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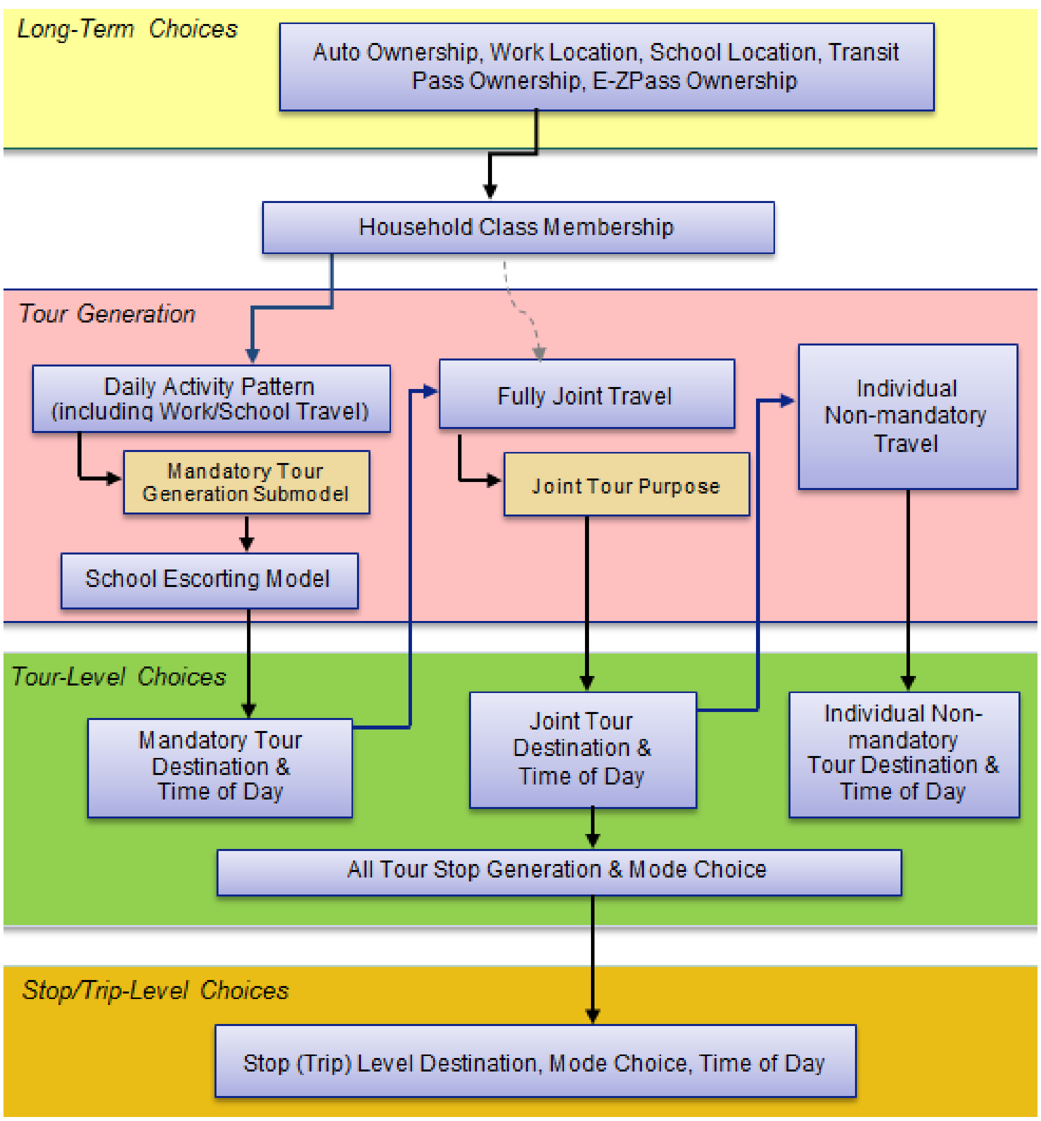
1.0 Introduction

1.1 Overview of InSITE

This report documents the model estimation for the components of the activity based model developed for the Baltimore Metropolitan Council (BMC) called InSITE. The model structure, shown in Figure 1.1, is documented in the model design report, *Model Design Plan for BMC Activity-Based Model* (Cambridge Systematics, Inc., 2013).

Figure 1.1 Activity Based Model Design



The report is organized as follows. This chapter presents an overview of InSITE and a discussion of how logsums are generated for the upper level choice models in InSITE. The sections of Chapter 2 document the model estimation results for the individual components of the activity based model.

1.2 Logsums for Upper Level Choice Models

This section details the development of logsums used for the upper level choice models of the BMC activity-based model.

Overview

For each model, different sets of logsums are used. In general, there are three types of logsums. The first two are workplace and school location logsums. These are based on the chosen workplace and school locations for workers and children and are across a single origin and destination pair. The other type is accessibility logsums, which are zone based accessibility measures across all destination zones.

For each worker in a household, the logsum between home and work zones is the workplace logsum, and for each child in a household, the logsum between home and school zones is the school location logsum. In this case, the logsums are taken across different modal options. The two types of logsums are identical in concept, the only difference being which members of a household they apply to and whether they utilize the workplace location or the school location. The logsum calculations will use the estimated parameters of the work and school tour mode choice models.

Accessibility logsums are more generic, and apply at the zone level (rather than a specific origin-destination pair). They measure the overall accessibility of a zone to all employment or other opportunities across all zones. Typically a zone located in the CBD will have higher accessibility values than a rural zone. Because these logsums are zonal based, they are taken across mode, time period (reduced to peak and off-peak periods), and destinations. Because logsums across destinations are involved, size terms are defined, which vary according to the specific accessibility logsum it is used for.

Depending on which model component the logsums are used for and attached to, different assumptions are used to generate the logsums. In every case, the logsums utilize parameters from the estimated tour mode choice models (see Section 2.14). Depending on the logsum, different tour mode choice model parameters are used. In addition, each logsum may utilize different sets of modal utility functions and make different assumptions about the number of vehicles in the household.

