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A Summary of Design Features of Activity-Based Microsimulation Models for U.S. MPOs

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This short paper provides a concise summary of important design features of various activity-based model systems that have been implemented or have recently been designed for planning agencies in the U.S. The models described are those for Portland, San Francisco, New York, Columbus, Atlanta, Sacramento, Bay Area, and Denver. We selected these models because they are in the same "family" of activity-based models, and one or both of the authors have been involved in the design of all of them except for New York. We have also included, in the summary table and supplementary text, two other examples of activity-based models in the U.S: the CEMDAP model for Dallas, and the FAMOS model for SE Florida. We have not included the TRANSIMS model or the TLUMIP model for the State of Oregon. Although those models share some of the features discussed here, we are not familiar enough with them to compare them at the level of detail included here, although that could be a useful extension of this paper.

All of the model systems described in this paper share a similar overall structure, with a hierarchy of levels from "top" to "bottom", with the lower choices predicted conditional on higher level choices. The levels are:

- **Population synthesis** (geographic allocation of households)
- **Longer term decisions**: auto ownership and (in some cases) work and school locations
- **Person/household-day level**: number of tours and activities made for various purposes
- **Tour-level**: The main destination and mode, begin/end times, and number of stops
- **Trip-level**: Intermediate stop location, and the mode and departure time of each trip

Within this structure, there are several important design features that distinguish the models, and these are summarized in the table below. The models are listed in the table more or less chronologically, with the earliest ones at the left and the later ones at the right. At the time of writing, the Bay Area (MTC) and Denver (DRCOG) models are in the design stage, and so the design characteristics shown for those models are those that are currently envisioned. Each paragraph below is a more detailed annotation of a row in the comparison table.

Controls/categories for population synthesis: All of the model systems simulate persons one by one, and require a representative sample of households and persons for the base year and forecast years. All of the regions use zone-level data and forecasts of household size and income as control variables for sampling households from the regional PUMS households. In addition, most of the regions have used the number of workers in the household as a third control variable, both because it is important behaviorally, and because CTPP Table 1-75 provides a useful 3-way joint distribution of household size, number of workers and income for 2000. The Portland (METRO) and San Francisco (SFCTA) models have also used age of head of household as a control variable, and Atlanta (ARC), Bay Area and Denver. Are all considering using age or age-related variables as well (e.g. presence of children and/or senior citizens). The sample generation software created for Atlanta has a flexible system for designating and combining control variables, as well as facilities for testing how well the synthetic population matches other variables which have not been controlled for explicitly. An important test will be how well the age distribution is matched when age is not one of the explicit control variables.

"Usual" work & school locations modeled at the top level?: There is a recognition that the choice of where to work and where to go to school are longer-term decisions that are not adjusted day to day, similar to the choice of residence (which is implicitly modeled in the synthetic sample). In most of the models, and all of the more recent ones, the "usual" work and school places are modeled at the "top" level, meaning that these are predicted before predicting any choices specific to the travel day. The home location is typically one of the alternatives in the choice set, for people whose main workplace is at home or who are home-schooled. Note that certain types of individuals such as construction workers or traveling salespeople may not have a "usual" workplace. Also note that this model formulation requires that data be collected on each worker's most frequent work location, even if that person does not visit that location on the survey diary day(s). The destination for any particular work tour will most often be the "usual" work location, but may be another location instead (a business meeting, for example), and that choice is modeled accordingly at the tour level. School tours nearly always go to the usual school location, so a separate school tour destination model may not be needed. In the future, it would be ideal for the population synthesis and longer term models to be replaced by a dynamic, integrated land use model that includes joint prediction of residential and workplace (re)location decisions.

Number of out-of-home activity purposes: The simplest purpose segmentations are in the first version of the Portland model, with 3 purposes (work/school, maintenance and discretionary), and in San Francisco, also with 3 purposes (work, school, other). Most other model systems have included at least 7 activity purposes, being work, school, escort (serve passenger), shopping, meals, personal business (or "other maintenance"), and social/recreation (or "other discretionary"). In some cases, social visit has been separated from recreation. The main reasons for splitting out the meal activity are that it tends to be done at certain types of locations, and has very specific time-of-day and duration characteristics. The escort activity also tends to be to specific locations at specific times in terms of driving children to/from school. Note that in tour-based models we do not need to treat non-home-trips as if they are separate "purposes", although all of the systems do have separate tour level models for work-based tours (often called "subtours" because they are tours within tours). In most of the model systems, the division of the school purpose into university, K-12 and pre-school is made in the lower level models based on the age and enrolment type of the particular person in the sample.

