DISAGGREGATE TREATMENT OF PURPOSE, TIME OF DAY AND LOCATION IN AN ACTIVITY-BASED REGIONAL TRAVEL FORECASTING MODEL

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1. INTRODUCTION AND MODEL SYSTEM OVERVIEW

This paper presents a regional travel forecasting model system under development in 2005 for the Sacramento (California) Area Council of Governments (SACOG). The system includes an integrated econometric activity-based demand microsimulation model with a highly disaggregate treatment of the purpose, time of day and location dimensions of the modeled outcomes. When completed, the model system will be used for transportation and land development planning, and air quality analysis. At the time of the 2005 European Transport Conference (ETC) the model system was fully designed, data had been prepared for model development, some major model components had been estimated, and a shell of the application program was complete. The model system will be completed, calibrated, sensitivity tested and used for forecasting in early 2006.

Current planning efforts in the region focus attention on the importance of development patterns at the neighborhood scale. A planning tool in use for scenario analysis called PLACE³S (Allen, *et al*, 1996) generates detailed descriptions of development scenarios, providing attributes for each parcel in the region. It is desired to accurately predict in the travel forecasting models the travel impacts of alternative neighborhood scale development patterns, including the effects of things such as increased development density, mixed use development, improved walkability, and convenient transit access, as captured by the current scenario planning tools.

To help achieve this objective, the model system under development represents travel in the context of an integrated disaggregate econometric model of each resident's full-day activity and travel schedule. Sensitivity to neighborhood scale is enhanced through disaggregation of the modeled outcomes in three key dimensions: purpose, time, and space. Each activity episode is associated with one of seven specific purposes, and with a particular property parcel on which it occurs. The beginning and ending times of all activity and travel episodes are identified within a specific 30 minute time period of the day.

This paper describes the model system design, data, and partial estimation results. Emphasis is placed on the techniques employed for effectively disaggregating the treatment of purpose, time and space. The reader is referred to the first author's website for a series of technical reports providing greater detail and results not yet complete at the time of ETC 2005.

Figure 1 shows the major components of the new travel forecasting model system. The Population Synthesizer (PopSyn) creates a synthetic population, comprised of households drawn from the region's U.S. Census Public Use Microdata Sample (PUMS), that is consistent with regional residential, employment and school enrollment forecasts. Each household is defined in terms of income and household size, plus the age, gender, employment status and student status of all household members. Using available aggregate census tables in the base year, appropriate numbers of each type of household are allocated to each Traffic Analysis Zone (TAZ). These are then drawn from PUMS and allocated to the parcels within the zone using information from SACOG's base year parcel database. For forecast years, households are synthesized using demographic forecasts and parcel level inputs from PLACE³S and the region's new economic and land development model called PECAS (Abraham, et al, 2004). Initially a simple population synthesizer, similar to the one in use by San Francisco County Transit Authority (SFCTA) is being implemented, but the intent is to implement a flexible population synthesizer along the lines of the synthesizer being developed for the Atlanta Regional Commission. See Bowman (2004) for a comparison of these and other population synthesizers.

Long-term choices (work location, school location and auto ownership) are simulated for all members of the population. The Person Day Activity and Travel Simulator then creates a one-day activity and travel schedule for each person in the population, including a list of their tours and the trips on each tour. These components of the model system, implemented jointly in a single software program (and subsequently referred to as DaySim), consist of a hierarchy of multinomial logit and nested logit models. The models are connected by adherence to an assumed conditional hierarchy, and by the use of accessibility logsums. This portion of the model system is the focus of this paper, and its components are described in detail in subsequent sections of this paper.

The trips predicted by DaySim are aggregated into trip matrices and combined with predicted trips for special generators, external trips and commercial traffic into timeand mode-specific trip matrices. The network traffic assignment models load the trips onto the network. Traffic assignment is iteratively equilibrated with DaySim and the other demand models. As shown here, the regional forecasts are treated as exogenous. In subsequent implementations, it is anticipated that the travel forecasting model will be embedded in PECAS, so that the long range PECAS forecasts will depend on the activity-based travel forecast of DaySim.

Figure 1: New SACOG Regional Travel Forecasting Model System



Table 1 lists the variables that are produced by the models. The variables are at five different levels: household, person, person day, tour and trip. The table also lists the range of values that are used for each output variable. The table contains only the most elemental variables. Other variables are computed from these, including characteristics of the household—such as household size and number of workers—that are aggregates of person characteristics, and characteristics of the day pattern or tour—such as number and purpose of tours and trips—that are aggregates of trip characteristics. Still more output variables can be computed in combination with the network and/or zonal data, such as the VMT traveled by a person.

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Table 1—Elemental variables produced by PopSyn and DaySim

2. DAYSIM MODEL OVERVIEW

2.1. Introduction and comparison with predecessors

The DaySim model follows the day activity schedule approach developed by Bowman and Ben-Akiva (2001), a modified version of which is currently in active use by the San Francisco County Transportation Authority (SFCTA). See Bradley, et al. (2001) and Jonnalagadda, et al. (2001) for details of the SFCTA model. DaySim retains the key structural advantages of the SFCTA model, including:

- 1 The model uses a microsimulation structure, predicting outcomes for each household and person in order to produce activity/trip records comparable to those from a household survey (Bradley, et al, 1999).
- 2 The model works at four integrated levels—longer term person and household choices, single day-long activity pattern choices, tour-level choices, and trip-level choices.
- 3 The upper level models of longer term decisions and activity/tour generation are sensitive to network accessibility and a variety of land use variables.