Workplace and School Location Logsum Formulations

As stated above, these logsums are based on fixed origin and destination locations. The specific formulation of the logsum is as follows:

$$MLS_{pvt} = \ln\left[\sum_{m} \delta_m \exp(U_{pvtm})\right]$$

Here, MLS_{pvt} is the mode logsum for tour purpose p, vehicle sufficiency v, and time period t, U_{pvtm} is the utility associated with mode m for tour purpose p, vehicle sufficiency v, and time of day t, and δ_m is an $0/1$ indicator denoting whether mode m is to be used in the logsum calculation.

The utility equations come from the coefficients estimated in the mode choice models. Because these are upper level logsums, many of the variables in the estimated mode choice models cannot be used. Table 1.1 shows the utility coefficients used in the workplace and school location logsum calculations.

Table 1.1 Utility Coefficients for Work and School Location Logsums

Mode	Variable	Coefficient	
		Work	School
All	Travel Time	-0.0228	-0.0152
All	Cost – Income < $15K	-0.4010	-0.4010
All	Cost – Income $15-30K	-0.2316	-0.2316
All	Cost – Income $30-50K	-0.1714	-0.1714
All	Cost – Income $50-100K	-0.1268	-0.1268
All	Cost – Income > $100K	-0.0878	-0.0878
TD,TW	Transfers	-0.0634	-0.0634
TD,TW	Local Bus Used (0/1)	-1.2535	-1.1597
TW	Income < $15K	1.870	2.769
TW	Income $15-50K	1.870	1.545
TW	Income > $100K	n/a	-2.058
TW	Intersection Density at Origin (1/2 mi buffer)	0.008	0.004
TW	Log (1+Employment Density at Destination) (1/2 mi buffer)	0.157	0.195
SB	Income > $100K	n/a	-1.092
SB	Intersection Density (1/2 mi buffer)	n/a	-0.010
SB	Log (1+Employment Density at Destination) (1/2 mi buffer)	n/a	-0.053
HOV3+	Household size = 2	-1.017	n/a
HOV	Household size = 1	-1.132	-0.834
HOV	Income < $50K	0.200	n/a
HOV	Income > $100K	-0.125	-0.804
Bike	Income < $30K	-1.267	0.951
Bike	Income $30-50K	-1.267	n/a
Bike	Income > $100K	0.920	n/a
Bike	Log (1+Employment Density at Destination) (1/2 mi buffer)	0.091	0.284
Walk	Income < $15K	0.631	1.047
Walk	Income $15-30K	n/a	1.047
Walk	Intersection Density at Origin (1/2 mi buffer)	0.006	0.008
Walk	Log (1+Employment Density at Destination) (1/2 mi buffer)	0.499	n/a

Since InSITE predicts specific XY coordinates for each household location and each destination location, these logsums can use specific location data in the logsum calculations, rather than zonal level information. This applies to use of density variables in the mode choice utility functions, for instance, where the calculations are based on half-mile buffers around specific origin and destination locations.

To account for the fact that a number of the variables from the estimated models are omitted here, the average effect of those variables in the survey data is added to each mode's alternative specific constant. In addition, there are four ways in which the vehicle availability variables can are included in the alternative specific constant formulation. Each model will specify one of these four options for how logsums are to be computed for that model. The first case uses generic constants, meaning they are not specific to any particular vehicle sufficiency level (and the average effect of all the vehicle sufficiency variables is added to the constants). The other three cases assume either zero vehicles in the household, vehicles are less than workers (and are greater than 0), or vehicles are greater than or equal to workers. Table 1.2 shows the constants for the workplace location logsums, and Table 1.3 shows the constants for the school location logsums. Note that school bus is not a valid mode for work tours and drive-transit is not a valid mode for school tours.

Table 1.2 Work Location Logsum Alternative Specific Constants

Mode	Vehicle Sufficiency Level			
	Generic	No Car	Cars < Workers	Cars >= Workers
Transit auto access	-0.267	-0.267	-0.267	-0.267
Transit walk access	-2.201	3.446	-1.131	-2.758
HOV3+	-3.462	-2.508	-3.209	-3.535
HOV2	-2.323	-2.323	-2.323	-2.323
SOV	-0.263	-4.949	-1.481	0.163
Bike	-6.288	-5.821	-5.821	-6.422
Walk	-6.391	-3.453	-6.522	-6.522

Table 1.3 School Location Logsum Alternative Specific Constants

Mode	Vehicle Sufficiency Level			
	Generic	No Car	Cars < Workers	Cars >= Workers
TW	2.056	7.586	4.084	1.228
SB	3.206	7.225	4.113	2.764
HOV3+	0.681	4.441	1.928	0.263
HOV2	-0.237	-0.237	-0.237	-0.237
SOV	-0.804	-7.673	-2.601	0.112
Bike	-4.849	-0.264	-4.157	-5.350
Walk	0.702	6.009	1.667	0.121

Accessibility Logsum Formulations

The accessibility logsum formulations use a similar mode choice logsum calculation for specific origin-destination zone pairs but also include logsum aggregations across time of day (TOD) and across destination zones. Formally, the accessibility logsum for zone i is computed as follows:

$$A_{ipvz} = \ln\left[\sum_{j} S_{zj} \times \exp\left(TMLS_{ijpv}\right)\right]$$

Here the sum is across all zones in the region. A_{ipvz} is the accessibility measure for zone i, tour purpose p, vehicle sufficiency category v, and size formulation z, S_{zj} is the size variable for zone j using size formulation z as defined later, and $TMLS_{ijpv}$ is the time of day/mode choice logsum as defined below. The time periods are peak and off-peak (there are only two).

$$TMLS_{ijpv} = \mu \times \ln\left[\sum_{t=pk,op} \exp\left(MLS_{ijpvt} + \alpha_{pt}\right)\right]$$

Here, $\mu = 1.0$ is a nesting coefficient for mode choice under time of day, α_{pt} is a constant for time period t, and MLS_{ijpvt} is the mode choice logsum for time of day t. The time of day constants vary based upon the purpose of the tour as shown in Table 1.4.

