Design and Development Plan for the MAG CT-RAMP Activity-Based Model (ABM)

Prepared for Maricopa Association of Governments

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1. Executive Summary

1.1. MAG ABM Development Approach

This document describes the Maricopa Association of Governments (MAG) Activity-Based Model (ABM) specification. This ABM will serve as the major travel forecasting tool in the Phoenix region for decades to come. This model has been designed to ensure that the regional transportation planning process can rely on forecasting tools that will be adequate for new socioeconomic environments and emerging planning challenges. It is equally suitable for conventional highway projects, transit projects, and various policy studies such as highway pricing and HOV analysis. The suggested MAG ABM design also addresses specific features of the Phoenix Metropolitan Region such as seasonal population segments and travel markets.

The MAG model is based on the CT-RAMP (Coordinated Travel Regional Activity-Based Modeling Platform) family of Activity-Based Models. The CT-RAMP model, which is fully described in the following sections, adheres to the following basic principles:

- The CT-RAMP design corresponds to the *most advanced principles of modeling* individual travel choices with maximum behavioral realism. In particular, it addresses both household-level and person-level travel choices including intra-household interactions between household members across a wide range of activity and travel dimensions.
- CT-RAMP is a proven design concept, intensively *tested in practice* in several regions. The New York, NY model was developed in 2002 and in use in the New York region to analyze numerous projects. The Columbus, OH model, which was the first fully fledged member of the family was developed in 2004 and since applied by the MORPC (Mid-Ohio Regional Planning Commission) for various transit and highway projects. The Lake Tahoe Area, NV model was created in 2006 largely by transferring main components of the Columbus model. The Atlanta, GA model (for ARC – Atlanta Regional Commission) has been co-developed with the San-Francisco Bay Area, CA Model (for MTC – Metropolitan Transportation Commission). Both models were completed in 2009. Ongoing developments of CT-RAMP in parallel with the MAG ABM include models for the San-Diego region (for SANDAG – San Diego Association of Governments) and Jerusalem, Israel (for JTMT – Jerusalem Transportation Master Plan Team). In each case, the model system has been tailored to address the specific issues and markets that are particular to the region. The MAG version of CT-RAMP is the latest and most advanced one that includes many significant improvements and unique features.
- Operates at a detailed *(half-hourly) level of temporal resolution*, with respect to modeling trip and activity timing and duration. This ensures consistency of the generated activity and travel patterns and schedules at the individual level that are essential for a proper modeling

of congestion and pricing effects on time-of-day of travel and peak spreading. This also provides for the possibility of integration of the MAG ABM with an advanced network simulation model, such as Dynamic Traffic Assignment (DTA).

- Reflects and responds to *detailed demographic and socio-economic information*, including household structure, aging, changes in wealth, and other key attributes observed or expected in the dynamic Phoenix metropolitan region. It is possible to include race/ethnicity as an explanatory variable in the model system. Innovative model features incorporated in the MAG ABM also include addressing such specific population segments as university students, seasonal and transient population, non-resident population staying in hotels, etc. This is ensured by the enhanced and flexible population synthesis procedures as well as by the fine level of model segmentation. In particular, the MAG ABM incorporates different household, family, and housing types including a detailed analysis of different household compositions in their relation to activity-travel patterns.

- Accounts for the *full set of existing and planned travel modes*. Our experience with previously developed ABMs has shown that mode choice is one of the least transferable model components, because each region has a specific mix of modes developed in the context of the regional urban conditions. The proposed design for the MAG ABM allows for addressing details of different auto modes (distinguished by occupancy, used toll facilities and HOV/HOT lanes), transit modes (distinguished by the main technology like bus, LRT, commuter rail as well access & egress options), and non-motorized modes as well as special modes relevant for particular travel markets (like air travel between Phoenix and Tucson or intensive use of taxis by visitors).

- The core CT-RAMP model is one component that relates to person travel of the resident population. However, it can *easily integrate with other components* such as the existing MAG truck model, a model of external travel to and from the region, models of non-resident visitor travel, airport travel, and special event travel. Specifically, integration of the core travel model with travel associated with special events represents one of the innovative features of the MAG ABM that was added because of the significant share of special events in the region and their impact on travel.

- The ABM developed for MAG will be compatible and *could be integrated with the AZ-SMART land-use model* in the future. AZ-SMART is the new land-use forecasting tool currently under development at MAG. Linking the travel ABM with land-use model provides a number of potential advantages and benefits both sides. In particular, the ABM would benefit from the detailed spatial information on population and employment by type. The land-use model would benefit from detailed measures of transportation accessibility. One of the most important components for both models that would immediately benefit from the integration is a spatial structure of labor flows that could be modeled at the detailed level of industry and occupation types.

- Flexibility with respect to the network simulation platform available. The current version of MAG ABM (similar to other operational ABMs currently in the US) will be first implemented in combination with a conventional static assignment as the only network simulation platform feasible for the entire Phoenix region. However, the CT-RAMP ABM structure can provide *detailed inputs needed for traffic micro-simulation software* for engineering-level analysis of corridor and intersection design. Moreover, it is expected that in the near future, DTA software will be able to simulate the entire regional network for a full-day period within reasonable run-time constraints. This will open a way to fully integrate transport demand and supply models in one coherent framework based on individual microsimulation. The proposed design of MAG ABM fully accounts for this future possibility.
- Is implemented in the PB Common Modeling Framework, an *open-source library* created specifically for implementing advanced models. This ensures a flexible and modular software architecture allowing for future modifications and adding model components at the subsequent Phases of ABM development.

1.2. Addressing MAG Planning Needs and Specifics of the Region

The MAG CT-RAMP model has been tailored specifically to meet MAG planning needs, considering current and future projects and policies and also taking into account the special markets that exist in the Phoenix Region. The model system addresses requirements of the metropolitan planning process, relevant federal requirements, and provides support to MAG member agencies and other stakeholders. In particular, the ABM structure fully complies with the following planning applications:

- *RTP, TIP, and Air Quality Conformity Analysis*. The ABM will be carefully validated and calibrated to replicate observed traffic counts and other monitoring data sources with the necessary level of accuracy. The output of traffic assignment can be processed in a format required by the emission calculation software used by MAG, including any advanced package that might be applied in future such as MOVES.
- *Corridor Studies, Development Impact Studies, and other planning studies*. The ABM will have more realistic travel patterns and will provide more detailed outputs compared to the 4-step model. This will lend itself to a high level of credibility with respect to routine planning studies conducted by MAG staff and other model users.
- *FTA New Starts Analysis*. The ABM application software package includes an option that produces the model output in a format required by FTA for the New Starts process. This output can be used as a direct input to the FTA software Summit used for calculation and analysis of the User Benefits. In order to meet the FTA “fixed total demand” requirement for comparison across the Baseline and Build alternatives, the ABM includes a run option for the Build alternative with certain travel dimensions fixed from the Baseline run.

- *Different highway pricing and managed lanes studies*. One of the advantages of an ABM over a 4-step model is a significantly improved sensitivity to highway pricing. This includes various forms of toll roads, congestion pricing, dynamic real-time pricing, daily area pricing, license plate rationing and other innovative policies that cannot be effectively modeled with a simplified 4-step model. The explicit modeling of joint travel was specifically introduced to enhance modeling of HOV/HOT facilities.

- *Other transportation demand management measures.* There are many new tendencies and policies aimed at reducing highway congestion in major metropolitan areas, including promoting telecommuting and teleshopping, compressed work weeks, and flexible work hours. ABMs are specifically effective for modeling these types of policies since these models are based on an individual micro-simulation of daily activity-travel patterns.

- *Enhanced Environmental Justice analysis.* The model system features a full micro-simulation of the population, providing the ability to perform virtually unlimited market analysis. Winners and losers analysis can be performed across highly disaggregated user groups, providing information for different types of environmental justice studies.

- *Seasonal travel.* Travel in the Phoenix metropolitan area is seasonal because of special travel markets. 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 the model to represent summer, winter, fall, or spring conditions.

- *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. The synthetic student population will be generated explicitly and students in the travel model will be considered as a special segment.

- *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 Event travel.* The Phoenix Metropolitan Region is characterized by a significant number of large-scale special events (sport event for example) and seasonal activities that attract a large number of visitors. MAG is currently conducting a new comprehensive survey of special events by location. The challenge taken in the MAG 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 daily activity-travel pattern 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 other activities and trips from the appropriate resident and visitor populations. The event participation sub-model will consider household and person characteristics (including the 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.

A summary of 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.

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 HH segments; general inability to address person variables	Rich set of HH and person variables including HH composition and interactions between HH 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

Policy / project / planning aspect	4-Step limitations	ABM advantage
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 TOD choice model	Rich user segmentation by VOT (including probabilistic situational variation); fully integrated mode and TOD choices sensitive to pricing
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 TOD periods	Linkage of Non-Home-Based trips to Home-Based trips and consistent tracking of auto availability; consistent tour-based mode choice for all TOD periods

Policy / project / planning aspect	4-Step limitations	ABM advantage
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 TOD period separately	Same parking lot for outbound and inbound trips with a proper TOD 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 emloyer
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

1.3. Phasing of the MAG ABM Development

We structured the ABM Development Project in four Phases, of which Phases 1-3 correspond to the core model development and full software implementation. Essentially, by the end of Phase 3, MAG will be delivered a first version of a fully operational ABM. Phase 4 is needed for an extensive validation, calibration, and testing of the entire model system before the final version of the software has been created and delivered to MAG. The experience with previously developed ABMs (and all regional models in general) has shown that certain amendments to the mode structure are always needed and become clear only after the testing of the entire model system. This is especially true for an advanced model like MAG ABM that includes many innovative components that have not been applied and tested in previously developed CT-RAMP ABMs. Phases 1-3 are compressed to the maximum extent in terms of schedule. Schedule for Phase 4 is more flexible. It will be finalized based on the actual validation results of the first version and required "fixes" to the software and amendments to the model structure.

The following deliverables are planned for phases 1 through 3 of the MAG ABM development:

- *Phase 1:* The ABM development plan covering all phases and a first set of working models and procedures. The first set includes population synthesizer; long-term models of usual workplace for workers and usual school location for students; mid-term models for household and person mobility attributes like car-ownership, person transit pass holding, transponder acquisition, and free parking eligibility; and coordinated individual daily pattern of tour/trip generation including individual participation in special events and trips to and from airport. Depending on the actual survey data availability some sub-models will only be calibrated to match aggregate statistics while more detailed estimation and calibration will be postponed to Phases 3 and 4.

- *Phase 2:* A full set of working day-level and tour-level choice models including all models related to tour generation and formation, primary tour destination choice, tour time-of-day choice, and tour mode choice for all tours including work and non-work purposes. After the completion of Phase 2, the skeleton of the full MAG ABM will be created. Only details associated with trip-level models such as stop frequency, stop location, trip mode, exact trip departure time, and parking location will be missing. All tour-level models will be validated and calibrated versus the compatible tour-level sources of information like expanded statistics from the Household Survey, home-based statistics from the transit On-Board Survey, and major screen-line traffic counts (not significantly subject to route deviations associated with intermediate stops). After the completion of Phase 2, the skeleton ABM model will delivered to MAG for the MAG staff to start testing and validation. This will minimize the learning curve and will shorten the final ABM validation / calibration schedule. Depending on the actual survey data availability some sub-models will only be calibrated to match aggregate statistics while more detailed estimation and calibration will be postponed to Phases 3 and 4.

- *Phase 3:* A set of tour-level and trip-level models will be added to the ABM system that will complete the MAG ABM model development process. Trip-level models include exact stop frequency, stop location, trip mode, exact trip departure time, and parking location choices for both auto and drive-to-transit trips. All trip-level models will be validated and calibrated versus the compatible trip-level sources of information like expanded statistics from the Household Survey, trip statistics from the On-Board Survey, and traffic counts. At this Phase, the core ABM model, highway and transit network procedures for assignment and skimming, as well as all additional sub-models (airports, universities, special generators, freight vehicles, and external visitors) will be consolidated in the corresponding software package delivered to MAG. This phase will also include an extensive testing of equilibration strategies between the core demand model and network assignments.

- *Phase 4:* This phase will be devoted to the complete ABM validation, final calibration (to the extent needed), intensive sensitivity testing, as well as MAG staff training. It should be noted that even if each sub-model has been carefully validated and calibrated, validation and calibration of the entire model system is typically needed. The details of schedule and budget for Phase 4 will be established together by the MAG staff and PB team and take into account the MAG staff involvement and learning curve.

The suggested phasing of the MAG ABM development is similar to the phasing of the San Diego and Jerusalem ABMs currently being developed by PB. It has been adopted by the corresponding agencies – San Diego Association of Governments (SANDAG) and Jerusalem Transportation Masterplan Team (JTMT). These ABM development projects represent a good example for MAG since the ABM design adopted in San-Diego and Jerusalem is from the same CT-RAMP family of models.

2. Core Design of CT-RAMP Family of Activity-Based Models

This section describes the core CT-RAMP features adopted for the MAG ABM. These features are shared by several other ABM in practice. In subsequent sections, specific innovative features unique for the MAG ABM are discussed.

2.1. Decision-Making Units

Decision-makers in the model system include both individual persons and households. These decision-makers are created (synthesized) for each simulation year based on tables of households and persons from the Census data and forecasted TAZ-level distributions of households and persons by key socio-economic categories. These decision-makers are used in the subsequent discrete-choice models to select a single alternative from a list of available alternatives according to a probability distribution at each step of the entire-day decision-making process. The probability distribution is generated from a logit model which takes into account the attributes of the decision-maker and the attributes of the various alternatives.

The decision-making unit is an important element of model estimation and implementation, and is explicitly identified for each model specified in the following sections. Advanced ABMs are characterized by a behaviorally-realistic and hence quite sophisticated decision-making tree covering all possible travel choice dimensions and situations when the corresponding decisions are made. In the MAG ABM, there are five basic decision-making units system that are used in most of the choice models:

- *Household*. Examples of choice dimensions pertinent to this unit include car ownership and frequency of joint travel tours.
- *Person*. Examples of choice dimensions pertinent to this unit include usual workplace and/or school location and frequency of individual discretionary activities. While these decisions are related to person attributes, the household which the person belongs in also plays an important role and provides additional variables and constraints explaining the person choices.
- *Tour*. Examples of choice dimensions pertinent to this unit include primary destination, time-of-day and tour mode choice. The person (or group of persons for joint tours) actually implementing the tour and household provide additional important variables and constraints explaining the choice.
- *Trip*. Examples of choice dimensions pertinent to this unit include trip mode choice and departure time. The tour that includes the given trip, person implementing it, and household provide additional important variables and constrains explaining the choice.

- *Activity*. Examples of choice dimensions pertinent to this unit include the person to whom this activity is allocated (for household maintenance activities) and tour where this activity is included either as primary destination or intermediate stop (for individual maintenance and discretionary activities). Depending on the choice context all relevant tour, person, and household attributes are used as explanatory variables and/or constraints.

2.2. Level of Spatial Resolution and Granularity

An ABM structure based on individual households, persons, and trips can exploit more explicit geographic and locational information, but the advantages of additional spatial detail must be balanced against the additional efforts required to develop zone and associated network information at this level of detail, as well as against the increases in model runtime associated with path-building and assignment.

The use of a spatially disaggregate zone system helps ensure appropriate model sensitivity. Use of large zones may produce aggregation biases, especially in destination choice, where the use of aggregate data can lead to illogical parameter estimates due to reduced variation in estimation data, and in mode choice, where transit access and non-motorized mode attributes (time and distance) may be distorted. Smaller zones help minimize these effects, and can also support more detailed network assignments.

In general, there are three possible approaches to build a zonal system to support an ABM for which the existing ABMs in practice provide good examples:

- *Traffic Analysis Zones (TAZ) subdivided into 2-3 subzones by transit access*. Most large metropolitan area travel demand models consider between 1,500 and 4,000 TAZs. For example, in the New York ABM, 4,000 TAZs are each subdivided into two sub-zones (1=no walk access, 2=walk access) which results in 8,000 spatial units. In the Columbus ABM, 1,800 TAZs are each subdivided into three sub-zones (1=no walk access, 2=short walk, 3=long walk) which results in 5,400 spatial units. Highway and transit assignments are implemented at aggregate TAZ level initially. Afterwards, transit walk time is modified according to the transit access sub-zones at the trips origin and destination according to predetermined rules. Walk-to-transit mode is not available if either the origin or the destination subzone does not have walk access.
- *Smaller spatial units than TAZ*. For example, the SANDAG CT-RAMP model will take advantage of Master-Geographic Reference Area (MGRA) zone system; the most disaggregate zonal system currently in use in any travel demand model in the United States. SANDAG's current MGRA system consists of 32,000 zones, which are roughly equivalent to Census block groups (although efforts are being made to move to a 22,000 MGRA-system in the near future). To avoid computational burden, SANDAG relies on a 4,600 Transportation

Analysis Zone (TAZ) system for highway skims and assignment, but performs transit calculations at the more detailed MGRA level. This is accomplished by generalizing transit stops into pseudo-TAZs called Transit Access Points (TAPs), and relying on TransCAD to generate TAP-TAP skims such as in-vehicle time, first wait, transfer wait, and fare. All access and egress calculations and ultimate Origin MGRA – Boarding TAP – Alighting TAP-Destination MGRA path are computed within custom-built software, and rely upon detailed geographic information regarding MGRA-TAP distances and accessibilities. A graphical depiction of the MGRA – TAP transit calculations is given in **Figure 1**. All activity locations are tracked at the MGRA level.

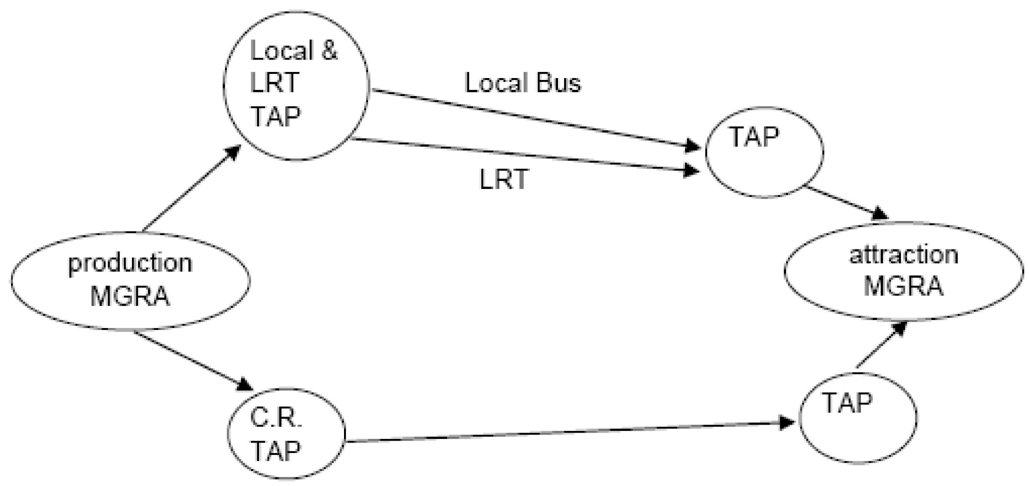

Figure 1: Example MGRA – TAP Transit Accessibility

- *Individual parcels*. There are model systems in use or under development which allocate activities to a unit smaller than the MGRA, such as a parcel. However, these model systems assume that the closest transit stop to the parcel is consistent with the TAZ-to-TAZ impedances calculated by the commercial transport software. In transit-rich environments, this may not be the case, and such assumptions can cloud User Benefit calculations required by FTA New Starts. The MGRA geography offers both the advantage of fine spatial resolution, and consistency with network levels-of-service, that makes it ideal for tracking activity locations.

A decision regarding the spatial structure of MAG ABM will be based on the available granularity of the socio-economic and land-use data as well as the state of the transit network. The MAG ABM model is designed in a flexible way; it can take advantage of any available spatial system. It is currently planned to use the first approach (TAZ with 2-3 transit access subzones) for Phase 1. Depending on the progress made by the Land-Use Group in development of AZ-SMART and ability to provide the necessary socio-economic and land-use data for the base and future years at a finer level of spatial resolution the MAG ABM will adopt the new system and adjust the corresponding network procedures and mode choice utilities to take full advantage of the available data.

2.3. Person-Type Segmentation

The MAG ABM system is implemented in a fully-disaggregate microsimulation framework. A key advantage of using the microsimulation approach is that there are essentially no computational constraints on the number of explanatory variables can be included in a model specification. However, even with this flexibility, the model system will include some segmentation of decision-makers. Segmentation is a way to characterize person roles within a household, and is a useful tool to structure models. For example, each person type segment can have its own model for certain choices. Note that segments can be created for households as well as persons. There is a variation in travel behavior within each segment due to variables like exact age, gender, exact income, education level, etc. However, the internal level of variation within each segment should be lower than the variation between the segments. In other words, the segmentation should encapsulate the most significant differences in travel behavior.

A total of eight segments of person-types, shown in **Table 2**, are used for the MAG model system. The person-types are mutually exclusive and collectively exhaustive with respect to age, work status, and school status. Every person modeled in the microsimulation process belongs to one and only one segment.

Table 2: Person Types

NUMBER	PERSON-TYPE	AGE	WORK STATUS	SCHOOL STATUS
1	Full-time worker	18+	Full-time*	None
2	Part-time worker	18+	Part-time	None
3	Non-working adult	18 – 64	Unemployed	None
4	Non-working senior	65+	Unemployed	None
5	College student	18+	Any	College +
6	Driving age student	16-17	Any	Pre-college
7	Non-driving student	6 – 15	None	Pre-college
8	Pre-school	0-5	None	None

*Full-time employment is defined as at least 30-35 hours/week depending on the definition used in the Household Travel Survey. Part-time is less than 30-35 hours/week but works on a regular basis. In the NHTS 2008 survey, full-time vs. part-time status was a direct question.

Further, workers can be stratified by their occupation, to take full advantage of information provided by the AZ-SMART land-use model. For example, in the current version of the SANDAG ABM, there are seven occupational categories, consistent with the PECAS land-use model for San-Diego. The categories are given in **Table 3**. These will be used to segment zonal terms for work location choice, based on the occupation of the worker.

Table 3: Occupation Types in the SANDAG ABM

NUMBER	DESCRIPTION
1	White collar labor
2	Work at home labor
3	Service labor
4	Health labor
5	Retail and food labor
6	Blue collar labor
7	Military labor

Segmentation of workers by occupation is a very welcome improvement for the workplace location choice model that is of crucial importance in the ABM model system chain. First, segmenting work flows by occupation allows for more behaviorally realistic structure where "right" people are sent to "right" places and not necessarily the closest jobs. In most of ABMs developed before the SANDAG ABM, segmentation by income groups was used in order to somewhat account for heterogeneity of labor force and jobs. In general, the higher is the income and more specialized is the occupation the longer is the average commuting distance. In order to support the segmentation of work flows by occupation both workers (in the population synthesis procedure) and jobs (as defined in the land-use model) should be segmented in a compatible way. This important model component should be finalized jointly with the MAG land-use group.

In the model estimation at Phase 1, the occupation categories included in the NHTS 2008 were used as shown in **Table 4** with their relation to the NAICS codes by which the zonal employment was provided. It should be mentioned that the categories used in the NHTS 2008 are not the best for travel modeling and they should be reconsidered in future.

Table 4: Occupation Types in the NHTS 2008

NHTS	DESCRIPTION	NAICS	DESCRIPTION
1	Sales or marketing	42	Wholesale Trade
		52	Finance and Insurance
2	Clerical administrative or retail	44	Retail Trade
		45	Retail Trade
		53	Real Estate and Rental and Leasing
		71	Arts, Entertainment, and Recreation
		72	Accommodation and Food Services
		92	Public Administration
3	Production, construction, manufacturing, or transport	11	Agriculture, Forestry, Fishing and Hunting
		21	Mining, Quarrying, and Oil and Gas Extraction
		22	Utilities
		23	Construction
		31	Manufacturing
		32	Manufacturing
		33	Manufacturing
		48	Transportation and Warehousing
		49	Transportation and Warehousing
4	Professional, managerial, or technical	51	Information
		54	Professional, Scientific, and Technical Services
		55	Management of Companies and Enterprises
		56	Administrative and Support and Waste Management and Remediation Services
		61	Educational Services
		62	Health Care and Social Assistance
5	Person care and services	81	Other Services (except Public Administration)

2.4. Household-Type Segmentation

The majority of household characteristics are derived from the characteristics of the household members. For example, such important household characteristics as number of workers, number of non-working adults, and number of children (altogether frequently referred to as household composition) are derived from the person-level attributes. However, there are several important attributes that related to the entire household and can be effectively used for a full or partial segmentation of the ABM sub-models.

Household-type segments are useful for pre-defining certain data items (such as destination choice size terms) so that these data items can be pre-calculated for each segment. Pre-calculation of these data items reduces model complexity and runtime. The household segmentation actually varies for any given model component, but to be complete the basic segmentation is presented here. The segmentation is based on household income as an important determinant of activities and travel behavior, and includes five segments, as shown in **Table 5**.

Table 5: Household Income Groups

TYPE	DESCRIPTION	HOUSEHOLD INCOME (2005 DOLLARS)
1	Very low income	$0-$25K
2	Low income	$25K-$50K
3	Medium income	$50K-$100K
4	High income	$100K - $150K
5	Very high income	$150K+

In addition to household segmentation by income group and after the household car-ownership model has been applied, household segmentation by relative car sufficiency is also applied in many models since car sufficiency has a strong impact on the mode preferences and derived accessibility measures used in almost all sub-models of ABM. Households are segmented by four car sufficiency groups: 1=zero cars, 2=low (cars fewer than workers), 3=balanced (cars equal to workers), 4=high (cars greater than workers) – as shown in **Table 6**.

Table 6: Household Groups by Car Sufficiency

Number of household workers	Number of household cars				
	0	**1**	**2**	**3**	**4+**
0	Zero	High	High	High	High
1	Zero	Balanced	High	High	High
2	Zero	Low	Balanced	High	High
3	Zero	Low	Low	Balanced	High
4+	Zero	Low	Low	Low	Balanced

2.5. Activity-Type Segmentation

Household Travel Surveys (and NHTS in particular) are characterized by more than 20 different activity codes. Modeling all 20 activity types would add significant complexity to estimating and implementing the model system and also the survey sample is too small to support such a level of details, so these detailed activity types are grouped into more aggregate activity types, based on the similarity of the activities. The activity types are used in most model system components, from developing daily activity patterns and to predicting tour and trip destinations and modes by purpose. The proposed set of activity types and associated trip purposes is shown in **Table 7**.

Table 7: Activity Types and Associated Trip Purposes

TYPE	PURPOSE	DESCRIPTION	CLASSIFICATION	ELIGIBILITY
1	Work	Working at regular workplace or work-related activities outside the home	Mandatory	Workers and students
2	University	College +	Mandatory	Age 18+
3	High School	Grades 9-12	Mandatory	Age 14-17
4	Grade School	Grades K-8	Mandatory	Age 5-13
5	Day care	All day care types	Mandatory	Age 0-4
6	Escorting	Pick-up/drop-off passengers (auto trips only).	Maintenance	Age 16+
7	Shopping	Shopping away from home.	Maintenance	Age 5+ (if joint travel, all persons)
8	Other Maintenance	Personal business/services, and medical appointments.	Maintenance	Age 5+ (if joint travel, all persons)
9	Social/Recreational	Recreation, sport, entertainment	Discretionary	Age 5+ (if joint travel, all persons)
10	Visiting relatives and friends	Visiting relatives and friends	Discretionary	Age 5+ (if joint travel, all persons)
11	Eat Out	Eating outside of home.	Discretionary	Age 5+ (if joint travel, all persons)
12	Other Discretionary	Volunteer work, religious activities.	Discretionary	Age 5+ (if joint travel, all persons)
13	Special event	Sport or cultural event	Discretionary	Age 5+ (if joint travel, all persons)
14	Trip to or from airport	Long-range travel by air	Special type	Age 5+ (if joint travel, all persons)

The activity types are also grouped according to whether the activity is mandatory, maintenance, or discretionary, and eligibility requirements are assigned determining which person-types can be used for generating each activity type. The classification scheme of each activity type reflects the relative importance or natural hierarchy of the activity, where work and school activities are typically the most inflexible in terms of generation, scheduling and location, whereas discretionary activities are typically the most flexible on each of these dimensions.

However, when generating and scheduling activities this hierarchy is not rigid and is informed by both activity type and activity duration.

Each out-of-home location that a person travels to in the simulation is assigned one of these activity types. In the MAG ABM, in addition to activities generated by the core demand models, several important activities, such as special events (as a special type of discretionary activity) and trips to and from airports are supply-driven and assigned to persons. Supply-driven activities have a predetermined location and are generated in a different way compared to demand-driven activities. In the subsequent sections we refer to activities as either demand-driven (generated by disaggregate core demand models) or supply-driven (generated by aggregate models and assigned to persons).

2.6. Level of Temporal Resolution

The proposed model system will function at a *temporal resolution of one-half hour*. These one-half hour increments begin with 3:00 AM and end with 2:59 AM the next day, though the hours between 1:00 AM and 4:59 AM will be aggregated to reduce computational burden. Temporal integrity is ensured so that no activities are scheduled with conflicting time windows (overlapping in time for the same individual), with the exception of short activities/tours that are completed within a one-half hour increment. For example, a person may have a very short tour that begins and ends within the 8:30 AM-8:59 AM period, as well as a second longer tour that begins within this time period, but ends later in the day.

Time periods are typically defined by their midpoint in both estimation (when the Travel Survey is processed) and application (when the demand model input and output are interpreted and coordinated with the network simulation software). For example, in a model system using one-half-hour temporal resolution, the 9:15 AM time period would capture activities or travel between 9:00 AM and 9:29 AM.

Tour-level time-of-day period combinations by outbound time interval (departure from home) and inbound interval (arrival back home) are summarized in **Table 8**. In this case, tour duration includes both time spent on participation in the activity and time spent on travel. A similar two-dimensional structure is applied for modeling time-of-day choice for work activity episodes where departure time is replaced with work activity start and arrival back home is replaced with activity end. In this case, duration includes the activity episode only.

Table 8: Tour-Level Time-of-Day Period Combinations

Tour-level TOD alternative	Departure from home (or activity start) time interval		Arrival back home (or activity end) time interval		Activity & travel duration average value	
1	1	3:00 AM-4:59 AM	1	3:00 AM-4:59 AM	0	0 min[1]
2	1	3:00 AM-4:59 AM	2	5:00 AM-5:29 AM	1	30 min
3	1	3:00 AM-4:59 AM	3	5:30 AM-5:59 AM	2	60 min
…	…	3:00 AM-4:59 AM	…	…	…	…
41	1	3:00 AM-4:59 AM	41	12:30 PM-12:59 PM	40	1,200 min
42	1	3:00 AM-4:59 AM	42	1:00 AM-2:59 AM	42	1,230 min
43	2	5:00 AM-5:29 AM	2	5:00 AM-5:29 AM	0	0 min
44	2	5:00 AM-5:29 AM	3	5:30 AM-5.59 AM	1	30 min
…	…	…	…	…	…	…
901	41	12:30 PM-12:59 PM	41	12:30 PM-12:59 PM	0	0 min
902	41	12:30 PM-12:59 PM	42	1:00 AM-2:59 AM	1	30 min
903	42	1:00 AM-2:59 AM	42	1:00 AM-2:59 AM	0	0 min[1]

[1]For open intervals like the first interval and last interval, average non-zero duration can be imputed for the inter-interval tours based on the observed durations in the Household Travel Survey.

By combining 42 departure intervals with 42 arrival intervals and taking into account that arrival interval must be later than or equal to the departure interval we arrive at 42×(42+1)/2=903 alternatives. A tour time-of-day choice model of this structure and level of resolution has been successfully estimated and applied in the San-Diego ABM.

A critical aspect of the model system is the relationship between the temporal resolution used for scheduling activities and the temporal resolution of the network simulation periods. Although each activity generated by the model system is identified with a start time and end time in one-half hour increments, level-of-service matrices are only created for several periods for which traffic and transit assignments are actually implemented. Thus, a certain aggregation of modeled trips by time-of-day periods has to be implemented. This limitation is purely technical and due to rapid advances in computer power and multiprocessing it will be lifted in the future in one of two possible ways: 1) Static simulations will be implemented for all half-hour periods separately, or 2) Dynamic Traffic Assignment will be applied for the entire regional network for a 24-hor period.

For the current Phase of MAG ABM development, six aggregate time periods – early AM, AM peak, early Midday, late Midday, PM peak, and night will definitely suffice. The trips occurring in each time period reference the appropriate transport network depending on their trip mode and the mid-point trip time. The definition of time periods for network simulations and level-of-service matrices is given in **Table 9** below.

Table 9: Time periods for Network Assignment and LOS Skimming

NUMBER	DESCRIPTION	BEGIN TIME	END TIME
1	Early	3:00 A.M.	5:59 A.M.
2	A.M. Peak	6:00 A.M.	8:59 A.M.
3	Early Midday	9:00 A.M.	11:59 A.M.
4	Late Midday	12:00 P.M.	3:29 P.M.
5	P.M. Peak	3:30 P.M.	6:59 P.M.
6	Evening	7:00 P.M.	2:59 A.M.

In terms of impact of the aggregation of network simulation periods on the ABM performance the sole limitation is that the LOS variables for each network simulation period will be shared across all half-hour intervals within the period.

Another important aspect that should be considered at the subsequent Phases of MAG ABM development is the level of temporal resolution for trips within the tour. The trip departure time model is simpler than the tour time-of-day choice model in a sense that it is one-dimensional with respect to time. It can be realistically implemented with a finer level of temporal resolution of 15, 10, or even 5 min since it is applied within the chosen tour window. This component becomes especially important if integration of ABM with Dynamic Traffic Assignment (DTA) is considered.

2.7. Trip Mode Classification

Travel modes are first specified at the elemental trip level and then tour modes are defined as possible and realistic combinations of those modes. The trip modes defined in the MAG models are listed in **Table 10**. There are 28 trip modes, including auto modes differentiated by three occupancy categories, toll/non-toll route type choice, and HOV lane choice; transit modes differentiated by five different transit line-haul modes and three access/egress sub-modes (walk, Park-and-Ride, and Kiss-and-Ride); non-motorized modes differentiated by walk and bike; and special modes that include school bus (for school trips only), taxi, and air (for intercity trips between Phoenix and Tucson).

Any trip for which the traveler used more than one mode is assigned a unique trip mode ID based on the rules reflected in the access / egress sub-modes for transit and special modes. Auto occupancy is not allowed to change within an elemental trip since each drop-off or pick-up of a passenger is consider as an activity (stop) that serves as a trip breakdown point.

Many of the modes listed in the table do not exist yet in the Phoenix region or only applicable for a certain limited travel market. In the MAG ABM application, mode availability switches will be applied to eliminate modes that are not relevant for the current model run. This will save computer run time since the network assignment and skimming procedures as well as mode utility calculations will only be implemented for relevant modes.

