Australasian Transport Research Forum 2011 Proceedings
28 - 30 September, 2011, Adelaide, Australia
Publication website: http://www.patrec.org/atrf.aspx

New Advancements in Activity-Based Models

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Abstract

Activity-Based models have been used in practice for more than a decade in the United States. Within the last year, a number of significant advances have been designed, developed and put into practice in Activity-Based Models to support a wide range of system level and individual project planning efforts. In San Diego, all location choices are now based upon a very fine level of spatial resolution that allows for improvements in understanding access and egress to public transport, better representation of non-motorized travel, and incorporation of explanatory variables that explicitly respond to transit-oriented development strategies and related plans.

In the Phoenix, there is now an explicit modelling of seasonality that distinguishes changes in travel demand behaviour between the summer and winter seasons. New submodels have also been developed to address the university-related travel segment for Arizona State University. The Phoenix Activity-Based models include modules that model the 6% of all regional households that are owned by seasonal residents. Additionally, Special event models have been developed for sporting and cultural venues which comprise a growing proportion of public transport ridership.

Other notable advancements in our Activity-Based models have been the modelling of travel time reliability as a function of perceived highway time and congestion levels, and the inclusion of parking choice and constrained parking equilibrium models in congested Central Business districts. The paper will describe the basic structure, implementation, and application of these new advancements.

1. Introduction

Activity Based Modeling (ABM) has become a new paradigm that is gaining traction for large-scale regional travel models developed for Metropolitan Planning Organizations (MPOs) in the U.S. There are already 14 MPOs that either have developed or are developing or planning an ABM, which constitutes more than a third of large MPOs in the U.S. These major regions include San-Francisco, New York, Columbus, Atlanta, Denver, Sacramento, San Diego, Phoenix, Seattle, Los-Angeles, Boston, Chicago, Baltimore, and Houston.

This paper describes the structure and evolution of main design features of seven different regional Activity-Based Models (ABMs) that share the Coordinated Travel - Regional Activity Modeling Platform (CT-RAMP) design and software platform. The paper ascribes the purpose for structural improvements to a general desire to increase the behavioural realism of the model system (where cross-pollination of ideas between the CT-RAMP family of ABMs and other ABMs developed elsewhere is quite frequent) or the necessity to address certain projects and policies for the particular MPO.

The paper is organized as follows. Section 2 provides a brief overview of the fundamental features of ABMs with references to several comprehensive surveys of the State of the Art and Practice. Section 3 presents main features of the CT-RAMP family of ABMs already in practice. Section 4 explains new models of the CT-RAMP family and advanced features added recently in order to better address certain projects and policies. Sections 5-8 contain more detailed technical discussion of selected model features. Section 9 contains main conclusions.

2. Fundamental Features of ABMs

There is a wide variety of particular ABM designs applied in practice – see {*Vovsha Bradley & Bowman, 2005; Bradley & Bowman, 2006; Davidson et al, 2007; Bowman, 2009*} for comprehensive surveys of the existing ABMs in practice and explanation of their main features. There is an even a wider variety of operational ABM systems designed and developed in academia, including FAMOS, CEMDAP, ALBATROSS, TASHA, and ADAPTS {*Pendyala et al, 2004; Auld, 2010; Eluru, 2010*}. There is a notable example of an application of the CEMDAP-based ABM for a large region of the Southern California Association of Governments (SCAG) – see {*Goulias et al, 2010*}. Despite the variations in technical details between existing ABM systems, there are common features across all models representing core concepts of the ABM paradigm. These features include:

- A **tour-based structure** where the tour – a closed chain of trips starting and ending at the base location (home or workplace) – is used as the main unit of modeling travel. This structure preserves consistency across trips included in the same tour by travel dimensions such as destination, mode, and time of day. Further, the whole spectrum of travel dimensions (mode, destination, and time of day) related to non-home-based travel can be properly linked to home-based travel. Interestingly, despite the unanimous agreement regarding this feature, there significant differences in the tour-formation mechanism across model systems, including: 1) a combinatorial "rubber-band" approach where tours are first generated, then the primary destination is identified for each tour, and finally intermediate stops are inserted (the most frequently used in practice including the current CT-RAMP ABMs), 2) sequential building of tours activity-by-activity within time-space constraints (FAMOS), 3) tours emerging from the scheduling procedure with an over-arching time allocation model (SCAG).
- An **activity-based platform** that implies that modeled travel is derived within the general framework of the daily activities undertaken by households and persons. This allows for

the consistency of the typological, spatial, and temporal dimensions of individual activity patterns, the substitution between in-home and out-of-home activities, the duration of activities in a coherent framework with trip departure and arrival times, intra-household interactions, and other aspects pertinent to activity analyses. This is the most loosely defined feature with a wide range of actual realizations, from simplified ABMs with a basic level of cross-consistency between multiple tours and trips for the same person, and more advanced ABM designs that include additional dimensions and interactions. A specific contribution of the CT-RAMP design in this regard has been the incorporation of various intra-household interactions and explicit modeling of joint travel {*Vovsha et al, 2005*}. Other examples of recent advances include a wide range of accessibility measures that enhance model sensitivity to transportation policies {*Bradley Bowman & Griesenbeck, 2009*} and continuous-time-based model designs with an explicit time allocation control {*Goulias et al, 2010*}. It is believed that this facet of ABMs will continue to evolve in the near future.

- **A microsimulation** modeling technique that is applied at the disaggregate level of persons and households, which converts activity and travel related choices from fractional-probability model outcomes into a series of ordinal or nominal decisions among the discrete choices; this method of model implementation results in more realistic model outcomes, with output files that look much like actual travel/activity survey data. There is general consensus among ABMs regarding this feature as opposed to aggregate approaches. The microsimulation application paradigm is also well-suited for parallel processing, which has been successfully used to realize reasonable run-times for advanced ABMs in several large regions.

