Australasian Transport Research Forum 2010 Proceedings
29 September – 1 October 2010, Canberra, Australia
Publication website: http://www.patrec.org/atrf.aspx

CT-RAMP Family of Activity-Based Models

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Abstract

This paper describes the structure, implementation, and application experience of seven different regional Activity-Based Models (ABMs) that share the Coordinated Travel - Regional Activity Modeling Platform (CT-RAMP) design and software platform. The CT-RAMP models are characterized by a number of features, including a full simulation of travel decisions for discrete households and persons; explicit tracking of time in half-hourly increments and use of time constraints on the generation of travel, as well as explicitly modelled intra-household interactions across a range of activity and travel dimensions. These important features allow for greater behavioral realism in representing the response to numerous transportation policies.

The first ABM of the CT-RAMP family was developed in 2004 for the Mid-Ohio Regional Planning Commission (MORPC) located in Columbus, OH, and was adapted for the Tahoe Regional Planning Agency (TRPA) in 2006. The third and forth ABMs were completed in 2009 in parallel for the Atlanta Regional Commission (ARC) and the San Francisco Bay Area's Metropolitan Transportation Commission (MTC). Three new ABMs are currently being developed, including: for the San Diego Association of Governments (SANDAG); for the Maricopa Association of Governments (MAG) in Phoenix, AZ; and for the Transportation Master Plan Team (JTMT) in Jerusalem, Israel.

Each implementation of the CT-RAMP model included refinements to address specific regional conditions and additional advanced features compared to previously developed models. These features are explained in this paper, and analysed in the context of model application for different transportation projects and policies.

1. Introduction

Activity Based Modeling (ABM) has become the leading paradigm for large-scale regional travel models developed for Metropolitan Planning Organizations (MPOs) in the U.S. There are already 15 MPOs that either have developed or are developing an ABM, which constitutes more than 50% of large MPOs in the U.S. This paper describes the structure, implementation, and application experience 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 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. Section 4 describes the CT-RAMP ABMs already in practice. Section 5 explains new models of the CT-RAMP family and advanced features added recently in order to better address certain projects and policies. Section 6 summarizes practical advantages of ABMs with respect to different transportation projects and policies. Section 7 contains main conclusions.

2. Fundamental Features of Activity-Based Models

There is a variety of particular ABM designs applied in practice – see [*Vovsha Bradley & Bowman, 2005; Bradley & Bowman, 2006; Davidson et al, 2007; Vovsha & Freedman, 2008*] for comprehensive surveys of the existing ABMs and explanation of their main features. 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 [*Vovsha & Freedman, 2008*].
- 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 [*Bradley & Vovsha, 2005; Vovsha et al, 2005*].
- **A microsimulation** modeling technique that is applied at the fully-disaggregate level of persons and households, which converts activity and travel related choices from fractional-probability model outcomes into a series of "crisp" 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. [*Castiglione Freedman & Bradley, 2003*]

The combination of these three features proves to be a powerful platform for constructing operational model structures that incorporate multiple advanced techniques from the behavioral research that had been largely unused within the 4-step modeling paradigm. It has been demonstrated that the time and cost associated with building an ABM compares favorably with 4-step model development. The data requirements are also identical and

ABM models can be implemented within any standard software package.. In the following sections, we will describe their integration in an operational ABM framework.

3. Main Features of CT-RAMP

This paper describes the structure and implementation of seven different regional Activity-Based Models (ABMs) that share the **C**oordinated **T**ravel and **R**egional **A**ctivity **M**odeling **P**latform (**CT-RAMP**) conceptual design and software platform. The CT-RAMP models explicitly represent intra-household interactions across a wide range of activity and travel dimensions [*Vovsha at al, 2005; Bradley & Vovsha, 2006*]. This important feature allows for greater behavioural 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 traveller 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.

The general design of the CT-RAMP model system is presented in **Figure 1** below. The following main sub-models and associated travel choices are included in the CT-RAMP structure:

1. **Population synthesis**. 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.