Table 10: Trip Modes

NO	MODE	MAIN MODE	OCCUP-ANCY	TOLL PAID	HOV LANE USED	ACCESS, EGRESS
1	Auto SOV (Non-Toll)	Auto	1	No	No	
2	Auto SOV (Toll)	Auto	1	Yes	No	
3	Auto 2 Person (Non-Toll, Non-HOV)	Auto	2	No	No	
4	Auto 2 Person (Non-Toll, HOV)	Auto	2	No	Yes	
5	Auto 2 Person (Toll, HOV)	Auto	2	Yes	Yes	
6	Auto 3+ Person (Non-Toll, Non-HOV)	Auto	3+	No	No	
7	Auto 3+ Person (Non-Toll, HOV)	Auto	3+	No	Yes	
8	Auto 3+ Person (Toll, HOV)	Auto	3+	Yes	Yes	
9	Walk-Local Bus	Local Bus				Walk
10	Walk-Express Bus	Express Bus				Walk
11	Walk-Bus Rapid Transit	BRT				Walk
12	Walk-Light Rail	LRT				Walk
13	Walk-Heavy Rail	Heavy Rail				Walk
14	PNR-Local Bus	Local Bus				Drive
15	PNR-Express Bus	Express Bus				Drive
16	PNR-Bus Rapid Transit	BRT				Drive
17	PNR-Light Rail	LRT				Drive
18	PNR-Heavy Rail	Heavy Rail				Drive
19	KNR-Local Bus	Local Bus				Passenger
20	KNR-Express Bus	Express Bus				Passenger
21	KNR-Bus Rapid Transit	BRT				Passenger
22	KNR-Light Rail	LRT				Passenger
23	KNR-Heavy Rail	Heavy Rail				Passenger
24	Walk	Walk				
25	Bike	Bike				
26	School Bus	School Bus				Any
27	Taxi	Taxi				Any auto
28	Air	Air				Any

2.8. General CT-RAMP System Design Modification Proposed for MAG ABM

The general design of the MAG CT-RAMP model is presented in **Figure 2** below. In general, it follows the main principles of CT-RAMP and includes all advanced components that have been included and tested in the previously developed ABMs of the CT-RAMP family in Columbus, OH, Atlanta, GA, San-Francisco Bay Area, CA, and San Diego, CA. However, the Phoenix version includes several innovations and improvements that are discussed in detail in subsequent sections. The following basic sequence of sub-models and associated travel choices is proposed:

1. *Population synthesis*. This procedure includes a new method for balancing of individual household weights in the zonal (TAZ) seed sample of households to match controlled household-level and person-level variables. It also includes household allocation to smaller spatial units within each TAZ. Another important improvement is an explicit accounting for university students living in dorms and apartments. Finally, the MAG population synthesis will address several important seasonal population segments such as seasonal residents, transient workers, and non-resident population living in hotels.

2. *Long-term models for mandatory activities*. These models include choices of usual location for each mandatory activity for each relevant household member (workplace/university/school) including work or school from home (home-schooled) as one of the alternatives. Additionally, for workers, usual work arrangements including regular frequency of commuting and telecommuting, regular schedule, and flexibility of schedule are modeled.

3. *Mid-term models for mobility attributes*. These models include household car ownership, free parking eligibility (determines whether workers pay to park if workplace is in a zone with parking cost), household transponder ownership for use of toll lanes, and person transit pass holding.

4. *Special generators of activities like special events and airports*. These models -provide aggregate forecasts of participants for each generator/venue by time-of-day, party size, and person type. The aggregate forecasts are further disaggregated by allocating attendance to synthetic households and persons. The integration of this model component with the core household activity models is an entirely new approach. It is recommended to better address a large number of special events in the Phoenix Metropolitan Region.

5. *Day-level models for activity participation, tour formation, and time allocation*:

    5.1. Coordinated daily activity-travel pattern type for each household member (main activity combination, at home versus on tour) with a linkage of choices across household members; this model also includes a binary indicator on fully joint tours for maintenance or discretionary purposes.

    5.2. Individual mandatory activities/tours for each household member (note that locations of most mandatory tours have already been determined in long-term choice model):

        5.2.1. Frequency of mandatory tours.

        5.2.2. Linkage of special activities and events to mandatory tours as stops.

        5.2.3. Mandatory activity time of day (start-end time combination).

5.2.4. Escorting children to school by school half-tours; this model either assign drop-off and pick up stops to work/university tours or allocates escorting tasks to household members. This is another innovative component that has not been yet included in previously developed ABMs.

5.3. Joint travel tours (conditional upon the available time window left for each person after the scheduling of mandatory activities)

5.3.1. Household joint tour frequency; for households with a joint tour indicator this model identified an exact tour frequency (1, 2) and purpose for each tour.

5.3.2. Travel party composition (adults, children, mixed) and person participation in each joint tour.

5.3.3. Primary destination for each joint tour.

5.3.4. Stop frequency for each joint tour.

5.4. Maintenance activities that are generated by the household and allocated as tasks to an individual for implementation:

5.4.1. Household frequency of maintenance tasks by purpose.

5.4.2. Maintenance task allocation to one person in household.

5.5. Individual discretionary activities (conditional upon the available time window left for each person after the scheduling of mandatory and joint non-mandatory activities):

5.5.1. Person frequency of discretionary activities.

5.6. Individual at-work sub-tours (conditional upon the available time window within the work activity duration):

5.6.1. Person frequency of at-work sub-tours

5.7. Individual tour formation that represents another principal improvement compared to the previously developed ABMs in practice:

5.7.1. Defining the most probable role for each activity in the tour structure (primary destination, outbound stop on work/university/school tour, inbound stop on work/university/school tour, outbound stop on maintenance tour, inbound stop on maintenance tour).

5.7.2. Tour frequency for each person.

5.7.3. Allocation of maintenance and discretionary activities to mandatory, maintenance, and discretionary tours.

6. *Tour-level models*. These models include choices of tour primary destination (for individual maintenance and discretionary tours), tour time-of-day (from departure from home to arrival back home), tour mode, frequency of additional stops not generated as main activities (so-called "stops on the way") by purpose, location of all stops, and their sequence of implementation by half-tours.

7. *Trip-level models*. These models include choices of trip mode conditional upon the tour mode, trip departure time within the half-tour tour window, parking location choice for auto trips, and transit station choice for P&R trips (and K&R trips if necessary to separate them).

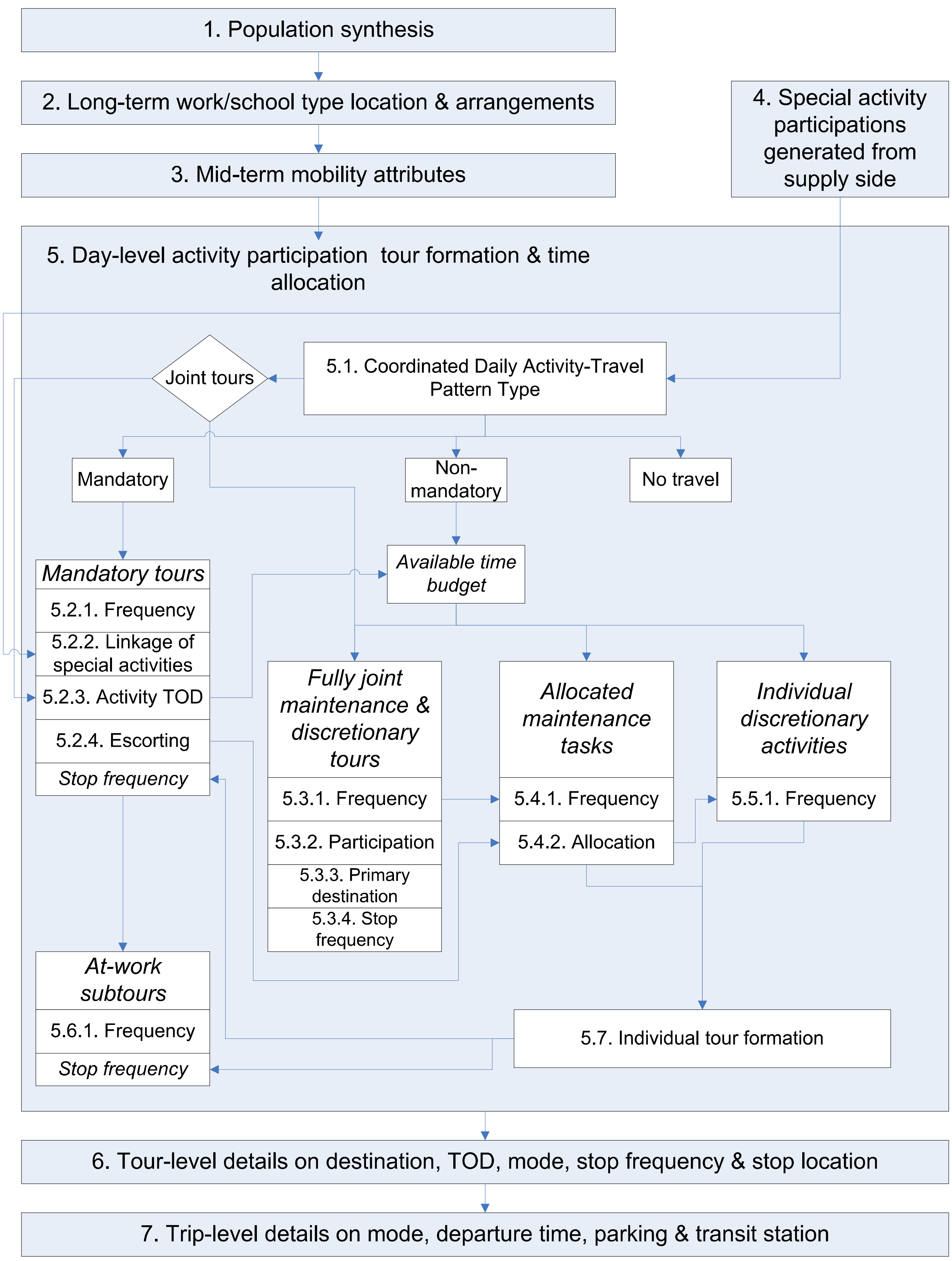

Figure 2: Basic Model Design and Linkage between Sub-Models

3. Description of Special and Seasonal Markets in Phoenix Region

Travel in the Phoenix metropolitan region is somewhat more seasonal than other similarly-sized areas, due to the presence of special travel markets. This section describes these markets in the context of activity-based modeling, and implications for data collection. In the next section, the corresponding model formulations are discussed.

3.1. University-Related Travel

Description of the Market

Arizona State University is the largest public higher-education learning center in the United States, with more than 62,000 students across four campuses in the Phoenix Metropolitan Area. The campus locations include:

- The main Tempe Campus, with approximately 50,000 students enrolled;
- The West Campus, northwest of downtown in Glendale, with approximately 9,000 enrolled students;
- The Polytechnic Campus, located southeast of Tempe in the East Valley, with approximately 8,000 enrolled students; and,
- The Downtown Campus, located in downtown Phoenix, with approximately 8,000 students enrolled.

Some students are counted at more than one campus (for example, both Tempe and Downtown); thus the campus enrollment does not add up to the total enrollment. Approximately 50,000 students are undergraduates and the remainder (12,000) are graduate students. Approximately 48,000 students attend full-time. Additionally, ASU employs approximately 12,000 staff, including approximately 3,000 instructional staff, across all four campuses. The figures cited above are from ASU Quick Facts, University Office of Institutional Analysis, published March 9, 2009. According to the ASU Common Data Set for 2008-09, 86% of students lived off-campus.

The Phoenix region contained approximately 4 million persons in 2008 according to the MAG Municipality Population And Housing Unit Update, so ASU accounts for almost 2% of total regional population (students plus workers), and has significant local effects (particularly around Tempe), 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 (approximately 9 months). While school is in summer recess, LRT ridership is significantly reduced, and activity in the Tempe area is generally lighter than when school is in session.

The University of Arizona is located in Tucson. It has a total enrollment of approximately 38,000 students, (36,000 full-time equivalents) and approximately 12,000 staff. Approximately 7,000 students are graduate students or medical students. According to the University of Arizona Common Data Set for 2008-09, 80% of students lived off-campus. As of July 2008, the Pima Association of Governments estimates the population of the Tucson metropolitan area to be approximately 1 million, so the University of Arizona (students plus staff) accounts for approximately 5 percent of the total regional population. The University is located just east of downtown Tucson, with a large University Medical Center located northeast of campus. The Regional Transit Agency for the Tucson region is currently seeking FTA approval for a streetcar project which would link the Medical Center and University to downtown.

Data Needs

The current MAG trip-based models were recently enhanced to explicitly model trips made by students to and from campus locations. The model was based on an on-line student and employee travel survey conducted by ASU in 2007. This survey was limited to trips made to and from campus by faculty and students, and had a total of 3,800 respondents, of which approximately 2,000 were students. The destination choice model component captures inter-campus trips explicitly, and the mode choice model explicitly considers inter-campus shuttle. However, the model does not cover trips made by students between non-campus destinations, such as non-campus related work travel or recreational trips in the evenings. All work and other non-student travel to/from campus is covered by the standard trip purpose models (Home-Based Work, Home-Based Other, and Non-Home-Based). Note that students living in group quarters (e.g. dormitories) generate trips similar to other single-person households in the current model system, which is likely to underestimate the social/recreational travel made by students.

In order to fully capture all travel made by students, a more complete student activity diary would be necessary, with a full day of travel data captured for each respondent. The sample size obtained from the last survey would be appropriate for this survey as well. It might be useful to instrument respondents with a wearable GPS logger for this survey, to provide more detailed locational data that can be used to explicitly track student travel around campus. A web-enabled survey option might be pursued for this survey as well, given that all students have internet access and are likely to be technically proficient.

The Trip Reduction Survey database is a thorough dataset, and may be useful for ASU modeling (all students/staff were surveyed).

3.2. Non-Resident Visitor Travel

Non-Resident Travel Markets

According to the 1995 Special Census for metropolitan Phoenix, approximately 6% of homes in the Phoenix metropolitan region were owned by seasonal residents. Seasonal population is defined as living more than 2 weeks but less than 6 months a year. The seasonal population tends to be heavily concentrated in the Scottsdale area, as shown on the map in **Figure 3** below.

In 2000, the average seasonal population in Maricopa County was 105,000 (ASU study). This ranges between 58,000 (summer) and 152,000 (winter). According to another study conducted by researchers at Arizona State University in 2004, 84,000 winter residents lived in Phoenix area mobile homes, RVs, and trailer parks. It is very likely that this share increased over the years leading to the downtown in the housing market in 2008, as Phoenix was one of the hardest-hit metropolitan areas, due in large part to the high share of second mortgages held.

According to the 2007 MAG land-use data file, there were 145,290 seasonal residents in the Phoenix region, representing 3.3% of total population. That estimate was prepared based on the 1995 Special Census data. The number reported in the socioeconomic input file is the average of the peak and low seasons.

In addition to travel by seasonal non-residents, the Phoenix region has many hotels, motels, and resorts, whose occupancy is also highly seasonal. According to the Phoenix Convention and Visitor's Bureau, there are approximately 500 hotels/motels with a total of approximately 57,000 hotel and motel rooms in the Phoenix region. The season high number of visitors is in the winter and spring months. According to the Convention and Visitor's Bureau, the Phoenix region draws approximately 13 to 15 million leisure travelers annually. The top attractions in the greater Phoenix region include:

- Tempe Town Lake
- Chase Field
- South Mountain Park and Preserve
- US Airways Center
- Arizona Temple and Visitors' Center

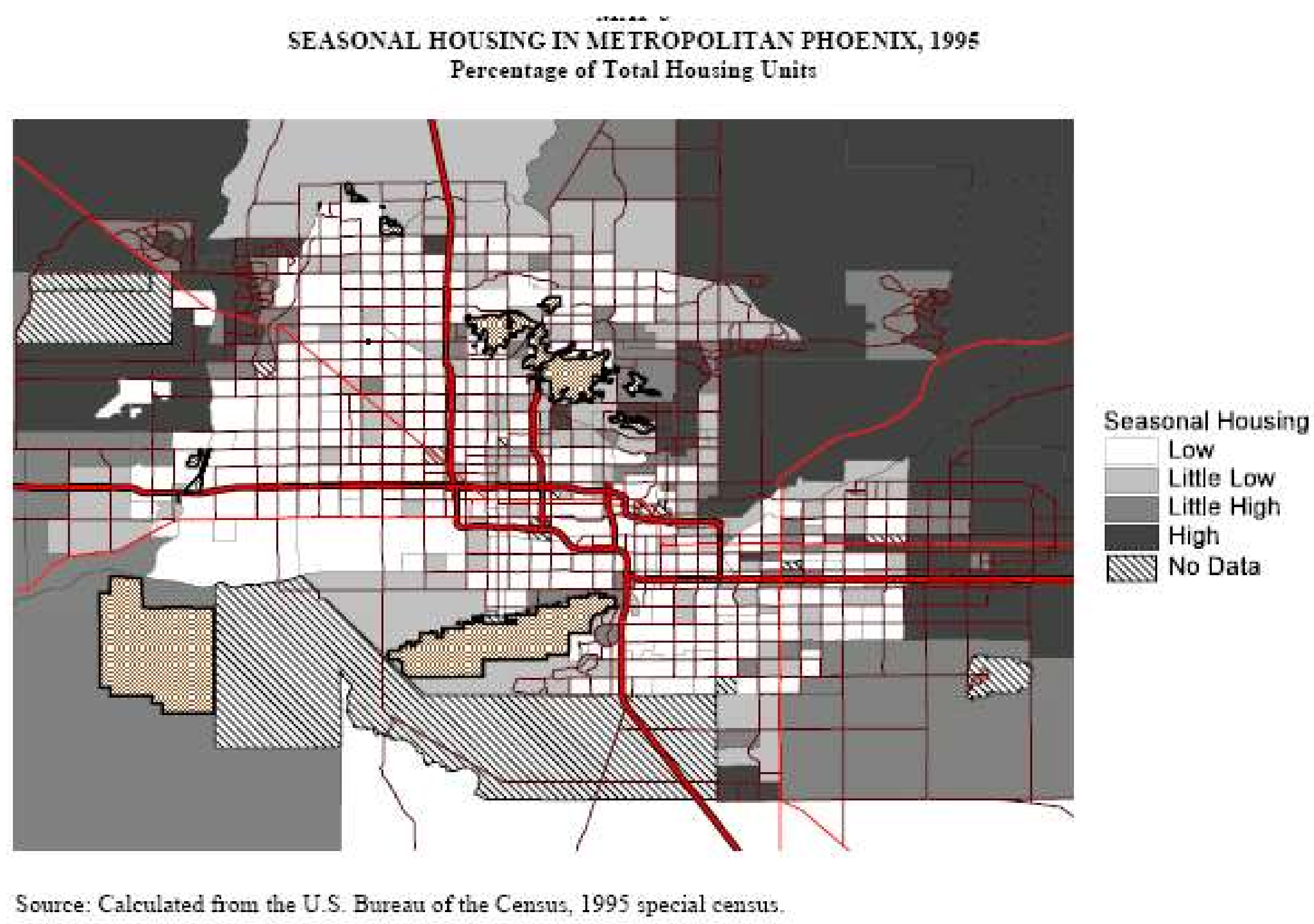

Figure 3: Seasonal Housing

Source: Rex, Tom R., Housing In Metropolitan Phoenix, Prepared for the Morrison Institute for Public Policy, School of Public Affairs, College of Public Programs, Arizona State University, August 2000.

Other noteworthy attractions include the Heard Museum, Desert Botanical Garden, Heritage and Science Park, and the Phoenix Zoo. Phoenix attracts large numbers of visitors during the Spring Training baseball season (mid February-early April), and is also the gateway to the Grand Canyon.

The current MAG models do not represent visitor travel explicitly. An airport ground access special generator model was recently updated to incorporate recent air passenger data, but the form of the model was left unchanged from the previous version, in which resident and visitor travel are undifferentiated. Presumably household occupancy factors account for seasonal residents, and are adjusted to represent 'average' fall occupancies. Hotel/motel/resort travel is not explicitly modeled and non-home-based model trip rates have been adjusted to capture their travel impacts.

Data Needs

The Sky Harbor ground access survey is a useful dataset for understanding visitor characteristics to the Phoenix region. However, there are some enhancements that could be made to the survey to better capture data suitable for model development, including a detailed geo-coding of trip origin (such data can be geo-coded in real-time using tablet-PC or laptop-based survey technology) and collection of more detailed socio-economic information.

There are three core data sets required for adequately representing non-resident travel:

1. A current count of seasonally occupied housing units by geography. Current MAG socio-economic data files include seasonal population and households, but the data is based on dated estimates. An extensive internet search did not reveal any available recent data other than that described above. MAG socio-economic forecasting group is analyzing utility data in an attempt to update these estimates for use in the AZ-SMART model.

2. An inventory of hotel/motel/resort rooms and other temporary housing for non-resident visitors to the Phoenix region, and their location. Seasonal occupancy rates, classification of room type by luxury and economy, and other characteristics would be useful in travel demand model development. The MAG socio-economic forecasting group currently maintains an estimate of hotel/motel rooms with address/XY precision, but it is not currently utilized in transport modeling.

3. A survey of visitor travel, with a full diary of activity-based travel data, and other key traveler characteristics. Such data would provide the foundation upon which to build activity patterns for visitors and model their travel decisions in a behaviorally-rich way and comparable to the models applied for the core resident population.

3.3. Special Events

Main Markets

Special Event travel contributes to the benefits that transit projects and other transport infrastructure provide and has been found to be a significant share of existing LRT ridership. Note that Phoenix is one of only six U.S. cities with eight professional sports franchises: Phoenix Suns (NBA), Arizona Diamondbacks (MLB), Arizona Cardinals (NFL), Phoenix Coyotes (NHL), Phoenix Mercury (WNBA), Arizona Rattlers (AFL), Arizona Sting (NLL) and Phoenix Roadrunners (ECHL).

Parsons Brinckerhoff originally developed a Special Events Model (SEM) for forecasting rail ridership in Phoenix, Arizona in 1999. As part of this effort, a survey was conducted that targeted persons attending special events in the Phoenix rail corridor in the summer of 1999, and gathered information about their trip to the event, including baseball and basketball games, as well as cultural events such as theatre, opera, and museum exhibits. Currently, Cambridge

Systematics (CS) is conducting a new Special Event survey in the Phoenix region, and developing a Special Event model based on the data collected.

Data Needs

The survey conducted by CS should be sufficient for model development. This survey was designed such that tour information (ultimate origin and destination for tour in which event is one stop) was collected.

3.4. Airports

Air Passenger Market

There are two airports with commercial air service in the Phoenix region. Phoenix Sky Harbor is the largest airport, with more than 100,000 passengers arriving and departing daily on over 1,200 aircraft. At almost 40 million enplanements in 2008, it is the eight-largest airport in the United States. There are more than 30,000 parking spaces at Sky Harbor, which is a hub for US Airways, US Airways Express, and Southwest Airlines. Sky Harbor consists of four terminals. There is a light-rail transit stop close to the airport (at 44th and Washington), with connections to the airport from LRT currently provided by shuttle bus. An airport people-mover system is currently being constructed in two phases. The first phase, currently under construction and due to open in 2013, will connect the light-rail transit station with the airport economy parking lot and terminal 4 (the busiest terminal served by US Airways and Southwest). The second phase of the people-mover would extend it to terminal 1 and the rental car center. It is currently unfunded, but plans are to complete it by 2020.

Phoenix-Mesa Gateway is a small airport with commercial services provided by only one airline, Allegiant Air. There were approximately 178,000 annual enplanements at Phoenix-Mesa Gateway in 2007, although the airport projects a twelve-fold increase in enplanements by 2027 (Phoenix-Mesa Gateway Airport Master Plan Executive Summary).

Tucson International Airport is served by eight major airlines and had approximately 4.2 million passenger arrivals/departures in 2008. There are approximately 7,600 parking spaces total available at the airport, with approximately 74 percent of those in an economy lot. Note that US Airways currently offers 11 flights daily to Phoenix from Tucson.

Data Needs

Sky Harbor conducted a passenger survey in 2005, which collected data on approximately 3,800 trips to the airport made by departing passengers. The data included purpose and mode, but no socio-economic data was collected and only the zip code of origin location was collected. This data was used to revise the trip rates and create calibration target values for the existing aggregate trip-based model for airport ground access. However, a more thorough survey would be useful for adequately modeling travel to/from the airport, which includes socio-economic data and address.

There may be survey data at Phoenix-Mesa Gateway Airport and Tucson International Airport that the author is not aware of. Efforts should be made to identify available data and determine its usefulness for modeling travel to these airports. Phoenix-Mesa Gateway Airport is treated as a special generator in the MAG travel demand models. The author is not aware of a special model for Tucson International Airport in the Pima Association of Governments (PAG) trip-based travel demand modeling system.

3.5. Other Secondary Markets

There may be a number of secondary markets whose travel is important to consider given the seasonality of impacts on transport demand. They are listed below.

Residents on Vacation

In the hot summer months, many Phoenicians take vacations. This adds to the seasonal low in transport demand in the summer. A seasonal 'vacation' rate should be estimated for residents, and applied to the synthetic population (possibly by income group), in essence removing households from the population who are away on vacation during the simulation period. The number of enplanements which forms the basis for airport travel should also be seasonally adjusted.

Transient Population

The Phoenix region has a large transient population, including agricultural and construction workers whose jobs are seasonal and/or temporary (less than 2 weeks per year). According to the MAG 2007 socio-economic data file, there were approximately 164,000 transients (3.7 percent of total population) living in the Phoenix region, in almost 100,000 households.

Transient population is also seasonal in nature having a peak in winter. For example, in 2005, MAG estimated average daily transient population as 154,000. This ranged between 116,000 (summer) to 190,000 (winter). According to the 2008 Arizona visitors report, the 2008 number for visitors is between 150,000 and 190,000.

Retirement Communities

The Phoenix metropolitan region is home to numerous retirement communities, whose inhabitants are 55 years or age or older. Sun City was the first planned retirement community in the United States, and has approximately 40,000 residents. There are many other deed-restricted communities. The MAG socio-economic forecasting group maintains a database of those communities. This information should be used in modeling to control persons by age, to ensure that the synthetic population accurately represents retired persons.

The retirement communities do not represent a special or seasonal market per se. The behavior of households and persons living in these communities should be captured by the core household / person behavioral models that is sensitive to person age and entire-household life cycle as well as travel environment and accessibility of different attractions.

4. Socio-Economic and Land-Use Inputs for ABM

4.1. State of Socio-Economic and Land-Use Forecasting at MAG

There are currently two different sets of tools used by MAG for land-use forecasts for the Phoenix region. The tools used to create the last series of land-use forecasts (Series 2007) include county-wide forecasts of population and employment prepared by the State of Arizona, a DRAM (Disaggregate Residential Allocation Model)/EMPAL (Employment Allocation Model) model, and SAM (Subarea Allocation Model) which is used to distribute population and employment from Regional Analysis Zones (RAZs) to one-acre grids. The forecasts at the one-acre grid level are then aggregated to Transportation Analysis Zones (TAZs). This process was used to create the 2007-series forecasts for 2005, 2010, 2020, and 2035. Intermediate years are available and were created using straight interpolation between forecasted years.

AZ-SMART is the new land-use forecasting tool currently under development at MAG. This model utilizes UrbanSim in place of DRAM/EMPAL and SAM. This model resulted in numerous improvements in UrbanSim, particularly in the user interface and database design, that are included in the current publically-available version. AZ-SMART has the capability of controlling to sub-regional geographies and incorporates the best features of SAM and UrbanSim. The model is being implemented in three versions:

1) The first version of AZ-SMART operated at the polygon level, and only considers total households and total employment. The model was a proof-of-concept and led to the identification of a number of improvements/changes in UrbanSim. A number of improvements were made in-house at MAG.

2) The second version of AZ-SMART operates at the parcel level, but only for three cities in the Phoenix region (Gilbert, Chandler, and Queen Creek). This version has 3 categories of households (by income) and 12 categories of jobs (by NAICS category). The version is up and running, and is being tested in various ways over the next few months.

3) The third version of AZ-SMART will operate at the parcel level for Maricopa County. The exact number of household categories in model is currently undefined and in principle can be adjusted to provide the necessary input to ABM. A key difference between this version and version 2 is that the third version would have an explicit Business Location Choice model (as opposed to employment location choice). Another feature of the model will be the ability to specify different controls at different levels of geography.

MAG has been constructing various parcel-level databases, including built space by land-use type on each parcel (using tax assessor data), for use in the second and third versions of AZ-SMART. Employment data in the model is based on a variety of sources, including Dunn & Bradstreet, Harris Info Source, the Maricopa Trip Reduction Database (which includes all employers with 50 or more employees annually) and public employment data from member agencies. All data is coded at the address level and then allocated to parcels. A residential database is also being constructed at the address level. A hotel/motel inventory is available. The model will be calibrated over the next two years with 2005 base data. New data collection activities are planned for 2010, to coincide with the 2010 census. Once this data becomes available, it will be incorporated into the AZ-SMART model, in order to produce a new series of forecasts in 2012.

4.2. Assessment of Data Needs for Core ABM Development and Application

In general, the existing MAG practices in socio-economic and land-use forecasting are adequate to support development of a very advanced ABM. Future AZ-SMART modifications offer even a better perspective to coordinate the structure of MAG ABM with AZ-SMART and take a full advantage of the rich set of variables generated by AZ-SMART. Table 11 summarizes data that may be produced by MAG socio-economic models. There are three classifications of data:

- *Needed* refers to data that is required from the current version of AZ-SMART. These data items represent essential inputs to ABM.
- *May add with additional research* refers to data that may be added depending on additional research, and availability and quality of the data. These data items can be incorporated in the ABM but are not essential
- *Can add If needed* refers to data that isn't likely to be required from AZ-SMART but would potentially be added if it was required for transport modeling.

Table 11: MAG Socio-Economic Modeling Needs

Category	Households/group of persons	Persons	Jobs (work location)	Business	Other Data
Needed	Number of persons (size): 1,2,3,4,5+	Age	NAICS sector		School / College / ASU enrollment
	Number of workers: 0,1,2,3+	Gender	Occupation (7 categories)		
	Housing type (single-family/detached vs. multi-family/apartment)	Work status	Wage classification		
	Income classification*				
	Race/Ethnicity (Minority indicator)**				
May Add with Additional Research	Neighborhood type classification (turnover in neighborhoods)	Worker details - shift work/part-time/multiple jobs	Business/Firm	Number of workers	
	Wealth indicator (for retirees)	Occupation	Non-location specific job indicator	Primary NAICS	
	Number of seasonal groups	Income classification		Business classification - multiple shifts/ non-location specific	
	Number of transient groups	Educational Level		Shift work indicator	
	Number of special population groups	Seasonal flag		Number of workers in one shift	
		Transient flag			
		Average length of stay if seasonal/ transient			
		Group quarter flag***			
		Group quarter type***			
		Primary work location			

Category	Households/group of persons	Persons	Jobs (work location)	Business	Other Data
Can Add If Needed	Auto ownership	Primary activity – work / school / at-home			Commercial enplanements
	Age of head of household				

*It is important to operate with absolute household income thresholds (for example, 0-30K, 30-60K, 60-100K, 100K+) rather than quintiles or quartiles in order to take into account income growth over years that affects travel behavior significantly. If households are categorized by percentage-based categories that are held constant into the future, the important overall trend will be lost.
**Projected at County level, may not be available by TAZ.
***Portion may be included in the special population groups.

In general these socio-economic and land-use variables provides almost all desired inputs the MAG ABM, and the population synthesis procedure in particular. When compared to the other ABMs developed elsewhere there only one household variable currently missing that is useful – dwelling type. Even in the most simplified way of a binary categorization (detached house vs. apartment) it can improve the population synthesis procedure. This variable will be discussed with the MAG Land-Use group.

All household and person variables used in the population synthesis form so-called aggregate controls, that is values that has to be matched for each TAZ. The population procedure can be fully specified when these controls are specified as a set of marginal one-dimensional distributions, for example household distribution by size or person distribution by age brackets. However, if AZ-SMART can generate a joint distribution of households or persons by several dimensions, for example a joint household distribution by size and number of workers, the population synthesis procedure would take an advantage of a more structural control.

In **Table 12** below is a summary of variables included in the socio-economic file provided as input to the existing MAG 4-step model in the currently adopted format for 2007. In the table, the variables are classified by their role in ABM.

Table 12: Format for Socio-Economic Input File

Item No.	Variable (field)	Role in ABM
1	Year	Model scenario
2	TAZ2003 (TAZ field in TAZi03.shp)	Key index
3	RAZ2003	Key index
4	MPA2003	Key index
5	Resident Population in Households	Population Synthesis – permanent component
6	Resident Population in Group Quarters (excluding institutional facilities, military and correctional facilities)	Population Synthesis – permanent component
7	Transient Population	Population Synthesis – seasonal component
8	Seasonal Population	Population Synthesis – seasonal component
9	Resident Households (Occupied Dwelling Units)	Population Synthesis – permanent component
10	Group Quarters Households (excluding nursing homes, military and prisons)	Population Synthesis – permanent component
11	Transient Households	Population Synthesis – seasonal component
12	Seasonal Households	Population Synthesis – seasonal component
13	Other Employment (excluding Work-at-home and Construction employment)	Workplace location and destination choice
14	Public Employment	Workplace location and destination choice
15	Retail Employment	Workplace location and destination choice
16	Office Employment	Workplace location and destination choice
17	Industrial Employment	Workplace location and destination choice
18	Households in lowest income quintile (Q1)	Population Synthesis – permanent component
19	Households in low income quintile (Q2)	Population Synthesis – permanent component
20	Households in medium income quintile (Q3)	Population Synthesis – permanent component
21	Households in high income quintile (Q4)	Population Synthesis – permanent component
22	Households in highest income quintile (Q5)	Population Synthesis – permanent component
23	Total Area (sq miles)	For calculation of density measures
24	Office Area (sq miles)	Currently not used
25	Post High School Enrollment excluding Arizona State University campuses	School location, destination choice
26	Retirement Zone Flag	Population Synthesis – permanent component
27	Originations (Sky Harbor and Williams Gateway Airport)	Generator of trips to and from airport

Item No.	Variable (field)	Role in ABM
28	Dwelling Units <10 Years Old	Currently not used
29	Dwelling Units 10-19 Years Old	Currently not used
30	Dwelling Units 20-29 Years Old	Currently not used
31	Dwelling Units 30+ Years Old	Currently not used
32	Single-family households	Population Synthesis – permanent component
33	Multi-family households	Population Synthesis – permanent component
34	Population in correctional facilities	Population Synthesis – permanent component
35	Population in institutional facilities	Population Synthesis – permanent component
36	Population in military group quarters	Population Synthesis – permanent component
37	Work-at-home employment	Workplace location type model
38	Construction employment	Workplace location type model
39	Public Employment on Office land use	Destination choice model
40	Public Employment on Public land use	Destination choice model
41	Area for Public Employment on Office land use (sq. miles)	Destination choice model
42	Enrollment in Arizona State University campuses	School location choice, synthesis of student population

In the zonal employment definition and classification it is important to distinguish between physically located job units and formal registration. In the current employment data there are some cases where there are a large number of jobs (100+) reported at a residential location; for example, a trucking dispatcher whose employees never report to work at the residence, or a landscaping company run out of a house. These types of jobs should be 'set aside' from a modeling perspective, so that work tours won't be attracted to the reported residential headquarters, and their work-related travel should be addressed via a separate model.

4.3. Potential Advanced Schemes for Population and Labor Force Generation

There are multiple additional aspects of data needs to support the advanced MAG ABM. These aspects relate to a more consistent generation of person attributes such as work and schooling arrangements that have a crucial impact on activity and travel choices. These attributes can be either generated by the land-use model or internalized as part of the population synthesis procedure (as was the case with the SCAG ABM). The attributes of primary importance for the ABM can be listed in the following approximate order of conditional generation:

- Labor participation (employed or not) and schooling status (study or not),
- If employed:
    - Number of jobs (1 or 2+),
    - Employment industry / occupation,
    - Work commitment:
        - Part-time or full-time,
        - Usual number of workdays per week,
        - Usual telecommuting frequency,
    - Usual workplace location:
        - Workplace type (home, out-of-home fixed, out-of-home variable),
        - Location (zone) if out-of-home,
    - Usual work schedule:
        - Usual start and end time,
        - Schedule flexibility (fixed, somewhat flexibly, fully/very flexible),
    - Person earnings (as part of the household income),
- If study:
    - Schooling from home (yes or no),
    - If no, school location.