The SACOG design includes a number of key enhancements relative to the SFCTA model:

- 1 The model uses 7 purposes for both tours and intermediate stops (work, school, escort, shop, personal business, meal, social/recreation), while the SFCTA model uses only 3 for tours (work, school and other), and 1 (other) for all intermediate stops.
- 2 The model allows the specific work tour destination for the day to differ from the person's usual work and school location. That is not the case in the SFCTA model, where the specific day's work location is modeled as if it were the usual location (separate data on both were not available).
- 3 The model predicts locations down to the single parcel level, whereas the SFCTA model works completely at the TAZ level. This provides important advantages in modeling mode choice and in capturing land use and accessibility effects.
- 4 The model predicts the time that each trip and activity starts and ends to the nearest 30 minutes, using an internally consistent scheduling structure that is also sensitive to differences in travel times across the day (Vovsha and Bradley, 2004). The SFCTA time-of-day model uses a much simpler structure with only 5 time periods across the day and no sensitivity to travel times and congestion.
- 5 The accessibility variables used in the upper level models are approximations to a true expected utility structure, with single variables ("aggregate logsums") encapsulating differences across different modes and destinations. The accessibility variables used in SFCTA are mode-specific with rather arbitrary definitions—e.g. the number of retail jobs that are accessible within 30 minutes by transit.
- 6 An improved representation of time-space constraints is used in destination choice and mode choice to improve parameter estimates and reduce the prediction of impossible combinations of choices.

2.2. Model hierarchy

Figure 2 presents DaySim's conditional heirarchy in outline form, identifying the program looping structure in which the models run. The models themselves are numbered in the figure; subsequently in this paper, parenthetical numerical references to models refer to these numbers. The hierarchy embodies assumptions about the relationships among simultaneous real world outcomes. In particular, outcomes higher in the hierarchy are treated as known in lower level models. It places at a higher level those outcomes that are thought to be higher priority to the decisionmaker. The model structure also embodies priority assumptions that are hidden in the hierarchy, namely the relative priority of outcomes on a given level of the hierarchy. The most notable of these are the relative priority of tours in a pattern, and the relative priority of stops on a tour. The formal hierarchical structure provides what has been referred to by Vovsha, Bradley and Bowman (2004) as downward vertical integrity.

Figure 2—DaySim models within the program looping structure

{Draw a synthetic household sample if specified} {Loop on households} {Loop on persons in HH} {Apply model 1.1 Usual Work Location and model 1.2 School Location} {Apply model 1.3 Household Auto Availability } {Loop on all persons within HH} {Apply model 2.1 Activity Pattern (0/1+ tours and 0/1+ stops) and model 2.2 Exact Number of Tours for 7 purposes} {Loop on home-based tours within person in tour priority sequence, {Apply model 3.1 Tour Destination} {If work tour, apply model 3.2 Number and Purpose of Work-Based Subtours, and insert work based tours after the work tour} {Apply model 3.3 Tour Mode and 3.4 Tour Destination Arrival and Departure Times} {Loop on tour halves (before and after primary activity)} {Apply model 4.1 Half Tour Stop Frequency and Purpose} {Loop on trips within home-based half tour (in reverse temporal order for 1st tour half)} {Apply model 4.2 Intermediate Stop Location} {Apply model 4.3 Trip Mode} {Apply model 4.4 Intermediate Stop Departure Time}

2.3. Accessibility Linkages

Just as important as downward integration is the upward vertical integration that is achieved by the use of composite accessibility variables to explain upper level outcomes. Done properly, this makes the upper level models sensitive to important attributes that are measured directly only at the lower levels of the model, most notably travel times and costs. It also captures non-uniform cross-elasticities caused by shared unobserved attributes among groups of lower level alternatives sharing the same upper level outcome. The well-known logsum variable is the prime example of a composite accessibility variable. It is a function of the utilities of a set of conditional alternatives in a hierarchical model, which in a formal nested logit model represents the expected maximum utility of those alternatives (Ben-Akiva and Lerman, 1985). Upward vertical integration is a very important aspect of model integration. Without it, the model system will not effectively capture sensitivity to travel conditions.

However, when there are very many alternatives (millions in the case of the entire day activity schedule model), the most preferred measure of accessibility, the expected utility logsum, requires an infeasibly large amount of computation. So, in this project approaches have been developed to capture the most important accessibility effects with a feasible amount of computation. One approach involves using aggregate logsums that approximate the expected utility logsum. They are calculated in the same basic way, by summing the exponentiated utilities of multiple alternatives. However, the amount of computation is reduced, either by ignoring some differences among decisionmakers, or by calculating utility for a carefully chosen subset or aggregation of the available alternatives.