Table 1.4 Time of Day Constants

Tour Purpose Model	Peak Constant	Off-Peak Constant
Work	0.0	-0.5
School	0.0	-0.8
University	0.0	+0.2
Other	0.0	+0.5
Joint	0.0	+0.5

The mode logsum is computed in a similar manner to those computed for the work and school location logsums:

$$MLS_{ijpvt} = \ln\left[\sum_{m} \delta_m \exp\left(U_{ijpvtm}\right)\right]$$

Here, δ_m is a $0/1$ indicator denoting whether mode m is to be used in the logsum calculation.

Like the work and school location logsums, many variables in the mode choice models are unknown when the upper level logsums are computed. Furthermore, due to computational demands, it is imperative that only a limited set of accessibility logsums be computed, that can be applied to large segments of households. For this reason, there is an even more limited set of variables included in the set of accessibility variables considered. Additionally, only two income segments are considered, low income (less than $50K) and high income (more than $50K). Table 1.5 shows the utility coefficients for the accessibility logsums. For accessibility logsums, all density variables are computed at the zonal level, to avoid the numerous calculations that would be needed in model application to support different accessibility logsums for each individual household.

Table 1.5 Utility Coefficients for Accessibility Logsums

Mode	Variable	Purpose				
		Work	School	University	Other	Joint
All	Travel Time	-0.0228	-0.0152	-0.0152	-0.0152	-0.0152
All	Cost – Income < $50K	-0.2316	-0.2316	-0.2316	-0.2316	-0.2316
All	Cost – Income > $50K	-0.1268	-0.1268	-0.1268	-0.1268	-0.1268
TD,TW	Transfers	-0.0634	-0.0634	-0.0634	-0.0634	-0.0634
TD,TW	Local Bus Used (0/1)	-1.2535	-1.1597	-1.1597	-1.9061	-1.9061
TD	Income < $50K	0.000	n/a	0.000	0.000	n/a
TW		1.870	1.903	1.932	2.014	2.004
SB		n/a	0.000	n/a	n/a	n/a
HOV3		0.200	0.000	0.000	0.169	0.169
HOV2		0.200	0.000	0.000	0.169	0.169
Bike		-1.267	0.465	0.531	-0.939	n/a
Walk		0.055	0.511	0.584	0.166	0.157
TD	Income > $50K	0.000	n/a	0.378	0.000	n/a
TW		0.000	-1.198	-1.024	0.000	0.000
SB		n/a	-0.636	n/a	n/a	n/a
HOV3		-0.070	-0.468	-0.400	-0.061	-0.062
HOV2		-0.070	-0.468	-0.400	-0.061	-0.062
Bike		0.511	0.000	0.000	0.000	n/a
Walk		0.000	0.000	0.000	0.000	0.000
TW	Intersection Density (Origin Zone)	0.008	0.004	0.004	0.008	0.008
SB		n/a	-0.010	n/a	n/a	n/a
Walk		0.006	0.008	0.008	0.007	0.007
TW	Log (1 + Employment Density) (Destination Zone)	0.157	0.195	0.195	0.086	0.086
SB		n/a	-0.053	n/a	n/a	n/a
Bike		0.091	0.284	0.284	0.000	0.000
Walk		0.499	0.000	0.000	0.175	0.175

Like the work and school location logsums, different sets of alternative specific constants are used depending on what vehicle sufficiency level is desired for the logsum variable. The constants are based on the estimated vehicle sufficiency variables from mode choice model estimation. Table 1.6 presents these constants for each tour purpose.

Table 1.6 Alternative Specific Constants for Accessibility Logsums

Vehicle Sufficiency Category	Mode	Purpose				
		Work	School	University	Other	Joint
Generic	TD	-0.267	n/a	-0.067	-1.650	n/a
	TW	-2.201	2.056	-1.348	-2.034	-4.561
	SB	n/a	3.206	n/a	n/a	n/a
	HOV3	-4.258	0.681	-2.040	-2.421	-2.119
	HOV2	-2.707	-0.237	-1.809	-1.412	-1.172
	SOV	-0.263	-0.804	-0.774	-0.548	n/a
	Bike	-6.288	-4.849	-6.538	-5.992	n/a
	Walk	-6.391	0.702	-1.391	-3.354	-3.975
No Car	TD	-0.267	n/a	-2.376	-4.011	n/a
	TW	3.446	7.586	6.493	2.797	0.374
	SB	n/a	7.225	n/a	n/a	n/a
	HOV3	-3.304	4.441	1.809	-2.235	-1.928
	HOV2	-2.707	-0.237	-1.809	-1.412	-4.023
	SOV	-4.949	-7.673	-7.628	-5.708	n/a
	Bike	-5.821	-0.264	-1.875	-4.082	n/a
	Walk	-3.453	6.009	4.012	-0.756	-1.364
Cars < Workers	TD	-0.267	n/a	0.160	-4.011	n/a
	TW	-1.131	4.084	2.990	-1.251	-3.725
	SB	n/a	4.113	n/a	n/a	n/a
	HOV3	-4.004	1.928	-0.705	-2.436	-2.128
	HOV2	-2.707	-0.237	-1.809	-1.412	-1.049
	SOV	-1.481	-2.601	-2.556	-0.636	n/a
	Bike	-5.821	-4.157	-5.768	-4.893	n/a
	Walk	-6.522	1.667	-0.331	-3.131	-2.966
Cars >= Workers	TD	-0.267	n/a	0.160	-1.475	n/a
	TW	-2.758	1.228	-3.532	-2.691	-5.164
	SB	n/a	2.764	n/a	n/a	n/a
	HOV3	-4.331	0.263	-2.369	-2.436	-2.128
	HOV2	-2.707	-0.237	-1.809	-1.412	-1.049
	SOV	0.163	0.112	0.157	-0.028	n/a
	Bike	-6.422	-5.350	-6.961	-6.419	n/a
	Walk	-6.522	0.121	-1.877	-3.602	-4.497