There are multiple approaches to generation of these important variables. In most ABMs in practice, these variables are either generated as uncontrolled attributes in the population synthesis procedure. This means that these variables are used in the ABM to explain activity & travel choices but cannot be subject to any policy or long-term trend. Some of these attributes, like telecommuting frequency or person earnings are normally omitted since it is difficult to reliably produce them even as an uncontrolled variable in the population synthesis. Another, and more advanced approach is to formulate explicit choice models for them (the SCAG ABM approach) and then employ parameters of these choice model to express policies and/or long-term trends. Finally, these attributes can be generated by an advanced land-use model but it may require addition of the corresponding components to the land-use model (AZ-SMART). It is recommended to make the final decision regarding these attributes at the beginning of Phase 2 and jointly with the MAG Land-Use group.

5. Advanced Sub-Models and Unique Features of the MAG ABM

5.1. Explicit Modeling of Seasonal Variations in Travel Demand

We propose to explicitly model major factors of seasonality. The ABM will have a switch that would allow for implementation of either a season-specific weekday run or general run that corresponds to an average weekday. This feature is unique compared to other regional travel models (including ABMs and 4-step models). The main seasonal factors are summarized in **Table 13**.

Table 13: Summary of Seasonal Factors

Factor / population / travel segment	Seasons			
	Summer	**Winter**	**Fall**	**Spring**
Universities (students and workers)	Recess			
Seasonal residents		Peak	Low	Low
Visitors for recreation staying in hotels	Low	Peak	Low	Low
Special events (sport and others)	Low	Peak	Low	Peak
Residents on vacations	Peak	Low	Low	Low
Transient population (seasonal workers in agriculture and construction)	Low peak	High peak	Low	Low

From this data on seasonal profiles of these main factors it can be concluded that each of the four seasons has certain specifics and the model switch will have five possible states: 1=summer, 2=winter, 3=spring, 4=fall, 5=average.

5.2. Special Markets

Special travel markets correspond to either special population segment and/or special activity generators. These special markets will be modeled explicitly since they have unique seasonal characteristics that cannot be fully captured by the core model of resident household travel behavior. The proposed MAG ABM design ensures that there is no double-counting of travel associated with these markets, and along with the core model they provide a complete and consistent picture of regional travel on a given weekday. The main special markets are summarized in **Table 14** below.

Table 14: Special Travel Markets

Population segment	Season associated with population segment	Activity generator and season associated with activity					
		1=Universities	2=General work (jobs other than universities)	3=General non-work	4=Special events	5=Airports (long-distance travel)	6=Agriculture or construction areas (jobs)
		Summer recess			Winter & spring spikes; summer recess		Winter higher peak; summer lower pick
1=Students in households		Core model (to and from university and between campuses)					
2=Students in rent apt		2.1 (to and from university and between campuses)					
3=Students in dorms		3.1 (to and from university and between campuses)					
4=Workers in university		Core model					
5=Seasonal residents ("winter birds")	Winter spike		Retired people and non-workers w/no special impact	5.3	5.4	5.5 (non-business travel)	
6=Visitors for business staying in hotels			6.2 (offices and other attractors)	6.3	6.4 (may attend)	6.5 (business travel)	
7=Visitors for recreation staying in hotels	Winter & spring spikes			7.3	7.4	7.5 (non business travel)	
8=Residents taking vacations	Summer peak		Core model (lower activity participation)	Core model (lower activity participation)	8.4 (lower activity participation)	8.5 (higher level for non-business travel)	
9=Residents not on vacations	Summer recess		Core model	Core model	9.4	9.5 (lower level for non-business travel)	
10=Transient population (seasonal workers)	Winter higher peak; summer lower peak			10.3 (low activity participation)	10. 4 (low activity participation)		10.6

The population segments defined in rows 1-10 are further discussed with regard to the population synthesis procedure. The activity generation specifics defined in columns 1-6 are taken into account when activity patterns are generated for each particular population segment and season.

In general, this table gives a wide list of possible special sub-models that correspond to a certain specific population group and/or specific activity type. For example, cell 5.3 refers to seasonal residents implementing general non-work activities. This cell like any other cell has to be addressed in the ABM structure. There are three general options to do that. The first option is to consider a special sub-model for this cell that is justified if the corresponding travel demand is significant and very different from any other cell. It is clear that only a few cells may justify this approach. Cell 5.3 quite probably will not qualify for a special sub-model although one can speculate that seasonal residents might have certain specifics with regard to general non-work activities that would make them different from the core household population. The second option that is more realistic is to consider entire row 5 (seasonal population) as a special population segment for which a separate set of activity-travel models should be developed (including general non-work activities). This approach, however, would require a comparatively large sub-sample of seasonal residents to be observed and singled out in the HTS that is not the case with the current NHTS 2008. The third option that looks the most practical at this point is to consider entire column 3 as the segment for modeling. This means that the behavior of seasonal residents with respect to general non-work activities and travel will modeled by a sub-model of ABM that is developed for the core household population (pooled together with the seasonal population for this purpose). It does not mean that the unique features of seasonal population will be completely ignored. Many of them would manifest themselves through such explanatory variables as person age (seasonal population is characterized by a large share of seniors), employment status (majority of seasonal population is non-workers), household composition (majority of seasonal population represents 1-2 person households without children), etc.

For several segments, recommendation for the model structure and segmentation can be made already at Phase 1. Some of the resulted sub-models are discussed in subsequent sections below and included in the Phase 1 estimation report. This relates to such population segments as university students (rows 2-3) and major universities as corresponding activity generators (row 1). Another example of a strategic decision made for the MAG ABM is the treatment of Special Events (column 4) not as a separate market (that is the prevailing practice) but rather as a special activity integrated within the daily activity-travel patterns of all population groups.

Some other components can only be finalized at Phase 2 since in many respects the decision is based on statistical analysis and availability of special surveys or other complementary data.

5.3. Implications for Population Synthesis

Population Synthesis Specifics for ASU

The existing practice of modeling university students in most travel demand models suffers from a principal drawback: students by place of residence are generated independently of the university enrollment projections. As a result, the model fails to recognize that each major university induces a large special population of students living in dorms and apartments in the vicinity of the campus. This drawback is especially apparent when a new university or significant growth of an existing university is projected. In the MAG ABM we propose a method that addresses this issue.

It is important to model the residential location for Arizona State University students as a function of distance/accessibility to campus – taking into account the primary campus that the student is enrolled in. First, the proportion of students living on the campus in dorms has to be assessed. The remaining off-campus synthetic student population would be generated explicitly by choice between living in a apartment or in a residential household in a certain TAZ given the 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 mandatory school location choice model for ASU students, which would ensure that their school tour primary destination is an ASU campus.

Arizona State University faculty and staff can be adequately represented within the CT-RAMP framework person-type categories (full time worker/part-time worker) generated by the core population synthesis procedure.

Population Synthesis Specifics for Seasonal Population

The following four specific seasonal population markets will be addressed in addition to the core permanent residential population:

- Seasonal residents (“snow birds”),
- Visitors staying in hotels for business purposes,
- Visitors staying in hotels for recreational purposes,
- Transient population of seasonal workers in construction and agriculture sectors.

Suggested Population Synthesis Procedure

Methods for synthesis of the different population segments are summarized in **Table 15** and **Figure 4** below where they are also related to usual workplace and school location choice.

Table 15: Methods to Synthesize Different Populations Segments

Population segment	Controlled input variables	Method	Predetermined travel components
1=Off-campus students in family households		PopSyn for core resident population with a person-level constraint on number of students generated by the residential choice model	Usual school location (university campus)
2=Off-campus students in apartments and homes	Total off-campus students for each university campus; zonal stock of available apartments	Residential choice model (including non-family household size choice)	Usual school location (university campus)
3=Students in dorms	Total on-campus students for each university campus	Direct (each student is 1-person household)	Usual school location (university campus)
4=Workers in university		PopSyn for core resident population	
5=Seasonal residents ("snow birds")	Dwelling units / households by season (from AZ-Smart)		Trips to and from airport for certain seasons (w/different probability than permanent residents if statistically significant)
6=Visitors for business staying in hotels	Hotel rooms and occupancy rates by month, distribution of visitors by duration of stay in days		Trips to and from airport (w/high probability)
7=Visitors for recreation staying in hotels	Hotel rooms and occupancy rates by month, distribution of visitors by duration of stay in days and party size (from AZ-Smart)		Trips to and from airport (w/high probability)
8=Residents taking vacations		PopSyn for core resident population	Trips to and from airport (w/different probability than residents not taking vacations)
9=Residents not on vacations		PopSyn for core resident population	
10=Transient population (seasonal workers)	Dwelling units / households by season (from AZ-Smart)		Usual workplace type/location area (from AZ-Smart if available; special choice model otherwise)

For certain segments like university students and transient workers, population synthesis is closely intertwined with workplace and school location choices since these populations are "induced" by the corresponding mandatory activity. The model components are numbered in accordance with the adopted sub-model numbering system that is summarized in **Section 6.1**.

Several technical details regarding the students' population are yet to be resolved. One of them relates to the disaggregate source of student-based households living in apartments and dorms that are, in general, are poorly represented in the Census Public Use Microdata Sample (PUMS). However, the model needs all household and person attributes of students (household size, composition, and income; person age and gender, etc) to generated their travel choices. Some simplified assumptions about household size (dominant share of singles) and age (dominant share of young adults of age 19-35) are normally adopted but they have to be verified against the actual data. The existing survey of ASU students represents a valuable source in this regard. This analysis has to be implemented at Phase 2 and the corresponding ABM components `should be finalized based on the results. Several sub-models have been already estimated at Phase 1 and presented in the Phase 1 Estimation Report.

Seasonal population segments are generated for an average weekday for the corresponding season. Thus, not only the total number of persons/households is accounted by also the average duration of stay in the region (less than 2 weeks for visitors and transient workers; from 2 weeks to 6 month for seasonal population).

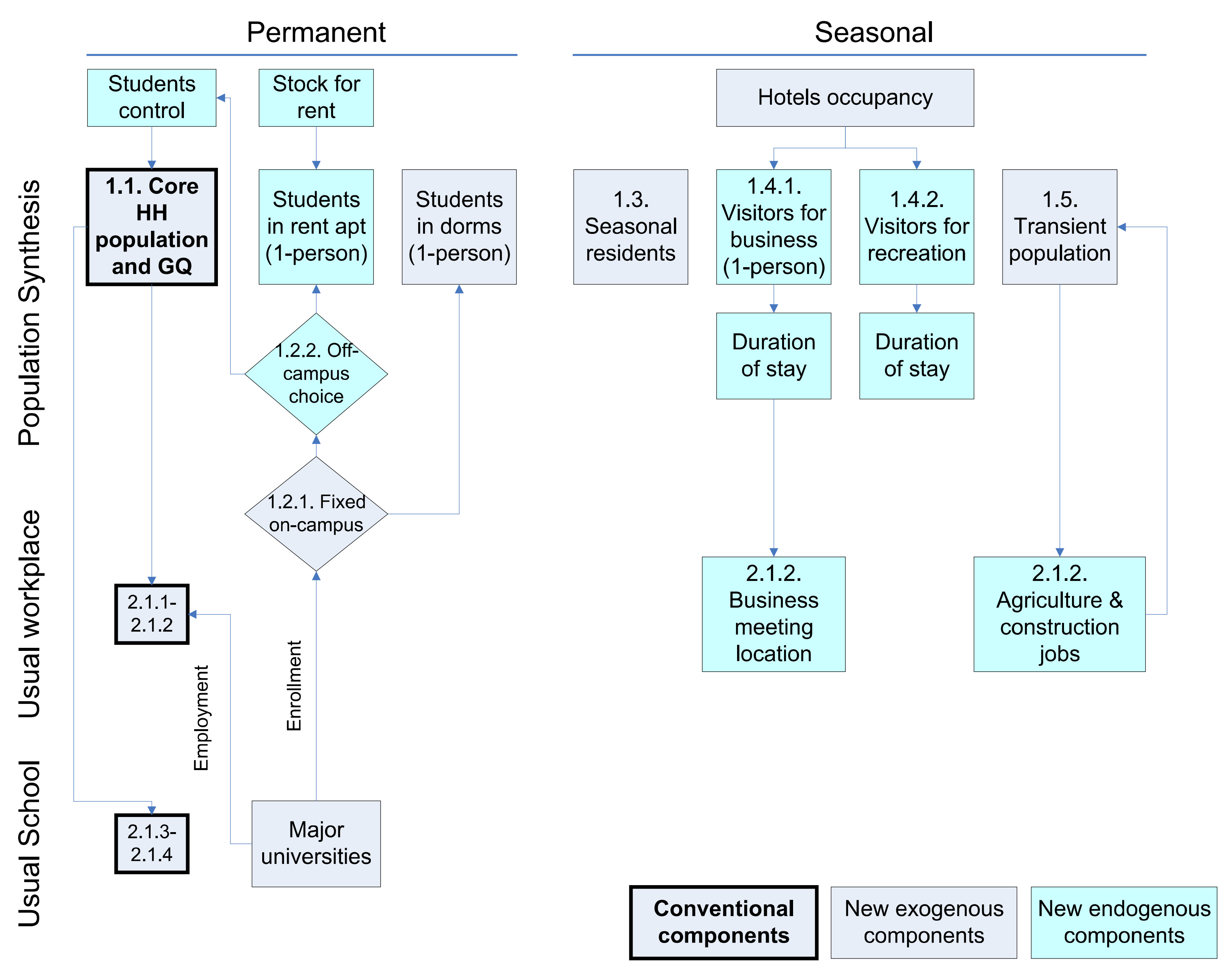

Figure 4: Population Synthesis and Choice of Usual Workplace & School

The following main principles are incorporated in **Figure 4**. For most population segments the corresponding population is generated first by place of residence. Then, for workers and students, usual workplace and school locations are modeled conditional upon the known residential place. This is the prevailing logic in practically all ABM structures. In this sense, the model chain in the figure starts at the top and ends the bottom. However, in the MAG ABM there are two segments – university students and transient workers, where the order of choice is reversed.

Modeling of university students should start from the bottom, i.e. university enrollment as the input. Then university students are divided into two main groups: living on campus and living off campus. Students living off campus further subdivided into students living in an apartment and students living in the family household (i.e. residents of the MAG region). Students living in the family households are integrated with the core synthetic population. This procedure is designed to replace the standard approach where university students are first randomly generated by place of residents and then assigned to a certain university. The standard procedure cannot adequately portray the impact of major universities like ASU that generate a large population of students living in the vicinity of the university.

A general structure of interrelated choice models for university students is presented in **Figure 5**. Technical details and estimation results for these models (based on the available survey of ASU students) are presented in the Phase 1 Estimation Report.

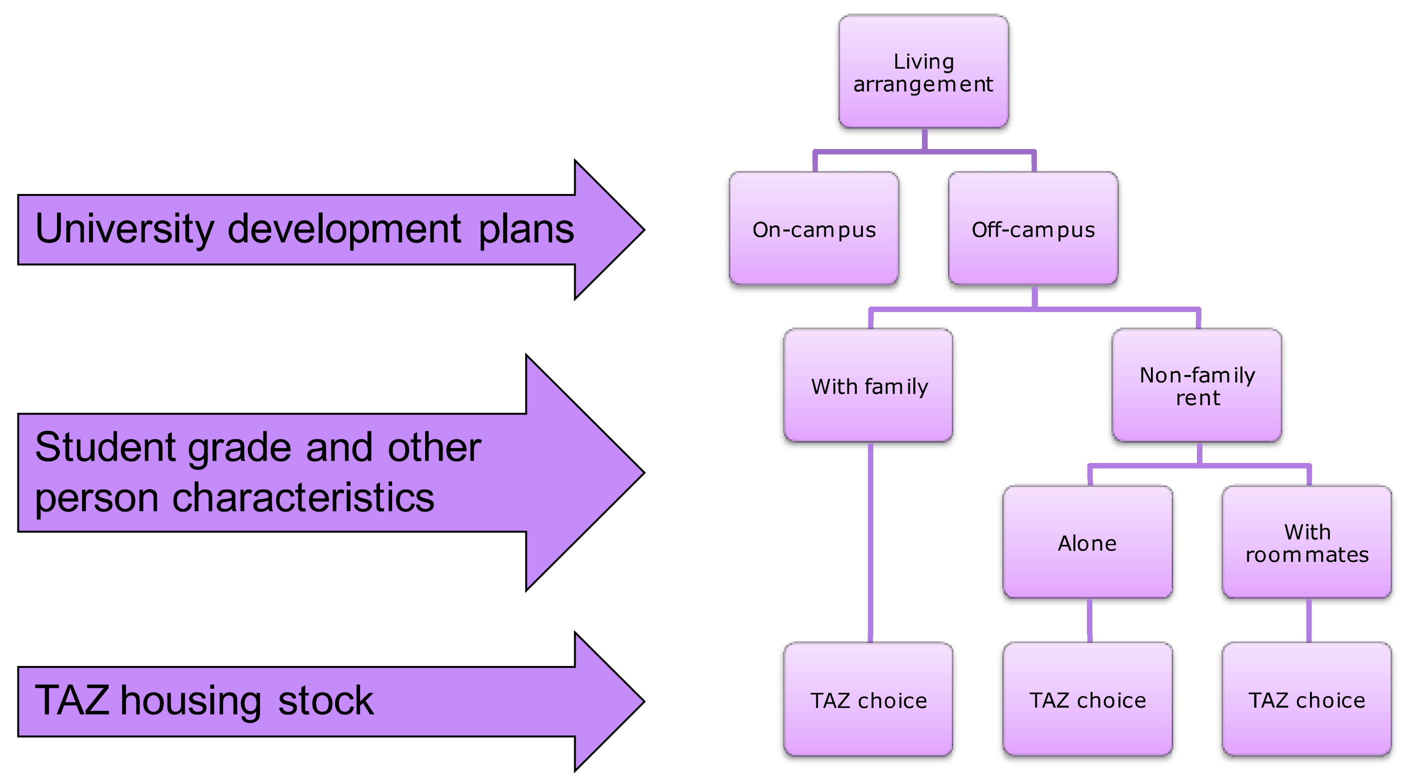

Figure 5: Residential Choice Structure for University Students

Certain technical details with this approach have yet to be resolved. For example, for the model that chooses residential location for off-campus students living in non-family rent apartments a corresponding zonal size variable should be provided. It should be discussed with the MAG land-use group if the AZ-SMART model could provide a variable like rental stock by TAZ (or even smaller spatial unit).

A similar methodological approach can be appropriate for modeling transient workers that mostly reside in areas close to their workplaces in such industries as agriculture and construction. For this population segment, it makes sense to model workplace location first based on the aggregate zonal number of jobs as the input. Residential location then should be modeled conditional upon the workplace location. This component, however, has to be finalized at Phase 2 with more substantial information about transient workers that was available at Phase 1.

5.4. Demand-Driven vs. Supply-Driven Activities

One of the innovative features of the proposed MAG ABM design is the integration of the core demand model with the models for special events at a disaggregate level. This means that participation in special events is organically incorporated in the individual daily activity-travel patterns of the resident and non-resident population.

The incorporation of special events in the fully disaggregate core activity-generation process can be done in two possible ways discussed below. In both cases, it is assumed that participation in a special event (like football game) is an activity that is normally planned by the individual in advance and has a high scheduling priority, i.e. the other activities on the same day will be scheduled around this planned participation, including potential adjustment of the work schedule.

Two possible ways to structure the corresponding chain of behavioral models are presented in **Figure 6**. The first one is to generate activities as pertinent needs of individual households and persons; i.e. a demand-driven activity generation. Further down the model chain, the activities are located and scheduled (if the schedule is not predetermined by the nature of event). After the individual special activities have all been generated and located, an iterative balancing process is normally needed to take into account the event or venue capacity or expected attendance. This process is similar to balancing workplace location choices to match the total number of jobs available in each zone. Aggregate balancing is needed since the corresponding individual choices are not constrained (and there is no mechanism to introduce an aggregate constraint in the individual choice framework *a priori*).

The second structure, which is more common for modeling special generators and events, relies on aggregate models to generate activity participation targets. With this ”supply-driven” formulation, the total attendance of the event (or attraction of the location) is identified first and the participants are allocated to places of residence (permanent for residents or temporal for visitors). This procedure may also require some balancing at the residential end to obey zonal population size constraints with respect to the proportion of special event participants (across all events).

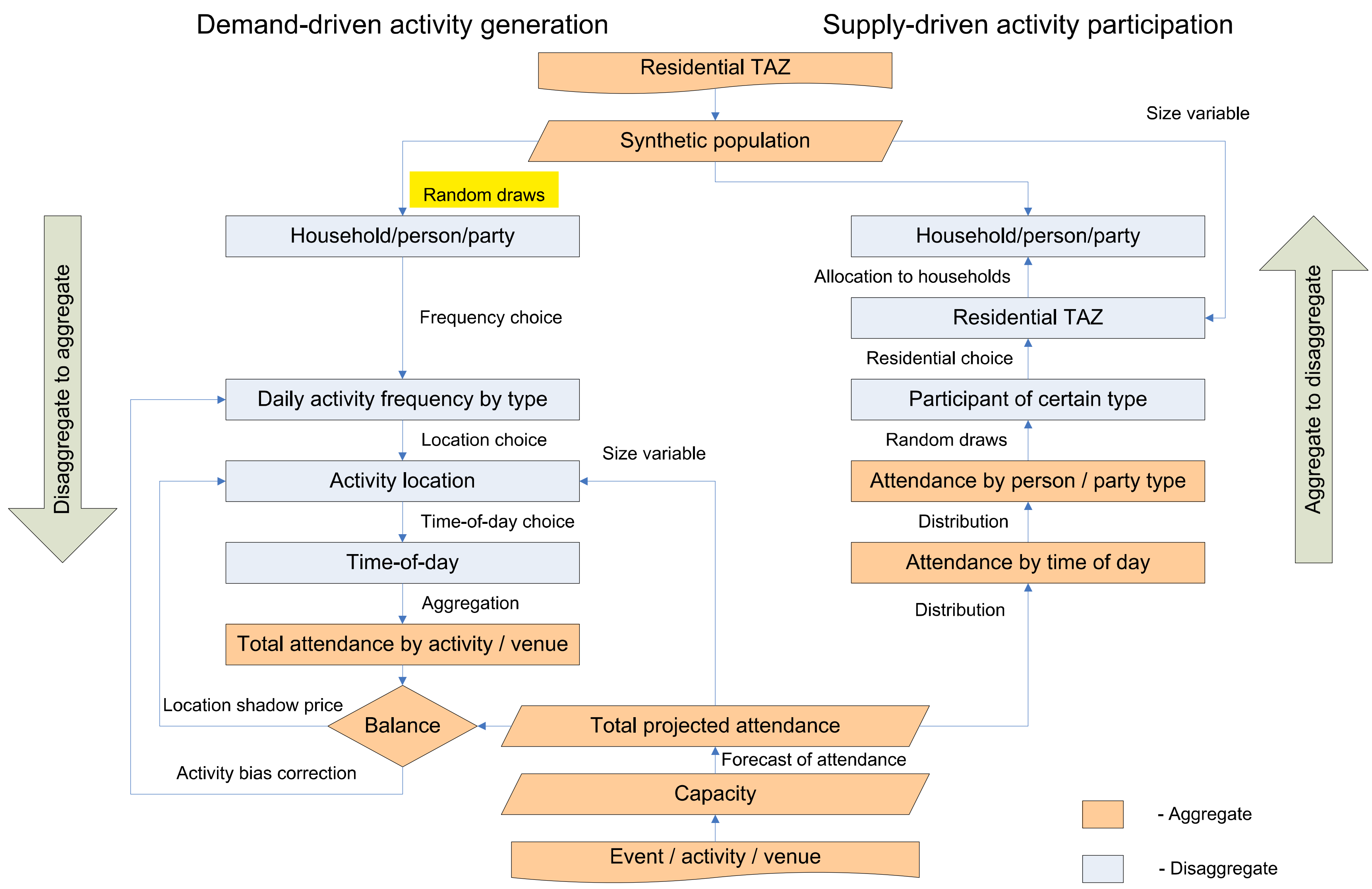

Figure 6: Demand-Driven Vs. Supply-Driven Model Chains

In the MAG ABM design, both principles are going to be intertwined and applied in parallel for different population and travel segments. For some of them, like special events and trips to airport, both ways are possible and the choice of approach is largely based on available data and manageability of model structure in calibration and application. In reality, both sides are applied simultaneously, activities are generated individually by persons in households, however, the capacity and location of the activity site imposes a constraint on the ultimate number of participants. Thus, a fully integrated demand-supply equilibrium approach is the most appealing one. However, to build an operational model it is necessary to put the associated choices in a manageable sequence.

Thus, one of the two approaches has to be chosen for each population and travel segment. It is useful to discuss the associated pros and cons of each approach in order to inform the choice of a particular structure for each particular segment.

A Demand-driven activity generation process has been applied in most ABMs for the core demand model. The advantages of this approach are:

- Comprehensive modeling of different activity types at the individual level with substitution and complementarity between them depending on the household composition and person type. In particular, the frequency of participation in several different activities and events by the same person can be incorporated.
- For future years and scenarios, the demand will be sensitive to population growth and demographic changes.
- The location of activities and associated time-of-day choices are modeled taking into account individual characteristics of persons and households as well as other activities undertaken by the same household and person and associated time-space and schedule constraints.

The disadvantages of this approach are:

- The demand-driven methodology requires disaggregate data for each person that indicates attendance at each event. Since special events are not attended frequently, household survey data typically does not yield enough observations to estimate robust disaggregate special event models. .
- The generation of activities and location choices for each individual does not guarantee that the total predicted attendance will correspond to the observed value or physical capacity constraint since there is no consideration of competition for a limited supply of activities. Thus, an aggregate balancing procedure has to be applied to the disaggregate choice models via the introduction of shadow prices.
- Shadow pricing is normally applied by location. Thus, it affects the spatial distribution of activities but not the generated total number. Job location choice is a typical example. It is possible to restructure the procedure to also ensure an automatic calibration of individual activity frequencies to match the predetermined total (for example, for a special event with a predetermined capacity).

A Supply-driven activity participation process is typically applied in an aggregate fashion for special generators and events. The advantages of this approach are:

- It guarantees matching observed total attendance of the event/location since the total attendance is the input to the process w/o any additional balancing.
- It guarantees matching the observed mix of participants in terms of their household and person characteristics as well as their spatial distribution.

- The supply-driven methodology relies on special generator surveys such as the Special Events survey currently being conducted by MAG (therefore this is listed as an advantage of this approach).

The disadvantages of this approach are:

- The approach is insensitive to overall population growth since the total number of activity participants is fixed. The model system relies on the external predictions of patronage of each special event for each year.

- The choice of participants cannot be fully integrated with the other activities and travel choices of the same person. Thus, participation choice for this activity has to be inserted into the "demand-driven" core activity sequence, which includes mandatory and other non-mandatory activities. It is difficult to assess and control participation of the same person in several activities or events on the same day. It is easier to assume that each person (or household if it comes to a joint participation) can only participate in one activity of the given type per day. This assumption is realistic for major special events like football games. It is less applicable to visiting museums or exhibitions.

With this general discussion in mind we further substantiate a practical approach to integration of special events with the core ABM.

5.5. Integration of Special Events with the Core Model

As was discussed in the previous section, this model component represents a fundamental shift in ABM paradigm. Rather than generate all activities in advance and then model the associated locations and schedules based on zonal "size variables" the proposed design of MAG ABM integrates special events with the core model where the activity-supply-side specifics are taken into account with the necessary level of detail. This approach also changes the default order of activity generation and scheduling that has been employed in most ABMs so far, i.e. mandatory activities (work and school) first, household maintenance errands second, and discretionary activity last. In reality, discretionary activities associated with special events often adjust their daily activity pattern and schedule other activities around the event (potentially including adjusting their work schedule).

The model results will be incorporated into the ABM system for both residents and non-resident visitors (see above). The model will select candidates for special event activities prior to generation of daily activity pattern from the appropriate resident and/or visitor population databases. The model could then 'reserve' time for the special event, assuming that it comes first in the daily activity hierarchy, and seek to optimize daily travel around the event. This would ensure consistency in daily activity patterns and schedules, and should allow for treatment of the special event as a tour primary destination or an intermediate stop on a work/university/school tour.

For the fullness of discussion and taking into account a very innovative model structure that arises, both possible approaches: demand-driven and supply driven are shown in flowcharts in **Figure 7** and **Figure 8** respectively. The supply-driven approach corresponds to the sub-model numbering system outlined in **Section 6.1**, since this is the approach that we currently suggest to implement.

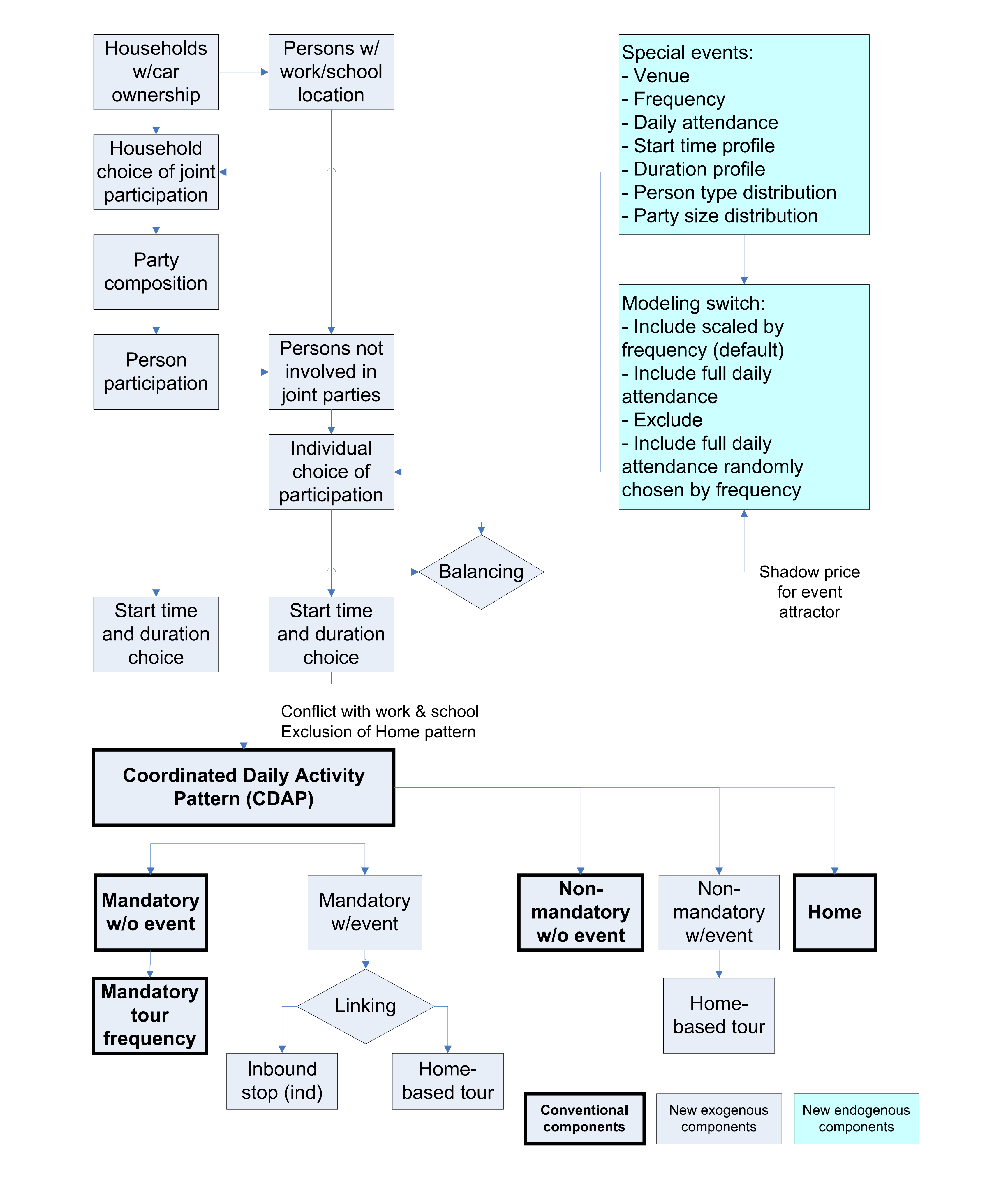

Figure 7: Integration of Special Events (Demand-Driven) with Core Individual Microsimulation

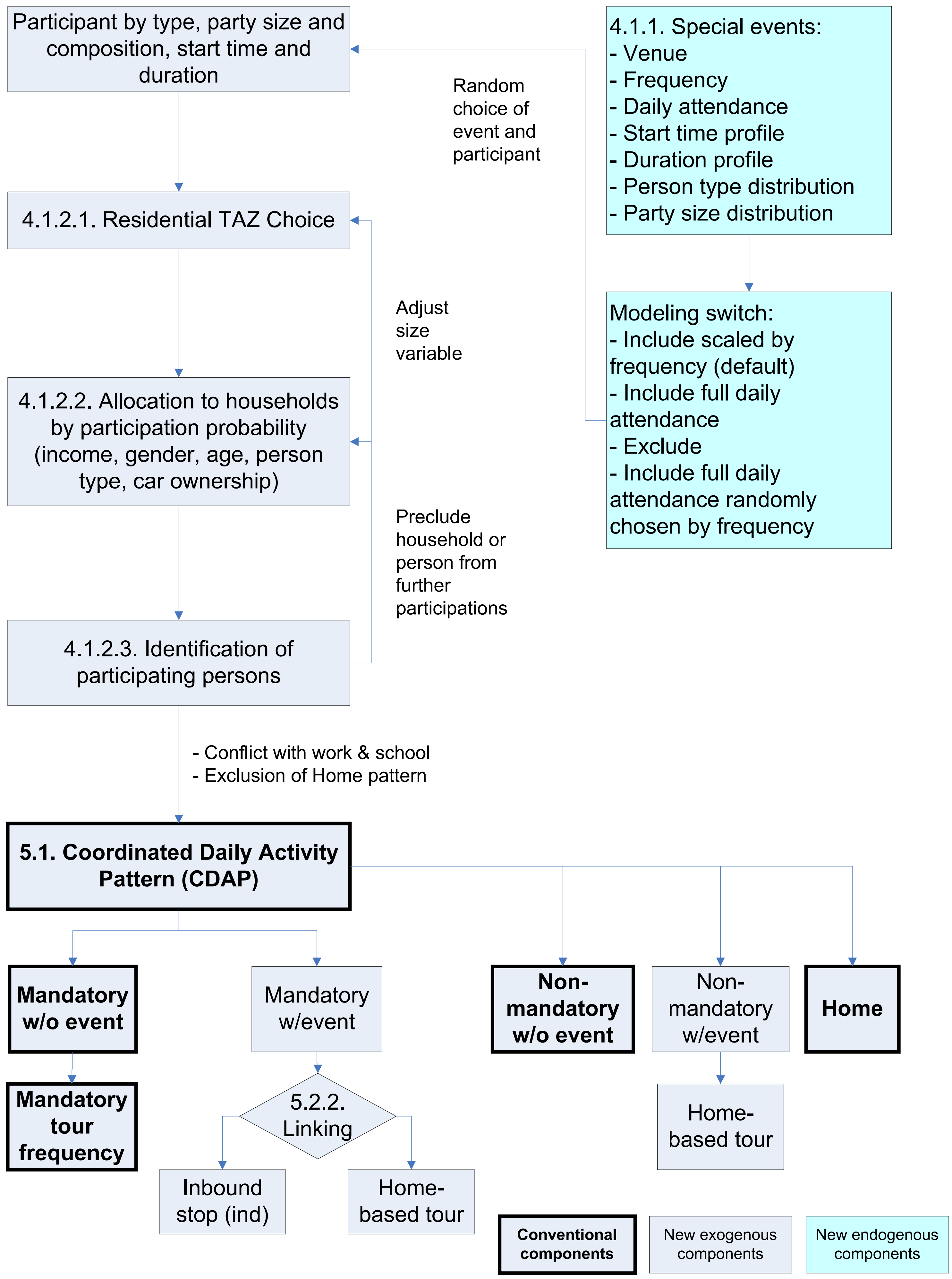

Figure 8: Integration of Special Events (Supply-Driven) with Core Individual Microsimulation

While there are many Special Events in Phoenix, they aren't held all the time. So, on an average weekday (regardless of season) there probably will only be one-three events that are possible to attend. And, each event has different travel implications. For example, certain events in the rail corridor have higher transit ridership than other events that aren't served by transit.