The model system uses aggregate mode-destination choice logsums extensively to indicate the accessibility around a parcel for non-mandatory activity purposes. To make it feasible to use them, they are pre-calculated and used as needed during the microsimulation. Eighty-four logsums are calculated for each TAZ, representing all combinations of 7 non-mandatory purposes, 4 car availability levels, and 3 transit accessibility categories:

Non-mandatory tour purpose	Car availability	Transit accessibility	
1) Home-based personal business	1) Child age under 16	1) Origin is within ¼ mile of	
2) Home-based shopping	2) Adult in HH with no	transit stop	
3) Home-based meal	cars	2) Origin is more than 1/4	
4) Home-based social/recreation	3) Adult in HH with cars,	mile from transit stop,	
5) Home-based escort	but fewer cars than	but walk to transit is	
6) All home-based purposes	drivers	available	
combined	Adult in HH with 1+	Walk to transit not	
7) Work-based	cars per driver	available	

Note that for the mandatory activity purposes—work and school—the usual workplace and usual school location are predicted at the highest level of the model system, so we can use full disaggregate mode choice logsums for those specific destinations instead of relying on more aggregate measures.

Another approach involves simulating a logsum. For example, in the tour destination choice model, where time-of-day is not yet known, a mode choice logsum is calculated based on an assumed time of day, where the assumed time of day is determined by a probability-weighted Monte Carlo draw. In this way, the distribution of potential times of day is captured across the population rather than for each person, and the destination choice is sensitive to time-of-day changes in travel level of service.

In many other cases within the model system, true expected utility logsums are used. For example, tour mode choice logsums are used in the tour time of day models.

In various models in the system, it is also useful to know the accessibility of particular O-D pairs for making intermediate stops. We calculate aggregate TAZ-based logsums to provide such a measure, using the logsum across all possible locations from simplified intermediate stop location model for non-mandatory stop purposes. These are calculated only for auto modes because there are very few intermediate stops on transit tours, and because localized land use density measures are adequate stop accessibility indicators for walk and bike tours.

3. DATA

Development of the model system requires the use of a household activity-diary survey, zone-to-zone travel level-of-service variables skimmed from a the base-year transport network, and a parcel database with base year attributes of each parcel, including employment and school enrollment by type, number of households, parking availability and price, and information about the transport network surrounding the parcel.

The seven defined purposes are an aggregation of over 20 purposes reported in the survey. The use of 10-minute time periods is possible because the survey reported arrivals and departures at specific points in time. The use of parcels is possible because SACOG maintains a database of parcel information for the region and was able to reconstruct reasonably well the needed base year data from their database.

The parcel data presented the biggest challenge in preparing data for model development. The parcel XY coordinates in the survey, and those of some parcel database attributes, had been assigned incorrectly by matching addresses to an incorrectly projected street network (TIGER line files widely available in the U.S.). It was necessary for SACOG staff to correctly reassign as many as possible, and to develop heuristics to reassign the rest as accurately as possible. It was also necessary to estimate some parcel attributes that were available only at the more aggregate block level from the U.S. census bureau. Finally, some of the needed parcel attributes used in the model are generated by aggregating, for each parcel, some network and parcel attributes from buffer areas surrounding the parcel, which is a time-consuming computational process. SACOG (2005) documents the details of the procedures used to develop the parcel data for model development.

The parcel data will probably present a similarly challenging task for model application. For each forecast scenario it will be necessary to produce the associated parcel level attributes and calculate buffer variables.

4. ACTIVITY PARTICIPATION MODELS

This and subsequent sections describe details of the various DaySim component models. Similar models are grouped together, for ease of presentation. Model estimation results are provided only in descriptive summary, and only for some of the models. Technical memoranda providing more details of some of the models, including estimation results, are available on the first author's website. Upon project completion a full set of technical memoranda, including descriptions of base year model calibration and sensitivity tests, will be available there as well.

4.1. Day activity pattern (2.1-2.2)

This model is a variation on the Bowman and Ben-Akiva approach, jointly predicting the number of home-based tours a person undertakes during a day for seven purposes, and the occurrence of additional stops during the day for the same seven purposes. The seven purposes are work, school, escort, personal business, shopping, meal and social/recreational. The pattern choice is a function of many types of household and person characteristics, as well as land use and accessibility at the residence and, if relevant, the usual work location. The main pattern model (2.1) predicts the occurrence of tours (0 or 1+) and extra stops (0 or 1+) for each purpose, and a simpler conditional model (2.2) predicts the exact number of tours for each purpose.

If the main pattern model were to include every combination of the 14 binary choice variables, there would be 2^14, or 16,384 alternatives. Based on an examination of the data, however, it is feasible to include only combinations that meet the following criteria:

There can be no intermediate stop purpose with 1+ stops unless there is at least 1 tour purpose with 1+ tours.

The maximum number of tour purposes with 1+ tours is 3.

The maximum number of stop purposes with 1+ stops is 4.

The maximum number of tour purposes + stop purposes with 1+ is 5.

There can be no intermediate Work stops or School stops unless there are 1+ Work tours and/or 1+ School tours.

The pattern cannot include both intermediate Work stops and School stops (if one is 1+, the other must be 0).

Following these rules, the number of alternatives in the model is reduced to 2,080, while approximately 99% of the observed patterns in the household survey data are accommodated.

The "base alternative" in the model is the "stay at home" alternative where all 14 dependent variables are 0 (no tours or stops are made).