2. **Long-term location choices.** Including the usual workplace choice for each worker taking into account the person occupation, and the usual school location choice for each student taking into account the school type (university, college, high school, elementary school, kindergarten, day care, etc).

3. **Individual mobility choices**. Including the following set of household and person attributes:

   3.1. Free Parking Eligibility (determines whether workers pay to park if workplace is a zone with parking cost).

   3.2. Household car ownership.

   3.3. Transponder ownership for use of toll lanes.

4. **Coordinated Daily Activity-Travel Pattern.** Generates travel tours for each household member, and includes the following sequence of sub-models:

   4.1. Coordinated pattern type for each household member (main activity combination, at home versus on tour) with a linkage of choices across various person categories.

   4.2. Frequency and schedule of individual mandatory (work and school) activities/tours for each household member (note that locations of usual destinations for mandatory tours have already been determined in long-term choice models):

      4.2.1. Frequency of mandatory tours.

      4.2.2. Mandatory tour time of day (combination of departure time from home and arrival time back home for each tour).

4.3. Household frequency of fully joint tours implemented for shared non-mandatory activities and person participation in joint travel. Joint travel tours are generated conditional upon the available time window left for each person after the scheduling of mandatory activities. The following sequence of sub-models is applied:

4.3.1. Joint tour frequency.

4.3.2. Travel party composition (adults, children, or mixed).

4.3.3. Person participation in each joint tour.

4.3.4. Primary destination for each joint tour.

4.3.5. Joint tour time of day (departure/arrival time combination).

4.4. Household frequency of maintenance tasks and their allocation to household members for implementation, including the following sub-models:

4.4.1. Household frequency of maintenance tours.

4.4.2. Maintenance tour allocation to one person in household.

4.4.3. Maintenance tour destination.

4.4.4. Maintenance tour time of day (departure/arrival time combination).

4.5. Individual discretionary activities/tours that are generated and scheduled conditional upon the available time window left for each person after the scheduling of mandatory and joint non-mandatory activities:

4.5.1. Person frequency of discretionary tours

4.5.2. Discretionary tour primary destination

4.5.3. Discretionary tour departure/arrival time

4.6. Individual sub-tours started from and ended at the workplace that are generated (conditional upon the available time window within the work tour duration):

4.6.1. Person frequency of at-work sub-tours.

4.6.2. Primary destination for each at-work sub-tour.

4.6.3. At-work sub-tour departure/arrival time.

5. **Tour-level choices.** Include each tour's following characteristics:

5.1. Tour mode combination.

5.2. Frequency of secondary stops (and their purpose).

5.3. Location of secondary stops.

5.4. Departure time for each trip from/to home, primary destination, or secondary stop.

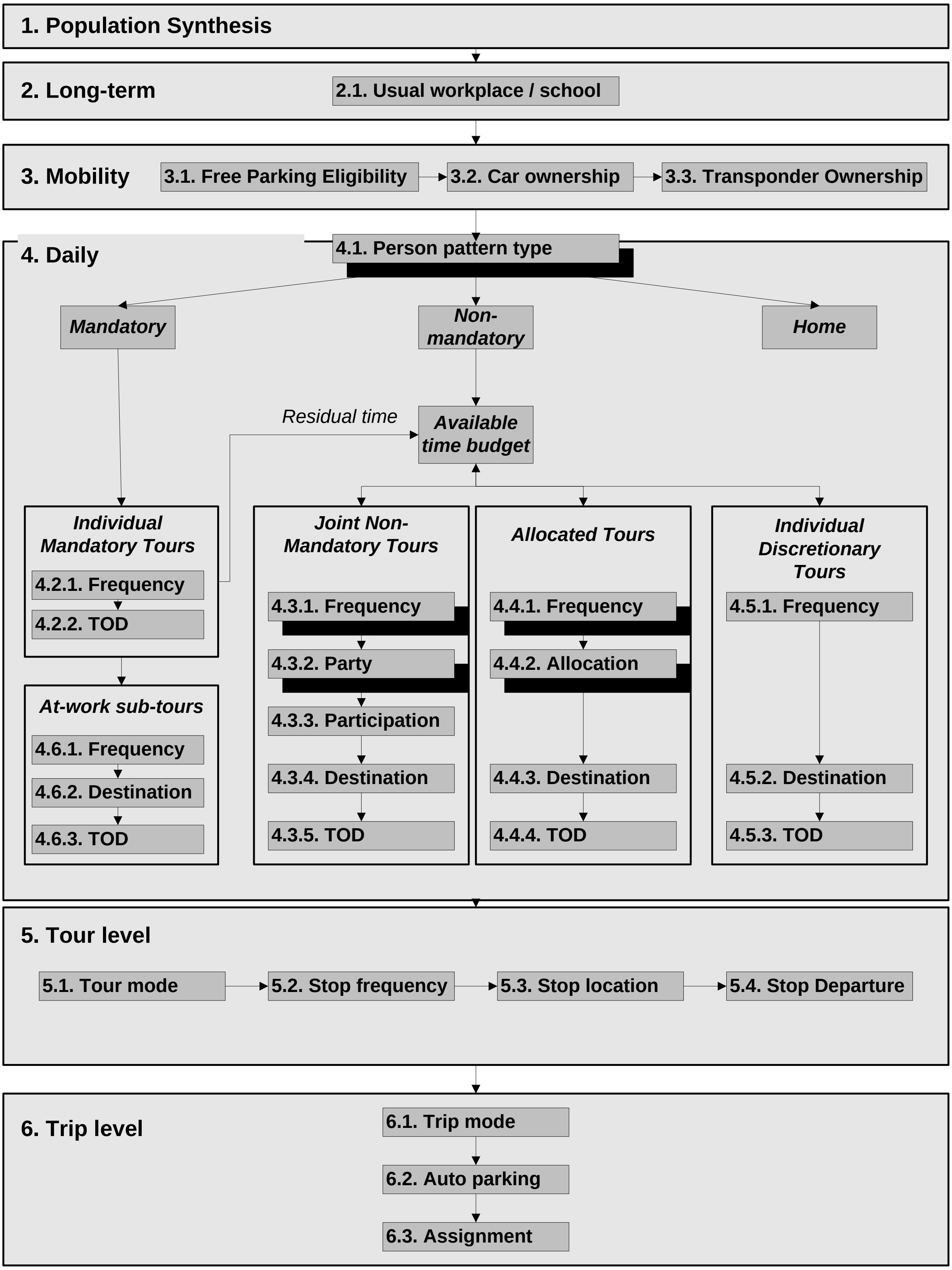
6. **Trip-level choices.** Include each trip's following choices:

6.1. Trip mode choice conditional upon the tour mode combination.

6.2. Auto trip parking location choice.

6.3. Trip assignments for auto and transit trips (route choice in the network equilibrium framework).

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 3.2, 4.1, 4.3.1, 4.3.2, 4.4.1, and 4.4.3) are shadowed in **Error! Reference source not found.**1. The other models are assumed to be individual-based for the basic design.

The model system uses synthetic household population as a base input (sub-model 1). It is followed by long-term choices that relate to the usual workplace/university/school for each worker and student (sub-model 2.1). Medium-term mobility choices relate to free parking eligibility for workers in the CBD (sub-model 3.1), household car ownership (sub-model 3.2), and toll transponder ownership (sub-model 3.3). 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 and 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 [*Bradley & Vovsha, 2005*].

The next set of sub-models (4.2.1-4.2.2) defines the frequency and time-of-day for each mandatory 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. At-work sub-tours are modeled next, taking into account the time-window constraints imposed by their parent work tours (sub-models 4.6.1-4.6.3).

The next major model component (4.3) relates to joint household travel. This component produces a number of joint tours by travel purpose for the entire household (4.3.1), travel party composition in terms of adults and children (4.3.2), and then defines the participation of each household member in each joint household tour (4.3.3). It is followed by choice of destination (4.3.4) and time-of-day (4.3.5).