The last piece needed for the accessibility logsums is the size variables. The size term in the accessibility logsum function is defined as follows:

$$S_{zj} = \sum_{k} \gamma_{zk} X_{kj}$$

Here, γ_{zk} is the kth coefficient for size function z and X_{kj} is the kth zonal variable (e.g., employment) for zone j. The size coefficients were estimated using linear regressions of zonal employment on number of tours attracted to zones. Each size function z considers either a different set of zonal variables, a different set of tours, or both. The size coefficients are outlined in Table 1.7.

Table 1.7 Size Coefficients for Accessibility Logsums

Size Description	Code	Size Variables								
		HHs	Ret	Off	Ind	Edu	Hlth	Food	Oth	Enroll
Work	wrk0	0.000	0.356	0.774	0.737	1.000	0.961	1.301	0.926	0.000
Work, Inc1	wrk1	0.000	0.984	0.216	1.182	1.000	0.384	1.436	0.111	0.000
Work, Inc2	wrk2	0.000	0.405	0.208	0.966	1.000	1.147	1.358	0.155	0.000
Work, Inc3	wrk3	0.000	0.545	0.214	0.240	1.000	0.472	0.193	0.814	0.000
Work, Inc4	wrk4	0.000	0.410	0.676	0.746	1.000	1.067	1.112	0.519	0.000
Work, Inc5	wrk5	0.000	0.094	1.445	1.045	1.000	1.210	2.393	1.682	0.000
School	sch0	0.276	0.000	0.000	0.000	0.283	0.000	0.000	0.000	1.000
University	uni0	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.000	0.000
Non-Mandatory	nm0	0.345	1.000	0.008	0.000	0.100	0.238	0.625	0.017	0.000
Meal	nm1	0.000	0.485	0.000	0.000	0.000	0.000	1.000	0.000	0.000
Shop	nm2	0.000	1.000	0.000	0.000	0.021	0.035	0.178	0.000	0.000
Pers. Bus.	nm3	0.466	1.000	0.037	0.000	0.040	0.944	0.654	0.182	0.000
Soc.-Rec.	nm4	1.998	1.000	0.061	0.230	1.130	0.669	3.456	0.236	0.000
Joint	fj0	0.188	1.000	0.000	0.000	0.076	0.160	0.299	0.000	0.000
FJ Meal	fj1	0.000	1.695	0.000	0.000	0.000	0.000	1.000	0.000	0.000
FJ Shop	fj2	0.000	1.000	0.000	0.000	0.064	0.012	0.112	0.000	0.000
FJ Pers. Bus.	fj3	0.407	1.000	0.000	0.000	0.000	1.111	0.000	0.026	0.000
FJ Soc.-Rec.	fj4	1.822	1.000	0.211	0.029	0.642	0.000	1.524	0.189	0.000

Level of Service Variables in the Logsum Calculations

The level of service attributes used in both the work/school location logsums and accessibility logsum calculations are round trip measures. Either peak period skims are used in both directions or off-peak period skims are used in both directions. Mixing of the skim periods is not done.

Generalized Travel Times

The travel time coefficients for each model are applied to a generalized travel time variable, which is in units of in-vehicle time (IVT). Therefore, all out-of-vehicle time (OVT) must be converted to IVT using a set of weights (consistent with the mode choice modes).

Auto generalized travel times are computed as follows:

TT_{auto} = +1.0 * [Auto time]
+2.5 * 2 * [Terminal time at origin + terminal time at destination]

We double count the terminal times since they are added once for each half-tour.

Transit generalized travel times are as follows:

TT_{TR} = +1.0 * [Transit Time]
+1.0 * [Transfer Time (walk & wait)]
+1.0 * [Drive Time]

+2.5 * 2 * [Terminal time at origin if drive-to-transit]
+2.5 * [Walk access & egress time]
+2.5 * [Initial wait time]
-1.0 * max(0, [Initial wait time] – 7)

Note that drive time and terminal times are only included for the drive-to-transit mode, not for the walk-to-transit mode.

For bike, walk, and school bus modes, generalized travel times are as follows:

TT_{BK} = +2.5 * (5.0 * [HOV Distance])

TT_{WK} =+3.0 * (20.0 * [HOV Distance])

TT_{SB} = +2.54 * ([HOV Distance])

Travel Costs

Auto costs include auto operating costs, tolls, and parking costs at the destination. Operating costs are equal to 0.099 * roundtrip distance. Parking costs use the hourly parking cost variables and assumptions about the duration of parking. The parking cost assumed for each logsum calculation depends on the tour purpose assumed for the logsum, as shown in Table 1.8.

Table 1.8 Parking Cost Assumptions

Assumption	Tour Purpose			
	Work	**School**	**Non-Mandatory**	**Work Based**
Park Cost Variable	Work	Non-Work	Non-Work	Non-Work
Park Duration (hrs)	8	6	2	1

All HOV2 costs are divided by 2.0, and all HOV3+ costs are divided by 3.5. The cost associated with the walk-transit mode is simply the skimmed transit fare. The cost associated with the drive-transit mode is the skimmed transit fare, plus the auto operating cost (drive distance times 0.099). School bus, bike, and walk modes are assumed to have no cost.

Note that tolls, parking costs, and transit fares are all reported in **cents** in the network skims. For the utility functions, all costs should be input in **dollars**.