The main utility component for each purpose-specific tour or stop alternative is a vector of person-specific and household-specific characteristics and accessibility measures. No set of variables used in the vector can cover the entire sample, so each characteristic used must have a base group. For the estimation, the following "base" characteristics are assumed to have coefficient 0, with the other person- and household-specific variables estimated relative to these:

Person type : Full-time worker

HH income : \$45-75K/year HH type: Family household (including single persons) Age group: 36-50 Gender/role : Male adult with no children under 16

For all alternatives other than the base (stay at home) alternative, which has utility 0, the utility consists of the following components:

- U = sum over p(Ip.BPp)
- + BT(NT)
- + BS(NS)
- + C(NT,NS)
- + sum over p,q (Tp.Tq.BXpq)
- + sum over p,q (Sp.Sq.BYpq)
- + sum over p,q (Tp.Sq.BZpq)

Where:

- p and q are indices that range from 1 to 7 for the 7 tourstop purposes
- Ip is 1 if there are EITHER 1+ tours or 1+ stops for purpose p, otherwise 0
- Tp is 1 if there are 1+ tours for purpose p, otherwise 0
- NT is the sum of Tp across the 7 purposes (1<=NT<=3)
- Sp is 1 if there are 1+ stops for purpose p, otherwise 0
- NS is the sum of Sp across the 7 purposes (0<=NS<=4)

The estimated coefficients are:

- BPp a purpose-specific array of coefficients related to making 1+ tours/stops for a specific purpose p, including a constant.
- BT an array of coefficients related to making more tours, not including a constant (the effect of each variable is proportional to the log of the number of tours)
- BS an array of coefficients related to making more stops, not including a constant (the effect of each variable is proportional to the log of the number of stops)

C(NT,NS) a set of constants related to making tours for NT different purposes and stops for NS different purposes. BX a matrix of coefficients for making tours for BOTH of a given pair of tour purposes. Only a half-matrix is estimated, with the diagonal constrained to 0. BY a matrix of coefficients for making stops for BOTH of a given pair of stop purposes. Only a half-matrix is estimated, with the diagonal constrained to 0. BZ a matrix of coefficients for making a stop of a given purpose in combination with a tour of a given purpose. Here, the full matrix can be estimated, as all stop purposes and tour purposes can occur together in the same pattern. The final version of this model has been estimated, and results are available in a project report. The main findings are:

- Many household and person variables have significant effects on the likelihood of participating in different types of activities in the day, and on whether those activities tend to be made on separate tours or as stops on complex tours.
- The significant variables include employment status, student status, age group, income group, car availability, work at home dummy, gender, presence of children in different age groups, presence of other adults in the household, and family/non-family status.
- For workers and students, the accessibility (mode choice logsum) of the usual work and school locations is positively related to the likelihood of traveling to that activity on a given day.
- For workers, the accessibility to retail and service locations on the way to and from work is positively related to the likelihood of making intermediate stops for various purposes.

Simpler models were estimated to predict the exact number of tours for any given purpose, conditional on making 1+ tours for that purpose. An interesting result is that, compared to the main day pattern model, the person and household variables have less influence but the accessibility variables have relatively more influence. This result indicates that the small percentage of people who make multiple tours for any given purpose during a day tend to be those people who live in areas that best accommodate those tours. Other people will be more likely to participate in fewer activities and/or chain their activities into fewer home-based tours.

4.2. Number and purpose of work-based tours (3.2)

For this model, the work tour destination is known, so variables measuring the number and accessibility of activity opportunities near the work site influence the number of work-based tours.

This model is very similar in structure to the stop participation and purpose models described next.

4.3. Stop participation and purpose (4.1)

For each tour, once its destination, timing and mode have been determined, the exact number of stops and their purposes is modeled for the half-tours leading to and from the tour destination. For each potential stop, the model predicts whether it occurs or not and, if so, its purpose. This repeats as long as another stop is predicted. The outcomes of this model are strongly conditioned by (a) the outcome of the day activity pattern model, and (b) the outcomes of this model for higher priority tours. For the last modeled tour, this model is constrained to accomplish all intermediate stop activity purposes prescribed by the activity pattern model that have not yet been accomplished on other tours.

The estimation results for this model indicate that accessibility measures are important in determining which stops are made on which tours, as well as the exact number of stops. An important feature of this model system is that we do not predict the number and allocation of stops completely at the upper pattern level, as is done in the Portland and SFCTA models, or completely at the tour level, as is done in other models. Rather, the upper level pattern model predicts the likelihood that ANY stops will be made during the day for a given purpose, at a level where the substitution between extra stops versus extra tours can be modeled directly. Then, once the exact destinations, modes and times of day of tours are known, the exact allocation and number of stops is predicted using this additional tour-level information. We think that this approach provides a good balance between personday-level and tour-level sensitivities.

5. LOCATION MODELS

5.1. Intermediate stop location (4.2)

For intermediate stop locations, the main mode used for the tour is already known, and so are the stop location immediately toward the tour destination (**stop origin**), and the **tour origin**. So the choice of location involves comparing, among competing locations, (a) the impedance of making a detour to get there, given the tour mode, and (b) the location's attractiveness for the given activity purpose.

Since over 700,000 parcels comprise the universal set of location choice alternatives, it is necessary to estimate and apply the stop location model with a sample of alternatives. For estimation, a sample of 100 parcels is used to represent the choice set for each observed choice. A randomly drawn subset of all parcels is used, with appropriate weighting, to represent the entire set of available parcels. The procedure uses importance sampling with replacement, in three stages: stratum, TAZ and parcel. Each stratum represents a particular band of impedance levels, and strata are sampled in proportion to their observed frequency of choice in the survey sample for a given type of intermediate stop. Strata include the tour origin TAZ, the stop origin TAZ, and three concentric ellipses surrounding those two points, with the size of the ellipses depending on stop characteristics. Since the stratum sampling procedure accounts for the effect of impedance, TAZ are drawn randomly within stratum. Then, within TAZ, parcels are drawn in proportion to their attracting size for the intermediate stop type. When the sample of parcels is drawn for estimation or application, infeasible destinations are excluded. Excluded parcels lack the employment, school enrollment or households needed to accommodate the stop's activity purpose, or are too far away in light of the available time, tour mode and stop purpose.