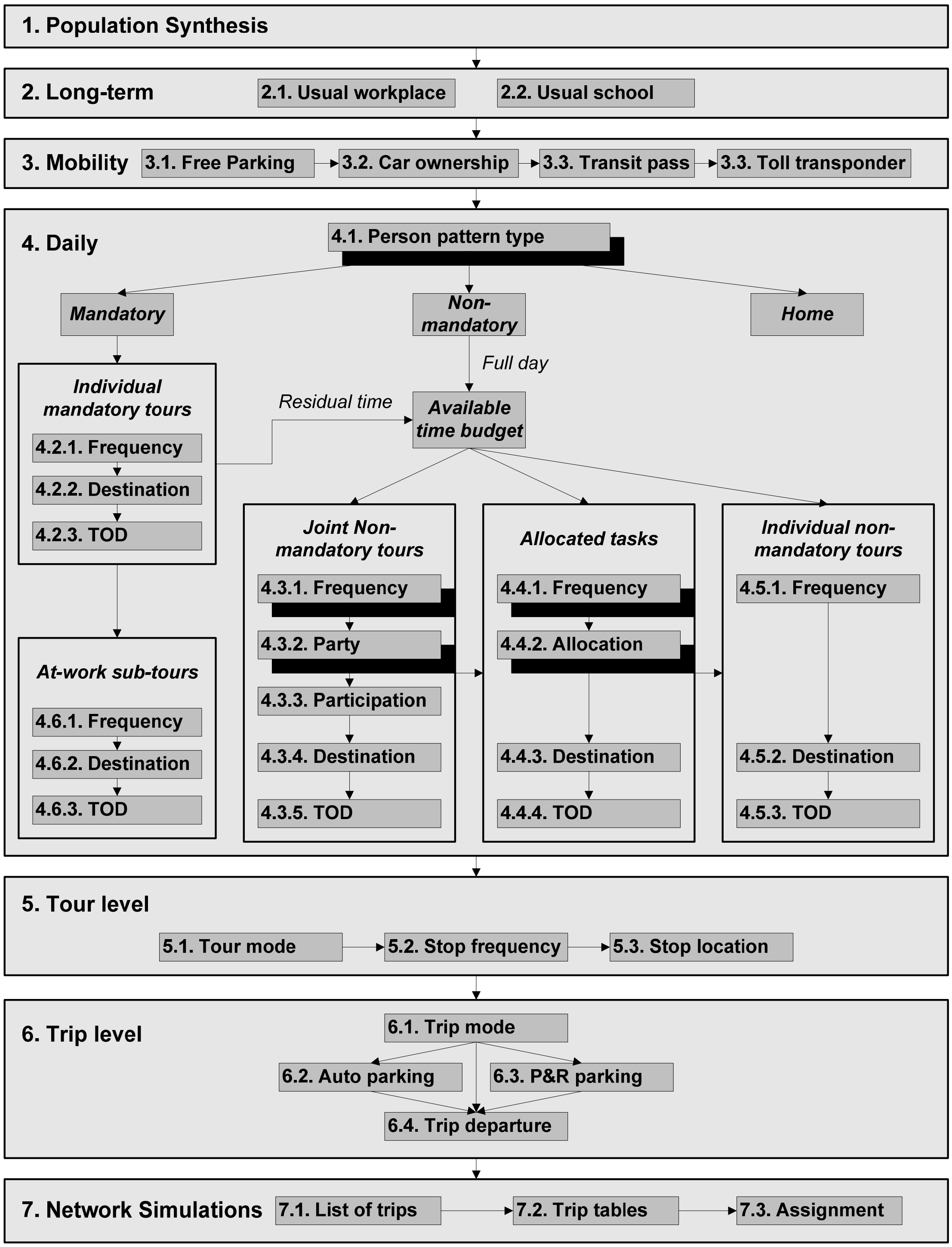
The combination of these three features proves to be a powerful platform for constructing operational model structures that incorporate multiple advanced techniques from behavioral research that had been largely unused within the 4-step modeling paradigm. In the following sections, we will describe their integration in an operational ABM framework.

3. Main Features of CT-RAMP

This section describes the structure and implementation of seven different regional Activity-Based Models (ABMs) that share the CT-RAMP conceptual design and software platform. A key feature of the CT-RAMP model is that intra-household interactions are explicitly represented across a wide range of activity and travel dimensions. This important feature ensures that the model system produces activities and tours that are reasonable at a household-level, and allows for greater behavioral realism in representing the response to numerous transportation policies. Modeling intra-household interactions allows for the very real travel constraints and synchronization among household members to influence traveler’s decisions. This feature of CT-RAMP is particularly relevant for modeling the response to the implementation or expansion High-Occupancy Vehicle (HOV) and High-Occupancy Toll (HOT) lane facilities as well as other projects and policies that specifically target vehicle occupancy. Another key distinguishing feature of CT-RAMP is that mandatory activities are generated and scheduled before non-mandatory activities are generated. The use of residual (available) time-windows in the generation of non-mandatory activities provides increased sensitivity to travel costs in the consideration of induced travel.

The general design of the CT-RAMP model system is presented in **Figure 1** below.

Figure 1: Basic CT-RAMP Design and Linkage between Sub-Models



Choices that relate to the entire household or a group of household members and assume explicit modeling of intra-household interactions (sub-models 4.1, 4.3.1, 4.3.2, 4.4.1, and 4.4.2) are shadowed in Figure 1. The other models are assumed to be individual-based for the basic design.

Sub-model set 1: Population synthesis. The model system uses synthetic household population as a base input. Thus, this component comes first in the model chain. The population synthesis procedure creates a list of households, with all household and person attributes based on the input (controlled) variables defined for each traffic zone. The procedure creates a household distribution in each zone that matches controlled variables and generates a list of discrete households with additional (uncontrolled) variables by drawing them from the microsample provided by the Population Census (PUMS or other source like ACS).

Sub-model set 2: Long-term location choices. These sub-models include the usual workplace choice for each worker (sub-model 2.1), taking into account the person occupation, and the usual school location choice for each student (sub-model 2.2) taking into account the school type (university, college, high school, elementary school, kindergarten, day care, etc). Work from home and schooling from home are singled out as special choices alternatives and modeled explicitly.

Sub-model set 3: Mid-term choices of individual mobility attributes. These sub-models predict the following set of household and person attributes: free parking eligibility for workers in the CBD or other parking-constrained areas (sub-model 3.1) that determines whether workers pay to park if workplace is a zone with a paid parking, household car ownership (sub-model 3.2), transit pass holding for each person (sub-model 3.3), and transponder ownership for use of toll lanes (sub-model 3.3).

Sub-model set 4: Coordinated Daily Activity-Travel Pattern. These sub-models generate and schedule main activities and travel tours for each household member.

The daily activity pattern type of each household member (model 4.1) is the first travel-related sub-model in the modeling hierarchy. This model classifies daily patterns by three types: 1) mandatory (that includes at least one out-of-home mandatory activity), 2) non-mandatory (that includes at least one out-of-home non-mandatory activity, but does not include out-of-home mandatory activities), and 3) home (that does not include any out-of-home activity or travel). However, the pattern type sub-model leaves open the frequency of tours for mandatory and non-mandatory purposes (maintenance, discretionary) since these sub-models are applied later in the model sequence. The pattern choice set contains a non-travel option in which the person can be engaged in an in-home activity only (purposely or because of being sick) or can be out of town. Daily pattern type choices of the household members are linked in such a way that decisions made by some members are reflected in the decisions made by the other members. It is implemented as a joint choice of pattern type by all household members that considers all possible combinations as alternatives.