Logsums

This section details the different logsums used for each upper level choice model in InSITE. For each model, a table is prepared detailing the following:

- **BMC Model** – This is the model the logsum is used in.

- **Logsum Type** – This denotes one of the three logsum types: Workplace Location (WP), School Location (SP), or Accessibility (Acc).
- **Purpose** – This denotes the tour purpose from which to draw the model parameters used in the utility calculations of the logsum (e.g., work, school, university, non-mandatory, or joint).
- **Vehicle Sufficiency** – This denotes what set of constants to use. Different constants are used depending on vehicle sufficiency ("0-veh", "cars<workers", "cars>=workers", "generic").
- **Modes** – This denotes the set of modes to include in the logsum calculation. All other modes will use a value of zero for δ_m in the logsum calculations. The set of possible values for this assumption are listed below.
    - *All Modes* – all relevant modes for the tour purpose (e.g., school bus is never allowed for non-school purpose, transit with auto access not allowed for school).
    - *Auto Only* – Includes SOV, HOV2, and HOV3+.
    - *Drive Alone* – Includes drive alone only.
    - *Walk-Transit* – Includes walk-transit only.
    - *Non-Auto* – Includes walk-transit, bike, and walk (does not include drive-transit).
    - *Non-Motor* – Includes bike and walk only.
    - *Walk* – Includes walk only.
- **TOD** – This is the time period to use for skims. For all accessibility logsums, a logsum across both peak and off-peak periods is included in the logsum calculation. Only for work and school location logsums will this ever be important.
- **Size Terms** – This indicates the set of size coefficients to utilize for the logsum. It is only relevant for the accessibility logsum measures.

Regular Work and School Location

For these models, the regular workplace and regular school location logsums are slightly different than all other models. The difference is that they are needed for all destination options, similar to the tour destination choice models. In all other models, work and school logsums will only be computed for the actual chosen work and school locations.

In addition, since a specific destination location is unknown for these models, the destination density variables should be based on destination zone, rather than half-mile buffer. Table 1.9 shows the needed logsums for the work and school location model datasets.

Table 1.9 Regular Work and School Location Model Logsums

BMC Model	Logsum Type	Purpose (to draw coefficients from)	Vehicle Sufficiency	Modes	TOD	Size Terms
Work Location	WP	Work	Generic	All	Pk/Pk	n/a
Work Location	Acc	Work	Generic	All	All	wrk0
Work Location	Acc	Work	Generic	All	All	wrk1
Work Location	Acc	Work	Generic	All	All	wrk2
Work Location	Acc	Work	Generic	All	All	wrk3
Work Location	Acc	Work	Generic	All	All	wrk4
Work Location	Acc	Work	Generic	All	All	wrk5
Work Location	Acc	Work	Generic	Auto only	All	wrk0
Work Location	Acc	Work	Generic	Non-auto only	All	wrk0
School Location	SP	School	Generic	All	Pk/Pk	n/a
School Location	Acc	School	Generic	All	All	sch0
School Location	Acc	School	Generic	Auto Only	All	sch0
School Location	Acc	School	Generic	Non-auto only	All	sch0

Vehicle Availability and Transit Pass

Table 1.10 shows the logsum calculations used for the vehicle availability model and the transit pass ownership model. In general, the sets of logsums for the two models are very similar. Both models utilize regular workplace location logsums of the workers in the household and utilize accessibility logsums for specific modes of transport. The transit pass model also includes accessibility logsums across all modes, but with varying car sufficiency levels.

Table 1.10 Vehicle Availability and Transit Pass Model Logsums

BMC Model	Logsum Type	Purpose (to draw coefficients from)	Vehicle Sufficiency	Modes	TOD	Size Terms
Vehicle Av.	WP	Work	Generic	Auto Only	Pk/Pk	n/a
Vehicle Av.	WP	Work	Generic	Non-Auto	Pk/Pk	n/a
Vehicle Av.	Acc	Other	Generic	Drive alone	All	nm0
Vehicle Av.	Acc	Other	Generic	Transit-walk	All	nm0
Vehicle Av.	Acc	Other	Generic	Walk	All	nm0
Transit Pass	WP	Work	Generic	Auto Only	Pk/Pk	n/a
Transit Pass	WP	Work	Generic	Non-Auto	Pk/Pk	n/a
Transit Pass	Acc	Other	No Car	All	All	nm0
Transit Pass	Acc	Other	Car < Wrkr	All	All	nm0
Transit Pass	Acc	Other	Car > Wrkr	All	All	nm0
Transit Pass	Acc	Other	Generic	Drive alone	All	nm0
Transit Pass	Acc	Other	Generic	Transit-walk	All	nm0
Transit Pass	Acc	Other	Generic	Walk	All	nm0

Daily Activity Pattern

Table 1.11 shows the logsum variables used for the daily activity pattern (DAP) model.

Table 1.11 DAP Model Logsums

BMC Model	Logsum Type	Purpose (to draw coefficients from)	Vehicle Sufficiency	Modes	TOD	Size Terms
DAP	WP	Work	No Car	All	Pk/Pk	n/a
DAP	WP	Work	Car < Wrkr	All	Pk/Pk	n/a
DAP	WP	Work	Car > Wrkr	All	Pk/Pk	n/a
DAP	SP	School	No Car	All	Pk/Pk	n/a
DAP	SP	School	Car < Wrkr	All	Pk/Pk	n/a
DAP	SP	School	Car > Wrkr	All	Pk/Pk	n/a
DAP	Acc	University	No Car	All	All	uni0
DAP	Acc	University	Car < Wrkr	All	All	uni0
DAP	Acc	University	Car > Wrkr	All	All	uni0
DAP	Acc	Other	No Car	All	All	nm0
DAP	Acc	Other	Car < Wrkr	All	All	nm0
DAP	Acc	Other	Car > Wrkr	All	All	nm0
DAP	Acc	Joint	No Car	All	All	fj0
DAP	Acc	Joint	Car < Wrkr	All	All	fj0
DAP	Acc	Joint	Car > Wrkr	All	All	fj0

Joint Tour Generation

Table 1.12 shows the logsum variables used in the joint tour model.