Number of in-home activity purposes: In the Portland models, in-home activities are distinguished between 3 purposes (work/school, maintenance and discretionary), but this distinction is only made for the "primary" activity of the day, and is only predicted in cases when the person has no out-of-home activities. This distinction did not appear to add substantially to the explanatory of the models. That fact, coupled with the fact that most survey respondents' are reluctant to provide much detail about their in-home activities, explains why none of the other models distinguish between types of in-home activities. Since some of the models predict which people work primarily at home, that provides some substitution between in-home and out-of-home work. It does not, however, handle the phenomenon of part-time telecommuting, which is the focus of some TDM policies. As a result, there is some interest in predicting work-at-home as a separate activity type in the Bay Area model if the data will support it.

Day pattern type linked explicitly across HH members?: This and the following three paragraphs are concerned with the modeling of explicit linkages between the predicted activities and travel of different members of the same household. All of the models treat such linkages implicitly through the use of a wide variety of person type and household composition variables, and indeed one of the main advantages of the microsimulation approach is the ability to reduce aggregation bias by including such case-specific variables. Using explicit linkages takes that ability one step further and reduces aggregation bias even more. One of the key linkages is a fairly simple one. If each person's full day activity pattern is classified into three main types—stay at home, go to work/school, or travel for some other purpose—then we see strong similarities between the patterns of members of the same household, even stronger than the similarities that would be predicted indirectly. The Columbus model system includes a sequential model of these linkages, simulating children first, and then adults conditional on what the children do. The Atlanta model system includes a similar model that is estimated simultaneously across all household members, avoiding the need to assume the order in which they are simulated and thus the direction of causality. A similar model is planned for the Bay Area system.

Joint activities linked explicitly across HH members?: Joint activities are cases in which two or more household members travel together to and from an activity location, and participate in the same activity while at that location. In the lower level models such as mode and destination choice, it is best to model such cases as a single joint decision, rather than as independent decisions made by different people. The Columbus and Atlanta model systems include models of household joint activity generation and participation. The application of the Columbus model has shown that predicting joint travel can have significant implications for mode choice, so this type of model has been recommended for the Bay Area model. However, in a wider sense the "jury is still out" as to what extent the additional accuracy of explicitly modeling household interactions will merit the additional complexity. For that reason, such models will not be included in the Denver system, at least in the initial version.

"Escort" trips linked explicitly across HH members?: Another type of joint travel is the case where two or more household members travel together to and/or from an activity location, but do not participate in the same activity there. The most common example is a parent driving a child to school and then either returning home (an escort tour) or else driving on to work (an escort stop on a work tour). Because these types of tours are partly joint and partly independent, it can be very complex to explicitly link them across persons. For that reason, explicit modeling of escort linkages has not been done in any of the applied models or recommended for the models under design. Most of the models, however, do include a separate "escort" purpose, so that the most important special characteristics can be captured—particularly that fact that the mode is nearly always auto, with the exception of infrequent cases of walk escort. Also, childrens' school locations can easily be included as special alternatives in the parents' escort tour destination choice sets, so that at least the location is accurate, even if the exact trip timing and car occupancy are not matched.

Allocated activities divided explicitly among HH members?: Certain types of activities such as grocery shopping, escorting, and some other "maintenance" chores, are likely to be allocated across individuals in a household, showing a negative correlation across frequencies within a household-day. The Columbus and Atlanta model systems include explicit models of the generation of these activities at the household level and then allocation to particular individuals. In the Atlanta case, this model was estimated jointly with the household joint travel generation model. Compared to explicitly linking people who make joint tours together, predicting which people within a household perform allocated activities appears less important to the model results—we are not changing anything fundamental about the tours, just which person makes them. So, in terms of the tradeoff between accuracy and complexity, these models seem less crucial than the joint travel models, and thus they have not been recommended for the Bay Area models. In addition, the limited number of activity categories offered in most surveys makes it rather difficult to determine which activities are most likely to be allocated. For example, grocery shopping is mainly an allocated activity, while shopping for a good book to read is an individual activity, but both are usually coded the same.