The next stage relates to maintenance (shopping and other household related) and discretionary tours. Maintenances tours are generated by the household (4.4.1) and allocated to a single person within the household (4.4.2). Their destination and time of day are chosen next (4.4.3 and 4.4.4). Discretionary tours are modeled entirely at the individual level. The models include tour frequency (4.5.1), choice of destination (4.5.2) and time of day (4.5.3). The next set of sub-models relate to the tour-level details on mode (5.1), exact number of intermediate stops on each half-tour (5.2), stop location (5.3), and stop departure time (5.4). It is followed by the last set of sub-models that add details for each trip including trip mode details (6.1) and parking location for auto trips (6.2). The parking location does not necessarily coincide with 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. The trips are then assigned to highway and transit networks depending on trip mode (6.3).

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 is integrated with highway and transit network simulation procedures and applied iteratively with special provisions for reaching global demand-supply equilibrium [*Vovsha Donnelly & Gupta, 2008*].

4. Current Members of the CT-RAMP Family

The first ABM of the CT-RAMP family was developed in 2004 for the Mid-Ohio Regional Planning Commission (MORPC) located in Columbus, OH. The Columbus core model structure was adapted for the Tahoe Regional Planning Agency (TRPA) in 2006. The Lake Tahoe ABM included special components to account for the seasonal variability in the Lake Tahoe Area's population and travel moving to/from/through the model's boundary.

The third and forth ABMs of the CT-RAMP family have been developed in parallel for the Atlanta Regional Commission (ARC) and the San Francisco Bay Area's Metropolitan Transportation Commission (MTC). These ARC model system is now fully calibrated and validated and is being applied to various policies, while the MTC models are undergoing final calibration and will be applied in 3rd quater 2010. The Atlanta and Bay Area Models have included the following refinements relative to the Columbus/Lake Tahoe models:

- Consideration of **long-term choices** (i.e. usual workplace, usual school location) prior to the car ownership model and subsequent chain of travel choices. In the Columbus/Lake Tahoe model, these choices were not modeled explicitly. They were "blended" with the non-usual locations in the work and school destination choice models.

- The **simultaneous choice of Daily Activity-Travel Pattern (DAP) type for all household members** that accounts for interactions between household members. This model replaced the sequential Daily Activity-Travel Pattern applied in the Columbus/Lake Tahoe models. This enhancement significantly improves the model system's integrity, and eliminates the need to arbitrarily order the household members (to then apply activity models sequentially).

- Consideration of **multiple intermediate stops** on each half-tour (up to four, depending on the tour purpose). In the Columbus/Lake Tahoe models, only one major stop was modeled on each half-tour. This enhancement allow for modelling complicated trip chaining patterns.

- Adding person type and trip purpose **explanatory variables** to the tour-level and trip-level mode choice models. In the Columbus/Lake Tahoe models, a simplified rule-based algorithm represented the trip-level mode choice decision because of a very low transit mode share. In the Atlanta and Bay Area models, a **trip-level choice** model was introduced and both tour-level and trip-level mode choices were significantly extended to account for each city's multi-modal regional transit network.

- Implementation of **distributed values of time** in the Bay Area ABM based on Stated Preference survey work performed for San Francisco County Transportation Authority as part of the San Francisco Mobility Study. This component represents an example of an advanced use of the concept of microsimualtion. Individual microsimulation not only opens a way to consider practically unlimited number of population and travel segments. It can also realistically portray a situational variability that is observed within each segment [*Erhardt et all, 2008*].

5. Recently Incorporated Advanced Features

Three new members of the CT-RAMP family were added in 2008 and 2009, including: San Diego, CA, for the San Diego Association of Governments (SANDAG); Phoenix, AZ, for the Maricopa Association of Governments (MAG); and Jerusalem, Israel, for the Jerusalem Transportation Master Plan Team (JTMT).

5.1. 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)[i].** 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 level 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.

- **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 this logic might be reversed: people synchronize their schedules and create time window overlaps in view 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.