Table 1.12 Joint Tour Generation Model Logsums

BMC Model	Logsum Type	Purpose (to draw coefficients from)	Vehicle Sufficiency	Modes	TOD	Size Terms
FJ Purpose	Acc	Joint	No Car	All	All	fj1
FJ Purpose	Acc	Joint	Car < Wrkr	All	All	fj1
FJ Purpose	Acc	Joint	Car > Wrkr	All	All	fj1
FJ Purpose	Acc	Joint	No Car	All	All	fj2
FJ Purpose	Acc	Joint	Car < Wrkr	All	All	fj2
FJ Purpose	Acc	Joint	Car > Wrkr	All	All	fj2
FJ Purpose	Acc	Joint	No Car	All	All	fj3
FJ Purpose	Acc	Joint	Car < Wrkr	All	All	fj3
FJ Purpose	Acc	Joint	Car > Wrkr	All	All	fj3
FJ Purpose	Acc	Joint	No Car	All	All	fj4
FJ Purpose	Acc	Joint	Car < Wrkr	All	All	fj4
FJ Purpose	Acc	Joint	Car > Wrkr	All	All	fj4

Individual Non-Mandatory Tour Generation

Table 1.13 shows the logsum variables used in the individual non-mandatory tour generation model.

Table 1.13 Individual Non-Mandatory Tour Generation Model Logsums

BMC Model	Logsum Type	Purpose (to draw coefficients from)	Vehicle Sufficiency	Modes	TOD	Size Terms
INM Generation	Acc	Other	No Car	All	All	nm1
INM Generation	Acc	Other	Car < Wrkr	All	All	nm1
INM Generation	Acc	Other	Car > Wrkr	All	All	nm1
INM Generation	Acc	Other	No Car	All	All	nm2
INM Generation	Acc	Other	Car < Wrkr	All	All	nm2
INM Generation	Acc	Other	Car > Wrkr	All	All	nm2
INM Generation	Acc	Other	No Car	All	All	nm3
INM Generation	Acc	Other	Car < Wrkr	All	All	nm3
INM Generation	Acc	Other	Car > Wrkr	All	All	nm3
INM Generation	Acc	Other	No Car	All	All	nm4
INM Generation	Acc	Other	Car < Wrkr	All	All	nm4
INM Generation	Acc	Other	Car > Wrkr	All	All	nm4

2.0 Component Model Estimation Results

This chapter provides documentation of the parameter estimation for the model components that comprise the activity based model (those shown in Figure 1.1). Some sections of this chapter describe single model components while others include descriptions of multiple interrelated model components as shown in Figure 1.1.

The estimated parameters themselves, as well as statistical information on the model estimation, are provided in companion spreadsheet files. The spreadsheet file for each component is specified in the corresponding section of this chapter.

2.1 Workplace Location Choice

Summary

The purpose of this model is to simulate the usual workplace location for each full-time or part-time worker in the synthetic population. The choice of the usual workplace location is a two-step modeling process:

1. **Workplace Type Model**, which simulates whether the worker has a usual workplace and whether that workplace location is inside the model region, or whether the worker usually works at home;

2. **"Usual" Workplace Location Choice Model**, if the result of the binary choice model is "usual" workplace.

The workplace type model is essential to determine who opts for the "no usual" workplace location choice. These individuals are then subject to the tour level (home-based) work destination choice model (documented in Section 2.8).

The "usual" workplace location choice model captures the usual location a person commutes to for work and work-related purposes. The final specification for both these models was reached by testing a wide range of model variables.

- For the workplace type model, most of the variables include person and household attributes, land use variables, and proximity to the external boundary of the region. The person and household attributes are the most significant indicators as to whether an individual desires to work at a specific location or not.

- For the location choice model, the variables entered were similar to those used in most destination choice models, including level of service (LOS), socioeconomic and demographic (SED) and land use (LU) variables. The models also include size functions, which are additive logarithmic functions of various types of employment, households and enrollment. This model has a similar structure to that of the work destination choice model.

Estimation Results

The estimation results for both models are presented in the companion spreadsheet *Workplace Loc 1.xlsx*.

Workplace Type Model

Model structure

This model has a multinomial logit form, and predicts the probability of having a usual workplace location or not, and if so whether the usual workplace location is inside or outside the model region, or is at the worker's home.

Alternatives

The four alternatives are:

1. Has usual workplace in the model region (utility = 0)
2. Has no usual workplace
3. Has usual workplace outside the model region (external)
4. Usually works from home

Variables

The following variables are used in this model.

Person and Household Attributes

Worker status – This indicates if the worker is full-time or part-time. Annual income level is used as a segmentation variable for full-time workers, with breakpoints at $15,000, $30,000, and $100,000.

Gender – Male or female.

Age – A piecewise linear formulation is used, with breakpoints at 17 and 40 years of age.

Household composition – This includes the following variables:

- Indicator variable whether there are children in the household; and
- Indicator variable whether the worker is the only person in his/her household.

Land use/zonal Variables

The employment density at the zone level of the home zone of the traveler is used in the utility functions for the "no usual workplace" and "usually work from home" alternatives. The logarithm of employment density in employees per acre was used in the following form: ln(density + 1), to ensure that the estimation process does not attempt to compute the logarithm of zero.

Transportation Level of Service

For the "usually work from home" alternative, a variable representing accessibility to workplaces is used. These are accessibility logsum variables that use work tour coefficients. Size coefficients in the logsum equation were developed from regression equations of tour attractions on size characteristics. Those size coefficients were developed separately for each of the five income categories. Section 1.2 provides more details on this.