Level at which intermediate stop purpose and frequency are modeled: When ordering the models in an activity-based system from "top" to "bottom", it is not always clear which decisions should be modeled conditional on which other decisions. A prime example is the generation of intermediate stops made during tours. Are activities planned and combined into trip chains when a person is planning their day, in which case the mode, timing and location of the tours may depend on which stops they contain? Or, conversely, do people make tours, and then decide during the tour how often and where to make stops depending on their mode and location? Clearly, both of these describe real behavior, and which description is more accurate depends on the particular person and the types of activities they are carrying out. The Portland and San Francisco models follow closely the original Bowman and Ben-Akiva day pattern approach, in which the number and purpose of any intermediate stops are predicted at the person-day level before any particular tours are simulated. In contrast, the Columbus, New York and Atlanta models predict only the number and purpose of tours at the person-day level, and then the number and purpose of intermediate stops on any particular tour are predicted at the tour level once the tour destination, time of day and main mode are known. In the Sacramento models, an intermediate approach is used. Some information about stop-making is predicted at the person-day level, predicting whether or not <u>any</u> intermediate stops are made for each activity purpose during the day (7 yes/no variables). These are predicted jointly with the choice whether or not to make any tours for each of the activity purposes (7 more yes/no variables), thus capturing some substitution effects between the number of tours and the number of trips per tour. Then, when each tour is simulated, the exact number of purpose of stops on each tour is predicted conditional on the mode and destination of that tour and conditional on what types of stops still need to be simulated to fulfill the person-day level prediction. There is no obvious behavioral reason for this structure, other than that it "balances" the model sensitivities between the two types of behavior described above. A similar approach is planned for Denver and recommended for the Bay Area.

Number of network zones used: The next three paragraphs discuss spatial aspects of the model systems. In all cases, the zone system used for model development and application is the same as was also used for trip-based models. The auto and transit networks and assignments are also the same as used in the trip-based models. This fact has facilitated the transition to activity-based models, but at the same time, the microsimulation framework can also be used with more detailed spatial systems, and would support more accurate traffic simulation methods as well.

Smaller spatial units used below zones? : Because the microsimulation framework is not tied as strongly to zone definitions, it is possible to use the zones only to provide the road and transit path level of service variables, while variables related to land use, parking, and walk access (which do not need to be stored as matrices) can specified at a finer level. The Portland model uses such an approach for roughly 20,000 "blocks", while the Sacramento models use over 700,000 parcels. The Denver MPO is also planning to predict demand at the parcel or building level, using a 2-stage destination choice model framework. An intermediate approach, which has been recommended for the Bay Area models, is to divide zones with heterogeneous transit and walk accessibilities into more homogeneous "subzones", but with assignments and skims still done at the larger zone level.

Simultaneous mode and destination choice model estimation?: It has become a sort of tradition in modeling to condition mode choice upon a known destination, sometimes using a sequential nested structure where the mode choice logsum is used in the destination choice model. That is probably appropriate for purposes such as work and school. For purposes such as shopping, however, the choice of store may depend more upon the mode used than vice-versa. Simultaneous estimation of mode and destination choice allows the modeler to test different nesting hypotheses. Such an approach was used in the Portland model, and may be used in Denver as well.

Network and modeled time periods: Most 4-step models only use two times of day—peak and off-peak, and use fixed time-of-day factors. All of the activity-based models contain tour time of day models that allow some sensitivity of time of day choice to network conditions. All of the models have used at least 4 network assignment periods—AM peak, midday, PM peak and off-peak. In some cases, free flow conditions are assumed for off-peak, so no traffic assignment is needed for that period. In some models, a fifth period has been added by splitting the off-peak period into early morning and evening/night. The more recent models, beginning with Columbus, use more precise time windows in order to schedule each tour and trip consistently during the day. This involves keeping track of the available time windows remaining after "blocking out" the time taken by each activity and associated travel. The time windows can also be used in the activity generation models. The Sacramento model and perhaps other models are moving to half-hour periods to provide even more detail. The main constraint on how small the time periods can be is the adequacy of the self-reported times in the diary survey data. There is evidence that people often round clock times to 10, 15 or 30 minute intervals.