The next set of sub-models (4.2.1-4.2.3) defines the frequency and time-of-day for each mandatory (work and school) activity/tour for each household member (note that locations of usual destinations for mandatory tours have already been determined in long-term choice models). Mandatory tour time of day (sub-model 4.2.3) is defined as a combination of departure time from home and arrival time back home for each tour. The scheduling of mandatory activities is generally considered a higher priority decision than any decision regarding non-mandatory activities for either the same person or for the other household members. As a result of the mandatory activity scheduling, “residual time windows” are calculated for each person and their overlaps across household members are estimated. Time window overlaps, which are left in the daily schedule after the mandatory commitment of the household members has been made, constitute the potential for joint and non-mandatory travel. In some CT-RAMP models, work or school tour destination is assumed to always be the usual workplace or school location, which is typically observed for more than 90% of mandatory tours. This eliminates sub-model 4.2.2; which is applied to identify cases where a different destination is visited.

The next major model component relates to joint household travel. Joint travel tours are generated and scheduled conditional upon the available time window left for each person after the scheduling of mandatory activities. This model component produces a number of joint tours by travel purpose for the entire household (sub-model 4.3.1), travel party composition in terms of adults and children (sub-model 4.3.2), and then defines the participation of each household member in each joint household tour (sub-model 4.3.3). It is followed by the choice of primary destination (sub-model 4.3.4) and time-of-day (sub-model 4.3.5) for each joint tour.

The next stage relates to maintenance activities (shopping and other household-related errands). Maintenances tours are generated by the household (sub-model 4.4.1) and allocated to a single person within the household for implementation (sub-model 4.4.2). Their destination and time of day are chosen next for each maintenance tour (sub-models 4.4.3 and 4.4.4). Time-of-day choices for multiple tours are modeled sequentially for each individual in order to ensure consistency of the person daily schedule.

Discretionary tours are modeled entirely at the individual level. These models include tour frequency (sub-model 4.5.1) followed by choice of destination (sub-model 4.5.2) and time of day (sub-model 4.5.3) for each tour. Again, time-of-day choices for multiple tours are modeled sequentially for each individual in order to ensure consistency of the person daily schedule.

At-work sub-tours (tours that start and end at the workplace) are modeled next, taking into account the time-window constraints imposed by their parent work tours. The sub-models include frequency of at-work sub-tours (sub-model 4.6.1) followed by primary destination choice (sub-model 4.6.2) and time-of-day choice (sub-model 4.6.3).

Sub-model set 5: Tour-level details. The next set of sub-models relate to the tour-level details including tour mode combination (sub-model 5.1), the exact number of intermediate stops on each tour and their purpose (sub-model 5.2), and the location of stops by order of implementation on each tour (sub-model 5.3). This sub-set of models is the least transferable compared to the other sub-models. This is primarily because of differences in modal options and the wide variation in specific travel markets in different regions.

Sub-model set 6: Trip-level details. These sub-models add details for each trip, including the specific trip mode used, (sub-model 6.1), the parking location for auto trips (sub-model 6.2), Park & Ride parking location choice (sub-model 6.3 in the Jerusalem ABM and explicit in transit path calculations for the San Diego ABM), and departure time for each trip within the tour time-of-day window (Sub-model 6.4.). Note that the parking location for auto trips is not necessarily the same as the trip destination. If parking capacity is constrained and/or parking cost is high, drivers may choose to park remotely and then walk to the destination.

Sub-model set 7: Network simulations. This component encapsulates the interface between the demand model system and network simulation model. The CT-RAMP ABM system first generates a full list of individual trips for the entire regional population with all necessary attributes for a network simulation such as origin, destination, mode, departure time, travel party size, value of time, etc (sub-model 7.1). This format can be utilized directly by a traffic microsimulation or DTA model. If needed, individual trips can be summarized into trip tables by mode and time-of-day as required for conventional static traffic assignments and transit assignments (sub-model 7.2). Finally, trip assignments for auto and transit trips based on route choice in the network equilibrium framework are implemented (sub-model 7.3).

In the CT-RAMP model chain, sub-models 4-6 are interlinked through various logsum measures and time-space constraints. In addition, the upper-level sub-models 2-3 are fed by various accessibility measures that are sensitive to travel time and land-use densities. The entire model system (sub-models 1-7) is integrated with highway and transit network simulation procedures and applied iteratively with special provisions for reaching global demand-supply equilibrium.

4. Recently Incorporated Advanced Features

4.1. Enhancements Incorporated in the San Diego ABM

The San Diego ABM development started in late 2008. Work to date includes a full model system specification document as well as a first set of estimated and implemented models. The following important new features were incorporated:

- **Improvement of the structure and segmentation of long-term models through integration with a land-use model (PECAS).** A significant effort was made to improve the workplace and school location models, using detailed labor force information provided by PECAS. The choice models include size terms and impedance measures that capture industry type, occupation, income group, gender, full-time/part time status, etc.

- **Fine spatial resolution.** The SANDAG ABM takes full advantage of the developed socio-economic and land-use database (supported by PECAS for future years) as well as network procedures at a highly disaggregate zonal system of 33,000 Master Geography Reference Areas (MGRAs). All location choices of the SANDAG ABM are implemented at the MGRA level. Transit and non-motorized procedures and mode choice are among the primary beneficiaries of the fine level of spatial detail.

- **Explicit stop-based path-building for transit.** The San Diego ABM utilizes a detailed, stop-based transit network for path-building. All transit times are based on explicit representation of boarding and alighting stops, and each origin and destination MGRA considers all potential stops within access/egress distance. The highest-utility paths are retained for each transit mode and used in a nested logit choice model. This provides complete consistency between transit path parameters and mode choice, and a very realistic representation of transit access times.

- **Improved Coordinated DAP type model integrated with joint activity episodes.** In the previous CT-RAMP ABMs, joint travel was generated after the DAP type and work/school tour schedules were defined for each person. Person availability to participate in joint activity was conditional upon the residual time window overlap with the residual time windows of the other household members. There is strong statistical evidence, however, that in reality this logic might be reversed: people synchronize their schedules and create time window overlaps in light of planned joint activities. This enhancement resolves this issue and allows for a more realistic decision-making mechanism where an indication on a joint activity episode is modeled simultaneously with the choice of DAP type of each household member. This feature is described in more detail in Section 8 below.