The current Special Events model is used to capture user benefits for all events, with the assumption that the travel model doesn't capture any of them. If we are modeling a realistic average weekday, only one or two events might be active. And these events might have a different transit share than 2 other events that aren't included. So scaling the results up for a year of benefits would likely under or over-estimate benefits. The model would have a high level of (local) variation in the results by including certain events in a simulation but not others.

In order to ensure compatible benefit measures from the ABM that the aggregate Special Events model already produces we specify four different ways how Special Events inputs (in terms of patronage) can be specified with the user option to choose one of them:

- Default option used for FTA runs to produce User Benefits and for other cases of aggregate entire-region analysis. With this option *each Special Event is included with an average number of participants scaled by the frequency of the event*. For example, if the hockey arena attracts 20,000 participants one out of five weekdays, the average daily patronage for a weekday will be 20,000/5=4,000. This is not a realistic number that could be observed on any given day but this is the only way to bring all Special Events together to a common daily denominator for calculation of average User Benefits.

- Inclusion of a Special Event with a *full daily attendance*. This option is applied by the user for selected events from the list that are subject to a local analysis where the peak traffic and/or ridership associated with these events are of interest. This option cannot be default and cannot be applied for all special Events simultaneously.

- *Exclusion of a Special Event*. This option is complementary to the previous one and is applied by the user for selected events from the list that are not in the focus of local analysis. This option cannot be default and cannot be applied for all special Events simultaneously.

- *Inclusion of Special Events chosen randomly with a full attendance*. With this option, each Special Event will be subject to a random choice based on the frequency. This option is useful for analysis of demand variability and associated travel time reliability.

5.6. Integration of Trips to and From Airports with the Core Model

Development of a mega-regional model for Phoenix and Tucson has two important implications for airport-related travel. First, Phoenix Sky Harbor and Tucson International Airport compete for travel to and from the Tucson region. Sky Harbor offers direct flights to many more destinations than Tucson. Therefore some Tucson travelers trade off auto travel to/from Phoenix with availability and convenience of flights. Second, travel between Tucson and Phoenix can be made by auto or air. A mode choice model which represents inter-city travel between these cities will consider air travel as an option – particularly if high-speed rail is introduced as a potential scenario.

Integration of trips to and from the airport with the core individual microsimulation model is a problem that is methodologically similar to the incorporation of special events discussed above. We again consider two possible schemes –a demand-driven approach (**Figure 9**) and a supply-driven approach (**Figure 10**). We currently propose to implement the supply-driven approach in light of the previous discussion, and the sub-models are numbered according to the outline of the entire model system in **Section 6.1**. Trip to or from the airport on a given day can be considered as a special event for the person and we may reasonably assume that this "activity" takes the higher scheduling priority over all other possible activities of the same person on the given day. The main specific feature of trips to and from airports is that they naturally create an incomplete tour (and incomplete daily pattern in general) depending on the time of arrival or departure. In many cases, when either arrival is late or departure is early the person would not have any other regional activity or travel. However, in general, airport passengers might have additional activities and trips on the same day.

However, we also plan to consider an alternative approach to modeling air travel would be a long-distance travel model, similar to the one applied for the Ohio Statewide model. It is a demand-driven model that first models whether a household/person will make a long-distance (50+ mile, non-regular commute) trip over a longer time horizon (two weeks), then determines whether the person will make the long-distance trip on the simulation day. The purposes are household travel (the entire household travels together), person-business and person-other travel. There is a mode choice model with auto, air, and transit competing. Such a model might be a good solution for forecasting rail demand between Tucson and Phoenix.

Development of a behavioral model for these "truncated" daily patterns will require a special survey since in the core Household Travel Survey, air passengers are normally not surveyed and consider absent (travel inactive) for the entire day. It will be decided after the statistical analysis if modeling the "truncated" daily patterns of air passengers is worth of the effort and if the associated non-airport travel is significant compared to the trips to and from airports. However, in any case, a better model for trips to and from airports as well as associated choice of ground access mode is a worthy effort.

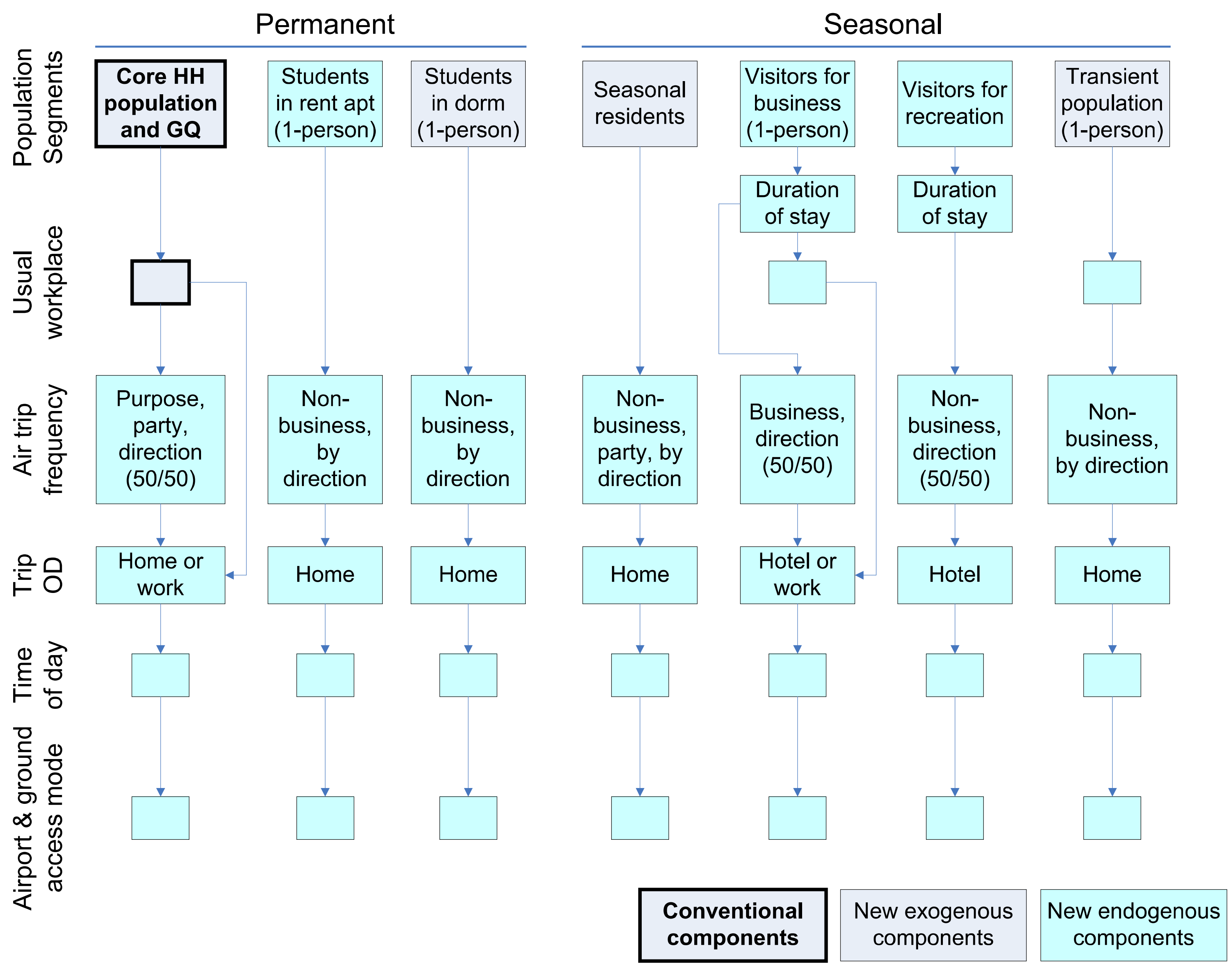

Figure 9: Modeling Trips To and From Airports (Demand-Driven)

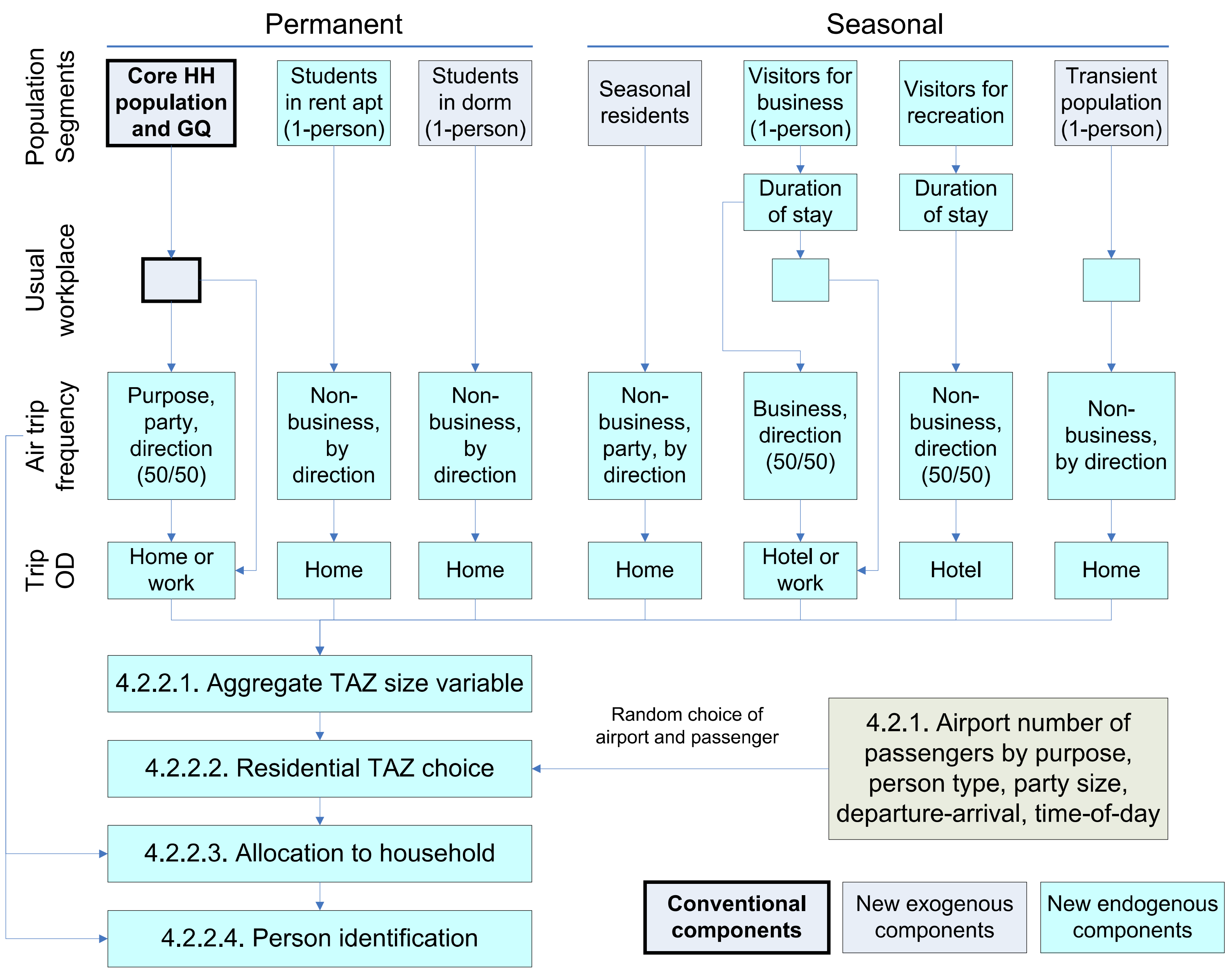

Figure 10: Modeling Trips To and From Airports (Supply-Driven)

The proposed approach will probably be simplified after analysis of the actual air passenger data. For example, it may not be needed to model student trips to/from the airport as a separate segment. These trips mostly happen at certain times of the year (start/end of semester), and they probably travel more on weekends in any event. Additionally, it will be decide after the data analysis if the transient population is significantly different from the core population with respect to air travel. Otherwise these segments will be combined in the air travel sub-model.

5.7. Escorting Children to School

Escorting children to school relates to partially joint tours that have not been yet included in the CT-RAMP structure. The proposed approach was tested as research based on the data for the Atlanta, GA, region. The approach is applicable for carpooling between workers as well. However, escorting children represents the most frequent type of partially joint tours, so we recommend developing it first.

Placement in the Model System Hierarchy

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 school, and the required schedule. It is also known for each household adult if he/she goes to work or university, the location of workplace or university, and the required schedule. 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. This way, the mode choice model would be predetermined to a large extent by the escorting choice. 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) would be 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, however these options are less frequent and not modeled explicitly. If escorting option is not chosen, then for both child and chauffeur there are several potential individual mode alternatives for the corresponding half-tours like transit, drive alone, shared ride with non-household members, school bus, non-motorized modes, etc. These options will be considered in the mode choice model. However, the composite quality of the individual service for child (in particular, transit availability, walk availability, and availability of school bus) is taken into account.

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 the 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.

Decision Making Unit and Choice Alternatives

Children within the household are ordered and modeled by age from youngest to oldest. The behavioral 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 modeled choice alternatives for each school tour are shown in **Figure 11** below.

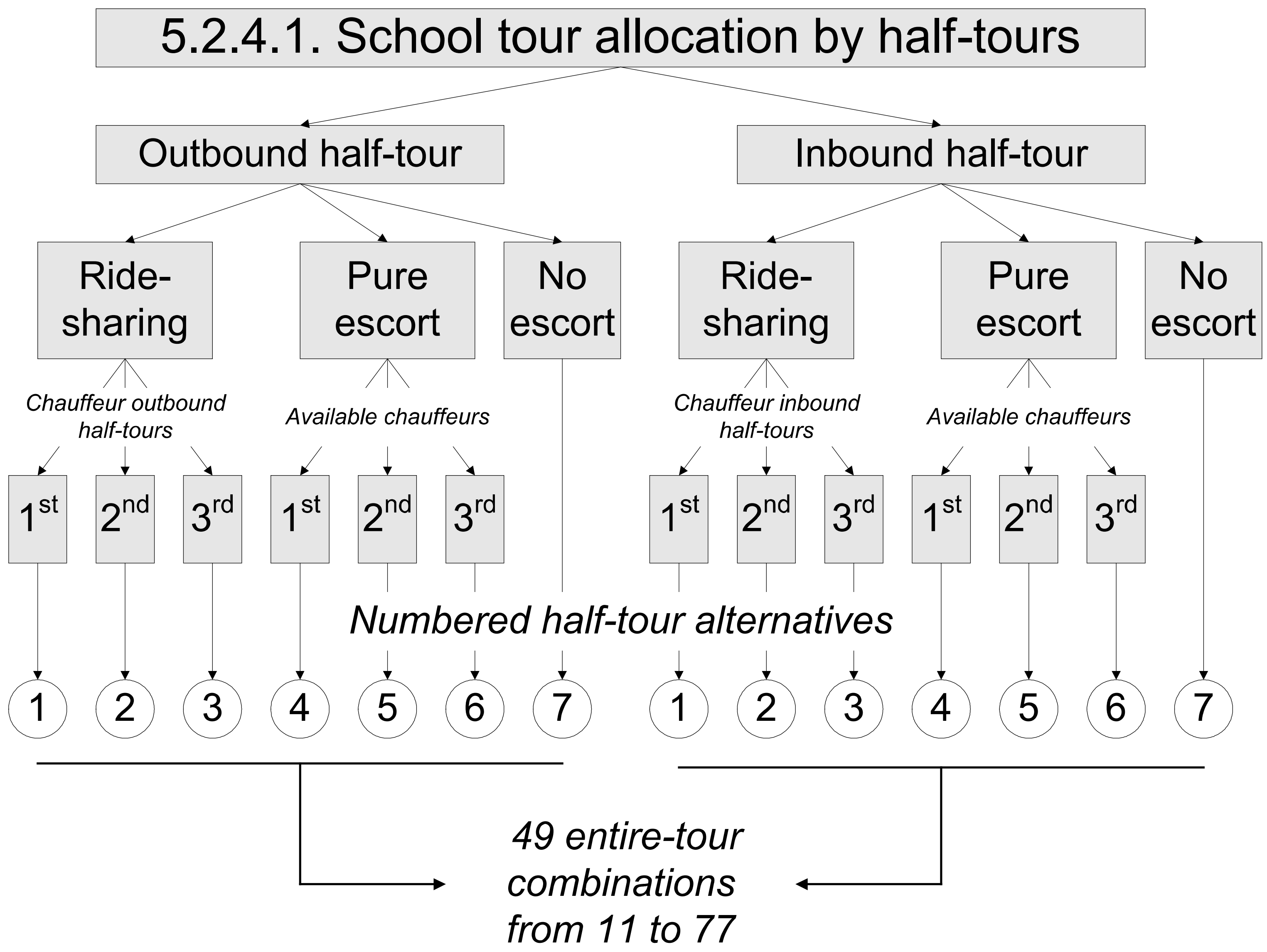

Figure 11: Escorting Choice Alternatives for Individual School Tour

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.

Utility Structure and Explanatory Variables

Numerous variables were tested in the statistical estimation procedure, including person attributes of the child and his/her school tour, person attributes of the potential chauffeurs and their work/university tours, and other household and zonal characteristics. The variables were grouped by meaningful utility components. Overall, 49 utility expressions were combined of a limited set of components in the following way:

$$T_{ij} = H_i^{out} + H_j^{inb} + E_{ij} ,$$ Equation 1

where:

$i = 1,2,...7$	=	outbound escort alternatives,
$j = 1,2,...7$	=	inbound escort alternatives,
T_{ij}	=	tour alternative utility
H_i^{out}	=	outbound half-tour utility component,
H_j^{inb}	=	inbound half-tour utility component,
E_{ij}	=	entire-tour combination component.

It is assumed that most of the tour utility components can be broken into the outbound and inbound half-tour parts with an additive effect on the entire-tour choice since the corresponding factors and variables are quite independent. There are, however, several entire-tour combination factors that cannot be broken into independent outbound and inbound parts.

The outbound half-tour utility component can be written in the following way:

$$H_i^{out} = \begin{cases} U_i^{out} & \text{for} \quad i = 1,2,3 \\ V_{i-3}^{out} & \text{for} \quad i = 4,5,6 \\ W^{out} & \text{for} \quad i = 7 \end{cases}$$ Equation 2

where:

U_i^{out}	=	(dis)utility of outbound ride-sharing for the i-th chauffeur,
V_i^{out}	=	(dis)utility of outbound pure escort for the i-th chauffeur,
W^{out}	=	the child (dis)utility of not being escorted in the outbound direction.

The inbound half-tour utility component has a symmetric form compared to the outbound half-tour component:

$$H_j^{inb} = \begin{cases} U_j^{inb} & \text{for} \quad j = 1,2,3 \\ V_{j-3}^{inb} & \text{for} \quad j = 4,5,6 \\ W^{inb} & \text{for} \quad j = 7 \end{cases}$$ Equation 3

where:

U_j^{inb}	=	(dis)utility of inbound ride-sharing for the i-th chauffeur,
V_j^{inb}	=	(dis)utility of inbound pure escort for the i-th chauffeur,
W^{inb}	=	the child (dis)utility of not being escorted in the inbound direction.

The non-additive entire-tour component is specified in the following form:

$$E_{ij} = \begin{cases} S^{ride} & \text{for} \quad i = j = 1,2,3 \\ S^{esc} & \text{for} \quad i = j = 4,5,6 \\ W^{both} & \text{for} \quad i = j = 7 \\ D & \text{for} \quad i = 1,2,3,4,5,6;\ j = 7 \end{cases}$$ Equation 4

where:

S^{ride}	=	added utility of convenience of ride-sharing with the same chauffeur in both directions,
S^{esc}	=	added utility of convenience of pure escorting by the same chauffeur in both directions,
W^{both}	=	added (dis)utility of the child of not being escorted in both directions,
D	=	added (dis)utility of the child being escorted in the outbound direction only.

Utility formation of the components described in expressions (1-4) for all alternatives is summarized in **Table 16**.

Table 16: Utility Formation for School Escorting Choice

Alternative	Description by half-tour directions		Utility
	Outbound	Inbound	
11	Ride by 1st chauffeur	Ride by 1st chauffeur	$U_1^{out} + U_1^{inb} + S^{ride}$
12	Ride by 1st chauffeur	Ride by 2nd chauffeur	$U_1^{out} + U_2^{inb}$
13	Ride by 1st chauffeur	Ride by 3rd chauffeur	$U_1^{out} + U_3^{inb}$

Alternative	Description by half-tour directions		Utility
	Outbound	**Inbound**	
14	Ride by 1st chauffeur	Escort by 1st chauffeur	$U_1^{out} + V_1^{inb}$
15	Ride by 1st chauffeur	Escort by 2nd chauffeur	$U_1^{out} + V_2^{inb}$
16	Ride by 1st chauffeur	Escort by 3rd chauffeur	$U_1^{out} + V_3^{inb}$
17	Ride by 2nd chauffeur	No ride/escort	$U_2^{out} + W^{inb} + D$
21	Ride by 2nd chauffeur	Ride by 1st chauffeur	$U_2^{out} + U_1^{inb}$
22	Ride by 2nd chauffeur	Ride by 2nd chauffeur	$U_2^{out} + U_2^{inb} + S^{ride}$
23	Ride by 2nd chauffeur	Ride by 3rd chauffeur	$U_2^{out} + U_3^{inb}$
24	Ride by 2nd chauffeur	Escort by 1st chauffeur	$U_2^{out} + V_1^{inb}$
25	Ride by 2nd chauffeur	Escort by 2nd chauffeur	$U_2^{out} + V_2^{inb}$
26	Ride by 2nd chauffeur	Escort by 3rd chauffeur	$U_2^{out} + V_3^{inb}$
27	Ride by 2nd chauffeur	No ride/escort	$U_2^{out} + W^{inb} + D$
…	…	…	**…**
61	Escort by 3rd chauffeur	Ride by 1st chauffeur	$V_3^{out} + U_1^{inb}$
62	Escort by 3rd chauffeur	Ride by 2nd chauffeur	$V_3^{out} + U_2^{inb}$
63	Escort by 3rd chauffeur	Ride by 3rd chauffeur	$V_3^{out} + U_3^{inb}$
64	Escort by 3rd chauffeur	Escort by 1st chauffeur	$V_3^{out} + V_1^{inb}$
65	Escort by 3rd chauffeur	Escort by 2nd chauffeur	$V_3^{out} + V_2^{inb}$
66	Escort by 3rd chauffeur	Escort by 3rd chauffeur	$V_3^{out} + V_3^{inb} + S^{esc}$
67	Escort by 3rd chauffeur	No ride/escort	$V_3^{out} + W^{inb} + D$
71	No ride/escort	Ride by 1st chauffeur	$W^{out} + U_1^{inb}$
72	No ride/escort	Ride by 2nd chauffeur	$W^{out} + U_2^{inb}$
73	No ride/escort	Ride by 3rd chauffeur	$W^{out} + U_3^{inb}$
74	No ride/escort	Escort by 1st chauffeur	$W^{out} + V_1^{inb}$
75	No ride/escort	Escort by 2nd chauffeur	$W^{out} + V_2^{inb}$
76	No ride/escort	Escort by 3rd chauffeur	$W^{out} + V_3^{inb}$
77	No ride/escort	No ride/escort	$W^{out} + W^{inb} + W^{both}$

The following considerations support the adopted utility structure:

- In general outbound and inbound escorting decisions and the corresponding utility components and factors are quite independent and frequently belong to different time-of-day periods with a significant duration of the school activity between them.

- Factors specific to the chauffeur person attributes are different across chauffeurs and require chauffeur-specific components in the utility functions such as gender, age, income, work status, and usual schedule. There are however, numerous variables that relate to the child person attributes such as age, walk distance to school, viability of transit, etc, that are generic across potential chauffeurs. They can be effectively modeled through the no-escort alternative utility in a form of disutility of the child of not being escorted.

- Statistical analysis has shown that there are several entire-tour considerations. They are expressed in frequently symmetric ride-sharing and pure escorting arrangements when the same chauffeur implements the escort travel in both directions. In short, usually it is one adult household member who is assigned responsibility for the children and will take charge of escorting in both directions.

- In the majority of cases, escorting is either implemented for both half-tours or not implemented at all, since escorting in one direction creates disutility for the child. The entire-tour components are specified "on the top" of the additive half-tour components.

The chauffeur-specific and child specific components ($U_i^{out}, U_j^{inb}, V_i^{out}, V_j^{inb}, W^{out}, W^{inb}$) are specified as linear functions of various person and zonal attributes. The entire-tour components ($S^{ride}, S^{esc}, W^{both}, D$) are specified as coefficients multiplied by the corresponding dummies.

The following variables were tested in the chauffeur-specific components for ride-sharing (U_i^{out}, U_j^{inb}):

- Availability for ride-sharing in terms of departure / arrival time synchronization of the chauffer mandatory half-tour with the school half-tour applied to outbound and inbound directions separately. A 1-hour discrepancy in actually reported departure / arrival times was used as a threshold of availability. If discrepancy was more than 1 hour, the chauffeur was considered unavailable for ride sharing. If the discrepancy was less than 1 hour, household members might be able to make schedule adjustments to allow a ride-sharing arrangement. This condition can be relaxed in order to eliminate the inevitable bias that stems from the fact that the data will only show well-coordinated activity schedules for escort pairs. The data does not really reveal their original schedule before the escort coordination was made. Thus, we plan to use usual work and school schedules with wide buffers for this model while applying the final time-of-day choice model after the escorting decisions have been made.

- Chauffeur person attributes like person type, gender, age, and driving license (a person without driver license was considered unavailable as a chauffeur).

- Route deviation that the chauffeur would experience in order to drop-off / pick-up child at school. It was calculated as the additional driving time of the corresponding chauffeur half-tour including the stop at school versus the direct commuting time.

- Did the chauffeur have access to work/university place by alternative modes, such as transit and non-motorized; the last was considered available if distance was less than 3 miles only. This component can be enhanced by considering the actual transit level-of-service as continuous measure rather than Boolean measure of availability.

The following variables were tested in the chauffeur-specific components for pure escorting (V_i^{out}, V_j^{inb}):

- Availability in terms of available time window necessary for pure escorting of the school half-tour, measured separately for outbound and inbound directions. If the departure / arrival time with the expected travel time entirely fell in the chauffeur available time window left after scheduling the mandatory activities, the chauffeur considered available for pure escorting.
- The chauffeur person attributes like person type, gender, age, and driving license.

In the adopted model specification for chauffeur-components $U_i^{out}, U_j^{inb}, V_i^{out}, V_j^{inb}$, the variables themselves were chauffeur-specific while the coefficients were generic across 3 potential chauffeurs since the model does not assume any meaningful ordering or ranking of chauffeurs in advance.

The following variables were tested in the child-specific components that are interpreted as disutilities of not being escorted (W^{out}, W^{inb}):

- Distance from home to school and school accessibility (level of service) by alternative modes (transit, non-motorized) versus driving/escorting to or from school.

- Child person attributes, like age category and possession of driver license.

- Potential outbound and inbound “bundling” with the other school tours of children in the household that should be synchronized with the current tour by departure / arrival time (a 15 min threshold was applied to decide whether school tours are synchronized or not).

- Household attributes, like household income group and car ownership / sufficiency versus the number of workers or number of potential drivers (including all adults and driving age children with driver license).

- Residential zone density and area type.

The proposed specification creates a manageable structure for model estimation and application. Though the number of alternatives (49) and variables to test (over 100 if various transformations are considered) is significant, the proposed breakdown of utility equations by components results in a parsimonious structure with a limited set of coefficients to estimate. The proposed structure avoids alternative-specific constants completely, except for those that can be interpreted behaviorally.

An additional issue that will be explored in the process of model estimation and development relates to the User Benefit Evaluation. Given that transit accessibility influences the utility of escorting children to school, it would make sense to quantify the corresponding benefits and include them in the model output along with the mode-choice related benefits.

"Bundling" of Multiple School Tours

The core model that was described above predicts the probability of each child to be escorted by different adult household members. If the household has only one child, this model is used directly to generate the escorting arrangement by microsimulation. However, if there are several children in the household implementing school tours on the given day, an additional "Bundling" model will be applied to predict the probability of several children to be escorted by the same household adult on the same tour. It is important to consider bundling instead of just independent microsimulation for each child for two reasons:

- If children have conflicting schedules or locations that prevent bundling and require separate escorting for each of them, assigning chauffeurs should take into account the marginal disutility for each household member (similar to allocation of maintenance tasks).
- If children can be escorted together this represents an opportunity for the adult household members to economize in terms of time and cost, and this is frequently observed in practice. Moreover, the necessity to escort one child may positively affect the probability to escort yet another child.

If we consider all possible tour formations and then allocation to chauffeurs, for most households, the task of listing all resulting combinations is not insurmountable. For example, in a household with 2 potential chauffeurs and 2 child tours (i.e. 4 half-tours) to handle, we will have 52 possible tour formation sets (including various options of serving only some of the 4 half-tours) and then from 2 to 16 allocation-to-chauffeurs alternatives for each of tour formation sets which results in approximately 500 escorting matrix alternatives. The corresponding choice tree is depicted in **Figure 12** below.

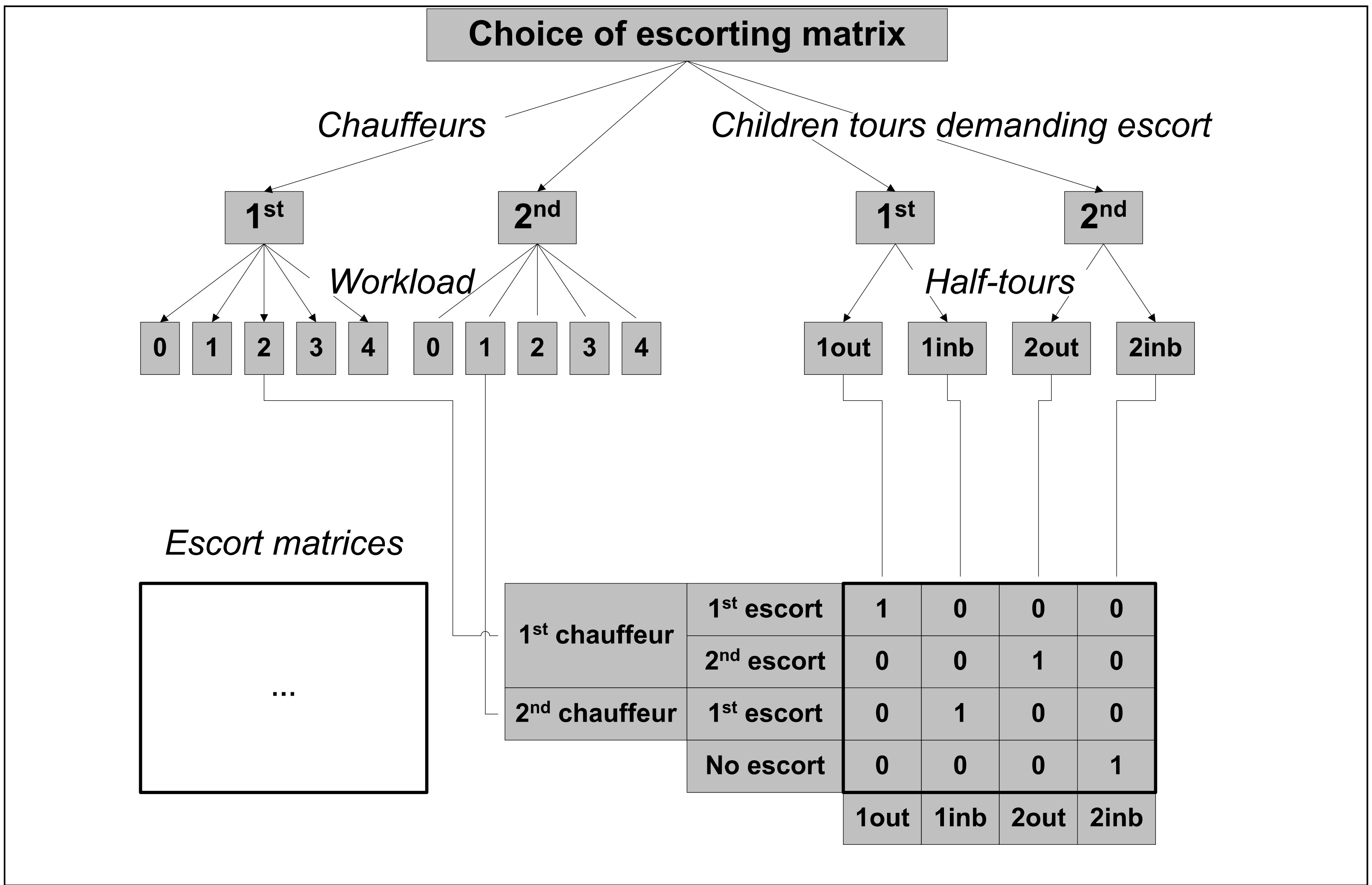

Figure 12: Escorting Choice Tree – General Case

However, after application of the tour-feasibility checks many of the tour-formation sets fail at the bundling stage. Further on at the chauffer availability check many of the matrices fail because at least one of the tours prove to be outside the available time window of the assigned chauffer. These two checks normally reduce the choice set size significantly.

5.8. Implications for Modeling Daily Activity Patterns

Specifics of Travel Choices for ASU

Within the CT-RAMP framework, travel of the Arizona State University students can be modeled in a similar way to non-student travel. However, university students typically have different travel patterns than non-university students, and a key differentiating characteristic is whether the students live with parents. Students who live with parents are sufficiently modeled based upon existing home-interview survey data, which typically captures part-time and commute students. Students who live in shared non-family households and group quarters will be defined as a special segment. The presence of a car must also be treated specially for this segment, given that students often live in non-family households where sharing an auto across household members may be less likely.

The model will be implemented with a seasonal "switch" can be set to allow the model to represent average fall conditions, when school is in session, versus summer conditions. In the summer period, enrollment and employment estimates would be reduced to summer levels, and ASU student population would be reduced accordingly. Workers at ASU will have a different set of parameters for mandatory tour generation under the summer season, to reflect a lower likelihood for travelling to work when classes are not in session.

Specifics of Travel Choices of Seasonal Residents and Non-Resident Visitors

Non-resident visitors may have different travel patterns than residents, depending on whether they are seasonal residents (which likely behave similar to the Retired person type), business travelers staying in hotels (who behave similar to workers with different transport options and non-business travel) or recreational travelers staying in hotels (who tend to chain trips and are often more flexible than residents in scheduling decisions). The model system must adequately capture these important market segments.