Tour time of day relative to mode and destination choice models: It is not obvious whether activity and departure times should be predicted before mode and destination choice, between them, or after both. There is some empirical evidence that shifts in time of day occur at two levels: the choice among broad periods of the day (e.g. morning, afternoon, etc.) is made fairly independently of accessibility, while smaller shifts of up to an hour or two are more sensitive to travel times and costs—the peak-spreading effect. Since all of the models use broad network time periods, the tendency has been to model the choice of these periods for tours at a fairly high level above mode and destination choice (although in most cases the usual destination for work and school tours has already been predicted). In some models, time of day choice is predicted between the destination and mode choice levels, which allows the use of destination-specific mode choice logsums in the time of day model, but requires that the destination choice model assume (or stochastically select) a specific time of day for the impedance variables.

Departure time choice modeled separately at the trip level?: Perhaps the placement of the model that predicts the choice of times for the overall tour is not as crucial if there is a separate model that predicts the departure time for each trip to the more detailed periods, conditional on the mode and OD of each trip. Some of the model systems include such a model as the "lowest" model in the system. It is also possible to include such a model for car trips only, in order to predict the shape of the demand profile within the broader peak periods.

Accessibility measures in the upper level models: Last, but certainly not least, is the issue of how to most accurately include accessibility and land use effects in the upper level models. Calculation of full logsums across all possible nests of lower level alternatives is clearly infeasible with so many levels of choices. The earliest Portland models came the closest to including "proper" individual-specific logsums, but the structure of that model was relatively simple, and the effect on model run-time was severe. The San Francisco models include mode-specific measures with set boundaries, such as the number of jobs accessible within 30 minutes by transit. The rather arbitrary cutoff boundaries in such measures can cause unexpected sensitivities when applying the models. The New York and Columbus models use mode-specific travel time decay functions that approximate the logsum from a simple destination choice model. Such measures perform better, but still have the problem that they are mode-specific, and that auto and transit accessibility tend to be correlated, so it is difficult to estimate model parameters for both of them. A method that solves this problem and is more consistent with discrete choice theory is to approximate joint mode/destination choice logsums. However, the mode choice logsums tend to vary widely across the population, so it is best to calculate different accessibility measures for different population segments. The Sacramento models use such an approach, with aggregate accessibility logsums for each combination of 7 travel purposes, 4 car availability segments, and 3 walk-to-transit access segments—as those tend to be the most important segmentation variables in the mode choice models.

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A brief description of CEMDAP (Provided by Prof. Chandra Bhat, Univ.of Texas)

Population synthesis

The Synthetic Population Generator (SPG) in CEMDAP uses census tract/block-group/block -level summary tables as control totals for synthesizing households and individuals from the 2000 5% PUMS data. Some of the summary tables contain the distribution of a single variable, while other tables describe the joint distribution of multiple variables. These tables are used to construct a full multi-way distribution using a *Recursive Merge Procedure* and the *Iterative Proportional Fitting* procedure. The SPG allows the user to specify the choice of control variables from a wide range of census variables at run-time.

Currently, for the Dallas Fort-Worth (DFW) application, four household-level variables and 3 individual-level variables are used as controls. The household-level variables are: household type (6 categories), household size (7 categories), presence of children (2 categories), and age of householder (2 categories). The individual-level variables are: gender (2 categories), race (7 categories), and age (10 categories). All other variables found in the PUMS data that are required for the activity travel pattern simulator, but that were not controlled during the population synthesis, are not directly used. Instead, their values are simulated based on a suite of models estimated using PUMS and other sources of data.

School and work locations

The "usual" school and work locations are modeled at the "top" level. Each and every work location zone is considered as an alternative in the choice set; *i.e.,* in order to avoid large prediction bias, the work location model is not applied to just a sample of zones. However, home location zone, adjacent location zone, CBD zones *etc* are given higher preference in the utility functions. In addition to modeling the "fixed" school and work locations at the "top" level, work-related activity (business meeting etc) destination choice models are implemented at the activity stop level.