- **Inclusion of a wide set of accessibility measures.** In upper-level models for car ownership, DAP choice and tour generation, broader accessibility measures are included to ensure sensitivity to improvements of transportation level-of-service (LOS), as well as changes to land use. The SANDAG ABM does not use any area-type dummy variables (e.g., CBD, urban, suburban). Continuous accessibility measures are created in order to reflect the opportunities to implement a travel tour for a certain purpose from a certain origin (residential or workplace). Accessibility measures play the role of simplified tour-level logsums used in upper-level models instead of full logsums (which is computationally infeasible to calculate over all modes, time-of-day periods, and destinations for each possible tour). There are more than 50 types of accessibility measures used in the SANDAG ABM. They are distinguished by the specification of the zonal attraction size variable, impedance function form, and time-of-day period used to generate LOS variables. This feature is described in more detail in Section 6 below.

- **Population synthesizer that incorporates both household and person controls**. The current version of the population synthesizer can only handle controls on the distribution of households, e.g., number of households by size, income group, dwelling type, etc. However, there are certain demographic dimensions, like population distribution by age brackets, that can be better expressed through person-level controls. A modified population synthesis algorithm that can incorporate both types of controls simultaneously is being developed for the SANDAG ABM.

4.2. Advanced Features for the Phoenix ABM

The Phoenix ABM development started in mid 2009. To date, a full model system specification document and an initial set of estimated and implemented models have been completed. The following important new features are under development:

- **Explicit modeling of seasonality.** The Phoenix ABM will be one of the first travel models that address seasonal fluctuations in travel demand. The model system will have a switch that allows for simulation of an average weekday in summer, winter, or fall/spring seasons. Travel in the Phoenix metropolitan area is seasonal because of special travel markets including visitors, seasonal residents, and university students. The main special markets and corresponding implications for the model structure are summarized in the subsequent bullets.

- **Special sub-models for university-related travel.** Arizona State University (ASU) is the largest public higher-education learning center in the United States, with more than 70,000 students. ASU accounts for almost 2% of the total regional population (students plus workers), and has significant local traffic effects, modal effects (particularly with respect to transit use by the student body for both school and non-school trips) and seasonal variation, with school in session from late August through mid-May. A key differentiating characteristic for modeling the behavior of students is whether students live with their parents. Students who live with their parents are sufficiently captured by the home-interview survey data, which typically captures part-time and commuting students. Students who live in shared non-family households and group quarters are defined as a special segment. It is also important to model the proper residential location for university students as a function of distance/accessibility to campus. The synthetic student population is generated explicitly, considering distance from campus and presence of group quarters and other zonal characteristics, and tracked as ASU students in household/person databases. This residential allocation (synthetic generation) model would replace the usual school location choice model for ASU students.

- **Sub-models for non-resident visitor travel.** Approximately 6% of homes in the Phoenix metropolitan region are owned by seasonal residents. In addition, the Phoenix region has many hotels, motels, and resorts, whose occupancy is also highly seasonal. Non-resident visitors are likely to have different travel patterns than residents, depending on whether they are seasonal residents, business travelers, or recreational travelers. The Phoenix ABM will account for non-residents explicitly in the population synthesis and subsequent chain of travel models.

- **Special Events integrated with the core travel model.** MAG has conducted a new comprehensive survey of special events by location including sport arenas, fairs, large-scale conventions, concerts, etc. The challenge is to integrate special events with the core model in a disaggregate fashion to ensure that participation in a special event is organically incorporated in the individual DAP for both residents and non-resident visitors. Each special event is considered as a special activity with a predetermined time schedule and expected patronage. The core ABM will select participants for special event activities prior to generation of DAP from the appropriate resident and visitor populations. The event participation sub-model will consider household and person characteristics (including probability of forming a party of several people), location and travel accessibility to the event, as well as the feasibility of participation in more than one event. For each participant, the model would then 'reserve' a time window for the special event, and seek to generate and schedule other activities for the person conditional upon the event.

- **Incorporation of passenger trips to and from the airport with, and explicit modeling of, choices of airport and ground access mode.** This model component becomes especially interesting with the expansion of the ABM modeling area to include the city of Tucson. There are three airports with commercial service in the Phoenix-Tucson region: Phoenix Sky Harbor (the eight-largest airport in the United States), Phoenix-Mesa Gateway (a small airport), and Tucson International Airport. Phoenix Sky Harbor and Tucson International Airport compete for travel to and from the Tucson region. This will require special sub-models for generation of long-distance trips through airports and airport choice.

4.3. Planned Advanced Features for the Jerusalem ABM

The Jerusalem ABM development started in 2008; the first phase of the project was devoted to implementation of a Household Travel Survey employing an innovative method of "prompted recall", with 100% of respondents equipped with a GPS device (currently under way). A full model system specification document has been completed and a first set of estimated and implemented models is planned by end of 2011. The following important new features are planned:

- **Explicit modeling of individual mobility attributes**. Person and household mobility attributes relate to the medium-term choices that are conditional upon long-term choices (residential, workplace, and school location), but logically precede short-term travel choices related to a particular day, tour, or trip. In most of the previously developed ABMs, mobility attributes included car ownership only. In the Jerusalem ABM, this component is significantly expanded to include a wider range of interrelated person and household attributes: possession of a driver license, disability or limited mobility, transit pass holders, transit ticket discounts and/or subsidies from the employer or school, employer provided transportation for commuting, employed provided or subsidized parking, school bus availability, holding a toll transponder, etc.

- **Intra-household car allocation**. The Jerusalem metropolitan region has comparatively low car ownership rates as compared to the US; the region has a large number of multiple worker 0-car households and 1-car households. A large share of mode choice decisions are determined by the intra-household car allocation priorities. A special model that allocates household cars to individual tours and creates a logical linkage across mode choice decisions for tours, overlapping in time, has been developed.

- **Perceived highway time by congestion levels as a proxy for travel time reliability**. While transit time components like in-vehicle time, wait time, and walk time have long been modeled with different weights, highway time has been always considered uniform in travel models irrespective of congestion. There is strong evidence that auto users perceive congested travel differently than uncongested travel: each minute spent in congested conditions is perceived almost two minutes of free-flow travel. This weight accounts for the negative psychological impact of congestion as well as the unpredictable nature of travel in congested conditions. The Jerusalem Household Travel Survey has several Stated Preference extensions devoted to measuring the impact of travel time reliability on choices of route, mode, and time-of-day.

- **Parking Choice and Constrained Parking Equilibrium.** The CBD area of Jerusalem has a limited parking supply and several parking policies are currently being considered. The ABM can explicitly incorporate parking behavior, making the model sensitive to constraints and policies associated with parking. By virtue of individual microsimulation and enhanced temporal resolution, the model can portray the dynamics of parking in each traffic zone during the day. This feature is described in more detail in Section 7 below.