- **Improved ABM system integrity by 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 will be one of the few travel models that do not use “flat” area-type dummy variables (e.g., CBD, urban, suburban). 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 from, and time-of-day period used to generate LOS variables.

- **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 has been developed and is planned for implementation in the SANDAG ABM.

5.2. Planned Advanced Features for the Phoenix ABM

The Phoenix ABM development started in mid 2009. To date, a full model system specification document has been completed; an initial set of estimated and implemented models is planned by mid 2010. The following important new features are planned:

- **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 implementation of a representation specific to summer, winter, or fall/spring. 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 62,000 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 the 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 will be 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 will be 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.** The Maricopa Association of Governments (MAG) is currently conducting a new comprehensive survey of special events by location. 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.

5.3. 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 2010. 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 [*Vovsha & Petersen, 2009*].

- **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 [*Petersen & Vovsha, 2005, 2006*].

- **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 [*Vovsha Davidson & Donnelly, 2005*]. 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. The most important variables that impact parking demand are tour destinations, arrival times, and planned activity durations (time for which the auto would occupy the parking space). Parking supply is estimated by free and paid parking capacity in each zone as well as parking rates including the daily rate (relevant for long parking) and hourly rate (relevant for short parking). The equilibrium mechanism is implemented by means of the parking choice model that is applied in combination with two functional models to estimate the associated parking search time and track the actual parking availability at any point of time during the day. With this model, a driver does not necessarily park in the destination zone but can choose to park in some other zone (where more or cheaper parking is available) and then walk to the final destination.

6. Summary of Practical Advantages of ABM

A summary of the main technical advantages of the proposed ABM compared to the 4-step model in the context of different projects, policies, and planning aspects is presented in **Table 1** below. This summary is based on a large number of applications of ABMs of the CT-RAMP family as well as other ABMs for different projects and policies in the recent years. The projects and policies are grouped into the following broad areas:

- Accounting for **socio-demographic dynamics** in metropolitan areas and changing patterns of travel. In this regard, the richness of microsimulation ABMs with respect to population segmentation is the key factor. Another related issue of practical importance is accounting for new commuting patterns due to growing number of telecommuters and occupation types associated with schedule flexibility. For this reason, the CT-RAMP model system includes special sub-models for predicting of work from home as the usual arrangement or predicting frequency of work from home as part of Daily Activity-Travel Pattern.

- **Highway pricing**. This has historically been one of the major reasons that generated interest to ABMs in practice. The CT-RAMP family of models were specifically design with a wide range of features addressing highway pricing studies including enhanced segmentation, an explicit modeling of joint travel and probabilistically distributed Value of Time [*Vovsha Davidson & Donnelly, 2005; Erhard et al, 2008*].

- **Public transit**. The ABM paradigm proved to be also very beneficial for transit studies due to a more consistent and behaviorally realistic mode choice that account for entire-tour constraints. Specifically, calculation of transit User Benefits for Non-Home-Based trips has been significantly improved compared to 4-step models. ABMs of the CT-RAMP family have been successfully applied for several major transit projects [*Castiglione Freedman & Davidson, 2004; Freedman, 2006; Vovsha, 2008*].

- **Auto parking**. ABMs offer a wide range and of options to model parking constraints and policies that are not available with 4-step models. In particular, the CT-RAMP family of ABMs includes parking lot choice and accounts for remote parking. In the Jerusalem ABM, explicit parking constraints and demand-supply parking equilibrium are planned to be included.

- **Equity analysis**. ABMs that provide a detailed microsimulation output are tailored for equity analysis. In particular, various income groups, ethnicities, person types (workers, university students, children, elderly people, etc) can be singled out and analyzed with respect to winners and losers from transportation projects and policies [*Castiglione, 2006*].