Non-resident visitor models will also consider special attractors as destinations, whose attendance is not necessarily directly related to employment. Special events with large number of attendees per employee include sporting events, concerts, conventions, the Phoenix zoo, and large regional parks. They are likely to draw a disproportionate share of visitors than other land uses. The details that relate to this aspect will be finalized after statistical analysis of the Special Events Survey.

Specifics of Travel Choices of Transient Workers

The transient population that primarily consists of agriculture and construction workers also has specific travel and activity patterns. This population segment will be created and located for each season separately to account for summer and winter peaks; of which the winter peak is the strongest. This population is characterized by a strong linkage to certain types of jobs in predetermined locations. Thus, they will have a separate workplace location choice model with a limited choice set of jobs and they will not compete with the core population for the same jobs. Additionally we expect that their activity patterns with respect to non-work trips will be somewhat different from the core resident population and probably closer to low-income one-worker households. This will be used as a working hypothesis for the first version of MGA ABM until more data on the transient workers has been obtained (a special survey).

5.9. Accounting for Travel Time Reliability

A considerable body of research has recently emerged regarding the the definition of travel time reliability, its measurement, as well as the treatment of reliability in modeling tools. The reliability measures suggested have been considered in the context of their effectiveness in evaluation of transportation projects, policies, and overall highway system performance.

In general, there are four possible methodological approaches to quantifying reliability suggested in the research literature or already applied in operational models:

- *Indirect measure: Perceived highway time* by congestion levels. This concept is based on statistical evidence that in congested conditions, travelers perceive travel time as more onerous. Perceived highway time is not a direct measure of reliability since only the average travel time is considered, though it is segmented by congestion levels. However, it can serve as a good instrumental proxy for reliability since the perceived weight of each minute spent in congestion is a consequence of associated unreliability.

- *1st direct measure: Time variability (distribution)* measures. This is considered as the most practical direct approach and has received considerable attention in recent years. This approach assumes that several independent measurements of travel time allow for forming the travel time distribution and calculation of derived measures, such as buffer time. Buffer time is normally defined as a difference between "bad" travel time (for, example, corresponding to the 90th percentile) and average (median) travel time. One important technical detail with respect to the generation of travel time distributions is that even if link-level time variation is known, it is a non-trivial task to synthesize OD-level time distribution (reliability "skims") because of the dependence of travel times across adjacent links.

- *2nd direct measure: Schedule delay cost*. This approach has been adopted in many research works on individual behavior in academia. According to this concept, the direct impact of travel time unreliability is measured through cost functions (penalties in expressed in monetary terms) of being late (or early) compared to the planned schedule of the activity. This approach assumes that the desired schedule is known for each person and activity in the course of the modeled period. This assumption, however, is difficult to meet in a practical model setting.

- *3rd direct measure: Loss of activity participation utility.* This method can be thought of as a generalization of the schedule delay concept. It is assumed that each activity has a certain temporal utility profile and individuals plan their schedules to achieve maximum total utility over the modeled period (for example, the entire day) taking into account expected (average) travel times. Then, any deviation from the expected travel time due to unreliability can be associated with a loss of participation utility in the corresponding activity (or gain if travel time proved to be shorter). Recently this approach was adopted in several research works on DTA formulation integrated with activity scheduling analysis. Similar to the schedule delay concept, however, this approach suffers from data requirements that are difficult to meet in practice. The added complexity of estimation / calibration of all temporal utility profiles for all possible activities and all person types is significant. This makes it unrealistic to adopt this approach as the main concept for the current project. This approach, however, can be considered in future research efforts.

A summary of perspectives for inclusion of reliability measures in operational models is presented in **Table 17**. It is important to address both the demand and network simulation aspects of reliability. The first two approaches are already operational although the second one requires a sophisticated route choice procedure with explicit route enumeration, only available in certain DTA software packages.

Table 17: Inclusion of Reliability in Operational Models

Method	Demand model (ABM)	Network simulation
Perceived highway time	Segmentation of auto time by congestions levels in mode choice (and mode choice logsums used in TOD and destination choice)	Applying weights in VDF; Skimming by congestion levels
Time distribution (mean-variance)	Inclusion of standard deviation or other measure in mode choice utility (and mode choice logsums used in TOD and destination choice)	Route choice with explicit enumeration and reliability measures; Generation of OD reliability measures
Schedule delay cost	Preferred arrival time should be estimated for each trip, this is still an *unresolved issue* in practice	Route choice with explicit enumeration and reliability measures; Generation of OD time distributions, this is still an *unresolved issue* in practice
Temporal utility profiles for participation in activity	Entire-day schedule consolidation procedures has to be developed; this is still an *unresolved issue* in practice	Route choice with explicit enumeration and reliability measures; Generation of OD time distributions, this is still an *unresolved issue* in practice

We plan to include travel time reliability in the MAG ABM at least with indirect measures like perceived travel time by congestion levels. Since this model component is new and experimental, it makes sense to test is first with the existing trip-based model. There have been already successful applications of this approach in demand models (specifically in the context of mode and time-of-day choice) reported in the SHRP 2 C04 project "Improving of Our Understanding of how Congestion and Pricing affect Travel Demand". However, application of this methods and associated weights in traffic assignment requires some other details be added to Volume-Delay Functions that reflect the underlying route choice preferences. In particular, freeway facilities should be also adequately weighted against lower-level facilities; otherwise this may result in excessive detouring in assignment due to the congestion weights, particularly since traffic signals are not properly reflected in auto assignments. This also may create a systematic bias sending too many vehicles off of freeways and onto arterials.

Depending on the progress on the DTA network simulation side, more advanced approaches will be also considered.

6. Technical Details on Sub-Models and Procedures of MAG ABM

6.1. Summary of Main Sub-Models and Procedures

Main sub-models and procedures applied in the MAG ABM are summarized in **Table 18**. New model components were discussed in the previous section. Other models in the CT-RAMP design are discussed in the subsequent sub-sections.

Table 18: Core Model Component Hierarchy for MAG ABM

Sub-models and procedures		Decision-making or analysis unit	What is predicted and choice alternatives
1	Population synthesis		
1.1	Core permanent resident household population and group quarters		
1.1.1	Seed sample of households reweighted and discretized to match controlled variables	TAZ	List of households and persons in each household with all attributes available in PUMS
1.2.1	Allocation to smaller spatial units	Household	Residential sub-zone within TAZ
1.2	University students		
1.2.1	Students living in dorms	University	List of students in each TAZ (or smaller spatial unit) where the dorms are located
1.2.2	Off-campus residential choice	Student not living in dorms	Living in a rent apartment vs. living in household & residential TAZ (or smaller spatial unit); provides an additional control for core synthesis
1.3	Seasonal residents	TAZ (or smaller spatial unit)	List of households and persons in each household with all attributes available in PUMS (for each season)
1.4	Visitors living in hotels		
1.4.1	Business visitors	TAZ (or smaller spatial unit) where hotel is located	List of persons with a set of attributes available from the visitors survey
1.4.2	Non-business visitors	TAZ (or smaller spatial unit) where hotel is located	List of persons with a set of attributes available from the visitors survey (for each season)
1.5	Transient workers population	TAZ (or smaller spatial unit) where transient population	List of persons with a set of attributes available from the visitors survey (for ecah season)
2	Long-term work/school type, location, and arrangements		
2.1	Usual work/school location		
2.1.1	Work location type	Worker	Usual workplace vs. variable workplace vs. work from home on a permanent basis

Sub-models and procedures		Decision-making or analysis unit	What is predicted and choice alternatives
2.1.2	Work location	Worker with usual or variable workplace	TAZ (or smaller spatial unit)
2.1.3	School location type	Student (not from dorms)	Usual out-of-home school location vs. schooling from home on a permanent basis
2.1.4	School location	Student (not from dorms) with usual school location	TAZ (or smaller spatial unit) where the school is located
2.2	Usual work arrangements	Worker	Regular weekly commuting frequency (1-7), telecommuting frequency (0-7), regular departure-arrival time and duration, and schedule flexibility (no, somewhat, free)
3	Mid-term mobility attributes		
3.1	Usual main commuting mode	Workers/university students with out-of-home workplace/school	Available modes
3.2	Household car ownership	Household	Number of cars available (0-4+)
3.3	Free parking eligibility	Worker with workplace in TAZ with parking cost	Free vs. paid
3.4	Transit pass holding	Person	Availability of transit pass by type
3.5	Household transponder ownership for use of toll lanes	Household	Availability of toll transponder
4	Special events and activities generated from the supply side		
4.1	Special events		
4.1.1	Aggregate attendance forecast	Venue	Aggregate forecast of daily participants by time-of-day, party size, and person type
4.1.2	Identification of individual participants and allocation to TAZs, synthetic households, and persons	Individual participant	TAZ (or smaller spatial unit), household within TAZ, and person within household
4.2	Trip to and from airports		
4.2.1	Aggregate forecast of number of passengers	Airport	Aggregate forecast of air passengers by time-of-day, party size, and person type
4.2.2	Identification of individual air passengers and allocation to TAZs, synthetic households, and persons	Individual participant	TAZ (or smaller spatial unit), household within TAZ, and person within household
5	Day-level models for activity participation, tour formation, and time allocation		

Sub-models and procedures		Decision-making or analysis unit	What is predicted and choice alternatives
5.1	Coordinated Daily Activity-travel Pattern type (CDAP)	Household-day	Joint trinary choice of pattern type (1=work/school out-of-home, 2=other regional travel, 3=no regional travel) and fully joint tour for maintenance/discretionary activity indicator (yes, no)
5.2	Work and school activities & tours		
5.2.1	Exact frequency of work/school tours and number of work/school activity episodes (at different locations) within each tour	Worker or student with work/school out-of-home pattern	6 main alternatives including 1=1 work tour, 2=2 work tours, 3=1 school tour, 4=2 school tours, 5=work tour followed by school tour, 6=school tour followed by work tour; the main alternatives are combined with sub-choices of 1,2, or 3 episodes for each tour
5.2.2	Linkage of special events and trips to/from airports to mandatory tours	Worker or student with work/school out-of-home pattern who participate in a special event or have a trip to/from airport	Trinary choice for each special event participation: 1=separate home-based tour with special event as the primary destination, 2=on the way to work/school (first tour, first episode), 3=on the way from work/school (last tour, last episode). Binary choice for each trip to/from airport
5.2.3	Start time (first episode of the first tour) and end time (last episode of the last tour) for work & school activities	Worker or student with work/school out-of-home pattern	903 half-hour combinations of start and end times conditional upon presence of joint household activity, participation in special events, and trips to/from airports.
5.2.4	Escorting arrangements for mandatory activities by half-tours		
5.2.4.1	Allocation of school half tours to work-half-tours and non-working chauffeurs	Outbound and inbound half-tours of school children	Outbound and inbound combinations of pair-wise linkages of each school half-tour to work/university half-tour or assigning to a potential non-working chauffeur; includes also a non-escort option
5.2.4.2	Bundling multiple escorting half-tours and schedule synchronization	Outbound and inbound half-tours of school children with potentially linked work/university half-tours and assigned chauffeurs for multiple-children households	Bundles of school half-tours of several children linked to the same work/university half-tour or same non-working chauffeur.
5.2.4.3	Bundling multiple work/university half-tours	Outbound and inbound work/university half-tours on household-day	Bundled work/university half-tours with assigning of driver and passenger roles
5.3	Fully joint tours for shared maintenance and discretionary activities		

Sub-models and procedures		Decision-making or analysis unit	What is predicted and choice alternatives
5.3.1	Frequency of fully joint tours	Household-day with the fully joint tour indicator in CDAP	20 alternatives including 5 one-tour alternatives by purpose and 15 two-tour alternatives by purpose combinations
5.3.2	Person participation in each fully joint tour	Fully joint tour in combination with each potential participant	Binary participation choice for each eligible household member with available time window overlapping with the other participants; person eligibility can be narrowed down by an auxiliary party type choice model (1=adults, 2=children, 3=mixed)
5.3.3	Primary destination of joint tour	Fully joint tour	TAZs (or smaller spatial units) with non-zero attraction size variable for the corresponding tour purpose
5.3.4	Stop frequency on joint tours	Joint tour	Combinations of 3 outbound and 3 inbound stop-frequency alternatives with sub-choices of exact purpose for each stop in a sequence.
5.4	Allocated maintenance tasks		
5.4.1	Frequency of out-of-home maintenance task by purpose	Household	Combinations of frequencies (0-3) of maintenance tasks by 3 purposes not including escorting tasks assigned previously.
5.4.2	Allocation of household maintenance tasks to household members	Household matrix of maintenance tasks by travel-active persons with residual travel window	Discretizing of household matrix of maintenance tasks using person choice frequency as marginal control; includes assigned chauffeuring of children to school
5.5	Individual out-of-home discretionary activities		
5.5.1	Person frequency of discretionary activities	Travel-active person with residual time window	Combination of frequencies (0-3) of discretionary activities by 3 purposes not including participation in special events identified previously
5.6	At-work sub-tours		
5.6.1	Frequency of at-work sub-tours	Work tour with minimal main activity episode duration (2 hours)	Combination of frequencies (0-2) of at work sub-tours by primary purpose (1=eating out, 2=business, 3=other maintenance)
5.7	Individual tour formation		

Sub-models and procedures		Decision-making or analysis unit	What is predicted and choice alternatives
5.7.1	Probabilistic role of each individual episode of maintenance or discretionary activity in tour structure	Maintenance or discretionary activity episode	9 alternatives: 1=primary destination (automatically assumed for special events), 2=outbound stop on work/university/school tour, 3=inbound stop on work/university/school tour, 4=outbound stop on maintenance tour, 5=inbound stop on maintenance tours, 6=outbound stop on discretionary tour, 7=inbound stop on discretionary tour, 8=outbound stop on at-work sub-tour, 9=inbound stop on at-work sub-tour
5.7.2	Probabilistic total frequency of individual maintenance and discretionary tours	Person-day with at least one generated maintenance or discretionary activity	0,1,2,3,4,5 individual maintenance and discretionary tours
5.7.3	Discretizing of matrix of tour structures	Person matrix of individual maintenance and discretionary activities by half-tours	Matrix of allocation of all individual maintenance & discretionary activities by work/university/school, maintenance & discretionary tours, and at-work sub-tours
6	Tour-level models		
6.1	Tour primary destination	Individual maintenance or discretionary tour	TAZs (or smaller spatial units) with non-zero attraction size variable for the corresponding tour purpose
6.2	Tour time-of-day choice	Mandatory tour or fully joint tour or individual maintenance tour, or discretionary tour	903 half-hour combinations of departure from home & arrival back home conditional upon the chosen work activity start and end times, escorting/carpooling synchronization, and schedules for special events
6.3	Tour mode	Mandatory tour or fully joint tour or individual maintenance tour, or discretionary tour	Tour mode with constraints by mode availability (SOV is not available for fully joint tours and group special events, only HOV is available for escorting and carpooled half-tours, HOV is available for individual tours to account for inter-household carpools)
6.4	Location of all stops and sequence of implementation	Half-tour with intermediate stops	Sequential choice of stop to implement by density of opportunities from origin versus destination with subsequent choice of TAZ (or smaller spatial unit) with non-zero attraction size variable for the corresponding trip purpose; for escorting stops and special events there place in the stop sequence is predetermined.

Sub-models and procedures		Decision-making or analysis unit	What is predicted and choice alternatives
6.5	Insertion of additional short stops "on the way"	Trip segment between two consecutive stops	Binary choice for additional short stops (not generated as main activities) by purpose (shopping, maintenance, eating out) and their location with minimal route deviation
7	Trip-level models		
7.1	Trip mode	Trip	Trip mode conditional upon tour mode; includes auto route type sub-choice (toll vs. free and HOV vs. general-purpose).
7.2	Trip departure time	Trip	Trip departure time within the tour window (half-tour window for work/university/school tours)
7.3	Auto trip parking location choice	Auto trip	Parking TAZ (or smaller spatial unit) conditional upon the trip destination and dependent on parking supply, parking cost, and walk time; parking constraint and demand-supply equilibration can be added
7.4	Transit station choice for P&R and K&R trips	Transit P&R or K&R trip	Parking lot at the level of designated TAZ (or smaller spatial unit) conditional upon the trip origin & destination and dependent on parking lot proximity, parking cost, and transit time; parking constraint and demand-supply equilibration can be added

6.2. Population Synthesis Procedure

Main Steps of Population Synthesis

The population synthesis procedure takes into account TAZ and regional controls and can also include a procedure to allocate households to smaller spatial units. A synthetic population is created using a modified open source PopSyn software originally designed for Atlanta Regional Commission (ARC). The ARC population synthesizer was developed by PB to be a flexible tool for creating synthetic populations for AB modeling. The population synthesizer takes as an input Census data and zonal-level and regional marginal distributions of households by various characteristics that are used as controls which the synthetic population is forced to match. The ARC population synthesizer is being enhanced to consider person-level attributes in the controls as well, in order to match workers by occupation or population distribution by age brackets provided by the Land-Use Model.

The population synthesis approach includes the following steps:

1. Create a *sample of households* in each TAZ (all households from the correspondent PUMA can be used in a simplified case).

2. Balance the *individual household weights* in each TAZ to ensure the controlled totals across all person and household dimensions.

3. Create a *list of households* by discretizing the individual weights.

The main difference of the proposed method compared to the other Population Synthesizers developed elsewhere is that it obviates a step of creating a (huge) joint multidimensional distribution of households in each TAZ. The advantage of working with the list of households compared to a multi-way distribution is that both person and household variables can be incorporated. If only household or only person attributes are controlled, the proposed procedure yields exactly the same multidimensional distribution as the conventional balancing of joint distribution. Also, the elimination of the drawing procedure allows for a theoretically closed formulation with no unnecessary empirical components.

General Formulation

Since the procedure is applied for each TAZ separately, we formulate the model for a single TAZ. Introduce the following notation:

$i = 1,2...I$	=	household and person controls,
$n \in N$	=	seed set of households in the Public Use Microdata Area (PUMA) (or any other sample),
w_n	=	a priori weighs assigned in the PUMA (or any other sample),
A^i	=	zonal control values,
$a_n^i \geq 0$	=	coefficients of contribution of household to each control.

The principal flexibility of the procedure is that the contribution coefficients can take any non-negative value, while in the conventional procedure the contribution coefficients are implied to be Boolean incidence indicators (belong or not belong). An example is shown in **Table 1** below for controls specified by household size and person age brackets.

Table 19: Controls and Contribution Coefficients

HH ID	HH size				Person age				HH initial weight
	1	2	3	4+	0-15	16-35	36-64	65+	
	$i=1$	$i=2$	$i=3$	$i=4$	$i=5$	$i=6$	$i=7$	$i=8$	ω_n
$n=1$	1							1	20
$n=2$		1			1	1			20
$n=3$			1			1	2		20
$n=4$				1		2	2		20
$n=5$				1	1	3	2		20
….									…
Control	100	200	250	300	400	400	650	250	

The first household has one person of age 65+. The second household has two persons: one of age 0-15 and another one of age 16-35. The third household has three persons: one of age 16-35 and another two of age 36-64. The fourth household has four persons: two of age 16-35 and anther two of age 36-64. The fifth household has size persons: one person of age 0-15, three persons of age 16-35, and two persons of age 36-64.

The balancing problem can be written as a convex entropy-maximization problem in the following way:

—, Equation 5

Subject to constraints:

, Equation 6

, Equation 7

where represents dual variables that give rise to balancing factors.

The objective function expresses the principle of using all households uniformly (proportionally to the assigned a priori weight). The constraints ensure matching the controls. This is a convex mathematical problem with linear constraints that can be solved by forming the Lagrangian and equating the partial derivatives to zero. The Lagrangian function can be written in the following way:

$$L(\{x_n\}) = \left(\sum_n x_n \ln \frac{x_n}{w_n}\right) - \sum_i \alpha^i \left[\left(\sum_n a_n^i x_n\right) - A^i\right]. \qquad \text{Equation 8}$$

We calculate partial derivatives and equate them to zero:

$$\frac{\partial L(\{x_n\})}{\partial x_n} = \ln\frac{x_n}{w_n} + 1 - \sum_i \alpha^i (a_n^i) = 0 \,.$$ Equation 9

By collect terms with constants on the right hand side and exponentiating both sides we obtain the following solution:

, Equation 10

where represents balancing factors that have to be calculated. Note that the balancing factors correspond to the controls, not to households. For each household, the weight is calculated as a product of the initial weight by the relevant balancing factors exponentiated according to the participation coefficient. A zero participation coefficient automatically results in a balancing factor reset to 1 that does not affect the household weight.

Solution Algorithm

The problem formulated in the previous section has a unique solution that can be achieved by the following iterative procedure:

Step 0: Set the iteration counter . Set initial weight for first iteration $x_n(1,0) = w_n$

For to (number of iterations):

For to (number of controls):

Step 1: Calculate balancing factor

$$\hat{\alpha}^i(k,i) = \frac{A^i}{\sum_n a_n^i x_n(k,i-1)} \,.$$ Equation 11

Step 2: Apply balancing factor (note exponentiation!)

$$x_n(k,i) = x_n(k,i-1) \times \left[\hat{\alpha}^i(k,i)\right]^{a_n^i} \,.$$ Equation 12

Step 3: Set starting weights for the next iteration

$$x_n(k+1,0) = x_n(k,I)$$ Equation 13

Step 4: Calculate convergence criterion:

. Equation 14

If (degree of accuracy) or , **Stop**.

Note that the solution is unique and independent of the order of controls. Normally, 100 iterations guarantee a very good degree of convergence.

Base Year Controls

The population synthesizer first develops a "base year" population distribution using year 2000 Census or 2005-2009 ACS data. A set of controlled for attributes are defined, and Census Summary File 1, Summary File 3, and the Census Transportation Planning Package information is used to develop single and multi-dimensional distributions of these attributes. These attributes, which are specified at the TAZ level in the base-year, include:

- *Household Controls*:
    - Number of households by population type (1=permanent residential, 2=GQ, 3=seasonal residential, 4=transient, 5=business visitors, 6=non-business visitors, 7=institutional),
    - Number of households by size (1,2,3,4,5+),
    - Number of household by number of workers in household (0,1,2,3+),
    - Number of households by income group in base-year dollars; the recommended groups are: 1=less than or equal to $30k (very low), 2=$30-60k (low), 3=$60-100k (medium), 4=$100-150k (high), 5=$150k+ (very high). All sources for the population sample like Census, PUMS, ASC and for the model estimation like Household Travel Survey and Transit On-Board Survey are to be brought to the base year with respect to the income data by using CPI,
    - Number of households by housing unit type (1=single-family detached, 2=multi-family).

- *Person Controls*:
    - Number of persons by age brackets: the following brackets the most important with respect to person activity and travel behavior: 1=0-5 (preschool children generally not traveling alone), 2=6-15 (school children of pre-driving age with limited person mobility), 3=16-18 (driving age high school children), 4=19-35 (young adults with a highest level of non-work activity but lower value of time), 5=36-64 (adults with the highest value of time), 6=65+ (retirees),
    - Number of workers by occupation; the following categories are recommended if they can be supported by AZ-SMART: 1=White collar labor, 2=Work at home labor, 3=Service labor, 3=Health labor, 4=Retail and food labor, 5=Blue collar labor, 6=Military labor.
    - Number of ASU students living in households (derived from the off-campus student location sub-model).

Group quarters residents are treated as a separate category of households. In the PUMS data, each group quarters resident has a record in the person format as well as a record in the household format representing a one-person pseudo-household containing only that individual. These fields are distinguished from the normal household records by the UNITTYPE field, which indicates if the record is a household record, a non-institutional group quarters record, or an institutional group quarters record. This field is used to distinguish the type of household, and group quarters residents are otherwise treated just like any other household record. Institutional group quarters residents are generated so that the total population matches control totals. However, because institutional residents are not expected to travel, these records are not printed to the population output file used by the model system.

Combinations of the dimensions that are excluded or merged include:

- Illogical combinations where number of workers is greater than the household size are excluded,
- For group quarters, transient workers, and visitors, no distinctions are made by household income,
- For group quarters, transient workers, and business visitors, no distinctions are made by household size,
- For group quarters, transient workers, and business visitors, no distinctions are made by person dimensions.

For the base-year application, the control totals can be derived entirely from 2000 Census data tabulated at the block-group level and converted to a TAZ-level. The controls may include the following one-dimensional and multi-dimensional tabulations:

- Households by Household Size (4 controls);
- Households by Household Size x Number of Workers (4x4=16 controls);
- Households by Household Income x Household Size (4x4=16 controls);
- Households by Household Income x Number of Workers (4x4=16 controls);
- Households by Household Income x Household Size x Number of Workers (3x4x4=48 controls);
- Households by housing type (2 controls);
- Households by Household Size x housing type (4x2=8 controls);
- Households by Group Quarters Type x Number of Workers (2x2=4 controls);
- Persons by age (6 controls);
- Workers by occupation (7 controls).

Future-Year Control Totals

For the forecast years, the set of controls of control totals is available from AZ-SMART. The forecast-year control totals from AZ-SMART will be finalized jointly with the socio-economic and land-use group. In particular, all controls can be kept at the level of one-dimensional (marginal) distributions or some joint distributions will be also available. At minimum, we expect the following one-dimensional distributions will be available:

- Household distribution by size (available at a TAZ level),
- Household distribution by income group (available at a TAZ level),

- Household distribution by number of workers (will be available at a TAZ level),
- Household distribution by housing type (available at a TAZ level),
- Distribution of workers by occupation (available at an TAZ or aggregate/county level),
- Distribution of persons by age brackets (county-level control),
- Special and seasonal population segment totals: Group Quarters, seasonal residents, transient workers, visitors in hotels (business and non-business), institutional.

6.3. Long-term Location Choices for Mandatory Activities

Long-term choices relate to *location of mandatory activities* and include the following dimensions:

- For each resident worker and visitor for business purpose: usual work arrangement type including the following alternatives: 1) permanent usual workplace, 2) variable workplace, and 3) work from home. For type 1, the usual workplace location (TAZ) is modeled. For type 2, typical workplace location (TAZ) is modeled.

- For each resident student living in a resident household: usual school arrangement type including the following alternatives: 1) usual school where the person goes, and 2) home-schooled. For type 1, the usual school location (TAZ) is modeled. Students living in dorms and rent apartments are synthesized with a predetermined university location.

Long-term location choices for mandatory activities are modeled separately for Work, Preschool, Grade School, High School, and University segments. For each of them a *location type* model separates those who are working or schooling from home on a permanent basis. The location type model for workers who do not work from home also distinguishes between usual workplace and variable workplace. In the last case, a typical location is modeled.

A *workplace location choice* model assigns a workplace TAZ (or smaller spatial unit) for every employed person in the synthetic population who does not work from home. This choice model is based on estimation results performed with the MAG 2008 Home-Interview Survey. The zonal size terms will be formed according to worker occupation, to reflect the different types of jobs that are likely to attract different (white collar versus blue-collar) workers. Accessibility is measured by a 'representative' mode choice logsum based on peak period travel (A.M. departure and P.M. return), as well as distance to the workplace.

Since mode choice logsums are required for each destination, a two-stage procedure is used for all destination choice models in the CT-RAMP system for MAG in order to reduce computational time. It would be computationally prohibitive to compute a mode choice logsum for each TAZ (not talking about smaller geographic units) and every worker in the synthetic population. In the first stage, a simplified destination choice model is applied in which all TAZs are alternatives. The only variables in this model are the size term and distance. This model creates a probability distribution for all possible alternative TAZs (TAZs with no employment are not sampled since they automatically obtained a zero size variable).

A set of alternatives are sampled from the probability distribution. These sampled alternatives constitute the choice set in the full destination choice model. Mode choice logsums are computed for these alternatives and the destination choice model is applied. A discrete choice of TAZ (or smaller spatial unit) is made for each worker from this more limited set of alternatives. In the case of the work location choice model, normally a set of 40 alternatives is sampled.

The application procedure utilizes an iterative shadow pricing mechanism in order to match the number of workers by workplace choice to input number of jobs available in the TAZ (size term). The shadow prices are written to a file and can be used in subsequent model runs for a warm start to cut down computational time.

A *preschool location choice* model assigns a school (day care, kindergarten) location for every preschool child (0-5) in the synthetic population who is not cared at home on the permanent basis. The size term for this model is the estimated mixed of total population and office employment since it is impossible to obtain direct data on the day care organizations many of which are very small.

A *grade school location choice* model assigns a school location for every grade-school aged person (6-13 years old) in the synthetic population. The size term in this model is grade school enrollment data (if available). However, it will be necessary to include both public and private grade school locations and enrollment. Another useful dataset would be school district boundaries, to the extent that they are relevant in restricting or affecting school location choices based on residential location. District boundaries can be used in application to calibrate alternative-specific constant terms.

Similarly, a *high school location choice* model assigns a school location for every high-school aged person (14-17 years old) in the synthetic population. The size term for this model is the high school enrollment. The same information regarding district boundaries would helpful to the high school location choice model.

The preschool, grade school, and high school location choice model parameters include person/household characteristics, representative school mode choice logsums, distance, and size terms.

A *university location choice* model assigns a university location for every university student in the synthetic population. The size term in this model is university enrollment. In the MAG ABM this model will only be needed for small colleges, universities, and adult schools. For students of ASU and other major universities, the population synthesis procedure will locate them by place of residence.

6.4. Mid-Term Models for Individual Mobility Attributes

Mid-term choices relate to household and person *mobility attributes* and may include the following dimensions:

- For each household: car ownership (0,1,2,3, or 4+ cars).
- For each person except preschool children of age 0-5: transit pass holding.

- For each worker and student with usual work/school location in an area where parking cost is applied: free parking eligibility at work/school (yes or no).
- For each household: having a toll transponder (yes or no).

The *household car ownership* model predicts the number of vehicles owned by each household. It is formulated as a choice model with five alternatives, including “no cars”, “one car”, “two cars”, “three cars”, and “four or more cars”. The model includes the following main explanatory variables:

- Household size and composition relative to the number of cars through car-sufficiency indices,
- Income,
- Parking cost and density in residential zone,
- Auto dependence measures for each worker and adult student who has a workplace or school outside of home that indicate if a car is essential for commuting or there are some competitive alternative modes (transit, non-motorized),
- Accessibility measures for non-work activities by different modes showing how essential is each additional car for shopping, household maintenance, escorting children, discretionary activities, etc.

The *free parking eligibility* model predicts whether workers who work in the CBD or some other area where parking is not free has their parking paid by their employer or not (i.e. has to incur parking cost). Development of this model will be based on available data from the Household Survey and possible special parking surveys to be administered in the subsequent phases of model development. Explanatory variables will likely include socio-demographic characteristics such as income, age, and especially occupation.

The structure of *person transit pass holding* model will be finalized based on the available data in the Household Survey. In general it assumes main binary choice (hold a pass or not to hold) with possible sub-choices for transit pass type.

A *toll transponder ownership* model predicts whether a household owns a toll transponder unit. It will be based on aggregate transponder ownership data. Therefore it will likely be estimated as a regression model that predicts the probability of owning a transponder unit for each zone based on aggregate characteristics of households in that zone and distance to the nearest major toll facility. Once the probability of owning a transponder unit is known, each household in that zone will determine whether they own a unit based on a Monte Carlo simulation. Since there are no toll facilities in Phoenix, this model would have to be “borrowed” from a different region.

Relevance of such mobility attributes as transit pass holding, free parking eligibility, and possession of a toll transponder for the Phoenix Region will be determined based on the statistical analysis of the Household Travel Survey, 2008 and other available sources. Free parking eligibility can be also included as a date item in a special parking survey.

6.5. Day-Level Models for Activity Pattern, Schedule, and Tour Formation

Main implications 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 13** below using the sub-model numbering system introduced in **Section 6.1**. In general, the proposed structure of day-level models preserves the main logic and sequence of sub-models embedded in the core CT-RAMP design applied for ABMs developed for Columbus, OH, Atlanta, GA, and San-Francisco Bay Area, CA. The preserved fundamental features include a Coordinated Daily Activity-Travel Pattern Type choice for each household member and distinguishing between four major activity types models according to the following sequence: 1=individual mandatory activities, 2=joint non-mandatory activities, 3=allocated maintenance tasks, and 4=individual discretionary activities.

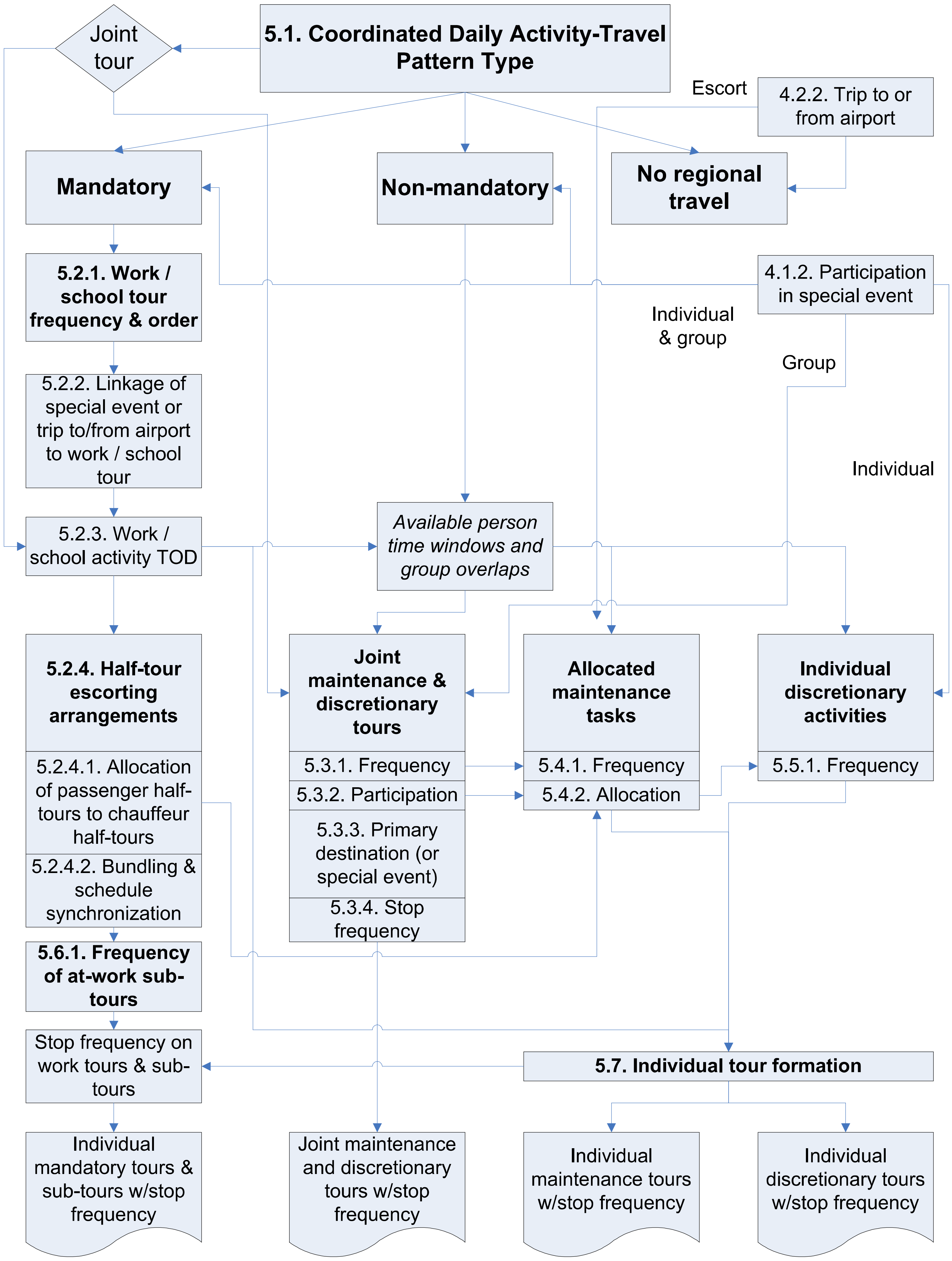

Figure 13: Modeling Day-Level Choices of Activity-Travel Patterns

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

- A *fully-joint tour indicator* (no tours vs. at least one tour) is included in the upper-level model for pattern types that is predicted simultaneously with the basic travel pattern for each household member. This feature, previously included in the SANDAG CT-RAMP model, enhances model integrity since there is a strong interdependence between the individual pattern choices and planning for a joint non-mandatory activity. Fully joint tours of several household members with shared non-mandatory activities (for example, for major shopping or eating out) generally have a high priority in the activity scheduling process that is at least at the level of mandatory activity and in many instances even higher. Thus, this decision is better to be modeled simultaneously with the go/no-go decision for mandatory activity embedded in the pattern type choice. Additionally, having a joint tour indicator earlier in the model chain would inform the subsequent time-of-day choice model for mandatory activities that a reasonable time window should be left by the potential participants. It is more behaviorally appealing that most of the workers would adjust and synchronize their work schedules to participate in a joint activity then assume that these schedules are defined independently and then joint activities would occur if there is an overlap between the residual time windows.