The model is a multinomial logit (MNL). Each alternative's utility function consists of the sum of several utility terms and one size function. The size function consists of several utility-like terms that are combined in the utility function in a form that corresponds with utility theory for aggregate alternatives (Ben-Akiva and Lerman,

1985). Although parcels are quite small, they must still be considered as aggregate alternatives because they have widely differing capacities for accommodating activities. For example, one residential parcel might include a large apartment building and another might have a single-family dwelling; the apartment building has a much larger capacity for accommodating activities that occur in homes. A size function is used instead of a single size variable because the defined activity purposes and size attributes do not have a simple one-to-one correspondence. Rather, several attributes can indicate capacity for accommodating a given purpose. For example, personal business could be conducted at many types of places, such as medical or retail establishments. The estimated coefficients give different weights to different size variables for a given purpose, and a scale parameter captures correlation among elemental activity opportunities within parcel. Equation 1 shows the form of the utility function, with size function included:

$$V_{in} = \sum_{k=1}^{K^{v}} \beta_{k} x_{ink} z_{nk} + \mu' \ln \sum_{k=K^{v}+1}^{K^{v}+K^{s}} \exp(\beta_{k}) x_{ink} z_{nk}$$
(1)

where:

 V_{in} is the systematic utility of parcel alternative *i* for trip *n*,

 K^{ν} is the number of utility parameters,

K^s is the number of size parameters,

 β_k , $k = 1, 2, ..., K^v + K^s$ are the utility and size parameters,

 x_{ink} is an attribute of parcel alternative *i* for trip *n*,

 z_{nk} is a characteristic of trip *n*,

 μ' is a scale parameter measuring correlation among elemental activity opportunities within parcels (1—no correlation, 0+--high correlation)

Various trip characteristics are used in the utility function, interacting with attributes so that the effect of attributes depends on the characteristics of the trip. They are all 0/1 indicator variables, with 1 corresponding to the identified trip type. Trip characteristics used in the model include stop purpose, tour purpose, tour mode, tour structure, stop placement in tour, person type, and household characteristics. The most important characteristics are the tour mode and the stop purpose. The tour mode restricts the modes available for the stop, and this affects the availability and impedance of stop locations. The availability and attractiveness of stop locations depend heavily on the stop purpose. Tour characteristics also affect willingness to travel for the stop, and the tendency to stop near the stop or tour origin. These trip and tour characteristics tend to overshadow the effect of personal and household characteristics in this model.

The main impedance variable is generalized time, as well as its quadratic and cubic forms, to allow for nonlinear effects. It combines all travel cost and time components according to assumptions about their relative values. Generalized time is used, instead of various separately estimated time and cost coefficients, because the intermediate stop data is not robust enough to support good estimates of the relative values. Generalized time is measured as the (generalized) time required to travel

from stop origin to stop location and on to tour origin, minus the time required to travel directly from stop origin to tour origin. It is further modified by discounting it according to the distance between the stop origin and the tour origin. The discounting is based on the hypothesis that people are more willing to make longer detours for intermediate stops on long tours than they are on short tours.

Additional impedance variables used in the model include **travel time as a fraction** of the available time window, which captures the tendency to choose nearby activity locations if there are tight time constraints on the stop, and **proximity** variables (inverse distance), which capture the tendency to stop near either the stop origin or the tour origin.

In the size function, one size variable serves as the 'base', setting the scale of the function, and parameters are estimated for all the other variables in the function, measuring their effect relative to the base. In the model, the size function differs by stop type. **Table 2** below shows the base size variable for each stop type, along with the other variables. It also identifies the effect of the other variables in the size function relative to the base variable. For most stop types, only one size variable has a significant effect. This is a very good result, indicating that the stop types and size variables have been defined narrowly enough so that relative parcel size in the various categories clearly impacts modeled location choice.

Stop type	Base size variable	Other variables in size function	Effect of other variables
			relative to base
Escort	K-12 enrollment	total employment	.007
(HH with kids)		households	.001
Escort	total employment	K-12 enrollment	.875
(HH with no		university enrollment	.582
kids)		households	.066
Meal	restaurant	total employment	.000
	employment	households	.000
Personal	Medical	service employment	.578
business	employment	restaurant employment	.110
		industrial and other employment	.013
		gov., office and educ. employ.	.075
		retail employment	.079
		university enrollment	.114
		households	.001
Grade school	K-12 enrollment	total employment	.001
		households	.000
University	university enrollment	total employment	.000
Shopping	retail employment	service employment	.007
		medical employment	.000
		total employment	.000
Social-	service employment	retail employment	.126
recreation		medical employment	.512
		total employment	.068
		households	.017
Work	total employment	None	

 Table 2: Size variables in the intermediate stop location model

A parcel's attractiveness can also be affected by employment, housing and school enrollment in the neighborhood, so the model includes zonal density variables, in logarithmic form, in the same categories as the size variables. Zonal density effects are estimated only for non-mandatory purposes, under the hypothesis that work and school stops are determined strictly by the need to visit a particular location, regardless of its surroundings.