Table 1: Summary of Practical Advantages of ABM vs. 4-Step Model

Policy / project / planning aspect	4-Step limitations	ABM advantage
Dynamic metropolitan area and changing patterns of travel:		
Complicated and changing demography	Limited number of household segments; general inability to address person variables	Rich set of household and person variables including household composition and interactions between household members, age, gender, ethnicity, occupation, etc
Fast growing population and employment with changing balance between the metropolitan core and suburbs	Crude trip distribution models with limited segmentation	Flexible destination choice models specific to various types of activities on both demand and supply sides
Land-use development policies including transit-oriented development, mixed-land-use development, and pedestrian/bike friendly environment	Very limited ability to accommodate a fine-grain spatial level of analysis; crude representation of transit access and non-motorized modes; general incapability to evaluate transportation impacts of these policies	Natural incorporation of a fine-grain spatial units for location choices and mode choice implemented at individual tour/trip level; significant improvement of transit access and non-motorized modeling
New commuting patterns and options such as growing telecommuting, work from home & self-employment, compressed work weeks, part-time work	Impossible to address	Explicit choice of usual workplace and commuting arrangements for each worker; explicit modeling of impact of changing commuting pattern on non-work travel through individual time-space constraints
Highway pricing:		
Variable congestion pricing including dynamic pricing, associated mode shifts and peak spreading	Limited number of user segments by VOT, theoretically impossible to apply a consistent Time of Day choice model	Rich user segmentation by VOT (including probabilistic situational variation); fully integrated mode and Time of Day choices sensitive to pricing

Policy / project / planning aspect	4-Step limitations	ABM advantage
HOV/HOT lanes and associated carpooling policies	Crude modeling of joint travel as part of mode choice with aggregate occupancy-specific constants	Explicit modeling of joint travel with associated individual constraints and propensities
Daily area pricing	Crude scaling of tolls by average number of trips made by the same person to the pricing area	Accounting for individual daily pattern and actual number of trips made to the pricing area
License plate rationing	Impossible to address	Individual microsimulation of car availability based on the rationing strategy
Transit:		
FTA New Starts analysis for mass rapid transit (LRT, commuter rail)	Systematic bias in mode choice and User Benefits calculation for Non-Home-Based trips because of inability to account for auto availability; inconsistent mode choice across different time-of-day periods	Linkage of Non-Home-Based trips to Home-Based trips and consistent tracking of auto availability; consistent tour-based mode choice for all time-of-day periods
Park & Ride Facilities	Unrelated choices for outbound and inbound trips or crude assumption of total symmetry of AM and PM periods; accounting for capacity constraint for each crude time-of-day period separately	Same parking lot for outbound and inbound trips with a proper time-of-day choice for each of them; accounting for capacity constraints by arrival & departure hour during the day
Transit fare policies, combined multi-modal transit pass, person-type discounts	Crudely addressed on a trip-by-trip basis in transit fare skims/mode choice	Explicit choice of person transit pass holding; incorporation of individual discounts
Auto parking:		
Parking constraints	Crude assumption that parking lot coincides with trip destination; no account for parking capacity constraint	Explicit parking choice and constrained parking demand-supply equilibrium
Parking policies	Crude zonal parking cost per trip	Parking cost differentiated by duration of parking
Free parking availability for certain users	Impossible to address	Probabilistic assessment of free parking eligibility at individual person level provided by the employer
Equity analysis:		
Environmental justice analysis	Very limited number of built-in segments, normally 3-4 income groups only	Disaggregate output for analysis by income group, disability status, ethnicity, age group, etc

7. Conclusions

Over the course of the last 5 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.

The CT-RAMP family of ABMs is the largest family of ABMs successfully developed and applied in practice in the U.S. The most salient feature of this family is explicit modelling of intra-household interactions. This adds complexity to the model system but this also ensures behavioural realism with respect to how travel is generated, scheduled and coordinated within the household. 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. However, each particular implementation of a CT-RAMP ABM for a particular metropolitan region has certain specific features included to better address the specifics of the region and planning needs of the MPO.

The growing interest in ABM in practice stems from the fact that more and more practitioners and a wider community of transportation planning analysts have recognized multiple, and significant advantages of ABMs in the context of important projects and policy evaluations where 4-step models are not capable of providing those answers. This primarily relates to such important planning issues, projects, and policies as 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 others.

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