A variable representing distance to the nearest external station is used in the utility function for the "usual workplace outside the model region" alternative. This defines the proximity of a commuter to the boundary of the model region, reflecting the likelihood that the usual workplace is within the model region. The logarithm of distance in miles was used in the following form: ln(distance + 1), to ensure that the estimation process does not attempt to compute the logarithm of zero.

Model Estimation Results

Some of the key findings of the model estimation are as follows:

- **Part-time workers** have a higher propensity for not having a usual workplace or for working from home. In some cases, they could be working multiple or temporary jobs.
- **The older the worker**, the lower the propensity to have a usual workplace location.
- **The higher the income level**, the more likely a full-time worker is to have a usual workplace location.
- **Females** are less likely to have usual workplaces.
- The **presence of children** makes it more likely for a worker to work at home.
- **Distance to the nearest external station** has a substantial impact on whether a worker has a usual workplace location outside the model region. The closer a full time or part time commuter is to the regional boundary, the more likely there is a usual workplace outside the region.
- **Greater accessibility to workplaces** makes it less likely to work at home.

Usual Workplace Location Choice Model

Model structure

This model has a multinomial logit form and predicts the probability of choosing each transportation analysis zone (TAZ) for the usual workplace location, based on the relative ease to get to the destination, the employment opportunities in the zone, the household and personal attributes of the worker, and the availability of modes to reach the destination. This model is applied only for workers who choose the "usual workplace in the model region" alternative; workplace locations outside the region for workers who choose the "usual workplace outside the model region" are not simulated.

Note that later in the modeling process a point (parcel) location is simulated for each simulated workplace location, within the zone chosen in this workplace location choice model.

Alternatives

Every internal TAZ in the BMC model region is a possible workplace location. Therefore, the alternatives are all internal TAZs. The logit structure is shown in Figure 2.1 where TAZs 1, 2, …, 2,934 are the alternatives under the main root. (Note that there are no TAZs numbered from 1388 to 1399.)

Figure 2.1. Multinomial Logit Structure for the Workplace Location Choice Model

Size function

Size functions are used to measure the amount of activity that occurs at each destination zone and incorporate this into the utility of alternative variables. This is similar to the way in which trip attractions are used as a variable in conventional trip distribution models. This type of variable is frequently used in destination choice models to account for differences in zone sizes and employment levels. The size variables used in these models are employment by type (office, industrial, retail, medical, education, restaurant, and other). The size function is included in the utility equation of each destination choice (TAZ) as shown below:

U = Coeff1 * Var1
+ Coeff2 * Var2
+ Coeff3 * Var3
+ ……..
+ Size function

Where:

Var1, Var2, Var3 are explanatory variables (e.g., distance, intrazonal, mixed density, etc.);

Coeff1, Coeff2, Coeff3 are coefficients for Var1, Var2, Var3;

Size function = LSM * ln {(Size variable1)
+ exp (coeff22) * Size variable2
+ exp (coeff33) * Size variable3
+ …….}

Where:

Size variable1 is the base variable (e.g., office employment);
Size variables 2 and 3 are other explanatory variables (e.g., retail employment);
Coeff22 and Coeff33 are coefficients for size variables 2 and 3; and
LSM is log size multiplier, which is multiplied by the entire size function.

Variables

The following variables are used in the usual workplace location choice model.

Transportation level of service

Distance – This is the round trip (RT) distance from origin to destination plus destination to origin, derived from the network skims and expressed in miles. To provide a non-linear relationship with distance, a piecewise linear formulation is used, with breakpoints at 5, 20, and 45 miles. The following estimation results show how this works:

Distance	-0.1300
Max(0, Distance - 5)	0.0793
Max(0, Distance - 20)	0.0241
Max(0, Distance - 45)	0.0057

For example:

- For 2 miles, the utility contribution of the distance variables is (-0.1300 * 2).
- For 7 miles, the utility contribution of the distance variables is:

  (-0.1300 * 7) + (0.0793 * (7-5)).

- For 22 miles, the utility contribution of the distance variables is:

  (-0.1300 * 22) + (0.0793 * (22-5)) + (0.0241 * (22-20)).

Distance is further segmented by worker type (full-time vs. part-time) and by income level for full-time workers.

Mode choice logsum – The disaggregate mode choice logsum is derived from the estimated tour mode choice models for the work purpose. This variable captures the accessibility and performance of each mode available to make the trip to the desired workplace location.

Transit access indicator – 1 if there is a transit walk access path between the home and workplace zones, zero otherwise. This variable is segmented by worker type (full-time vs. part-time).

Intrazonal indicator – 1 if the workplace zone is the same as the home zone, zero otherwise.

Model Estimation Results

Some of the key findings of the model estimation are as follows:

- The key level of service variable, **distance**, affects utility of choosing a TAZ inversely, as expected, with the effect diminishing as distance increases.
- The **mode choice logsum** coefficients are constrained to 0.5.
- The **intrazonal indicator** variable has a positive coefficient for all types of workers, but it is lower for full-time workers than part-time workers. That is, full-time workers are less prone to find a workplace location closer to or at home than part-time workers.
- The **size function** has **office employment** as the base variable.
- The other employment types in the size function were **segmented by income level**, to estimate the relative impact of various segments of population on usual workplace location choice.

2.2 School Location Choice

Summary

The purpose of this model is to simulate the school location for each pre-school or school age child in the synthetic population. The model captures the location where a child attends preschool, daycare, or K-12 school. This model handles the entire school location choice for a child; there is no tour destination choice model for school tours. This is different from work tours, which have a usual work location, determined by the work location choice model, and a tour destination choice model, which captures the destination choice of workplace of each person who does not have a usual workplace and the destination choices of workers who do not travel to their usual workplaces on the travel day.

Children of a similar age in the same household are likely to attend the same school. "Lining up" the usual school location decisions among children in the same household makes the school escort activity by an adult in the household more likely to be coordinated. The school locations in a household are simulated sequentially from the youngest to the oldest child. Therefore, the usual school locations of the younger children in the household are known when simulating the school locations of older children. This information is used in the model to group the school location choice for children in the same household.