In addition to impedance, size and density variables, the model includes measures of mixed parking and employment, connectivity to the transit network, and connectivity of the road network. Of these, the most significant effect comes from the parking variable, where a mix of parking and employment on a parcel increases attractiveness, as does a mix of parking and employment in the TAZ of the parcel.

Details of the intermediate stop model, including the sampling procedure and estimation results, are provided in Bowman and Bradley (2005a).

5.2. Usual work (1.1) and school (1.2) locations, tour destinations (3.1)

Like the intermediate stop model, the dependent variable in the usual location and tour destination models is the parcel. Unlike the intermediate stop model, all these models have a single anchor point from which impedance is measured. For the

usual location models and most tours, the anchor is the person's home; for workbased tours, it is the work location. This simplifies considerably the measurement of impedance, and as a result the sampling of alternatives is simpler than in the intermediate stop model. In particular, the sampling of alternatives is a two stage importance sampling with replacement; first a TAZ is drawn according to a probability determined by its size and impedance, and then a parcel is drawn within the TAZ, with a size-based probability.

Some differences among the models come from the assumed model hierarchy of Figure 2. For the usual location models, auto ownership is assumed to be unknown, based on the assumption that auto ownership is conditioned by work and school locations of household members, rather than the other way around. For the tour destinations, auto ownership levels are treated as given, and affect location choice. For university and grade school students who also work, the usual school location is known when usual work location is modeled; for other workers who also go to school, the work location is known when usual school location is modeled. For the tour destination models, all usual locations are known.

There are additional structural differences among these models. For the two usual location models (work and school), the home location is treated as a special location, because it occurs with greater frequency than any given non-home location, and size and impedance are not meaningful attributes. As a result, both of these models take the nested logit form, with all non-home locations nested together under the conditioning choice between home and non-home. In the estimation data, all workers have a usual work location and all students have a usual school location, so the model does not have an alternative called "no usual location".

Because a large majority of work tours go to the usual work location, the work tour destination model has this as a special alternative. Therefore, the model is nested, with all locations other than the usual location nested together under the conditioning binary choice between usual and non-usual.

Nearly all school tours go to the usual school location. Therefore, there is no school tour destination choice model. When students with a non-home usual location have a school tour, it is always assigned to the usual location. School tours are excluded from the day pattern choice set of students having home as the usual school location.

Since there are no modeled usual locations for activities other than work and school, the destination choice model of all remaining purposes is simply a multinomial logit model.

The utility function, including a size function component, takes the same form as shown above for the intermediate stop location model. **Table 3** provides an overview of the explanatory variables. The left-hand column lists the alternative attributes for the binary choice (special vs. regular alternative) as well as for the conditional MNL choice among regular parcel alternatives. To the right is a column

for each of the four models, and in each model's column are the characteristics associated with each of the applicable attributes.

In the binary choice between the special alternative and all other possible locations, an alternative specific constant captures the basic tendency to choose one or the other, and dummy variables capture significant differences in this effect among various population segments. The logsum variable from the regular alternatives captures the effect of level of service on this basic choice. In all three cases the parameter is larger than zero, but quite small; that is, the tendency to choose home as the usual location, or to choose the usual location for the work tour, is barely affected by level of service. In the case of the work tour choice, at parameter values close to zero the likelihood function is very flat, so it is difficult to accurately estimate its exact size. Therefore, it is constrained to a specific small value.

Two important variables in all four models are the disaggregate mode choice logsum and network distance. The logsum represents the expected maximum utility from the tour mode choice, and captures the effect of transportation system level of service on the location choice. Distance effects, independent of the level of service, are also present to varying degrees depending on the type of tour being modeled. Since the logsum variable and distance are highly correlated it was difficult in estimation to separately identify the magnitude of their parameters. Therefore, the logsum parameters are constrained to the value one, representing the simple assumption of a multinomial logit form for the joint choice of mode and destination. In nearly all cases, sensitivity to distance declines as distance increases; in some cases this is captured through a logarithmic form of distance. In other cases, where there is plenty of data to support a larger number of estimated parameters, a piecewise linear form is used to more accurately capture this nonlinear effect.

In most cases the models include an aggregate mode-destination logsum variable at the destination. A positive effect is interpreted as the location's attractiveness for making subtours and intermediate stops on tours to this location. A mix of parking and employment, at both the zone and parcel level, as well as street connectivity in the neighborhood, attract workers and tours for non-work purposes. Also, as in the case of intermediate stops, parcel size variables and TAZ-level density variables affect location choice.

Details of the intermediate stop model, including the sampling procedure and estimation results, are provided in Bowman and Bradley (2005b).