5. Making Upper-Level Models Sensitive to Travel Conditions

There are multiple accessibility measures used in the San Diego and Phoenix ABMs that are conceptually similar to the set of accessibility measures applied in the Sacramento ABM {*Bradley Bowman & Griesenbeck, 2009*} but with some additional refinements. The applied accessibility measures represent simplified destination choice logsums, which is the composite utility of travel across all modes to all potential destinations from an origin zone to all destination zones in different time-of-day periods.

These accessibility measures are primarily needed to ensure that the upper-level models in the ABM hierarchy such as car ownership, daily activity pattern (DAP), and (non-mandatory) tour frequency are sensitive to improvements of transportation level-of-service across all modes, as well as changes in land use. Accessibility measures are similar in nature to density measures and can be thought of as continuous densities.

Accessibility measures are needed since it is infeasible to link all choices by full logsums due to the number of potential alternatives across all dimensions (activities, modes, time periods, tour patterns, and daily activity patterns). Accessibility measures reflect the opportunities to implement a travel tour for a certain purpose from a certain origin (residential or workplace). They are used as explanatory variables in the upper level models (daily activity pattern type and tour frequency) and the corresponding coefficients are estimated along with the coefficients for person and household variables.

The San Diego and Phoenix ABMs completely avoid area-type dummies (such as CBD, urban, suburban, and rural area-type variables frequently used in models).

The applied accessibility measures have the following general form:

$$A_i = \ln\left[\sum_{j=1}^{I} S_j \times \exp\left(TMLS_{ij}\right)\right],$$ **Equation 1**

where:

$i, j \in I$	=	origin and destination zones,
A_i	=	accessibility measure calculated for each origin zone,
S_j	=	attraction size variable for each potential destination zone,
$TMLS_{ij}$	=	time-of-day and mode choice logsum as the measure of impedance.

The composite travel impedance measure between zones is calculated as a two-level logsum taken over the time-of-day periods and modes:

$$TMLS_{ij} = \mu \ln\left[\sum_{t=1}^{2} \exp\left(MLS_{tij} + \alpha_t\right)\right],$$ **Equation 2**

where:

$t = 1,2$	=	time-of-day periods (currently peak and off-peak are used),
MLS_{ij}	=	mode choice logsum for a particular time-of-day period,
α_t	=	time-of-day-specific constant,
μ	=	nesting coefficient for mode choice under time-of-day choice.

In this form, the destination choice accessibility measure is the sum of all attractions in the region weighted by travel impedance. This measure is sensitive to travel improvements in both peak and off-peak periods. The relative impact of each period is regulated by the time-of-day-specific constant that is estimated for each travel segment (or activity type).

Accessibility measures are linearly included in a utility function of an upper-level model. To preserve consistency with random-utility choice theory, the coefficient for any accessibility measure should be between 0 and 1; though it is not as restrictive as in a case of a proper nested logit model.

The set of accessibility measures incorporated in the San Diego and Phoenix ABMs is summarized in **Table 1**. The variety of measures stems from the combination of different size variables by the underlying activity type and different impedance measures by person/household type {*Freedman, et al, 2010*}.

Table 1: Accessibility Measures incorporated in the San Diego and Phoenix ABMs

No	Description	Model where it is used	Attraction size variable S_j	Modes included in logsum MLS_{ij}
1	Access to non-mandatory attractions by SOV	Car ownership	Total weighted employment for all non-mandatory purposes	Single Occupancy Vehicle (SOV)
2	Access to non-mandatory attractions by transit	Car ownership	Total weighted employment for all non-mandatory purposes	Generalized best walk-to-transit
3	Access to non-mandatory attractions by walk	Car ownership	Total weighted employment for all non-mandatory purposes	Walk available if distance is 3 miles or shorter
4-9	Access to non-mandatory attractions by all modes	CDAP	Total weighted employment for all non-mandatory purposes	SOV , transit, non-motorized for person-level choices; HOV, transit, non-motorized for interaction terms; both segmented by 3 car-availability groups
10-12	Access to shopping attractions by all modes except SOV	Joint tour frequency	Weighted employment for shopping	HOV, transit, non-motorized segmented by 3 car-availability groups
13-15	Access to maintenance attractions by all modes except SOV	Joint tour frequency	Weighted employment for maintenance	HOV, transit, non-motorized segmented by 3 car-availability groups
16-18	Access to eating-out attractions by all modes except SOV	Joint tour frequency	Weighted employment for eating out	HOV, transit, non-motorized segmented by 3 car-availability groups
19-21	Access to visiting attractions by all modes except SOV	Joint tour frequency	Total households	HOV, transit, non-motorized segmented by 3 car-availability groups
12-24	Access to discretionary attractions by all modes except SOV	Joint tour frequency	Weighted employment for discretionary	HOV, transit, non-motorized segmented by 3 car-availability groups