Out-of-home and in-home activity purposes

CEMDAP application for the DFW area includes <u>11 out-of-home activity types for adults:</u> work, school, work-related, drop-off at school, pickup from school, joint discretionary activity with children, grocery shopping, household and/or personal business, social/recreational, eat out, and other serve passenger activities; and <u>3 out-of-home activity types for children:</u> school, joint discretionary activity with parent, and independent discretionary activities. CEMDAP does not distinguish between types of in-home activities.

Intra-household interactions and explicit allocation of activities

In CEMDAP, the activity generation and allocation decisions are simulated in the following three sequential steps: (1) the generation of work and school activity participation, (2) the generation of children's travel needs and explicit allocation of escort responsibilities to one of the parents, and (3) the generation of independent activities for personal and household needs.

Linkage of joint activities and/or travel is implemented between parents and children (in single parent and nuclear family households) in two ways: (1) drop-off/pick-up to/from school, and (2) joint discretionary activities. Due to data limitations, the nature of these interactions is restrictive at this point. For instance, CEMDAP does not consider the case of one of the parents dropping off/picking up multiple school children at multiple locations.There is also an "other serve passenger" activity type recognized in CEMDAP, but the activity/travel pattern linkage across household members is not explicitly implemented for this activity type currently because of lack of data.

The grocery shopping activity is modeled to be generated at the household level and is allocated to one of the adults. Joint participation of adults in activities is currently not considered because of lack of good data to estimate these models in the Dallas-Fort Worth area.

Level at which intermediate stop purpose and frequency are modeled

Activity travel patterns are modeled separately for workers (adults who go to school or work on travel day) and non workers (adults who neither got to work nor attend school during the day). The daily pattern of workers is characterized by four different sub-patterns: before-work pattern, which represents the activity-travel undertaken before leaving home to work; commute pattern, which represents the activity-travel pursued during the home-to-work and work-to-home commutes; work-based pattern, which includes all activity and travel undertaken from work; and after-work pattern, which comprises the activity and travel behavior of individuals after arriving home at the end of the work-to-home commute. Within each of before-work, work-based, and after-work patterns, there might be several tours. Each tour, the home-to-work commute, and the work-to-home commute may include several activity stops. In the case of non workers, the activity-travel pattern is considered as a set of tours, each of them comprising a sequence of out-of-home activity stops.

The number of tours is predicted at the sub-pattern level for workers (pattern level for non workers), while the tour mode and the stop frequency are predicted at the tour level. The activity purpose, activity duration, home stay/work stay duration before the activity, travel time to the activity stop, and the destination are predicted for each of the individual activity stops. In essence, the stop purpose is modeled at stop level and the stop frequency is modeled at the tour level. The purpose and frequency of stops are modeled conditional on a higher level choice of each person to undertake activities of various types (activity generation models).

Time of day, mode and destination choice modeling sequence

The work and school locations are predicted at the "top" level while the work start and end times and work commute mode choice are modeled in sequence at the travel day level. The school start and end times are also predicted before the to- and from- school mode choice models. For all other activities, the tour mode is predicted at the tour level, followed by predicting the time of day and then the destination choice at the activity stop level. The departure time is derived from the predicted home stay/work stay duration before each tour, activity duration at- and travel time to- each stop.

Network features, level of service variables and modeled time periods

CEMDAP can be used with any level of spatial resolution of zones and any number of time periods for level-of-service (LOS) variables. The DFW application uses 4784 TAZ system for spatial representation and five time of day periods (AM off peak, AM peak, midday off peak, PM peak, and PM off peak) for LOS characteristics. No finer spatial units are used for land use variables.

The effect of time varying LOS characteristics is considered directly in work scheduling, and indirectly in activity generation models through accessibility measures. The LOS attributes are also used in commute mode choice and non work activity stop location choice models.

Any time of day feature in CEMDAP is predicted in continuous time. The simultaneous work-start and end time prediction is currently implemented at 30 minute time periods, but it can be implemented at any finer time intervals. The school- start and end times are predicted in continuous time using hazard based duration models. The departure time for all other activities is also scheduled in continuous time. "Available time windows" are used in both the worker and non worker scheduling models at the sub-pattern level, tour level and stop level.