Table 3—Otility	iunction variable		choice models	
Attributes	Usual work location	Work tour destination	Usual school location	Non-work tour destination
Binary choice	Home vs other	Usual vs other	Home vs other	not applicable
Constants	by person type*	By person type* tour type	By person type* HH size	
Disaggregte logsum among regular locations	Yes	Yes	yes	
	Conditiona	I MNL choice among regu	lar locations	
Disaggregate mode choice logsum to destination	Yes	Yes	Yes	Yes
Piecewise linear driving distance function	For fulltime workers		For children under age 16	By Purpose Priority Pattern type
Natural log of driving distance	For other then fulltime workers by person type* income	By person type* tour type	For persons age 16+ by person type*	By tour type income person type* time available
Distance from usual work location		Yes	for not student aged	
Distance from usual school location	for student aged	for student aged		Yes
Aggregate mode-dest logsum at destination	By person type	By person type	By person type	By purpose
Parking and employment mix	For daily parking in parcel and in TAZ	for daily parking in parcel and TAZ		For hourly parking in parcel and TAZ by car availability
Ratio of neighborhood nodes with 3 or 4 entering links	Yes	By car availability		By car availability
employment, enrollment and households by category:	by person type income	By person type Income	by person type	by purpose (and by 'kids in household' for escort tours)
Zonal density	yes	yes	yes	yes
Parcel size	yes	yes	yes	yes
Person type categories in the models	full-time worker part-time worker not full- or part-time	full-time worker part-time worker not full- or part-time	child under 5 child 5 to 15 child 16+ university student not student aged	full-time worker part-time worker retired adult other adult university student child 16+ child 5 to 15 child under 5

Table 3—Utility function variables in the location choice models

6. MODE CHOICE MODELS

6.1. Tour main mode (3.3)

The tour mode choice model determines the main mode for each tour (a small percentage of tours are multi-modal), There are eight modes, although some of them are only available for specific purposes. They are listed below along with the availability rules, the same priority order as used to determine the main mode of a multi-mode tour:

(1) DT- Drive to Transit: Available only in the Home-based Work model, for tours with a valid drive to transit path in both the outbound and return observed tour

- (2) WT- Walk to Transit: Available in all models except for Home-based Escort, for tours with a valid walk to transit path in both the outbound and return observed tour periods.
- (3) SB: School Bus: Available only in the Home-based School model, for all tours.
- (4) S3- Shared Ride 3+: Available in all models, for all tours.
- (5) S2- Shared Ride 2: Available in all models, for all tours.
- (6) DA- Drive Alone: Available in all models except for Home-based Escort, for tours made by persons age 16+ in car-owning households.
- (7) BI- Bike: Available in all models except for Home-based Escort, for all tours with round trip road distance of 30 miles or less.
- (8) WK- Walk: Available in all models, for all tours with round trip road distance of 10 miles or less.

Transit has less than 1% mode share and Bicycle has less than 2% mode share for all purposes except Work and School. In order to get enough transit and bicycle tours to provide reasonable estimates, the home-based non-mandatory purposes of shopping, personal business, meal and social/recreation were grouped in a single model, but using purpose-specific dummy variables to allow for different mode shares for different purposes. Some comments on the estimation results follow:

Level of service variables: In general, it was possible to obtain significant coefficients for out-of-vehicle times, but not for travel costs or in-vehicle times. This is a typical result for RP data sets, particularly when there are few transit observations. As a result, many of the coefficients for cost and in-vehicle time were constrained at values that met the following criteria: (1) the in-vehicle time coefficients meet the United States Federal Transit Administration (FTA) guidelines, (2) the imputed values of time are reasonable and meet FTA guidelines, and (3) the values were kept as close as possible to what the initial estimation indicated.

The resulting values of time and out-of-vehicle/in-vehicle time ratios are shown in the following table:

Model	Value of time (\$/hr)	Ratio Walk to In-Vehicle	Ratio Wait to In-Vehicle
Home-Based Work	\$11.20	2.95	2.50
Home-Based School	\$6.00	2.20	2.20
Home-Based Escort	\$7.50	3.00	N/A
Home-Based Other	\$7.50	2.72	2.72
Work-Based	\$7.50	2.84	2.84

The number of transfers was not found to be significant in any of the models, however transfer wait time is included in the out-of-vehicle time coefficients.

Other LOS-related variables are included in the Home-Based Work model. Having an LRT stop as the closest stop to home significantly increases the probability of choosing Walk to Transit. Also, the higher the percentage of time in a Drive to Transit path that is spent in the car rather than on transit, the lower the probability of choosing it. This is a result often found in other cities as well, which serves to discourage park-and-ride choices that include long drives followed by short transit rides.

Land use variables: Two land use variables came out as significant in many of the models, increasing the probability of walk, bike and transit.

Mixed use density: This is defined as the geometric average of retail and service employment (RS) and households (HH) within a half mile of the origin or destination parcel, in units of thousands of persons ($= 0.001 \times RS \times HH / (RS + HH)$). This value is highest when jobs and households are both high and balanced. High values near the tour origin tend to encourage walking and biking, while high values near the tour destination more often encourage transit use.

Intersection density: This is defined as the number of 4-way intersections plus one half the number of 3-way intersections within a half mile of the origin or destination parcel. Higher values tend to encourage walking for School and Escort tours, where safety for children is an issue, and also to encourage walking, biking and transit for Home-Based Other tours.

Pattern-specific variables: In terms of the activity pattern, the variable that influences mode choice the most is whether or not there are intermediate stops along the tour. With our model design, we do not predict the exact number and purpose of stops on a tour until AFTER tour mode choice is predicted, so we do not know the exact stops on the tour. From the pattern model, however, we do know how many tours are made during the day, as well as for which purposes stops and tours are made. So, if the tour is the only one made during the person-day (which is true in the majority of cases), then we do know when we apply the mode choice models whether or not there are stops on the tour for each purpose. Two variables are used in the models to reflect this type of knowledge:

Escort stop dummy divided by the number of tours in the day: The higher this variable, the higher the chance that there is an escort stop on the tour (the maximum value is 1.0). This variable significantly increases the chance of choosing Shared Ride and decreases the chance of choosing Drive Alone, as one would expect. The effect is strongest for Work tours, but also found for School and HBOther tours.