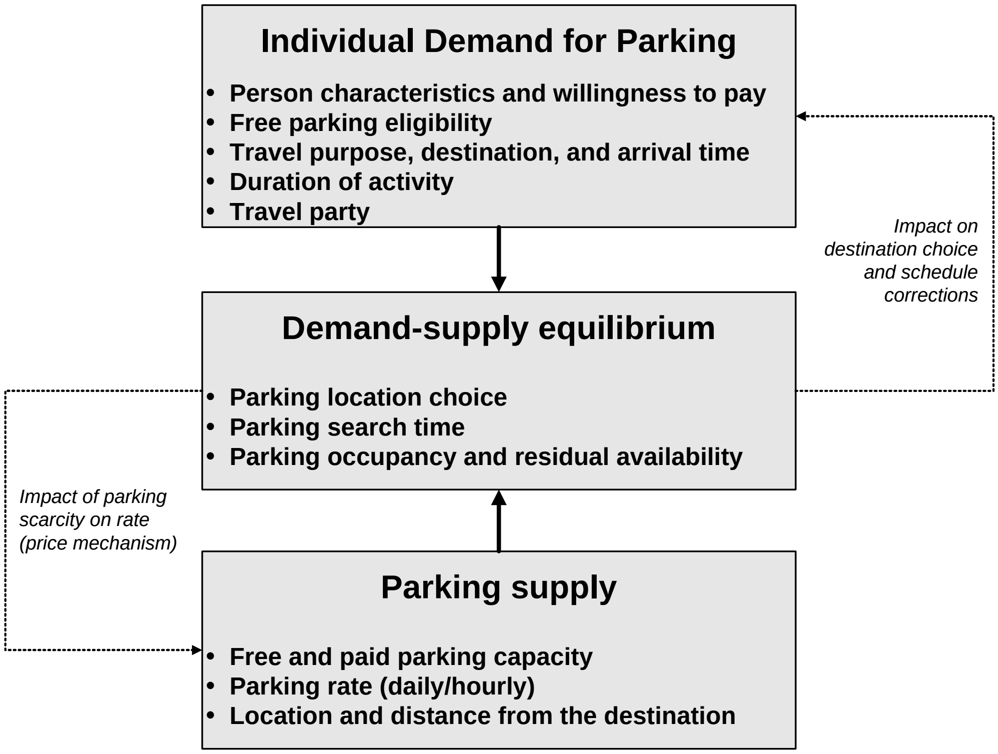
No	Description	Model where it is used	Attraction size variable S_j	Modes included in logsum MLS_{ij}
25-27	Access to escorting attractions by all modes except SOV	Allocated tour frequency	Total households	HOV, transit, non-motorized segmented by 3 car-availability groups
28-30	Access to shopping attractions by all modes except HOV	Allocated tour frequency	Weighted employment for shopping	SOV, transit, non motorized segmented by 3 car-availability groups
31-33	Access to maintenance attractions by all modes except HOV	Allocated tour frequency	Weighted employment for maintenance	SOV, transit, non motorized segmented by 3 car-availability groups
34-36	Access to eating-out attractions by all modes except HOV	Individual tour frequency	Weighted employment for eating out	SOV, transit, non motorized segmented by 3 car-availability groups
37-39	Access to visiting attractions by all modes except HOV	Individual tour frequency	Total households	SOV, transit, non motorized segmented by 3 car-availability groups
40-42	Access to discretionary attractions by all modes except HOV	Individual tour frequency	Weighted employment for discretionary	SOV, transit, non motorized segmented by 3 car-availability groups
43-45	Access to at-work attractions by all modes except HOV	Individual sub-tour frequency	Weighted employment for at work	SOV, transit, non motorized segmented by 2 car-availability groups

6. Parking Choice & Constrained Parking Equilibrium

One of significant advantages of an ABM structure is the ability to explicitly incorporate parking behavior that makes the model sensitive to constraints and policies associated with parking. The corresponding modeling framework is shown in **Figure 2**. Most of the associated components and choice models have already been tested in previous ABMs developed for Columbus, Atlanta, and San-Francisco Bay Area. We plan to build on this experience with some specific refinements for the Jerusalem ABM.

By virtue of individual microsimulation with an enhanced temporal resolution, the proposed model structure can portray daily dynamics of parking in each traffic zone. The parking simulation is realistically modeled as equilibrium between the parking demand and supply. Demand for parking is directly associated with individual auto tours (a different approach requires for park & ride parking lots at transit stations that is part of transit sub-model). The most important individual variables that relate to parking demand are tour destinations, arrival times, and planned activity durations (time for which the auto would occupy the parking space). All these variables are endogenous to the ABM and available in the process of microsimulation.

Figure 2: Parking Model Components



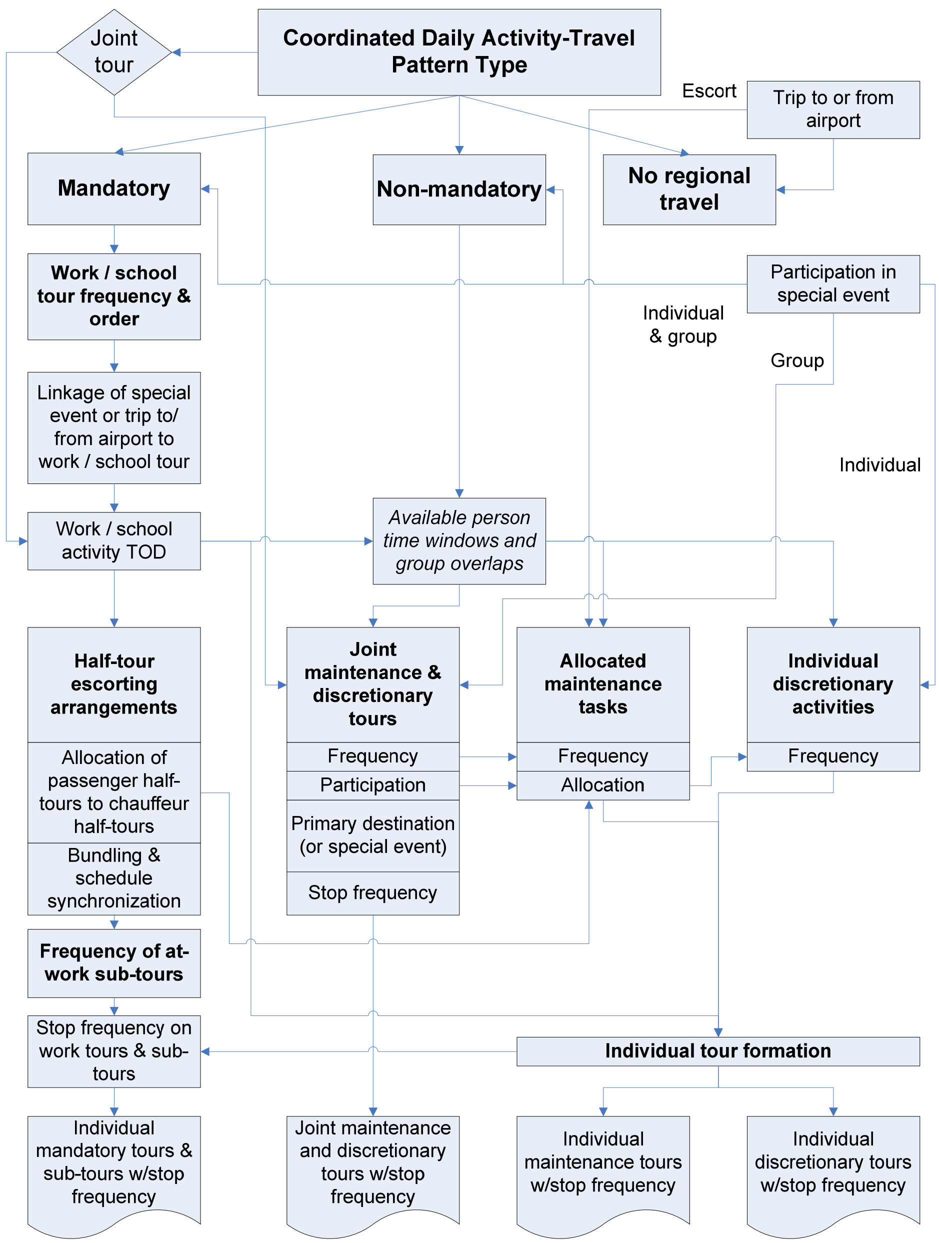
If the parking supply had been unlimited and free, the parking model would have been reduced to a simple counter of the occupied parking spaces in each zone assuming that each individual auto would park in the destination zone. The presence of parking constraints and variable rates requires demand-supply equilibrium where some parking demands may not be satisfied. The model requires consideration of person characteristics, willingness to pay and eligibility for free parking, as well as the number of passengers traveling with the driver. Eligibility of free parking is an important characteristic since many drivers are fully or partially reimbursed by their employer.