Accessibility measures

Measures of accessibility from the home zone are used in activity generation models. The accessibility of a zone to another zone is calculated as the ratio of an attraction measure in the other zone relative to an impedance measure between the two zones (which is a function of travel times and costs). The parameters of these attraction and impedance functions were pre-determined from a destination choice model. The overall accessibility of a zone is then calculated as the average of the zone-to-zone accessibility measure.

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Brief note on FAMOS (provided by Prof. Ram Pendyala, Univ. of South Florida)

FAMOS was completed in 2004 with a full-fledged development and application in Southeast Florida. Since that time, work has progressed to re-engineer FAMOS and integrate it with the land use model UrbanSim in conjunction with an ongoing 3-year EPA project.

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Model design feature	Portland METRO	San Fran. SFCTA	New York NYMTC	Columbus MORPC	Atlanta ARC	Sacramento SACOG	Bay Area MTC (*)	Denver DRCOG (*)	Dallas CEMDAP	SE Florida FAMOS
Controls / # categories for population synthesis	4 hh size 4 income 4 age	4 hh size 3 # workers 4 income 3 age	5 hh size 4 # workers 4 income	5 hh size 4 # workers 4 income	100+ comb. of hh size, # workers, income, age	4 hh size 4 # workers 4 income	4 hh size 4 # workers 4 income Age (?)	4 hh size 3 # workers 4 income age (?)	6 hh type, 7 hh size, 2 # children 2 gender, 7 race, 10 age	4 hhld size, 2 dwelling unit type, 4 veh ownership, 6 age
"Usual" work & school locations at top level?	No / Yes	Yes	No	No	Yes	Yes	Yes	Yes	Yes	Yes
Number of out-of-home activity purposes	3 / 8	3	4	7	8	7	7 or 8	7 or 8	11 for adults 3 for children	6
Number of in-home activity purposes	3	1	1	1	1	1	1 or 2	1	1	2
Day pattern type linked explicitly across HH?	No	No	No	Yes, sequential	Yes, simultaneous	No	Yes, simultaneous	No	Yes sequential	Yes, sequential
Joint activities linked explicitly across HH?	No	No	No	Yes	Yes	No	Yes	No	Yes (Between parent & child)	Yes
Allocated HH activities allocated explicitly?	No	No	No	Yes	Yes	No	No	No	Yes	Yes
"Escort" trips linked explicitly across HH?	No	No	No	No	No	No	No	No	Yes	Yes
Level where stop purpose and frequency modeled	Person-day	Person-day	Tour	Tour	Tour	Person-day and tour	Person-day and tour	Person-day and tour	Person-day and tour	Person-day and tour
Network zones used (approx)	1,250	1,900	6,000	2,000	2,500	1,300	1,600	2,800	4,800	3,000
Smaller spatial units used below zones?	No / Yes 20K blocks	No	No	No	No	Yes, 700K parcels	Transit acc. subzones (?)	Yes, buildings	No	No
Mode and destination model estimation	Simultaneous	Sequential	Sequential	Sequential	Sequential	Sequential	Sequential	Simultaneous for non-work	Sequential	Simultaneous
Network time periods	5 per day	5 per day	4 per day	5 per day	4 per day	4 per day	5 per day	10 per day	5 per day	3 per day
Modeled time periods	5 per day	5 per day	4 per day	1 hour	1 hour	30 min	30 min (?)	30 min	Continuous time; 1 min	Continuous time; 1 min
Use of time window duration in scheduling?	No	No	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes, time-space prisms
Tour time of day relative to mode and destination	Above both	Above both	Between them	Between them	Between them	Between them	Between them	Above both for non-work	Between them	Above both
Departure time modeled separately at trip level?	No	No (may be added)	No	No	Yes, lowest model	Yes, lowest model	Yes, lowest model	Yes, lowest model	Yes, before stop-location	Yes, lowest model
Accessibility measures in upper level models	Person-specific mode / dest logsums	Jobs reached by zone/ mode/ time band	Dest choice logsums by zone / mode / segment	Dest choice logsums by zone / mode / segment	Dest choice logsums by zone / mode / segment	Mode & dest logsums by zone / segment	Mode & dest logsums by zone / segment	Mode & dest logsums by zone / segment	In person-level activity generation models: Hansen-type measure	Time-space prism accessibility; mode-destination logsums

(*) These model systems are currently in the model design phase.