Number of other stop purposes divided by the number of tours in the day. This variable is analogous to the one for escort stops, but adds together all other stop purposes. The higher this variables, the higher the chance of choosing both Shared Ride and Drive Alone, as the automobile is more conducive to making multi-stop tours. The effects are not as strong as those found for escort stops, however.

Other variables: The other variables in the model are those that are related to the household and the person, and many are those typically found in mode choice models:

Car availability: There are three separate variables:

HH has no cars HH has cars but fewer cars than drivers, HH has cars but fewer cars than workers

All of these variables have significant effects in most of the models.

Income: The income effects are not very strong, but there are a few effects discouraging car use for lower income households.

Gender. The only gender effect is one that is often found – that males are more likely to go by bicycle than females.

Age: As one would expect, the strongest age effects are in the School model, with students of various age groups preferring different modes. For the other purposes, there is less chance of choosing Bike (and sometimes Walk) for those over age 50,

Household size: There are strong effects that reduce the chance of Shared Ride 3+ in 1-person or 2-person households and reduce the chance of Shared Ride 2 in 1person households, reflecting the fact that most "carpools" are intra-household, even for Work tours. There are also effects by age group, with the number of children under 5 and age 5-15 increasing the probability of Shared Ride for Work and Other tours, and the number of children age 16-17 and non-working adults decreasing the probability of Shared Ride. Household size is the strongest variable in the Escort tour model, with both Shared Ride 3+ and Walk becoming more likely relative to Shared Ride 2+ as the number of young children increases.

Davis: The choice of the Bike mode is much more likely in the city of Davis than in other areas in all of the models. Walk is also more likely in Davis for HBOther tours.

Mode to work: It is a typical finding that the most important single variable determining mode choice for work-based tours is the mode used to get to work, with people tending to use that same mode for their work-based tours.

Sub-purposes: In the HBOther model, the results show that, relative to Personal Business tours...

- Shopping tours are more likely to go by Shared Ride and less likely to go by Transit.
- Meal tours are more likely to go by Shared Ride, Transit and Walk.
- Social/recreation tours are more likely to go by Shared Ride, Bike and Walk.

Nesting: A number of different nesting structures were tested. In the chosen nesting structure, three nests that combined:

- (1) Drive to Transit with Walk to Transit
- (2) Shared Ride 2 with Shared Ride 3+
- (3) Bike with Walk

were tested with separate coefficients, and all coefficients were less than 1.0 but not significantly different from each other, so a single estimated nesting parameter

applies to all 3 nests (as well as to the 2 additional "nests" that only have one alternative each: Drive Alone, and School Bus). Note that the Transit nest only has a single alternative – Walk to Transit - in all models except for Work.

The estimated logsum parameters are 0.51 for Work, 0.86 for School, and 0.73 for Other. For Work-Based tours, it was not possible to obtain a stable estimate, so a constrained value of 0.75 (similar to HBOther) was used. No nesting was used for the Escort model, as it contains only 3 alternatives and is a very simple model.

Details of the estimation results are available in Bradley and Bowman (2005).

6.2. Trip mode (4.3)

The trip-level mode is conditional on the predicted tour mode, but now uses a specific OD pair and a time anchor, and also the trip mode for the adjacent, previously modeled trip in the chain. The majority of tours use a single mode for all trips, so this model only explains the small percentage of trips that are made by modes other than the main mode. The most common occurrence of this is a Drive Alone trip that is made as part of a Shared Ride tour after the passenger has been picked up or dropped off. These cases are most common on Escort tours, where predicting the trip(s) that is Drive Alone is mainly a function of the half tour (away from home or towards home) and the time of day.

Estimation results are available in a project report from the first author's website.

7. AUTO AVAILABILITY (1.3)

This model is applied at the household level, and determines the number of vehicles available to the household drivers. It is structured as a multinomial logit (MNL) with five available alternatives: 0, 1, 2, 3, and 4+. The 4+ aggregate category is used because very few of the 3942 households in the sample have five or more autos, and all but 12 of those have less than five drivers, so households with 4+ autos almost never have competition for autos within the household.

Key variables are the numbers of working adults, non-working adults, students of driving age, children below driving age and income. Statistically significant policy variables affecting car ownership include mode choice logsums measuring accessibility to the workers' and students' usual work and school locations, a mode-destination choice logsum measuring accessibility from home to non-work activities, distance from home to the nearest transit stop, parking prices in the home neighborhood, and commercial employment in the home neighborhood. Although the policy variables are significant, the model's auto ownership elasticity with respect to changes in these variables is less than 0.1 in nearly all cases and often much lower, the lone exception being very low income households.

Details of the estimation results are available in Bradley and Bowman (2005c).

8. CONCLUSIONS

Since the model system has not yet been fully implemented and used, it is too early to draw conclusions about its effectiveness, including the value of disaggregating the models by purpose (7 purposes), location (parcels) and time (30 minute time periods). However, the preliminary estimation results indicate that it is feasible to disaggregate at this level, and the estimated models appear to be superior in some ways related to this disaggregation. For example, in the mode choice models, parcel-based walk access to transit measures have the statistically most significant parameter estimates, and in the location choice models, purpose-specific parcel-level size variable parameters were identified.

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