- Explicit modeling of *half-tour escorting arrangements* between workers and school children (as well as between workers if it proves to be frequent). Fully joint tours implemented for shared non-mandatory activities have always been a part of the basic CT-RAMP design. However, partially joint tours majority of which relates to escorting children to school and other activities have not been yet 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 considered 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 chauffeur has to be modeled separately. Escorting can take two different forms. In the first form, the chauffeur travels from home to a different activity (or from a different activity back home) and drop off (or pick up) the escorted person on the way. This form is most frequent for workers escorting school children. In the second form, the chauffer escorts a non-driving household member to his activity with no other purpose except for escorting. This form is most frequent for non-workers escorting children to school as well as other activities ("soccer mom"). In both cases the escorting arrangements can occur either in outbound direction or outbound direction or both. Depending on the direction of escorting, the corresponding half-tours should be synchronized in time and space. The resulted choice model considers all possible combinations and is not trivial. It is proposed to be included in the MAG ABM after testing it in a stand-alone research.

- 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 it was also aggregate or implemented in a microsimulation fashion). The challenge taken in the MAG 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 Daily Activity Pattern (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, 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. It will be further determined after statistical analysis of the Special Events survey if it is reasonable to adopt a simplifying assumption that each individual can participate in only one special event per day or it is necessary to consider participation in multiple events.

- Explicit *formation of individual tours* based on the generated activities. This is a significant improvement of the ABM paradigm compared to the previously applied models (CT-RAMP and others) 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. Then, these activities are grouped into tours including already 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 represents a better behavioral unit for modeling than just a shared activity episode.

6.6. Coordinated Daily Activity Pattern (CDAP) Model

In the CT-RAMP structure each individual is assigned a DAP that is classified by three main types:

- *Mandatory pattern (M)* that includes at least one of the three mandatory activities – work, university or school. This constitutes either a workday or a university/school day, and may include additional non-mandatory activities such as separate home-based tours or intermediate stops on the mandatory tours.
- *Non-mandatory pattern (NM)* that includes only maintenance and discretionary activities and tours.

By virtue of the tour primary purpose definition, maintenance and discretionary tours cannot include travel for mandatory activities.

- *Home pattern (H)* that includes only in-home activities. At the current stage of model development, at-home patterns are not distinguished by any specific activity (e.g., work at home, take care of child, being sick, etc). Cases with complete absence from town (e.g., business travel) are also combined with this category.

Statistical analysis implemented with the Columbus, Atlanta, and San Francisco Bay Area data has shown that there is an extremely strong correlation between DAP types of different household members, especially for joint NM and H types. For this reason, the DAP for different household members cannot be modeled independently. Therefore, alternative DAP types are broken into two groups. Mandatory activities form the first group; these activities are assumed to be undertaken individually. The second group contains two patterns – NM and H – that have the potential to be jointly utilized if several household members choose the same pattern.

The total number of possible DAP type combinations is significant, especially for large households, that results in the following number of alternatives in the choice model:

- 3 for one-person household,
- 9 for two-person households,
- 27 for three-person households,
- 81 for four-person households,
- 243 for five-person households,
- 363 total for all types of households if only up to five household members are modeled simultaneously.

However, there are several important considerations that significantly reduce the dimensionality of the simultaneous model. First of all, mandatory DAP types are only available for appropriate person types (workers and students). Even more importantly, intra-household coordination of DAP types is relevant only for the NM and H patterns. Thus, simultaneous modeling of DAP types for all household members is essential only for the trinary choice (M, NM, H), while the sub-choice of the mandatory pattern can be modeled for each person separately.

The Coordinated Daily Activity Pattern (CDAP) model in the basic CT-RAMP design, features simultaneous modeling of trinary pattern alternatives for all household members with the subsequent modeling of individual alternatives, as shown in **Figure 14**. Tour frequency choice is a separate choice model conditional upon the choice of alternatives in the trinary choice. This structure is much more powerful for capturing intra-household interactions than sequential processing.

For a limited number of households of size greater than five, the model is applied for the first five household members by priority while the rest of the household members are processed sequentially, conditional upon the choices made by the first five members. The rules by which members are selected for inclusion in the main model are that first priority is given to any full-time workers (up to two), then to any part-time workers (up to two), then to children, youngest to oldest (up to three).

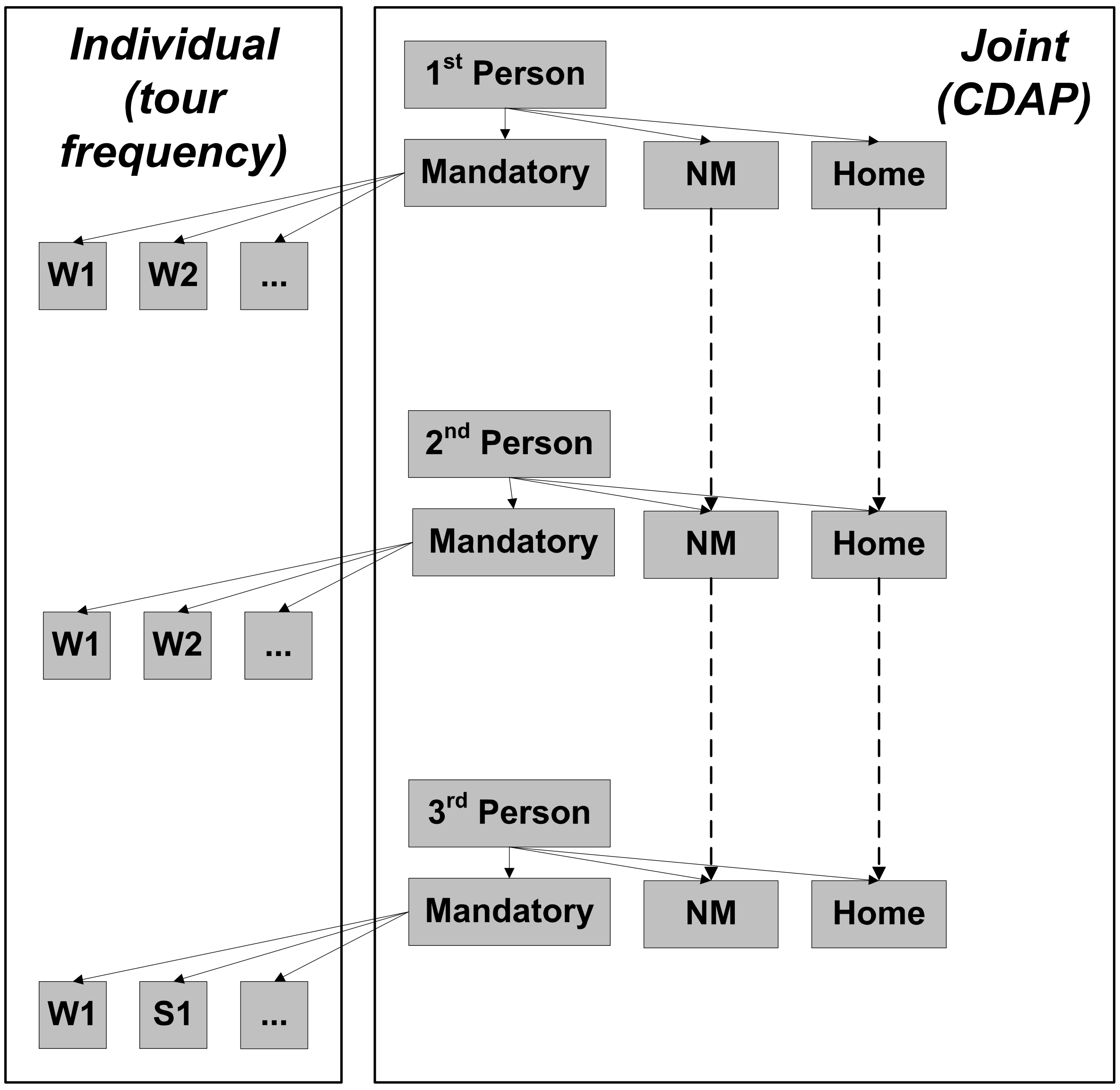

Figure 14: DAP Type Choice Structure

The CDAP model contains a number of explanatory variables including person and household attributes, accessibility measures, and density/urban form variables. Since the model features intra-household interactions, a number of the parameters in the model are specified as interaction terms. These terms are based on the contribution to the total utility of an alternative from either a two-person interaction, a three-person interaction, or an entire-household interaction. For example, the contribution of a two-worker interaction to the utility for each worker to stay home on the simulation day is positive, indicating that it is more likely that both workers will attempt to coordinate their days off to engage in recreational opportunities together. Similarly, the contribution of a pre-school child to a worker mandatory pattern is negative, indicating the likelihood that if a pre-school child stays at home, a worker also is more likely to stay at home with the child.

The proposed improvements of the choice structure of CDAP for the MAG ABM are shown in **Figure 15**. For simplicity, an example of a two-person household is shown. A generalization for a large household is straightforward. There are two improvements compared to the basic CT-RAMP structure:

- A binary *sub-choice of (indicator on) joint activity & travel episode* is included (as in the SANDAG ABM where it was successfully estimates and applied). This allows for capturing the impact of joint tours on other travel decisions earlier in the decision-making chain that in the basic CT-RAMP design. In particular, the time-of-day choice model for work tours benefits from this indicator since, in reality, workers frequently adjust their schedules to accommodate a joint activity episode. Each =household activity pattern alternative where at least two members have non-home patterns is considered with and without joint travel as two different alternatives. At this modeling level, we do not distinguish between single and multiple joint tours. These details are added further down the model chain by means of a joint tour frequency model, which predicts the exact number of joint tours by purpose.

- An *intermediate nesting level* is introduced to account for principal differences between Mandatory and Non-Mandatory patterns. In all previous CDAP formulations, the main trinary choice at the person level (1=Mandatory day, 2=Non-mandatory travel day, 3= staying at Home) was modeled by a MNL model. This created some IIA effects that were difficult to explain. For example, for school children, dense urban environment induced more non-mandatory activity patterns compared to children living in suburban areas. However, with the MNL structure, this trade-off was not limited to Non-mandatory and Home patterns but also affected the frequency of Mandatory patterns, which is not logical. The proposed nested structure accounts for these effects and gives a more reasonable structure of the trade-offs. The dichotomy of patterns associated with the joint tour indicator can also be incorporated as the lower-level nest in this nested structure.

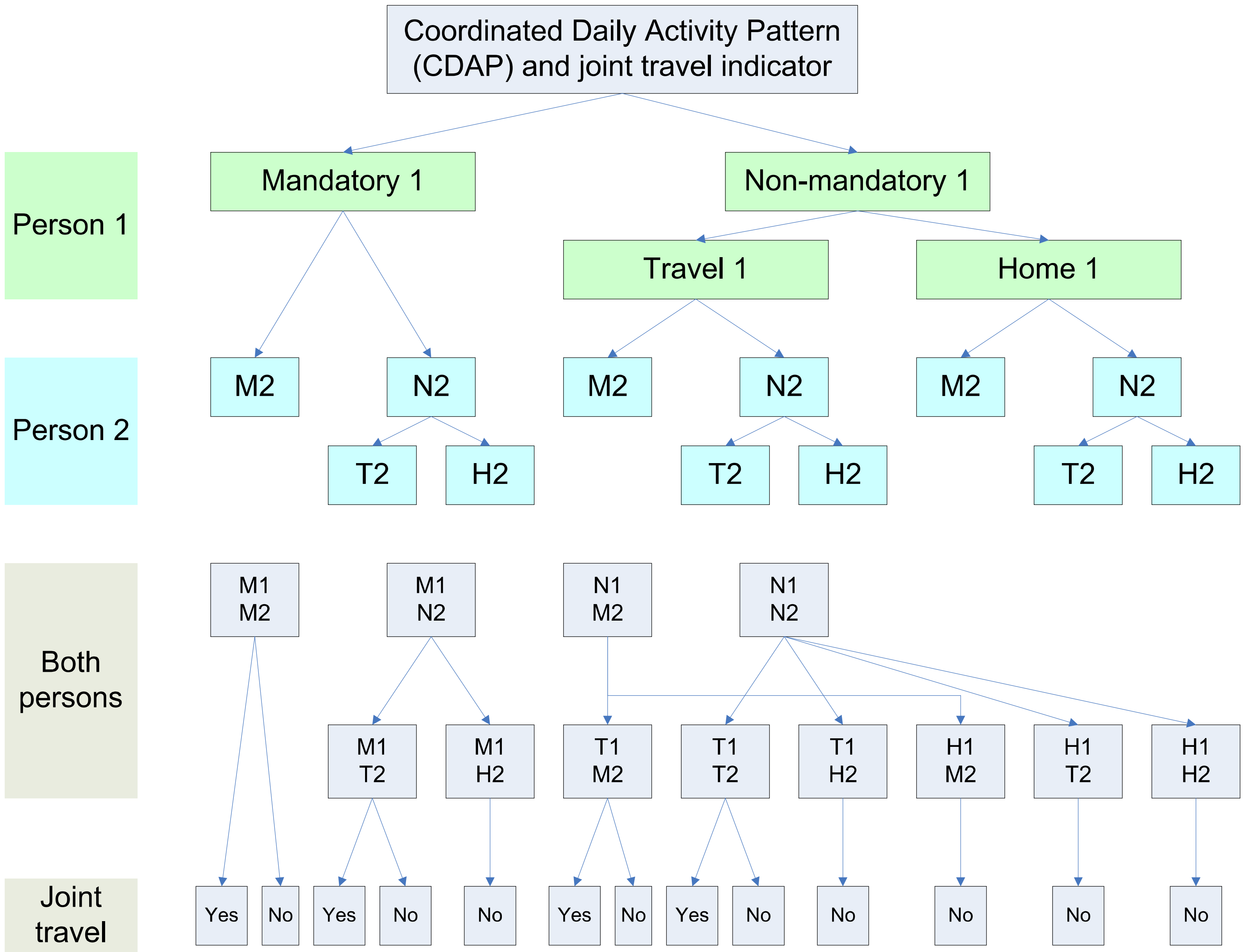

Figure 15: Choice Structure of Coordinated Daily Activity Pattern (Example for 2 Persons)

The utility functions of this model are formed in a parsimonious component-wise fashion that is conceptually similar to the escort model described above. With the component-wise structure, a utility for each alternative is linearly combined of several meaningful components. While the total number of alternatives is greater than 2,000, the number of components is slightly over 100 and the number of coefficients to estimate is less than 300. This is a manageable structure in both estimation and application. The following main utility components are included:

- *Person-type-specific utility* of choosing one of the three individual patterns (M, N, or H). This component includes most of the person and household variables like age, gender, income, car ownership, presence of children, usual work and/or school location, etc, as well as general accessibility to different non-mandatory activities. The total number of utility components of this type is 8 (person types) × 3 (pattern types) = 24.

- *Household-level added utility of having a fully joint non-mandatory activity* in a separate home-based tour. This is a single component that is largely based on the number of available travel-active household members with either N (preferably) or M (less preferable but possible) patterns by person type as well as accessibilities to non-mandatory activity locations using HOV mode.

- *Within-the-household pair-wise interaction terms* that express added utility of having the same daily pattern for each couple of household members. The total number of utility components of this type is 36 (possible pairs formed of 8 person types) × 3 (pattern types) = 108.

- *Additional triple-wise and entire-household interaction effects* beyond a sum of pair-wise interactions. These terms are examined statistically one by one and normally 10-15 of them are included.

A detailed description of this model structure and estimation results are presented in the Phase 1 Estimation Report

6.7. Mandatory Tour Frequency Choice

Based on the DAP chosen for each person, individual mandatory tours, such as work, school and university tours are generated at the person level. The model is designed to predict the exact number and purpose of mandatory tours (e.g., work, school, or university) for each person who chose the Mandatory DAP type at the previous decision-making stage. Since the DAP type model at the household level determines which household members engage in mandatory tours, all persons subjected to the individual mandatory tour model implement at least one mandatory tour. The model has the following six alternatives:

- One work tour,
- One school tour,
- Two work tours,
- Two school tours,
- One work tour followed by one school tour,
- One school tour followed by one work tour.

The observed frequency of patterns with three or more mandatory tours is negligible. A chronological order of tours in mixed-purpose patterns is important for the subsequent time-of-day (TOD) choice model. The mandatory TOD choice model is a complicated one with a large number of alternatives and explanatory variables. The experience with TOD choice models estimated previously for Columbus, Atlanta, and the San Francisco Bay Area has shown that additional complexity arises from handling mixed-purpose double-tour patterns where the chronological order of tours by purpose proved to be a significant factor affecting how other variables are applied. Since the mandatory tour frequency model is much simpler compared with the TOD choice model it makes sense to move some of the complexity of TOD choice to mandatory frequency choice. It is also behaviorally appealing that people make a decision on the order of mandatory tours as part of the pattern type and before their exact scheduling. It is also expected that the order of mandatory tours will be strongly correlated with person type.

For most of workers who attend adult schools, the work tour will be first while the school tour will be second. For most school children and full-time university students, the school tour will be first while the work tour will be second.

Depending on the person age and school type, only one type of school tour (either school K-12 or university/college) is applied to each person.

6.8. Generation of Fully Joint Tours and Person Participation in Them

Sub-Models for Fully Joint Tours

In the current CT-RAMP structure, joint travel for non-mandatory activities is modeled explicitly in the form of fully joint tours (where all members of the travel party travel together from the very beginning to the end and participate in the same activities along the way). This typically accounts for more than 50% of joint travel. Other types of joint travel, such as worker carpooling and escorting children, are handled by a different sub-model (5.2.4).

An explicit model of joint travel constitutes one of the primary advantages of the CT-RAMP modeling paradigm. Each fully joint tour is considered a unit of modeling with group-wise decision-making for primary destination, mode, frequency and location of stops, etc. Joint tours are only modeled for households that included (at least one) joint activity predicted by the CDAP model (sub-model 5.1). Formally, modeling joint activities involves two linked stages:

- A tour generation stage that generates the number of joint tours by purpose/activity type made by the entire household. This is the joint tour frequency model.
- A tour participation stage at which the decision whether to participate or not in each joint tour is made for each household member and tour. This is the joint tour participation model. For analytical convenience, this model is broken into two sub-models. The first addresses travel party composition, and the second focuses on person participation choice.

The procedure for generation of fully joint tours and identification of participants for each tour in a schematic form is presented in **Figure 16**.

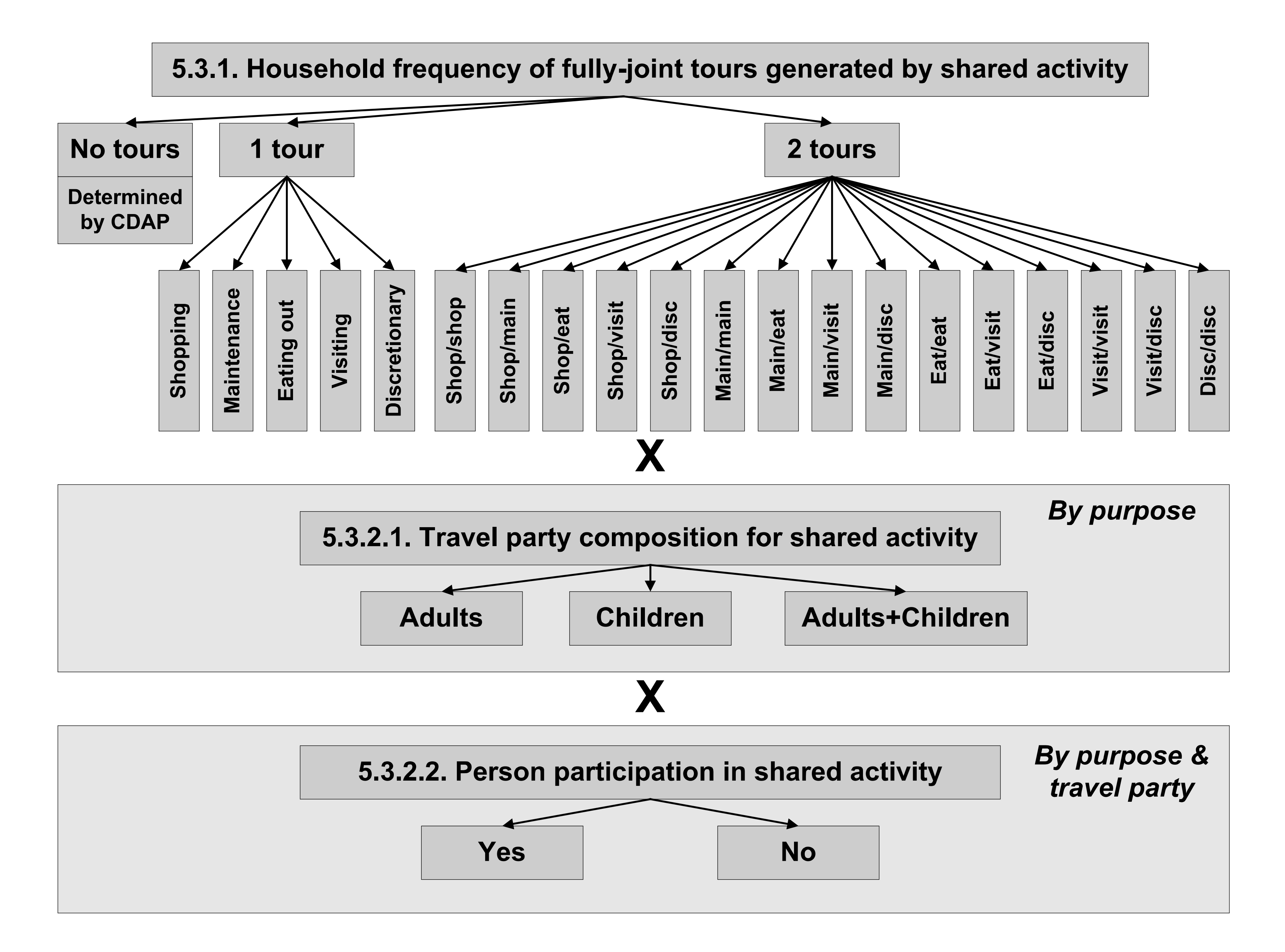

Figure 16: Household Generation and Person Participation in Fully Joint Tours

The joint tour frequency, composition, and participation sub-models are described below.

Joint Tour Frequency

Joint tour frequencies are generated by households, and include the number and purposes of the joint tours. The choice model has 20 alternatives including 5 one-tour alternatives by purpose and 15 possible non-ordered pair-wise combinations by purpose.

Later sub-models determine who in the household participates in the joint tour. The explanatory variables in the joint tour frequency model include household variables, accessibilities, and other urban form type variables. One of the most significant variables in the joint tour frequency model is the presence and size of overlapping time-windows, which represent the availability of household members to travel together after mandatory tours have been generated and scheduled. This formulation provides 'induced demand' effects on the generation and scheduling of joint tours; the frequency and duration of mandatory tours affects how many joint tours are generated and for what purpose.

Joint Tour Party Composition

Statistical analysis and model estimation has shown a strong linkage between trip purpose and typical party compositions. The essence of the joint party composition model is to narrow down the set of possible person participation choices modeled by the subsequent sub-model. Joint tour party composition is modeled for each tour, and determines the person types that participate in the tour. The model is trinary multinomial logit and has the following alternatives:

- Adults only,
- Children only,
- Adults and children.

Main explanatory variables include maximum time window overlaps across adults, children and adults or children after mandatory tours have been scheduled. Other variables include household structure, area type, and the purpose of the joint tour.

Person Participation in Joint Tour

Joint tour participation is modeled for each person and each joint tour as binary choice (to participate or not to participate). If the person type does not correspond to the composition of the tour determined in the joint tour composition model, they are ineligible to participate in the tour. Similarly, persons whose daily activity pattern type is Home are excluded from participating. Additionally, the model is constrained to only consider members with available time windows that have a minimal overlap.

In this approach, a binary choice model is estimated for each activity, party composition and person type. The model iterates through household members, and applies a binary choice to each to determine if the member participates. The model relies on microsimulation to assure that the appropriate persons participate in the tour as per the composition model. The model follows the logic depicted in **Figure 17** for a mixed party of adults and children. Explanatory variables include the person type of the decision-maker, the maximum pair-wise overlaps between the decision-maker and other household members of the same person type (adults or children), household and person variables, and urban form variables.

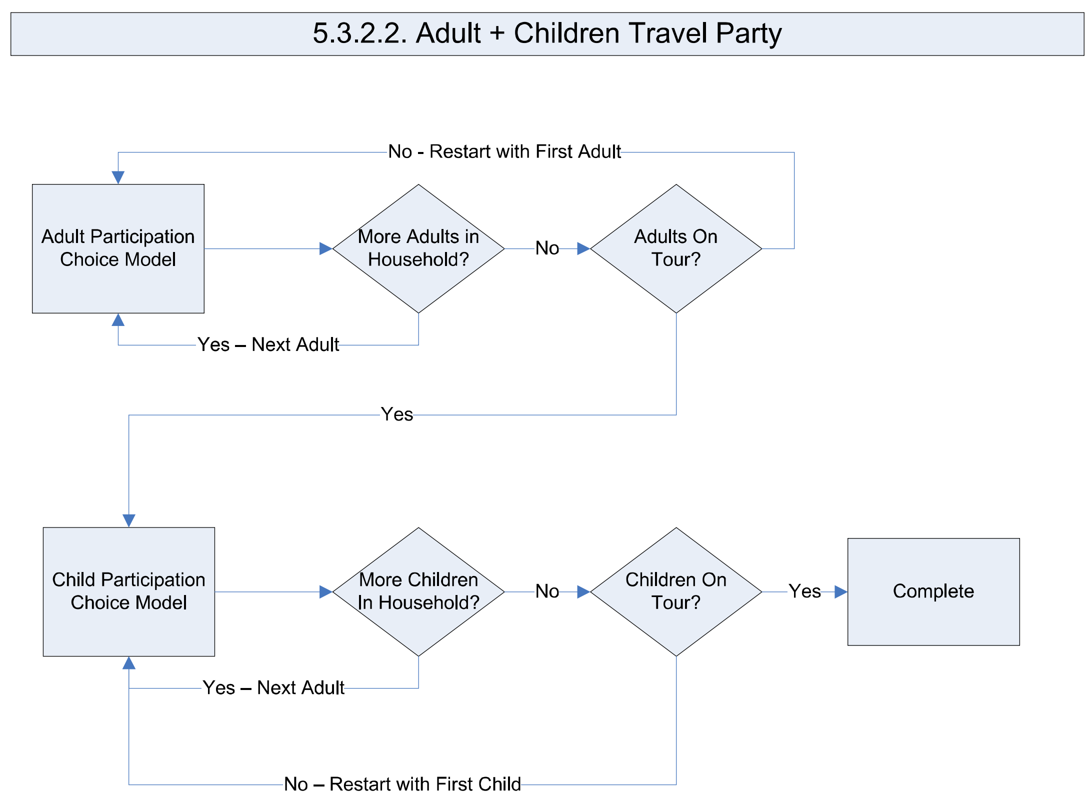

Figure 17: Application of the Person Participation Model

6.9. General Structure of Time-of-Day (TOD) Choice Model

The TOD choice model is a hybrid discrete-choice and duration construct that operates with tour departure-from-home and arrival-back-home time combinations as alternatives. TOD choice models of this type have been successfully applied in CT-RAMP ABMs developed in Columbus, Atlanta, and the San Francisco Bay Area as well as in non-CT-RAMP models developed in Denver and Sacramento.

The proposed utility structure is based on "continuous shift" variables, and represents an analytical hybrid that combines the advantages of a discrete-choice structure (flexible in specification and easy to estimate and apply) with the advantages of a duration model (a simple structure with few parameters, and which supports continuous time). The model has a temporal resolution of one-half hour between 5:00 AM (in the morning of the modeled day) and 1:00 AM (next day) that is expressed in 903 half-hour departure/arrival time alternatives. The model utilizes direct availability rules for each subsequently scheduled tour, to be placed in the residual time window left after scheduling tours of higher priority. This conditionality ensures a full consistency for the individual entire-day activity and travel schedule as an outcome of the model.

The model utilizes household, person, and zonal characteristics, most of which are generic across time alternatives. However, network LOS variables vary by time of day, and are specified as alternative-specific based on each alternative's departure and arrival time. By using generic coefficients and variables associated with the departure period, arrival period, or duration, a compact structure of the choice model is created, where the number of alternatives can be arbitrarily large depending on the chosen time unit scale, but the number of coefficients to estimate is limited to a reasonable number. Duration variables can be interpreted as "continuous shift" factors that parameterize the termination rate in such a way that if the coefficient multiplied by the variable is positive, this means the termination rate is getting lower and the whole distribution is shifted to the longer durations. Negative values work in the opposite direction, collapsing the distribution toward shorter durations.

In the CT-RAMP model structure, the tour-scheduling model is placed after destination choice and before mode choice. Thus, the destination of the tour and all related destination and origin-destination attributes are known and can be used as variables in the model estimation.

The choice alternatives are formulated as tour departure from home/arrival at home half-hour combinations (g,h), and the mode choice logsums and bias constants are related to multi-hour departure/arrival periods (s,t). Tour duration is calculated as the difference between the arrival and departure half-hours ($h-g$) and incorporates both the activity duration and travel time to and from the main tour activity, including intermediate stops.

The tour TOD choice utility has the following general form:

$$V_{gh} = V_g + V_h + D_{h-g} + \mu \ln\left(\sum_m V_{stm}\right) \qquad \textit{Equation 15}$$

where:

V_g, V_h	=	departure and arrival time-specific components
D_{h-g}	=	duration-specific components
m	=	entire-tour modes (SOV, HOV, walk to transit, drive to transit, non-motorized)
V_{stm}	=	mode utility for the tour by mode *m*, leaving home in period *s* (containing half-hour *h*) and returning home in period *t* (containing *g*)
μ	=	mode choice logsum coefficient.

For model estimation, the following practical rules can be used to set the alternative departure/arrival time combinations:

- Each reported/modeled departure/arrival time is related to the corresponding half-hour. For example, the half-hour "3" includes all times from 5:30 AM to 5:59 AM.
- Any times before 5 AM are collapsed to a single category and shifted to 5 AM, and any times after 1 AM are collapsed to a single category and shifted to 1 AM. This typically results in a shift for relatively few cases, and limits the number of half-hours in the model to 42.
- Every possible combination of the 42 departure half-hours with the 42 arrival half-hours (where the arrival half-hour is the same or later than the departure hour) is an alternative. This gives 42 × 43/2 = 903 choice alternatives.

The network simulations to obtain travel time and cost skims can be implemented for broader periods, for example:

- Early AM
- AM peak
- Early midday
- Late midday
- PM peak
- Night (evening, and late night)

Mode-choice logsums are used for all relevant combinations of the six time periods above. The model could include more TOD periods for network simulation, ultimately approaching a resolution of dynamic traffic assignment. In particular, the 7-8 a.m. peak hour can be singled out of the AM period and distinguished from the a.m. shoulders (6-7, 8-9). This would lead to a network simulation system with seven TOD periods, which is manageable, though an increase over the time periods considered by the existing four-step model.

For work and school activities, the TOD choice model is applied twice. First time, as sub-model 5.2.3 it is applied to define start and end times of the work and school activity episodes. At this stage, the details of work and school tours (and details of the other activities of the person day) are not known except for linkage of possible special event and possible participation in a fully joint tour. If there are several activity episodes allocated to several tours, the start time of the first one and the end time of the last one is modeled. Later on, in sub-model 6.2, the entire work and school tour TOD choice is modeled conditional upon the work / school activity schedule, other intermediate stops assigned to the work / school tour, and other activities and tours planned by the person.

6.10. Generation of Household Maintenance Tasks and Allocation to Persons

In the proposed structure for MAG ABM and in line with the general CT-RAMP methodology, household maintenance tasks are generated at the entire-household level and then allocated to household members for individual implementation. These tasks do not include joint maintenance activities and tours that are modeled earlier in the model system chain.

The *maintenance task generation* model represents a simultaneous choice of household task frequency by three maintenance activity types (escorting, shopping, and other maintenance). Statistical analysis with many metropolitan surveys including the NHTS 2008 in Phoenix and Tucson has shown the following ranges of frequencies for each maintenance task that cover over 99% of all observed household-days:

- 0 through 6 for escorting (7 alternatives),
- 0 through 5 for shopping (6 alternatives),
- 0 through 6 for other maintenance (7 alternatives).

Even a direct Cartesian product of these frequencies results in a manageable choice structure with 7×6×7=294 alternatives. However, the number of alternatives can be further significantly reduced by applying a threshold on the total number of maintenance activity episodes and excluding escorting of children to school if it is modeled by a separate model earlier in the model system chain as described above. The threshold for total number of maintenance activity episodes can be realistically set to 12. This would cover more than 99% of all observed household-days while a simple Cartesian product would include alternatives with up to 7+6+7=20 episodes. An explicit modeling of escorting children to school would significantly reduce the maximum number of remaining escorting episodes (to 3). Thus, the total number of alternatives in the maintenance task generation model can be reduced to 100-200. This is a comparatively simple choice structure where the component-wise structure of utilities can be successfully applied. The following main utility components will have to be estimated:

- Utility of implementation of a certain single maintenance task. Three components of this type (for escorting, shopping, and other maintenance) are estimated. This component includes the most explanatory variables that relates to household size, composition, income, car ownership; the chosen daily pattern types for all household members; and accessibility to the corresponding activity locations. If multiple activities of the same type or different types are implemented the utility is assumed to be linearly additive.
- Purpose-specific saturation effects. These components are normally estimated as frequency-specific dummies specified separately for escorting, shopping, and other maintenance. The maximum total number of possible dummies is 6+5+6=17 taking into account that zero episodes serves as the reference alternative. Some ways of parameterization of the activity-specific saturation effects can be also explored, for example making them specific to the household size.
- Over-arching saturation effects across all maintenance activity types. These components are normally estimated as frequency-specific dummies. The maximum total number of possible dummies is 11 taking into account that zero episodes serves as the reference alternative. Again, some ways of parameterization of the over-arching saturation effects can be explored.