Parking supply estimation is based on an estimate of free and paid parking capacity in each zone as well as the daily and hourly parking rate. The equilibrium mechanism is important for making the model sensitive to parking capacity constraints and/or pricing policies. A prototype sub-model of parking choice was estimated for the Columbus ABM and also applied in the Atlanta ABM. With this model, a driver does not necessarily park in the destination zone but can choose to park in some other zone (where parking is more available or cheaper) and then walk to the final destination. The choice utility includes the person/tour variables as well as characteristics of the competing parking zones. In the model application, it is applied successively for all tours with dynamic update of the parking availability. Associated parking search time is estimated as a function of the distance from the final destination and parking occupancy. All else being equal, parking in remote zones when the destination zone and adjacent zones are occupied would be associated with longer walk and longer search time. This makes the auto mode less attractive in the mode choice model, which is linked to the parking model either directly through parking choice logsums or via a feedback/shadow pricing mechanism.

7. Further Improvements of Day-Level Models

Several interrelated improvements for modeling individual Daily Activity Patterns for special population segments and the way to incorporate special travel markets in Daily Activity Patterns for all individuals are summarized in **Figure 3** as they are being implemented for the Phoenix ABM.

Figure 3: Modeling Day-Level Choices of Activity-Travel Patterns



In the Phoenix ABM, this model component has a more advanced design than in previously developed CT-RAMP models. In particular, it includes the following new features:

- A **joint tour indicator** (zero joint tours vs. at least one joint tour) is included in the upper-level model for pattern types, and predicted simultaneously with the basic travel pattern for each household member. This feature, previously included in the San Diego CT-RAMP model, enhances model integrity since there is a strong interdependence between the scheduling of mandatory activities and participation in joint non-mandatory activities. The presence of a joint tour indicator earlier in the model chain informs the subsequent time-of-day choice model for mandatory activities that a reasonable time window should be left by potential participants. It is behaviourally appealing that workers may adjust and synchronize their work schedules to participate in a joint activity, as opposed to assuming that these schedules are defined independently.

- Explicit modeling of **half-tour escorting arrangements** between workers and school children. Fully joint tours implemented for shared non-mandatory activities have always been a part of the basic CT-RAMP design. However, partially joint tours (the majority of which relate to escorting children to school) have not yet been included because of the complexity of the associated choice structures. In fact, modeling fully joint tours is a comparatively simple component since each fully joint tour is a unit for which all choices (destination, time of day, and mode) are predicted for the entire travel party. Partially joint tours are not associated with a shared activity and the choice of destination for both the escorted person(s) and the chauffeur has to be modeled separately. Technical details for this sub-model are discussed in the next section.

- Incorporation of **special events and trips to & from airports with the core individual microsimulation**. Practically all models developed for special events and trips to and from airports so far have been aggregate and applied separately from the core demand model (whether aggregate or implemented via microsimulation). The challenge taken in the Phoenix ABM design is to integrate special events with the core model in a disaggregate fashion to ensure that participation in a special event is organically incorporated in the individual DAP for both residents and non-resident visitors. Each special event is considered as a special activity with a predetermined time schedule and expected patronage. The core ABM will select participants for special events prior to the generation of a DAP from the appropriate resident and visitor populations. The event participation sub-model will consider household and person characteristics (including probability of forming a party of several people), location and travel accessibility to the event, as well as the feasibility of participation in more than one event. For each participant, further in the model chain, the event can be linked to the work or school tour (most frequently, in the inbound direction). This linkage is modeled prior to the work tour time-of-day choice (only preliminary start and end times for work activity are known that are synchronized with the special event schedule). Work tours that include a special event as a stop are assigned a final time-of-day choice to accommodate participation in the special event.

- Explicit **formation of individual tours** based on the generated activities. This is a significant improvement of the CT-RAMP model structure compared to the previously applied models that have been relying on tour generation rather than activity generation as starting point in simulating individual patterns. In the proposed structure, individual non-mandatory activities are generated first for each person. These activities are grouped into tours including previously generated mandatory tours (where non-mandatory activities are inserted as intermediate stops) and newly formed non-mandatory tours (where non-mandatory activities can play either a role of the primary destination or role of an intermediate stop). The tour-formation procedure and activity trade-offs between mandatory and non-mandatory tours relate to individual activities only. Shared non-mandatory activities are generated as part of fully joint tours and are not directly substitutable with individual activities (even for the same formal purpose like shopping or eating out). Since these activities and associated travel arrangements are to be planned and coordinated across several household members we can generally assume that these activities and corresponding tours are generated simultaneously. Thus, joint travel tour probably represents a better behavioral unit for modeling than just a shared activity episode.

8. Escorting Children to School

The proposed approach for explicitly modelling escorting children to school was tested as research based on the data for the Atlanta, GA, region {*Vovsha & Petersen, 2005*}. The approach is applicable for carpooling between workers as well. However, escorting children represents the most frequent type of partially joint tours, thus we recommend developing it first.

This model is applied after the generation, primary destination choice, and usual time-of-day choice for mandatory activities for all household members. Thus, at this modeling stage, it is known for each child if he/she goes to school, the location of the school, and the departure and arrival period. It is also known for each household adult if he/she goes to work or university, the location of workplace or university, and the work tour departure and arrival period. From this perspective, the escorting model can be thought of as a matching model that predicts whether escorting occurs, and if so which adult household members are chauffeurs and which children are escorted to school.

The model is applied before mode choice for mandatory tours and also before generation, location, and scheduling of non-mandatory activities. The escorting model predicts mode choice to a large extent; if the child is escorted to school then both the child's mode choice for the corresponding school half-tour as well as the mode choice for the corresponding chauffeurs' tour (work, university, or pure escorting) is predetermined (HOV car passenger for the child, HOV car driver for the chauffeur). It is also possible to escort on transit as well as by walk modes; however, these options are not modeled explicitly. If the escorting option is not chosen, then for both child and chauffeur there are several potential individual mode alternatives for the corresponding half-tours including transit, drive alone, shared ride with non-household members, school bus, non-motorized modes, etc. These options will be considered in the subsequent mode choice model. However, the composite quality of the individual service for the child (in particular, transit availability, walk availability, and availability of school bus) is taken into account at the escorting decision stage.

