trip generation, origin-destination distribution, and model split) to make the final model outcomes compatible with the prevailing "culture" and commonly adopted analyses.

4.4. Valid concerns that need to be addressed in future research

Although many of the concerns and skepticism involved in moving the new generation of travel demand models into can be addressed by better explanation and practical demonstration of the advantages of the new models, there are a number of fundamental issues that are frequently forgotten in the current discussions, but relate to some theoretically unresolved problems. The following issues, in our view, can be classified as valid concerns that need to be addressed by the research community in order to accelerate the widespread application of activity-based models in practice:

- Complexity of activity-based models and the larger number of interacting model components makes it difficult to trace the sensitivity of the model to input factors in an analytical sense. In our experience with sensitivity tests with model systems for San Francisco, New York and Columbus, in many cases it was difficult to distinguish between program "bugs", Monte-Carlo variability, and valid model system responses until numerous tests have been implemented. This greater complexity may be an inevitable price to pay for behavioral realism, since travel behavior cannot be described exhaustively by a small number of analytical formulas. However, more work can be done in order to better understand and describe the output of the activity-based model system framework from the analytical point of view including estimation of the Monte-Carlo "clouds" for statistics under the interest.
- One of the important theoretical achievements associated with aggregate models is a closed and elegant theory of the network equilibrium in combination with logit-based (or entropy-based) demand models. This theory guarantees a unique stationary point for the equilibrium state as well as provides effective analytical methods for finding this equilibrium even for large and over-congested networks. So far, no attempts have been made to extend the theory of the network equilibrium to the activity-based models. The major theoretical problems associated with this extension relate to analytical complexity of the model chain, details of how the choice models are applied in micro-simulation, and Monte-Carlo variability. However, a closer look at these complications shows that none of them is essentially "fatal".

- The purpose of a realistic description of travel behavior and the corresponding intricate structure of decision-making have led many researches to the understanding that the analytical framework of the activity-based models should be extended to incorporate various non-compensatory decision rules and mechanisms. The micro-simulation framework opens a way to explicitly model interactions between participating agents (persons, households, firm) on the individual basis and “skim” aggregate behavior patterns without the explicit analytical formulation of the closed choice models. This concept proves very attractive and has also produced numerous (currently academic) attempts to formulate simulation models with numerous heuristic components and rules. Though this way may eventually be a new breakthrough into more flexible modeling paradigms it is important in our view <u>to preserve a reasonable level of theoretical foundation</u> (comparable to the theory of random-utility choice that stand behind applied choice models) before these types of constructs can be seriously considered for practical application. In particular such theoretical attributes as clear formulation of behavioral assumptions, analytical properties of the resulting model structures, and ways to statistically estimate the model parameters have to be addressed.

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