The *allocation algorithm* is schematically shown in **Figure 18**. The procedure includes three major steps:

- Calculation of choice probabilities for each task to be implemented by a certain household member. The results of this step are written as an allocation probability matrix.
- Calculation of choice probabilities for each household member to implement a certain total number of household maintenance tasks. These probabilities are used to generate discrete choice for each person by random draw. The total across household members is compared to the given number of household maintenance tasks. If the total does not match the given number all person choices are redrawn again until the total has been matched.

- Discretiziation of the allocation matrix using the person totals as constraints. The discretizing procedure is applied in the following order: 1) eliminate all persons with zero totals, 2) rescale probabilities for each row to make total equal to 1, 3) choose a task randomly, 4) randomly choose the person for this task by the row probabilities, 5) eliminate the row, 6) if no more tasks left, go to End, 7) reduce the person active constraint by 1, 8) go to Step 1. Alternatively, discretization can be implemented in a standard microsimulation way after each choice for each task. However, experience has shown that in this case some unrealistic extreme cases can be generated with some household members significantly overloaded. The proposed matrix discretization allows for a better control over the entire-household consistency.

5.4.1. Household maintenance tasks	5.4.2.1. Task allocation choice probabilities	Household members by person type					
		Full-time worker	Part-time worker	Non worker	University student	School child	Pre-school child
Escorting		0.1	0.4	0.4	0.1	0.0	0.0
Escorting		0.1	0.4	0.4	0.1	0.0	0.0
Shopping		0.1	0.2	0.5	0.1	0.1	0.0
Other maintenance		0.1	0.4	0.4	0.1	0.0	0.0
Other maintenance		0.1	0.4	0.4	0.1	0.0	0.0

Redraw if does not match HH total

5.4.2.2. Total frequency choice for each person					
1	2	1	1	0	0

5.4.2.3. Discretize by row in random order and eliminating persons who reached the total					
1	0	0	0	0	0
0	1	0	0	0	0
0	0	1	0	0	0
0	1	0	0	0	0
0	0	0	1	0	0

Figure 18: Allocation of Household Maintenance Tasks

6.11. Tour Formation for Maintenance and Discretionary Activities

One of the limitations of the previous versions of the CT-RAMP structure was a sequential process where tours for all purposes were generated first while intermediate stops where added afterwards by means of stop-frequency models applied at the tour level. Two points of weakness have been mentioned with regard to the previous structure:

- Dominance of the tour-based modeling technique over an activity-based modeling technique. In a genuine activity-based paradigm, activities are modeled first as the fundamental component of the daily activity pattern, and tours are formed as a means to reach those activities in the most effective way. This is of course, not an absolute principle. One can arguably mention that not all activities are premeditated and some of them are generated spontaneously within the tour. For example, stopping at Starbucks on the way to or from work or other primary destination can be rather driven by the immediate opportunity rather than preplanned at the day level. In this regard, an appealing way to address this issue is to classify all activity episodes as either major (assuming they are preplanned) or travel-driven (was convenient to stop on the way). Within this paradigm, the tour formation model should only address the major activities while the travel-drive activities should be inserted as additional stops on the tours (in the way similar to the tour-level stop-frequency models applied in most ABMs in practice). This approach should be explored at Phase 2. The issue that has to be resolved is how the travel-driven activities can be singled out in the HTS by using the observed parameters like activity type, activity duration, and route deviation.

- Only partial integrity with respect to the resulted number of activities generated as tour primary destinations and intermediate stops. Stop frequency for each tour is conditional upon the tour frequency for the given person and household. However, there is no conditional linkage across stop frequencies for different tours as well as any upward impact of stop-frequency on the number of tours. One of solutions, incorporated in the Sacramento ABM was to predict first the total number of stops for each person and then use the generated stops as a “queue” (or constraint) from which the subsequent tour-level stop-frequency models would take stops until the queue has been exhausted. This scheme, however, is dependent upon the order of tour processing.

Several simpler approaches and enhancements to the basic CT-RAMP structure have been recently applied in the San Diego ABM in order to add more integrity in the tour-formation procedure and specifically better balance the daily tour frequency and stop frequency on each tour. In the San Diego ABM, first all tours are generated and then intermediate stops are inserted. However, many explanatory variables have been added to the stop-frequency models (number of tours by purpose, their attributes, number of stops already assigned to the higher-priority tours, etc). The San-Diego ABM structure in this regard can be considered as the fall-back approach if the more advanced procedure outlined below cannot be implemented. However, our intention is to develop and test an advanced approach that would address the substitution effect between number of tours and number of stops in an explicit and behaviorally appealing way.

The proposed tour-formation procedure is designed to address these two aspects for allocated maintenance tasks and discretionary activities implemented individually. The procedure is applied after all maintenance tasks have been allocated to the household members. It is applied for each person separately assuming that the person will work the allocated maintenance tasks and individual discretionary activities into his/her schedule individually. At this stage, for each person the following components of the DAP are already known:

- Participation in a special event with activity location, start time, and end time
- Traveling to / from a certain airport with departure / arrival time
- The type (work, school) and frequency (1 or 2 tour episodes) of mandatory activities, with start time and end time for each episode
- Linkage of special events or trips to / from airport to mandatory tours (outbound stop, inbound stops, or separate home-based tour)
- Participation in fully joint household tours with primary activity location, tour start time, tour end time, and stop frequency (additional joint activities)
- The number of maintenance tasks by purpose (escorting, shopping, other maintenance)[1]

The non-mandatory activity allocation procedure is presented in **Figure 19**.

[1] In subsequent versions of CT-RAMP, these tasks can be associated with certain attributes (location if predetermined, mode accessibility constraints, activity start and end time constraints, etc) that can be taken into account in the tour-formation procedure. These attributes may affect the consideration of each activity to be a part of the commuting tour or form a seed for a separate home-based tour or be a stop on some other maintenance tour. For each activity modeled as a special event (i.e. with the supply side in a particular location preceding the household/person generation), this create a mechanism to account for this activity specifics from the trip chaining standpoint. The proposed model structure is open for further enhancements in line with more substantial differentiation of activities from the supply side and integration with the demand side. In the current version, however, only mandatory activities and special events are modeled with already known location and schedule.

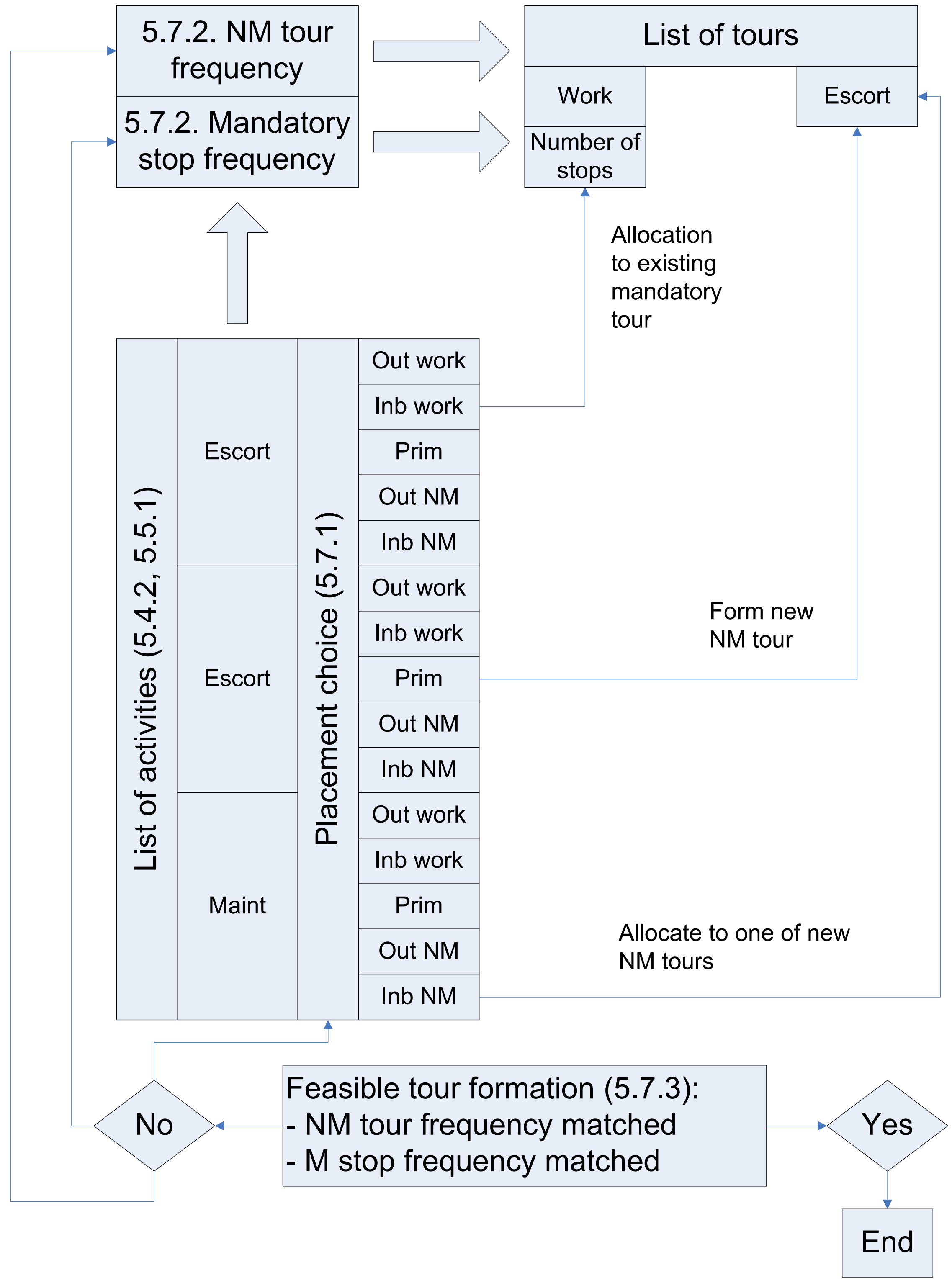

Figure 19: Tour Formation for Maintenance Tasks and Individual Discretionary Activities

The non-mandatory activity allocation procedure includes the following steps:

1. Calculate probabilities for total individual non-mandatory tour frequency based on a choice model with the following set of alternatives: 0,1,2,3,4,5+. This model is needed to reasonably constrain the total number of tours and also link the tour frequency to accessibility and density variables, as well as the number and duration of the previously scheduled activities. This model, however, is used only as a stochastic constraint, not as the final outcome.

2. Calculate probabilities for total maintenance and discretionary stop frequency for mandatory tours based on the choice model with the following set of alternatives: 0,1,2,3,4,5,6+. This model is needed to reasonably constrain the complexity of work/school tours in the given urban and travel conditions as well as the number of previously scheduled activities. This model is also used only as a stochastic constraint, not as the final outcome.

3. Calculate placement-in-the-tour probabilities for each activity in the list (that was either allocated to the person as maintenance task or generated as individual activity) for the following alternatives: 1=outbound stop on the first work/school tour, 2=inbound stop on the first work/school tour, 3=outbound stop on the second work/school tour, 4=inbound stop on the second work/school tour, 5=primary destination for a separate non-mandatory tour, 6=outbound stop on a non-mandatory tour, 7=inbound stop on a non-mandatory tour. Alternatives 1-4 are unavailable if the person does not have mandatory tours. Alternatives 3 and 4 are also unavailable if the person has only one mandatory tour. The placement probabilities are functions of the number of non-mandatory activities, person and household characteristics, urban and travel environment, as well as the schedule for the mandatory activity. The proportion between primary destinations vs. stops on mandatory and non-mandatory tours reflects trip chaining propensities.

4. Randomly choose one total non-mandatory tour frequency based on the probabilities calculated at Step 1.

5. Randomly choose one total stop frequency on mandatory tours based on the probabilities calculated at Step 2.

6. Randomly choose one placement alternative for each activity in the list based on the probabilities calculated at Step 3.

7. Perform a feasibility check of tour formation with respect to the number of non-mandatory tours. The total generated at Step 4 should be equal to the total number of primary destinations generated at Step 6. If not, go to step 4. Restarting from Step 4 allows for a greater sensitivity to urban and travel conditions expressed in the placement probabilities. In this case, the resulted total tour frequencies might be different from the frequencies embedded in the frequency model at Step 1 due to selective feasibility rules favoring frequencies that structurally match the placement probabilities. An alternative option is to restart from Step 5 or Step 6 only that would guarantee the replication of aggregate tour frequency shares generated by the model at Step 4.

8. Perform a feasibility check on tour formation with respect to the number of maintenance stops on mandatory tours. The total generated at Step 5 should be equal to the total number of outbound and inbound stops on non-mandatory tours. If not, go to step 4.

9. Form non-mandatory tours according to the primary destinations identified at Step 6.

10. Distribute non-mandatory stops by mandatory & non-mandatory tours and half-tours according to the placement choice made at step 6. If there are multiple mandatory or non-mandatory tours where the stop can be placed, choose one randomly.

There are many ways how the tour-formation procedure could be improved in future. However, these improvements would require new type of data that is not available in conventional household surveys. For example, for a better understanding and modeling of tours it would be beneficial to distinguish between three types of activities:

- Activities with a fixed location and schedule (start and end time). These activities are not bound to work and school (in fact, mandatory activities are frequently characterized by a certain degree of flexibility with respect to the timing) but also include doctor/dentist appointments, shows, sport events, dropping-off and picking-up passengers, etc. It is reasonable to assume that individuals build their daily schedules and travel tours pivoting-off these activities. Joint activities of this type are especially important for constraining schedules of the household members.
- Activities with a fixed location but flexible schedule like visiting a certain store for a particular shopping type. It is reasonable to assume that individuals try to link these activities to the other activities in order to optimize their travel arrangements and capitalize on the schedule flexibility. It can be reasonably assumed that most of travel tour skeletons are defined by the first two types of activities.
- Activities with a flexible location and schedule like grocery shopping or visiting a coffee shop. It can be reasonably assumed that these activities are most frequently "inserted" in the travel tours depending on the time-space constraints but rarely play a role of the primary destination (except for short non-motorized tours).

6.12. Tour-Level and Trip-Level Models

Principal structure of the tour-level and trip-level models is shown in **Figure 20** for four main tour types generated by the day-level models at the previous stage. While all tour types follow a similar sequence of sub-models, there are certain specifics of each of them. Each of sub-models is described below.

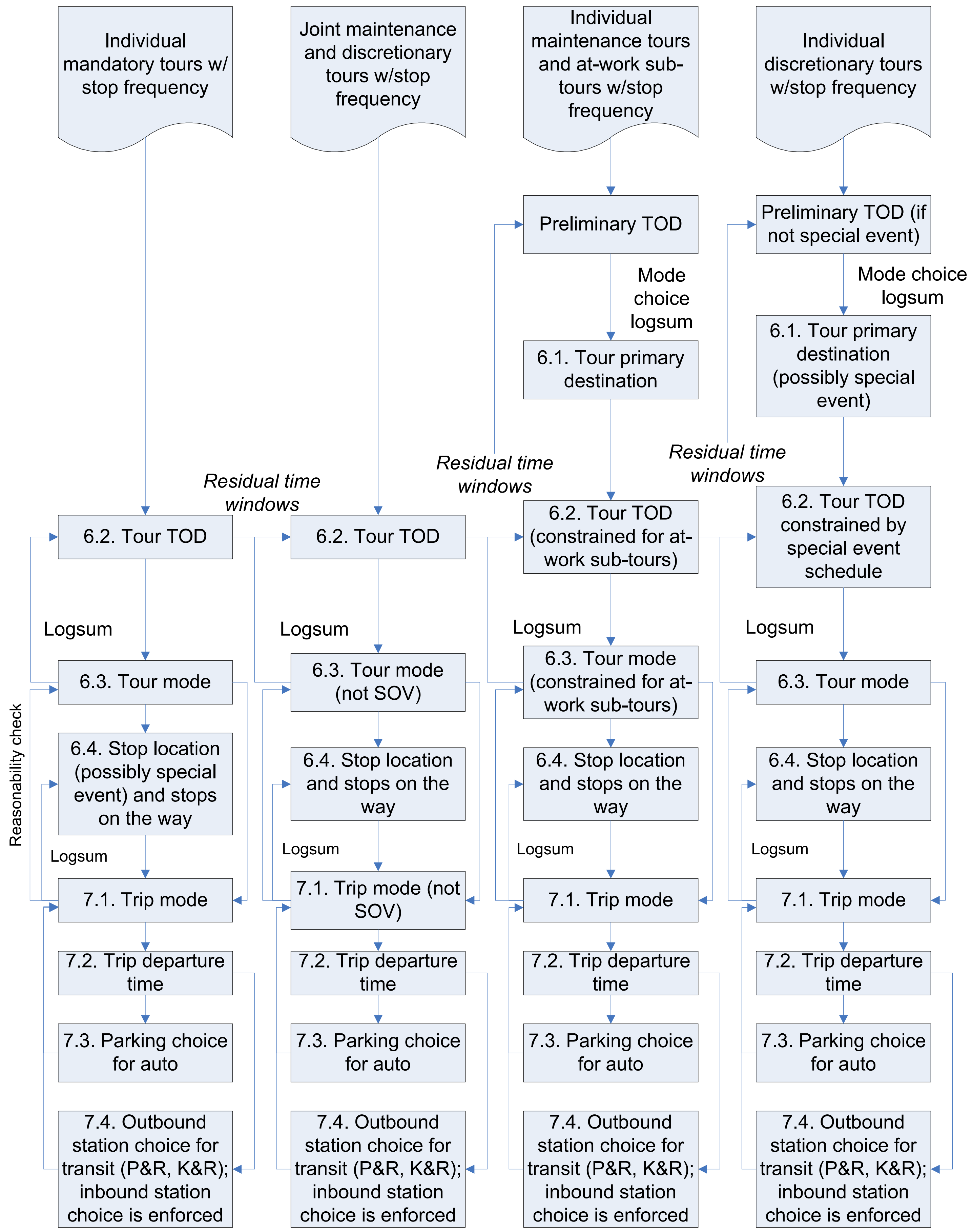

Figure 20: Tour-Level and Trip-Level Models

Tour Primary Destination Choice

The primary destination choice model determines the location of the tour primary destination. The model is applied for each tour and, in general, it has the same MNL form for all tour types and purposes.

However, there are many details that differ by tour type including the model placement in the model system:

- For *mandatory* tours, the primary destination is modeled early in the model chain (and is largely defined by the usual location from sub-model 2.1) since it plays an important role as determinant of the mobility attributes and entire day pattern. It will be determined after statistical analysis with the new Household Travel Survey, if it is necessary to have an additional model for work tour destination or the usual work location can be automatically adopted.

- For *fully joint tours*, the primary destination is modeled immediately after joint tour frequency (sub-model 5.3.3) since it is necessary for identification of the time windows available for the other activities before individual tour formation. For fully joint tours, the destination is chosen for the entire tour and assigned to all tour participants.

- For *individual maintenance and discretionary* tours as well as at-work sub-tours, the primary destination is modeled later for each tour (sub-model 6.1), taking into account the residual time window left for the corresponding activity. d

The model works at a TAZ level (or smaller spatial units if applied including a possible parcel-level implementation), and sampling of destination alternatives is implemented in order to reduce computation time. Explanatory variables include household and person characteristics, the tour purpose, logged size (i.e. attraction) variables, round-trip mode choice logsum, distance, and other variables. Note that the mode choice logsum used is based a preliminary chosen "representative" time period for each tour type and purpose, since the actual time period is not chosen until sub-model 6.2.

In general, in the model estimation and application, all TAZs in the region with non-zero size variables are considered available for each corresponding tour. We plan to enhance the availability rule by application of time-space constraints. Only destinations that can be reached within the available time window will be considered. Tracking time-space constraints as well as some computational considerations makes it appealing to apply all linked tour-level models (primary destination, TOD, and mode) at the same time for each tour and then move to the next tour in the person hierarchy.

Tour Time of Day Choice

The same basic structure of TOD choice model that was fully described above with 903 alternatives (combinations of tour departure half-hour and arrival half-hour back at home) is applied for each tour type and purpose. The TOD choice implementation for a person with multiple tours follows the logical conditional sequence:

- Tour TOD choice is first modeled for *mandatory tours*. It is conditional upon the primary location and duration for mandatory activity, tour structure and presence of outbound and inbound stops (including possible participation in special events) as well as necessity to reserve time window for fully joint tours (if the person participates). If escorting or carpooling synchronization was applied in sub-model 5.2.4.2 the tour departure time and/or arrival time for all "bundled" persons is enforced to be equal to the departure / arrival time of the driver.

- After *joint tours* have been generated and assigned a primary location, the tour departure time from home and arrival time back at home for them is chosen simultaneously. However, a unique condition applies when applying the time-of-day choice model to joint tours. That is, the tour departure and arrival period combinations are restricted to only those available for each participant on the tour, after scheduling mandatory activities. Once the tour departure/arrival time combination is chosen, it is applied to all participants on the tour.

- Next, *individual maintenance* tours are scheduled in the residual time windows left for the person after mandatory and joint tours have been scheduled.

- Next, *individual discretionary tours* are scheduled in the residual time windows left for the person after mandatory, joint, and individual maintenance tours have been scheduled. If primary destination is a Special Event the tour arrival and departure times are conditional upon the start time and duration of the Special Event.

- Finally, after *at-work sub-tours* have been generated for each work tour and assigned a primary destination, they are scheduled within the parent work tour activity window (between the work start and end time).

At-Work Sub-Tour Frequency

Work-based sub-tours are modeled last, and are relevant only for those persons who implement at least one work tour. These underlying activities are mostly individual (e.g., business-related and dining-out purposes), but may include some household maintenance functions as well as person and household maintenance tasks assigned by the tour-formation procedure as stops. There are the following 10 alternatives in the model for each work tour, corresponding to the most frequently observed patterns of at-work sub-tours (the alternatives define both the number of at-work sub-tours and their purpose by MNL or NL model):

- No sub-tours
- 1 eating our tour
- 1 business tour
- 1 maintenance tour
- 2 eating out tours (infrequent alternative that might be dropped if not observed in the Survey)
- 2 business tours
- 2 maintenance tours (infrequent alternative that might be dropped if not observed in the Survey)
- 1 eating out tour and 1 business tour

- 1 eating out tour and 1 maintenance tour (infrequent alternative that might be dropped if not observed in the Survey)

- 1 business tour and 1 maintenance tour (infrequent alternative that might be dropped if not observed in the Survey)

Explanatory variables include household and person attributes, duration of the parent work tour, the number of joint and individual non-mandatory tours already generated in the day, as well accessibility and urban form variables.

Tour Mode Choice

By means of this model, the "main tour mode" used to get from the origin to the primary destination and back is determined. Tour mode choice model is normally fully segmented by at least six main tour types and purposes (work, university, school K-12, joint non-mandatory, individual non-mandatory, and at-work) while additional segmentation by purpose is applied for specific variables (most frequently, mode-specific constants).

The tour-based modeling approach requires a certain reconsideration of the conventional mode choice structure. Instead of a single mode choice model pertinent to a four-step structure, there are two different levels where the mode choice decision is modeled:

- The *tour* mode level (upper-level choice). The tour mode is defined based on the anchor locations of tour origin and primary destination with not knowing yet exact locations for each stop although the number of intermediate stops is already known.

- The *trip* mode level (lower-level choice conditional upon the upper-level choice). Trip mode choices are also coordinated between different trips on the tour to ensure a consistent and feasible chain of trips.

The tour mode level reflects the most important decisions that a traveler makes in terms of using a private car versus using public transit, non-motorized, or any other mode. Trip-level decisions correspond to details of the exact mode used for each trip. Modes for the tour mode choice model are shown in **Figure 21**, along with the most common nesting principles. The model is distinguished by the following characteristics:

- Segmentation of the HOV mode by *occupancy* categories, which is essential for modeling specific HOV/HOT lanes and policies

- An explicit modeling of *toll vs. non-toll* route type choices as highway sub-modes, which is essential for modeling highway pricing projects and policies

- Distinguishing between certain *transit sub-modes* that are characterized by their attractiveness, reliability, comfort, convenience, and other characteristics beyond travel time and cost (such as

Local Bus, Express Bus, Bus-Rapid Transit, Light-Rail Transit, and Commuter Rail)

- Distinguishing between *walk and bike* modes if the share of bicycle trips is significant. This is essential if policies associated with improved pedestrian environment or bicycle lanes are considered.

- Consideration of *special modes* that are relevant for certain travel markets. School bus is a frequent mode for school trips. Taxi is a frequent mode for trips to and from airports and (possibly) special events attended by non-resident visitors. Air link between Phoenix and Tucson can compete with auto and transit for intercity trips.

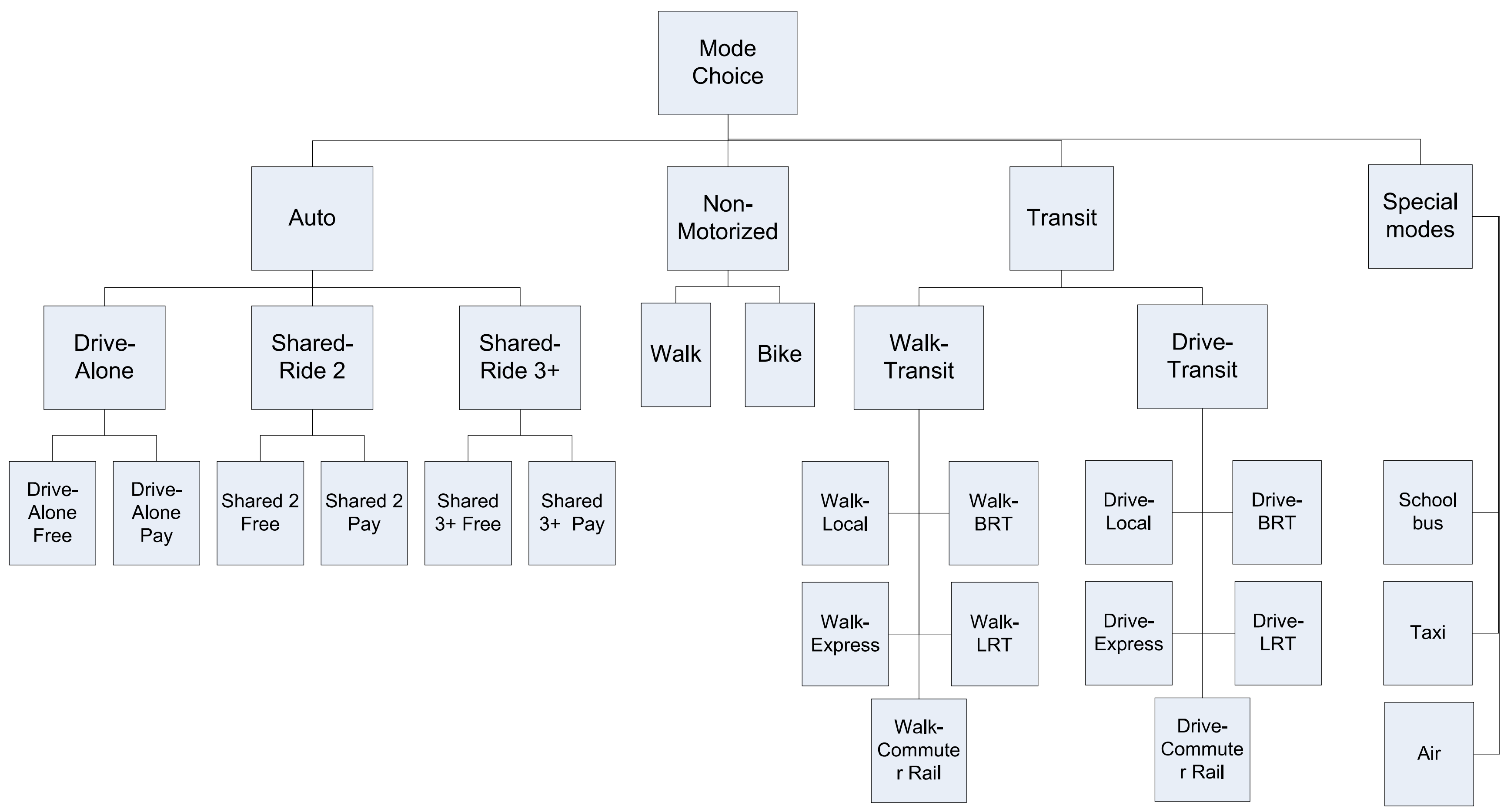

Figure 21: General Structure of Tour Mode Choice Model

Note that free and pay alternatives for each auto mode provide an opportunity for toll choice as a path choice within the nesting structure. This requires separate free and pay skims to be provided as inputs to the model (where free paths basically "turn off" all toll and HOT lanes). Transit skims are segmented by local versus premium (express bus, BRT, LRT, and commuter rail) modes, but as described below, the mode used for the longest segment of in-vehicle time is used to define the actual premium ride mode in the creation of transit level-of-service. Transit ride modes are based on a modal hierarchy in which modes that are ranked lower in the hierarchy are used as feeder modes to modes ranked higher.

The tour mode choice model is based on the round-trip level-of-service (LOS) between the tour anchor location (home for home-based tours and work for at-work sub-tours) and the tour primary destination. The tour mode is chosen based on LOS variables for both directions according to the time periods for the tour departure from the anchor and the arrival back at the anchor. This is one of the fundamental advantages of the tour-based approach. For example a commuter can have very attractive transit service in the a.m. peak period in the outbound direction, but if the return home time is in the midday or later at night, the commuter may prefer private auto due to lower off-peak transit service.

The tour mode choice model contains a number of household and person attributes, including income, auto sufficiency, age, etc. Urban form variables are also important, particularly related to the choice of non-motorized modes.

Intermediate Stop Location Choice Model

The stop location choice model predicts the location of outbound and inbound stops along the tour other than the primary destination. The stop-location model is structured as a MNL model using zonal attraction size variable and route deviation measure as impedance. The alternatives are sampled from the full set of zones (at either TAZ level or smaller units), subject to availability of a (non-zero) zonal attraction size term. The sampling mechanism is also based on accessibility between tour origin and primary destination, and is subject to certain rules based on tour mode. All destinations are available for auto tour modes, so long as there is a positive size term for the zone. Intermediate stops on walk tours must be within 4 miles of both the tour origin and primary destination zones. Intermediate stops on bike tours must be within 8 miles of both the tour origin and primary destination zones. Intermediate stops on walk-transit tours must either be within 4 miles walking distance of both the tour origin and primary destination, or have transit access to both the tour origin and primary destination. Additionally, only zones within walking distance to the tour transit mode are available destinations on walk-transit tours.

The intermediate stop location choice model works by cycling through stops on tours. The LOS variables (including mode choice logsums) are calculated as the additional utility between the last location and the next known location on the tour. For example, the LOS variable for the first stop on the outbound direction of the tour is based on additional impedance between the tour origin and the tour primary destination. The LOS variable for the next outbound stop is based on the additional impedance between the previous stop and the tour primary destination. Stops on return tour legs work similarly, except that the location of the first stop is a function of the additional impedance between the tour primary destination and the tour origin. The next stop location is based on the additional impedance between the first stop on the return leg and the tour origin, and so on.

The stop-location model is normally segmented by six main tour types and purposes (work, university, school, joint non-mandatory, individual non-mandatory, at work). Additional segmentation rules can be established by stop activity type as part of statistical analysis and model estimation. Two additional auxiliary procedures will be considered and adopted after statistical analysis with the new Household Travel Survey:

- *Order of implementation of outbound and inbound stops by purpose*. The individual tour-formation procedure (sub-model 5.7) and as stop-frequency model for fully joint tours (sub-model 5.3.4) only define a set of stops for each sub-tour but not their sequence of implementation. The sequence of implementation is not trivial if there are two or more stops on either outbound or inbound half-tour with different purposes. An algorithm for stop implementation order will be developed and calibrated based on the stop-purpose-specific densities around the tour origin and destination.

- *Insertion of secondary stops "on the way"*. The majority of stops associated with significant planned activities are modeled explicitly as allocated maintenance task and individual discretionary activities (for individual tours) as well as intermediate stops (for fully joint tours). However, in reality some stops are induced by density of opportunities on the way rather than planned in advance as separate activity episodes. A good example is multiple stops for shopping on a shopping tour. Another typical example is a "Starbucks" stop for short eating. There are two distinctive features of stops "on the way": 1=short activity duration, 2=insignificant route deviation. In addition , stops "on the way" frequently have a duplicative purpose compared to the primary destination and other stops. Stops "on the way" are also more frequent on auto and non-motorized tours and less frequent on transit tours. A statistical procedure will be developed for screening stops "on the way" in the Household Travel Survey. Subsequently, a probabilistic choice model will be developed for each tour and trip to have a stop "on the way" and to find a location for it.

Trip Mode Choice Model

The trip mode choice model determines the mode for each trip along the tour. Trip modes are constrained by the main tour mode. The linkage between tour and trip levels is implemented through correspondence rules (which trip modes are allowed for which tour modes). The model can incorporate asymmetric mode combinations, but in reality, there is a great deal of symmetry between outbound and inbound modes used for the same tour. In particular, symmetry is enforced for drive-transit tours, including choice of the same parking lot in both directions.

The tour and trip mode correspondence rules are shown in **Table 20**. Note that in the MAG trip mode choice model, the trip modes are exactly the same as the modes in the tour mode choice model. However, every trip mode is not necessarily available for every tour mode. The correspondence rules depend on a kind of hierarchy, which is similar to that used for the definition of transit modes. The hierarchy is based on the following principles:

1) Pay trip modes are only available for pay tour modes (for example, drive-alone pay is only available at the trip mode level if drive-alone pay is selected as a tour mode).

2) The auto occupancy of the tour mode is determined by the maximum occupancy across all auto trips that make up the tour. Therefore, the auto occupancy for the tour mode is the maximum auto occupancy for any trip on the tour.

3) Transit tours can include auto shared-ride trips for particular legs. Therefore, "casual carpool", wherein travelers share a ride to work and take transit back to the tour origin, is explicitly allowed in the tour/trip mode choice model structure. This proved to be important for such metropolitan regions as San Francisco. However, the relevance of this model component for the Phoenix region will be determined after statistical analysis with the new Household Travel Survey.

4) The walk mode is allowed for any trip on a tour except for drive-alone, wherein the driver must use the vehicle for all trips on the tour.

5) The transit mode of the tour is determined by the highest transit mode used for any trip in the tour according to the transit mode hierarchy as described in **Table 20**. As previously mentioned, free shared-ride modes are also available in transit tours, albeit with a low probability.

For parsimony, drive-transit modes are not included in **Table 20.** Because intermediate stops are infrequent on drive-transit tours, the availability rules simply for them would follow the transit mode hierarchy.

The trip mode choice models explanatory variables include household and person variables, LOS variables between the trip origin and destination according to the time period for the tour leg, urban form variables, and alternative-specific constants segmented by tour mode.