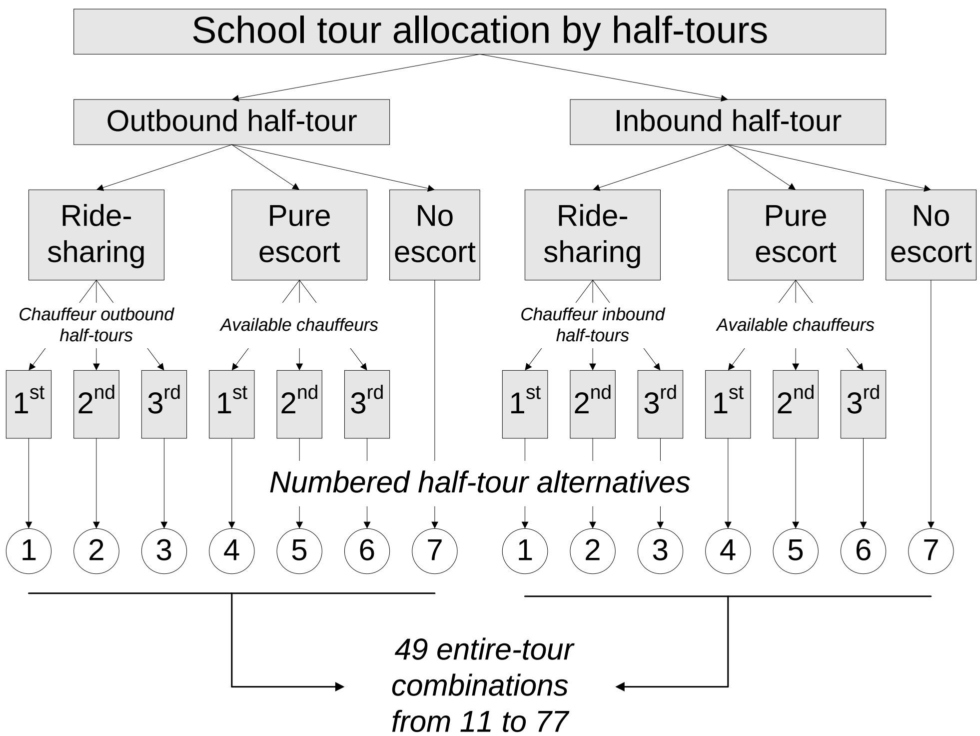
Since a significant percentage of workers are involved in ride-sharing with school children, we expect that inclusion of the proposed model before mode choice can significantly change the structure and sensitivity of the model choice model for the work commute. In reality, some workers may prefer the private auto because of the joint travel arrangements with children rather than consideration of the relative time and cost of auto versus transit. The proposed model would capture this effect. In conventional model systems, the choice of commute mode by workers is entirely attributable to the time and cost characteristics of the modes with the impact of intra-household interactions captured implicitly by household composition variables and constants. As the result, conventional mode choice models frequently tend to overestimate the response of commuters on transit network improvements. We believe that explicit modeling of joint travel arrangements will help to achieve more realistic forecasts for mode choice switches of commuters.

Children within the household are ordered and modeled by age from youngest to oldest. The behavioural assumption behind this decomposition rule is that, all else being equal, a younger child has a more limited individual mobility compared to an older child; thus, escorting younger children would be considered first in the household decision making process.

The maximum number of adult household members considered as potential chauffeurs is limited to 3. Statistical analysis has shown that households with 4 or more adults and also having children under 18 years old constitute only about 0.5% of the total number of households. For these infrequent cases, the number of alternatives is truncated, dropping excessive chauffeurs who were picked randomly — but never dropping the chauffeur who actually implemented an observed escorting task.

The modelled choice alternatives for each school tour are shown in **Figure 4** below.

Figure 4: Escorting Choice Alternatives for Individual School Tour



For each individual school tour, there are at most 7 outbound alternatives and 7 inbound alternatives including ride-sharing with one of the 3 potential chauffeurs, pure escorting by one of the 3 potential chauffeurs, and a non-escort option. At the level of entire school tour this gives 7×7=49 escort alternatives. If less than 3 chauffeurs are available for either outbound or inbound half-tour, the alternatives that correspond to non-available chauffeurs are blocked out in the choice model.

9. Conclusions

Over the course of last 10 years, ABM has become the leading travel modelling technology in the U.S., adopted by a large number of MPOs. While this modelling technology is still a very much in motion and different approaches have been used by different MPOs, there is a certain level of convergence with respect to the most basic modelling features and components. However, there is also very active research into better model structures and healthy debate on the technical implementation of these features.

The growing interest in ABMs stems from the fact that more and more practitioners and the wider transportation planning community have recognized significant advantages of ABMs over 4-step models in the context of important projects and policy evaluations. These include accounting for socio-demographic dynamics in metropolitan areas and changing patterns of travel, highway pricing, public transit investments, auto parking policies, equity analysis, and many other policies and variables.

The CT-RAMP family of ABMs includes many core structures similar to other ABM systems, but each implementation represents an evolution where the behavioral fidelity of the system in increased and specific policies and markets that are appropriate to each region are addressed

The CT-RAMP family of models is defined by a structural core and corresponding software platform that includes six major groups of sub-models and procedures: 1=population synthesis, 2=long-term location choice models, 3=model for individual mobility attributes, 4=coordinated Daily Activity-Travel pattern, 5=tour-level models, 6=trip-level models. The entire model system is integrated with highway and transit network simulation procedures and applied iteratively with special provisions for reaching global demand-supply equilibrium. One of the most salient features of this family is the explicit modelling of intra-household interactions, which ensures behavioural realism with respect to how travel is generated, scheduled and coordinated within the household. Subsequent implementations of the mode build upon this concept with explicit representation of escorting activities.

Each implementation of the CT-RAMP model also includes many refinements to address specific regional conditions and provide additional features compared to previously developed models and the basic design. These features are explained in the paper, and analysed in the context of model application for different transportation projects and policies. Some of these features stem from ongoing intensive research and development in the field including cross-pollination of ideas between the CT-RAMP family and other ABMs developed elsewhere, but many other features were largely driven by practical needs. The main conclusion of the paper is that it is too early to establish a completely generic and standard approach to an ABM design in practice. The evolution still continues and it is equally driven by theoretical achievements in behaviour research and practical considerations.

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