Table 20: Tour and Trip Mode Correspondence Rules

Tour Mode	Drive Alone Non-Toll	Drive Alone Toll	Shared 2 Non-Toll, Non-HOV	Shared 2 Non-Toll, HOV	Shared 2 Toll, HOV	Shared 3+ Non-Toll, Non-HOV	Shared 3+ Non-Toll, HOV	Shared 3+ Toll, HOV	Walk	Bike	Walk-Transit	PNR-Transit	KNR-Transit
Drive-Alone Non-Toll	Must	Cannot	Cannot	Cannot	Cannot	Cannot	Cannot	Cannot	Cannot	Cannot	Cannot	Cannot	Cannot
Drive-Alone Toll	Can	Can	Cannot	Cannot	Cannot	Cannot	Cannot	Cannot	Cannot	Cannot	Cannot	Cannot	Cannot
Shared 2 Non-Toll, Non-HOV	Can	Cannot	Can	Cannot	Cannot	Cannot	Cannot	Cannot	Can	Cannot	Cannot	Cannot	Cannot
Shared 2 Non-Toll, HOV	Can	Cannot	Can	Can	Cannot	Cannot	Cannot	Cannot	Can	Cannot	Cannot	Cannot	Cannot
Shared 2 Toll, HOV	Can	Can	Can	Can	Can	Cannot	Cannot	Cannot	Can	Cannot	Cannot	Cannot	Cannot
Shared 3+ Non-Toll, Non-HOV	Can	Cannot	Can	Cannot	Cannot	Can	Cannot	Cannot	Can	Cannot	Cannot	Cannot	Cannot
Shared 3+ Non-Toll, HOV	Can	Cannot	Can	Can	Cannot	Can	Can	Cannot	Can	Cannot	Cannot	Cannot	Cannot
Shared 3+ Toll, HOV	Can	Can	Can	Can	Can	Can	Can	Can	Can	Cannot	Cannot	Cannot	Cannot
Walk	Cannot	Cannot	Cannot	Cannot	Cannot	Cannot	Cannot	Cannot	Must	Cannot	Cannot	Cannot	Cannot
Bike	Cannot	Cannot	Cannot	Cannot	Cannot	Cannot	Cannot	Cannot	Can	Can	Cannot	Cannot	Cannot
Walk-Transit[2]	Cannot	Cannot	Can	Can	Cannot	Can	Can	Cannot	Can	Cannot	Can	Cannot	Cannot
PNR-Transit	Cannot	Cannot	Cannot	Cannot	Cannot	Cannot	Cannot	Cannot	Cannot	Cannot	Cannot	Must	Cannot
KNR-Transit	Cannot	Cannot	Cannot	Cannot	Cannot	Cannot	Cannot	Cannot	Cannot	Cannot	Cannot	Cannot	Must

[2] For transit modes, any mode ranked higher in the modal hierarchy is unavailable as a trip mode on the tour. For example, if the tour mode is LRT, then local bus, express bus, bus-rapid transit, and LRT are available for any trip on the tour, but commuter rail is not available.

Trip Departure Time Choice

This sub-model depends on the type of network assignment procedures. With conventional static assignments implemented by crude 3-4 hour time-of-day periods this sub-model can be simplified or even eliminated. In the latter case, the chosen half-tour hour (or half-hour with the enhanced temporal resolution) is assigned to each trip on the half-tour (the way how the Columbus and Lake Tahoe ABMs are implemented). To refine this approach, in the CT-RAMP ABMs developed for Atlanta and Bay Area, a probabilistic choice model for trip departure time within the tour was applied.

This sub-model becomes much more important in view of the forthcoming integration of the MAG ABM with DTA. This requires from trip departure time choice model to operate with a finer level of temporal resolution and be sensitive to network conditions including congestion and pricing. The following structural details of the trip departure time model can be outlined at this stage:

- Trip departure time choice model is applied *after the tour time-of-day choice model*; thus tour departure from home and arrival back home half-hour intervals are known. For example, consider a work tour that departs from home between 7:00 AM and 7:30 AM and arrives back home between 7:00 PM and 7:30 PM with two inbound stops the first one for maintenance (banking) and the second one for shopping. This means that the tour contains one outbound trip (home-work) and three inbound trips (work-maintenance, maintenance-shopping, shopping-home).

- Departure time choice for each trip is preceded by the tour *main activity start & end time choice* within the tour window that also operates with half-hour resolution and accounts for the minimal required commuting time by the chosen mode and number of stops in each direction. The commuting time with stops includes total time between all consecutive trips plus minimum stop activity durations. Let's assume that the main work episode starts between 8:00 and 8:30 AM and ends between 4:30 and 5:00 PM.

- The trip departure time choice in the *outbound* direction is implemented with a 5-min temporal resolution and should be scheduled around the chosen half-hour intervals for the departure from home and work activity start. The choice set should include 7 departure time alternatives (7:00, 7:05, 7:10, 7:15, 7:20, 7:25, and 7:30 AM). Feasibility of each alternative should be additionally checked against the preferred arrival time at work (between 8:00 and 8:30 AM) using the predicted travel time. The alternative should be made unavailable if this constraint is not met. For a trip between home and primary destination where intermediate stops are not involved the departure time alternatives are only distinguished by travel time and associated arrival time at work.

- The trip departure time choice for the *first trip in the inbound* direction is implemented with a 5-min temporal resolution and should be scheduled around the chosen half-hour intervals for the departure from work (work activity end). The choice set should include 7 departure time alternatives (4:30, 4:35, 4:40, 4:45, 4:50, 4:55, and 5:00 PM). Let's assume that 4:40 PB has been chosen. Let's also assume that the predicted trip time between work and 1st stop (maintenance) is 15 min and the minimum duration for maintenance activity is 5 min. This means that the earliest possible departure time for the 2nd trip (from the maintenance activity location to shop location) is 5:00 PM. For a trip between the primary destination and first stop, the departure time alternatives are only distinguished by travel time and associated departure time from work.

- The trip departure time choice for the *second trip in the inbound* direction is implemented with a 5-min temporal resolution and should be scheduled after the earliest possible departure from the maintenance activity location (5:00 PM). On the other hand the latest possible departure is constrained by the necessity to arrive back home no later than 7:30 PM and reserve time for the subsequent trip from the maintenance to shopping location (let's assume that estimated travel time is 20 min), implement a shopping activity (let's assume the minimum duration of 15 min), and implement a trip from the shopping location home (lets' assume 25 min). Then the choice set should end at 6:30 PM and should include 19 departure time alternatives (5:00, 5:05, 5:10 ... 6:20, 6:25, and 6:30 PM). Let's assume that 5:45 PB has been chosen. This means that the earliest possible departure time for the 3rd trip (from the shopping activity location home) is 6:20 PM. For a trip between the first stop and second stop, the departure time alternatives are distinguished by travel time and associated duration of the first-stop activity (maintenance).

- The trip departure time choice for the *third trip in the inbound* direction is implemented with a 5-min temporal resolution and should be scheduled after the earliest possible departure from the shopping activity location (6:20 PM). On the other hand the latest possible departure is constrained by the necessity to arrive back home no later than 7:30 PM and reserve time for the subsequent trip from the shopping location home (assumed 25 min). Then the choice set should end at 7:05 PM and should include 10 departure time alternatives (6:20, 6:25, 6:30 ... 6:55, 7:00, and 7:05 PM). For a trip between the second stop and home, the departure time alternatives are distinguished by travel time and associated duration of the second-stop activity (shopping).

It is important to mention that while activity duration can be adequately taken into account by activity type and person/household variables, travel time and cost can be effectively used only if they are supplied with the logical variation across the 5-min intervals within each choice set. If the ABM is combined with conventional static assignments implemented by crude time-of-day periods, the time and cost variables will be largely identical across most of the compared alternatives. Thus, the ultimate purpose of this model can be fully achieved only if the ABM is integrated with DTA.

Parking Location Choice

The parking location choice model will be applied to tours with a destination in the urban area/city center with parking charges. The Columbus ABM incorporates three of the following interrelated sub-models to capture the current parking conditions in CBD, and allows for testing various policies:

- Parking cost model: sensitive to buffered zonal density and parking capacity. This auxiliary model provides important input to the parking location and mode choice models. In absence of this model, this input has to be prepared along with the other land-use variables.
- Person-free parking eligibility model: formulated as binary characteristic for each worker (whether he/she has to pay for parking in the CBD or not). This sub-model is included in the set of mid-term models for individual mobility attributes.
- Parking location choice model: this is for the primary destination of each tour that is a nested logit structure. At the upper level, the binary choice between parking in versus outside the destination TAZ is modeled. At the lower level, the choice of parking zone is modeled for those who did not park in the destination TAZ.

We plan to include these three sub-models in the MAG AB model basic design. This model can also incorporate parking supply constraints and parking allocation process over the day, and feed back the parking choice logsums to the upper-level choice models (i.e., the mode and destination choice models).

The parking lot choice model will be estimated with Household Travel Survey data and any additional data collected. The model will be applied within the software architecture of the ABM system and tested to ensure that it is behaving as expected. The model will be calibrated to ensure that it is adequately reflecting observed base-year parking lot choice data.

7. General Software Architecture

The MAG CT-RAMP system is implemented within the Java programming language. The software development tools, methods, and approaches ensure the shortest possible run times, longevity of the developed routines, quality of the software architecture, effectiveness and efficiency of the development process, and subsequent easy maintenance and improvement processes. The CT-RAMP package is characterized by the fully Object Oriented Programming (OOP) modular design.

The software is based upon a flexible application programming structure, the common modeling framework (CMF). The CMF is an object-oriented class library written in the JAVA programming language. Groups of classes with a similar functionality are grouped into "packages" that can be imported and used in any model development project. The CMF is not sold as commercial software, but is protected by the Apache License. This is an open-source software license that guarantees the CMF and all modifications to the CMF will remain open-source and free of charge. In other words, the CMF code cannot be sold and the source code is available in order to foster understanding of and improvement to the underlying algorithms. A brief description of some of the packages that currently exist within the CMF follows:

- *Matrix package*: Most current tour-based models continue to rely on commercial transportation modeling software to develop mode-specific LOS matrices (skims) and for highway and transit assignment. The matrix package was developed specifically to allow the representation of skims in memory for rapid access and to allow read/write functionality to/from all major transportation planning packages. This package also includes classes for efficient memory management of sets of sparse matrices (such as transit) and for software-neutral disk representations of compressed matrices using zip format. Finally, an n-dimensional matrix class was developed to allow the representation and iterative proportional fitting of n-way distributions of households, or any other data, primarily for use in the generation of synthetic populations.
- *Model package*: This package provides classes for the construction and application of discrete-choice models. It uses an interface class to represent alternatives within a discrete-choice model (i.e., any object can be an alternative in a model as long as it implements the alternative interface). It can be used to create and solve both multinomial and nested logit models. This feature is particularly useful for more advanced tour-based models, where the decision maker and the alternatives can vary from model to model (e.g., a fully joint tour can "choose" which household members will participate in it in one model, and a traveler can choose which TAZ to travel to in another). The package also contains a class to apply and solve "special event" models for use in both tour-based and advanced trip-based model systems.
- *Calculator package*: A flexible user interface has been created for the specification of utility

equations used in discrete-choice models. The utility expression calculator (UEC) class and supporting infrastructure relies on Microsoft Excel spreadsheets that are used to specify input data and utility expressions for any number of alternatives. A discrete-choice model is built using the model package, a UEC is constructed, and a solve method is called to return an array of utilities. The class has built-in intelligence on data formats and efficient storage, a built-in text parser with all standard mathematical formulas (e.g., if/then, trigonometric functions, etc.) and has been optimized for performance. The UEC can also be passed objects with data members that can change based on the outcomes of previous models, as opposed to relying on disk representations of all data required for utility calculations. The package was developed specifically to relieve programmers from coding a seemingly infinite number of utility equations, allowing them to focus on overall software design and avoid bugs.

- *CT-RAMP package*: The core models described above have been implemented in a package that is independent of regional specifics such as number of zones, modal choices, socioeconomic data, etc. Market segmentation and choice details are self-contained within agency-specific packages, or simply contained in the Utility Expression Calculator spreadsheets for each specific model implementation. The CT-RAMP package specifies the choice models, controls the flow between model components, manages household/person/tour/trip data structures, utilizes parallel processing (see below) and provides for reporting and database management (via SQL).
- *Parallel Processing*: With the advent of multi-core processors, parallel processing has become at least as important as distribution. The latest incarnation of CT-RAMP utilizes the Java Parallel Processing Framework (JPPF) for taking advantage of both multiple machines and multiple cores on a single machine. JPPF (www.jpf.org) is coded very similarly to java threads, but the underlying implementation allows threads to be assigned on both local and remote machines. It is highly scalable and extremely robust, allowing for dynamic machine availability (machines can be added to or removed from the application process in real time).

8. Model Development Plan

8.1. Phasing of ABM Development Project

We structure the ABM Development Project in four Phases, of which Phases 1-3 correspond to the core model development and full software implementation. Essentially, by the end of Phase 3, MAG will be delivered a first version of a fully operational ABM. Phase 4 is needed for an extensive validation, calibration, and testing of the entire model system before the final version of the software has been created and delivered to MAG. The experience with previously developed ABMs (and all regional models in general) has shown that certain amendments to the mode structure are always needed and become clear only after the testing of the entire model system. This is especially true for an advanced model like MAG ABM that includes many innovative components that have not been applied and tested in previously developed CT-RAMP ABMs. Phases 1-3 are compressed to the maximum extent in terms of schedule. Schedule for Phase 4 is more flexible. It will be finalized based on the actual validation results of the first version and required "fixes" to the software and amendments to the model structure.

The following deliverables are planned for phases 1 through 3 of the MAG ABM development:

- *Phase 1:* The ABM development plan covering all phases and a first set of working models and procedures. The first set includes population synthesizer; long-term models of usual workplace for workers and usual school location for students; mid-term models for household and person mobility attributes like car-ownership, person transit pass holding, transponder acquisition, and free parking eligibility; and coordinated individual daily pattern of tour/trip generation including individual participation in special events and trips to and from airport. Depending on the actual survey data availability some sub-models will only be calibrated to match aggregate statistics while more detailed estimation and calibration will be postponed to Phases 3 and 4.

- *Phase 2:* A full set of working day-level and tour-level choice models including all models related to tour generation and formation, primary tour destination choice, tour time-of-day choice, and tour mode choice for all tours including work and non-work purposes. After the completion of Phase 2, the skeleton of the full MAG ABM will be created. Only details associated with trip-level models such as stop frequency, stop location, trip mode, exact trip departure time, and parking location will be missing. All tour-level models will be validated and calibrated versus the compatible tour-level sources of information like expanded statistics from the Household Survey, home-based statistics from the transit On-Board Survey, and major screen-line traffic counts (not significantly subject to route deviations associated with intermediate stops). After the completion of Phase 2, the skeleton ABM model will delivered to MAG for the MAG staff to start testing and validation. This will minimize the learning curve and will shorten the final ABM validation / calibration schedule. Depending on the actual survey data availability some sub-models will only be calibrated to match aggregate statistics while more detailed estimation and calibration will be postponed to Phases 3 and 4.

- *Phase 3:* A set of tour-level and trip-level models will be added to the ABM system that will complete the MAG ABM model development process. Trip-level models include exact stop frequency, stop location, trip mode, exact trip departure time, and parking location choices for both auto and drive-to-transit trips. All trip-level models will be validated and calibrated versus the compatible trip-level sources of information like expanded statistics from the Household Survey, trip statistics from the On-Board Survey, and traffic counts. At this Phase, the core ABM model, highway and transit network procedures for assignment and skimming, as well as all additional sub-models (airports, universities, special generators, freight vehicles, and external visitors) will be consolidated in the corresponding software package delivered to MAG. This phase will also include an extensive testing of equilibration strategies between the core demand model and network assignments.

- *Phase 4:* This phase will be devoted to the complete ABM validation, final calibration (to the extent needed), intensive sensitivity testing, as well as MAG staff training. It should be noted that even if each sub-model has been carefully validated and calibrated, validation and calibration of the entire model system is typically needed. The details of schedule and budget for Phase 4 will be established together by the MAG staff and PB team and take into account the MAG staff involvement and learning curve.

The suggested phasing of the MAG ABM development is similar to the phasing of the San Diego and Jerusalem ABMs currently being developed by PB. It has been adopted by the corresponding agencies – San Diego Association of Governments (SANDAG) and Jerusalem Transportation Masterplan Team (JTMT). These ABM development projects represent a good example for MAG since the ABM design adopted in San-Diego and Jerusalem is from the same CT-RAMP family of models.

Phase 1: ABM Development Plan and First Set of Models

The first phase of the ABM development includes the following main tasks:

- *Task 1:* Prepare a detailed *ABM development plan*, including scope of the development, schedule, and budget estimate as well as methodological approaches to main development issues. This task is fully addressed in the current report.

- *Task 2:* Develop a first set of *working sub-models of ABM* and corresponding documentation as per developed plan and in accordance with the technical requirements for the specific tasks as outlined in this RFP.

Phase 1, Task 1: Prepare Detailed ABM Development Plan

The detailed ABM specifications and development plan is presented in the current report. In general, it is based on the preliminary plan outlined in the PB proposal. However, in the course of work on Task 1, the MAG staff and PB team have significantly revised and added many details the ABM development plan based on the available information as well as MAG priorities in terms of planning needs and corresponding desired model features. The CT-RAMP model structure outlined in this document has been presented to MAG and its stakeholders at the 2-day workshop, and very intensive and productive discussions regarding potential modifications and inclusion of optional advanced features were held after that between the MAG staff and PB. Decisions regarding model structure and included advanced features described in the current report were made based on its relevance for the MAG planning applications, associated technical complexity, and possibility to support it by data sources adequate for estimation, calibration, and application for future years. The completed subtasks included in Task 1 and associated deliverables are summarized in **Table 21**:

Table 21: Subtasks and Deliverables for Phase 1 Task 1

Subtask	Content	Deliverables
1.1. Coordination workshop with interested MAG member agencies and major stakeholders	PB Team presented summary of accumulated experience in ABM-based development and applications including CT-RAMP models and others, presented the ABM preliminary development plan, and led discussions on future planning needs of MAG and modeling requirements.	PowerPoint presentations summarizing State-of-the-Art & Practice in ABM development and applications with references to specific regions, models, and projects.
1.2. Review of foreseeable planning tasks and associated requirements to ABM	Extensive review of the projects and policies currently underway or envisioned by MAG, existing modeling tools, and identification of policies that cannot be adequately addressed in the framework of the 4-step model. Formulation of recommended model development activities, software, cost, and schedule.	Current Technical Report (Sections 1-7) documenting state-of-the-practice in ABM development and application; main planning issues in MAG region and benefits of ABM in responding to those issues; and recommendations regarding model structure, innovative methodologies and software
1.3. Detailed ABM development plan	Final ABM design and specification of all sub-models and procedures, full list of deliverables, and other project management documents.	Detailed Project Management document (Section 8) including scope documents (numbered sub-models, procedures, and other components), activity documents (steps for model estimation, implementation, validation, and calibration), schedule and itemized budget for major development milestones.

Phase1, Task 2: Produce a First set of Technical Deliverables

We are currently proposing the following set of technical deliverables at Phase 1 as shown in **Table 22**. This set was adjusted after the implementation of Task 1 and finalization of the ABM structure as well as after discussion with the MAG staff. It remains uncertain at this point if the new Household Travel Survey is going to be available for the estimation and calibration of the core behavioral models. This may affect the level of estimation and calibration of all core sub-models. In case of a further delay in delivery of the survey, the calibration for this Phase will be implemented based on the available aggregate sources of information. More detailed recalibration will be implemented at subsequent Phases 2, 3, and 4.

Table 22: Subtasks and Deliverables for Phase 1, Task 2

Subtask	Content	Deliverables
2.1. Population synthesizer	Population synthesis procedure for the core household population and group quarters including household distribution in each zone and list of households selected from the micro-sample (sub-model 1.1)	Population Synthesizer software and documentation including model structure, inputs, outputs, and user guide
	Population synthesis procedures for university students (sub-model 1.2)	Population Synthesizer documentation; software implementation is dependent on availability of person & household samples for these population segments
	Population synthesis procedures for seasonal residents (sub-model 1.3)	
	Population synthesis procedures for visitors living in hotels (sub-model 1.4)	
	Population synthesis procedures for transient workers (sub-model 1.5)	
2.2. Long-term choice models	Usual workplace for workers (sub-models 2.1.1-2.1.2)	Long-Term Model software and documentation including model structure, estimation, and calibration
	Usual school location for students (sub-models 2.1.3-2.1.4)	
2.3. Mid-term models for individual mobility attributes	Car ownership choice (sub-model 3.2)	Mid-Term Model software and documentation including model structure, estimation, and calibration
	Person transit pass holding choice (sub-model 3.4)	
	Transponder acquisition choice (sub-model 3.5)	
	Free parking eligibility (sub-model 3.3)	
2.4. Special events and trips to and from airports	Aggregate attendance forecast for each special event (sub-model 4.1.1)	Special Events Model software and documentation including model structure, estimation, and calibration
	Individual participation in special events (sub-model 4.1.2)	
	Aggregate forecast of number of air passengers (sub-model 4.2.1)	

Subtask	Content	Deliverables
	Identification of individual air passengers (sub-model 4.2.2)	
2.5. Coordinated daily activity pattern type (CDAP)	Trinary choice of daily activity pattern type for each person coordinated with the other household member with indicators on participation in joint activities, special events, and trips to and from airports (sub-model 5.1)	CDAP software and documentation including model structure, estimation, and calibration

All models at Phase 1 will be estimated for core household population based on the new Household Travel Survey with possible placeholders for special markets that will be filled up when the additional surveys are available at later Phases 2-4.

Phase 2: Day-Level and Tour-Level Models

We are currently proposing the following preliminary set of technical deliverables at Phase 2 as shown in **Table 23**. This set will be adjusted after the implementation of Phase 1 and finalization of the entire ABM structure.

Table 23: Subtasks and Deliverables for Phase 2

Task	Content / Subtasks	Deliverables
3.1. Frequency of work and school activities, TOD choice, linkage of special events and escorting	Choice models for exact frequency of tours & episodes (sub-model 5.2.1), linkage of special events (sub-model 5.2.2), mandatory activity TOD (sub-model 5.2.3), and escorting arrangements (sub-model 5.2.4)	Mandatory Activities software and documentation including model structure, estimation, and calibration
3.2. Generation of fully joint tours & shared non-mandatory activities	Choice models for household joint tour frequency (sub-model 5.3.1), travel party type and person participation (sub-model 5.3.2), primary destination (sub-model 5.3.3), and stop frequency (sub-model 5.3.4)	Fully Joint Tour software and documentation including model structure, estimation, and calibration
3.3. Generation and allocation of household maintenance tasks	Choice models for household frequency of maintenance tasks (sub-model 5.4.1) and task allocation to the household members (sub-model 5.4.2)	Maintenance Task software and documentation including model structure, estimation, and calibration
3.4. Generation of person discretionary activities	Choice models for frequency of discretionary activities by person type (sub-model 5.5.1)	Individual Discretionary Tour Generation software and documentation including model structure, estimation, and calibration

Task	Content / Subtasks	Deliverables
3.5. Generation of work-based sub-tours	Choice models for frequency of work-based sub-tours implemented by workers (sub-model 5.6.1)	Work-Based Subtour Generation software and documentation including model structure, estimation, and calibration
3.6. Individual tour formation	Probabilistic role of each individual non-mandatory episode in the tour skeleton structure (sub-model 5.7.1), total frequency of individual non-mandatory tours (sub-model 5.7.2), matrix of half-tours (sub-model 5.7.3)	Individual Tour Formation software and documentation including model structure, estimation, and calibration
3.7. Primary tour destination choice model	Models for choice of tour primary destination by purpose and person type (sub-model 6.1)	Primary Tour Destination Choice software and documentation including model structure, estimation, and calibration
3.8. Tour time-of-day choice model	Models for tour time-of-day choice by purpose and person type (sub-model 6.2)	Tour Time-of-Day Choice software and documentation including model structure, estimation, and calibration
3.9. Tour mode choice model	Models for tour mode combination by purpose and person type (sub-model 6.3)	Tour Mode Choice software and documentation including model structure, estimation, and calibration

Phase 3: Complete Operational ABM

We are currently proposing the following preliminary set of technical deliverables at Phase 3 as shown in **Table 24**. This set will be adjusted after the implementation of Phases 1-2 and finalization of the entire ABM structure.

Table 24: Subtasks and Deliverables for Phase 3

Task	Content / Subtasks	Deliverables
4.1. Stop-location model	Model for choice of stop sequence & location for each subsequent stop on a half-tour based on the density of attractions and route deviation (sub-model 6.4)	Stop Location software and documentation including model structure, estimation, and calibration
4.2. Stop-frequency model for stops "on the way"	Model for insertion of additional stops for each trip segment (sub-model 6.5)	Stops on the Way software and documentation including model structure, estimation, and calibration
4.3. Trip mode choice model	Model for trip mode choice conditional upon the tour mode, stop frequency and location (sub-model 7.1)	Trip Mode Choice software and documentation including model structure, estimation, and calibration
4.4. Model for trip departure time	Choice model for trip departure time conditional upon the tour time-of-day choice (sub-model 7.2)	Trip Departure Time software and documentation including model structure, estimation, and calibration
4.5. Trip parking location choice (if necessary)	Model for choice of parking location for auto trips (sub-model 7.3) and park-and-ride trips (sub-model 7.4)	Trip Parking Location software and documentation including model structure, estimation, and calibration

Task	Content / Subtasks	Deliverables
4.6. Special Travel and Traffic components	Adaptation of models for special traffic components included freight trucks, commercial & delivery vehicles, and external travel	Integration of existing special market models with ABM.
4.7. Model system Integration	Integration of the core ABM model with all other models, highway and transit network procedures, and reporting	Integrated System software and documentation including model system structure and user guide
4.8. Preliminary validation and calibration for the base year	Validation and calibration against aggregate statistics from the Household Survey, CTPP, On-Board Survey, and screen-line traffic counts	

Development (or improvement of the existing) additional sub-models can start at Phase 2 in parallel with the core ABM development if it is necessary for enhancement of the existing 4-Step model.

Phase 4: Extensive Validation, Calibration, and Testing for Each Season

We currently envision the following preliminary set of tasks for Phase 4 as shown in **Table 25**. This set will be adjusted after the implementation of Phases 1-3 and finalization of the ABM structure.

Table 25: Subtasks and Deliverables for Phase 4

Task	Content / Subtasks	Deliverables
5.1. Validation and calibration of the complete ABM system for the base year at sub-area or corridor level.	Validation and calibration of the entire chain of core choice models against the expanded statistics from the Household Survey, CTPP and/or ACS data, traffic counts, and Transit On-Board Survey	Calibrated software and documentation on the required adjustments of model parameters
5.2. Sensitivity testing for selected projects and policy scenarios	Specification and analysis of several scenarios for testing including population / employment growth, highway and transit network improvements, highway pricing project and others by MAG choice amongst the anticipated projects	Memo documenting the model results, aggregate elasticities and individual behavioral responses, impact on highway and transit conditions; suggestions for adjustment of model parameters if needed
5.3. Training course for the MAG staff and other ABM users	Comprehensive hands-on training course (normally 5-day long) delivered in the MAG offices for the model users	ABM User Guide updated after the course

Task	Content / Subtasks	Deliverables
5.4. Model support, troubleshooting and participation in user group meetings	On-call model support and troubleshooting services to MAG and other users based on the hourly rates with a cap established by MAG; participation in user group meetings if necessary	Documented changes in the software or User Guide if needed

8.2. Project Schedule and Budget Estimation

We propose a schedule and budget for the current Phase 1 with detailed breakdown by task and for the subsequent Phases 2-4 in a more aggregate fashion. Our plan is based on our unique accumulated experience in development of ABMs for large metropolitan areas and our deep knowledge of the possible factors that can result in delays and/or budget overruns. It should be noted that most of the cases of significant schedule delays in ABM development projects in the past were associated with software development and debugging as well as the entire-system integration and calibration. To resolve these issues, PB has developed generic pieces of software (Common Modeling Framework) that will provide most of the modeling components as building blocks for the MAG CT-RAMP ABM despite the fact that the model design includes many advanced and innovative features that have not been applied yet in previous ABMs.

Another important detail that makes the MAG ABM Phasing and associated schedule different compared to the most of previous ABM development projects is that in the previous projects, the phasing was associated with model development step rather than final deliverables. All models were designed and estimated at the first phase (with no real outcome that could be used or at least tested). Then the entire model system was implemented at the second phase. As the result the entire bulk of issues associated with the software development and calibration was moved to the second phase. Our proposed development plan for the MAG ABM is principally different and much more balanced. The models are broken into groups and each group is structured, estimated, and implemented within a certain Phase.

We suggest a realistic time framework for the MAG ABM development projects that includes 36 months for Phases 1-3 (a fully operational ABM) and open-ended framework for Phase 4 (validation, testing, training, support, and additional development / modification by requests from MAG) that will be determined by completion of Phase 3 and largely dependent on the MAG needs and further plans for development the modeling tools. Additional details for each Phase are provided in the corresponding subsections below.

Proposed Schedule and Budget for Phase 1

The time frame for Phase 1 of the ABM development is currently identified as 12 months (July 2009-July 2010) with the budget of $270,000 for Phase 1 of which Task 1 has been completed. Below in **Table 26** is the detailed schedule and budget breakdown by task.

Table 26: Schedule and Budget for Phase 1

Subtask	Schedule (start and end months)	Budget
1.1. Coordination workshop with interested MAG member agencies and major stakeholders	1-2	$10,000
1.2. Review of the region-specific foreseeable planning tasks and associated requirements to ABM	3-4	$10,000
1.3. Detailed ABM development plan and project management documents	5-6	$30,000
2.1. Population synthesizer	6-9	$50,000
2.2. Long-term choice models	7-9	$60,000
2.3. Mid-term models for individual mobility attributes	8-10	$30,000
2.4. Incorporation of special events	8-11	$40,000
2.5. Coordinated daily activity pattern type	9-12	$40,000
Total for Phase 1	1-12	$270,000

Schedule and Budget Suggested for Phase 2

We suggest a time frame for Phase 2 of the ABM development of 12 months (anticipated start in August 2010 and the corresponding end in August 2011). We also consider the budget of $500,000 suggested in RFP for Phase 2 as sufficient. Below in **Table 27** is the schedule and budget breakdown by major task groups.

Table 27: Schedule and Budget for Phase 2

Task	Schedule (start and end months)	Budget
3.1. Frequency of mandatory activities, linkage of special events, escorting arrangements	13-18	$250,000
3.2. Generation of fully joint tours for shared non-mandatory activities		
3.3. Generation and allocation of household maintenance tasks		
3.4. Generation of person discretionary activities		
3.5. Generation of work-based sub-tours		
3.6. Individual tour formation		
3.7. Primary tour destination choice model	19-24	$250,000
3.8. Tour time-of-day choice model		
3.9. Tour mode choice model		
Total for Phase 2	13-24	$500,000

Schedule and Budget Suggested for Phase 3

We suggest a time frame for Phase 3 of the ABM development of 12 month (anticipated start in August 2011 and the corresponding end in August 2012). We suggest a budget of $500,000 for Phase 3. Below in **Table 28** is the schedule and budget breakdown by major task groups.

Table 28: Schedule and Budget for Phase 3

Task	Schedule (start and end months)	Budget
4.1. Stop-location model	25-28	$150,000
4.2. Stop-Frequency model for minor stops		
4.3. Trip mode choice model		
4.4. Model for trip departure time		
4.5. Trip parking location choice		
4.6. Integration of additional sub-models	25-28	$100,000
4.7. Model system integration	25-30	$130,000
4.8. Validation and calibration for base year	31-36	$120,000
Total for Phase 3	25-36	$500,000

Schedule and Budget Considerations for Phase 4

It is extremely beneficial to apply the ABM for different types of projects and policies to gauge its ability to meet the needs of MAG. The scenarios for ABM testing should include significant socio-economic changes in population and employment, transit improvement (for example a new LRT or commuter rail line), highway pricing, etc. At this phase we expect that MAG staff will be significantly involved in the application of the model to these scenarios. The estimates of the main budget items for Phase 4 are summarized in **Table 29**.

Table 29: Schedule and Budget for Phase 4

Task	Schedule (start and end months)	Budget
5.1. Detailed validation and calibration of the complete ABM system for the base year at sub-area or corridor level and for different seasons	37-40	$130,000
5.2. Sensitivity testing for selected projects and policy scenarios	39-40	$80,000
5.3. Training course for the MAG staff and other ABM users	41-42	$20,000
5.4. Model support, troubleshooting and participation in User Group meetings	TBD	TBD
Total for Phase 4	37-42	$230,000

We propose a 1-week hands on course for the MAG staff and other model users with at least two full-time instructors from the consultant (the PM and DPM). The subsequent model support, troubleshooting, and possible participation in User Group meetings will be discussed with MAG and planned depending on the MAG needs. For example, the New York Metropolitan Transportation Council (NYMTC) holds bi-monthly User Group meetings that include more than 30 local agencies and consultants using the New York ABM.

9. Existing Data Surveys and Suggested Data Collection Efforts

Development of the MAG ABM might require data collection efforts specifically designed for this purpose. However, in general, the main database for ABM estimation and calibration will come from the existing sources of information. It should be also noted that in the process of ABM estimation, validation, and calibration the different available sources of information will be consolidated and brought to a common denominator.

In general, the following main sources of information will be used at different stages of ABM development, disaggregate model estimation, and aggregate calibration, as shown in **Table 30**. New surveys that have not been implemented yet are highlighted in red.

Table 30: Data Sources

Model Component	Disaggregate estimation of individual sub-models or distributions	Aggregate validation, calibration, and constraining
Population synthesizer	PUMS, ACS	Census 2000, MAG Population Projections
	Sample for university (ASU) students living in rent apartments	Estimates of available rent apartments by TAZ
	Sample for seasonal residents	MAG counts and projections for seasonal residents by TAZ and season
	Sample for visitors living in hotels	Inventory of hotel/motel/resort rooms by type and seasonal occupancy rates; Forecast of hotel visitors by TAZ and season
	Sample for transient workers population	MAG projections for transient workers by TAZ and season
Usual workplace and school location choice	Household Travel Survey, 2001; Add-On NHTS, 2009	CTPP JTW tables, MAG Population Projections
Household car ownership and other individual mobility attributes	Household Travel Survey, 2001; Add-On NHTS, 2009	Census 2000 Expanded and aggregated Household Travel Survey, 2001
Core demand models of travel generation and scheduling for the household resident population	Household Travel Survey, 2001; Add-On NHTS, 2009	Regional On-Board Transit Survey, 2007; Traffic counts; Expanded and aggregated Household Travel Survey, 2001; Expanded and aggregated Add-On NHTS, 2009;

Model Component	Disaggregate estimation of individual sub-models or distributions	Aggregate validation, calibration, and constraining
Models of travel generation and scheduling for the non-household and non-resident population	On-line ASU student & employee travel survey 2007, trip reduction database; Survey of travel behavior of university students living in dorms	Data on number of students living in dorms from Universities
	On-line ASU student & employee travel survey 2007, trip reduction database; Survey of travel behavior of university students living in rent apartments	Data on number of students living in rent apartments
	Survey of travel behavior of seasonal residents	Expanded survey of travel behavior of seasonal residents
	Survey of travel behavior of visitors living in hotels	Expanded survey of travel behavior of visitors living in hotels
	Survey of travel behavior of transient workers	Expanded survey of travel behavior of transient workers
Model for Special Events	Special Events survey, 2009	Capacity and attendance data for Special Events
Models for trips to and from airports	Sky Harbor passenger survey, 2005; Survey of airport passengers including socio-economic data and origin/destination TAZ	Air passenger data by airport
Tour and trip destination, TOD, and mode choice	Household Travel Survey, 2001; Add-On NHTS, 2009	Employment and LU data (floor area / land area and other special size variables on the activity supply side); Expanded and aggregated Household Travel Survey, 2001; Expanded and aggregated Add-On NHTS, 2009; Regional On-Board Transit Survey, 2007
Parking choice	Household Travel Survey, 2001; Add-On NHTS, 2009; Special survey of parking users with SP components	Parking Inventory (capacity by parking type and parking rates by TAZ)

The table is limited to data sources and surveys directly needed for development and calibration of the travel ABM. It does not include surveys that relate to other components like trucks, commercial & delivery vehicles, external traffic, etc.