The final specification was reached by testing a wide range of model variables—level of service, socioeconomic and demographic and land use. The models also include size functions, which are additive logarithmic functions of elementary, middle school, and high school enrollment and households (for pre-school age children only).

Estimation Results

The estimation results for this model are presented in the companion spreadsheet *School Loc 1.xlsx*.

Model Structure

This model has a multinomial logit form and predicts the probability of choosing each TAZ for the school location, based on the relative ease to get to the destination, the usual school locations of younger children in the household, the household and personal attributes of the student and his/her household, and the availability of modes to reach the destination.

Note that later in the modeling process a point (parcel) location is simulated for each simulated school location, within the zone chosen in this school location choice model.

Alternatives

Every internal TAZ in the BMC model region is a possible school location. Therefore, the alternatives are all internal TAZs. The logit structure is the same as for the workplace location model (see Figure 2.1).

Child Type Definition

The usual school location is expected to have different attributes depending on the age of the child. Preschools are often located in local neighborhoods. Elementary schools are typically smaller and more local while middle and high schools are more regional and often require the children to travel farther. To distinguish the different types of school locations between children of different ages, they have been segmented into the following categories:

Type	Age	School Level
1	0-4	preschool
2	5-9	elementary school
3	10	elementary-middle
4	11	middle-elementary
5	12	middle school
6	13	middle-high
7	14	high-middle
8	15	high school - no license
9	16-18	high school - license

As discussed in Section 2.1, size functions are used to measure the amount of activity that occurs at each destination zone and incorporate this into the utility of alternative variables. The size variables used in the school location choice models are school enrollment by level (elementary, middle, high) and number of households (since many day care establishments are located within homes). The size function is included in the utility equation of each destination choice (TAZ) as shown below:

U = Coeff1 * Var1
+ Coeff2 * Var2
+ Coeff3 * Var3
+ ……..
+ Size function

Where:

Var1, Var2, Var3 are explanatory variables (e.g., distance, intrazonal, mixed density, etc.);
Coeff1, Coeff2, Coeff3 are coefficients for Var1, Var2, Var3;
Size function = LSM * ln {(Size variable1)
+ exp (coeff22) * Size variable2
+ exp (coeff33) * Size variable3
+ …….}
Where:
Size variable1 is the base variable:
Households for children under 5 years old
Elementary enrollment for children age 5-10
Middle school enrollment for children age 11-13
High school enrollment for children age 14 and over
Size variables 2 and 3 are other explanatory variables (other types of enrollment or combinations thereof)
Coeff22 and Coeff33 are coefficients for size variables 2 and 3
LSM is log size multiplier, which is multiplied by the entire size function

The size function of a zone must be non-zero for an observation to be available in estimation. Survey data set records where the child's school location was recorded in a zone where all components of the size variable were zero were dropped from the estimation data set.

Variables

The following variables are used in the usual workplace location choice model.

Transportation level of service

Distance – This is the round trip distance from origin to destination plus destination to origin, derived from the network skims and expressed in miles. To provide a non-linear relationship with distance, a piecewise linear formulation is used, with breakpoints at 5, 20, and 45 miles. The following estimation results show how this works:

Distance	-0.2653
Max(0, Distance - 5)	0.0929
Max(0, Distance - 20)	0.1337
Max(0, Distance - 45)	-0.0898

For example:

- For 2 miles, the utility contribution of the distance variables is (-0.2653 * 2).
- For 7 miles, the utility contribution of the distance variables is:

  (-0.2653* 7) + (0.0929 * (7-5)).

- For 22 miles, the utility contribution of the distance variables is:

  (-0.2653 * 22) + (0.0929 * (22-5)) + (0.1337 * (22-20)).

Distance is further segmented by child type.

Mode choice logsum – The disaggregate mode choice logsum is derived from the estimated tour mode choice models for the school purpose. This variable captures the accessibility and performance of each mode available to make the trip to the desired school location.

Other

Intrazonal indicator – 1 if the school zone is the same as the home zone, zero otherwise.

Different county indicator – School districts in Maryland are organized by county. A vast majority of students therefore attend school in their own county. The indicator variable is used with a highly negative coefficient to effectively prohibit out of county school locations.

Younger child school location indicators – These variables equal 1 if the zone is the same as the chosen school location for a previously simulated child. One variable is used if the child being simulated is the same child type (age group) as the previously simulated child; one is used if the previously simulated child is in the next youngest age group; and one is used always regardless of the ages of the children.

Model Estimation Results

Some of the key findings of the model estimation are as follows:

- The **distance variable** coefficient decreases as children age, indicating that older children tend to travel farther for school. This makes sense if the school system is organized around local elementary and more regional middle and high schools. However, the distance effect increases for very long distances (greater than 45 miles). This seems reasonable as travel to distant schools is uncommon.

- The **mode choice logsum** coefficients are constrained to 1.0.

- The **intrazonal indicator** has a positive coefficient, which makes sense given the existence of neighborhood schools (and perhaps home schooling).

- The **younger child school location indicators** have positive coefficients, as expected.

2.3 Vehicle Availability

This model estimates the number of vehicles owned by each household in the synthetic population. It is a multinomial logit model with alternatives representing having zero, one, two, three, four, or five or more vehicles.

This model was estimated by BMC staff and is documented separately.

2.4 Transit Pass Ownership

For each household in the synthetic population, this model simulates whether the household has a transit pass. It is a binary model with alternatives representing having a transit pass or not.

This model was estimated by BMC staff and is documented separately.

2.5 E-ZPass Transponder Ownership

Summary

This model predicts whether or not a household in the synthetic population has an E-ZPass transponder to use when driving on toll roads. It is a binary model with alternatives representing having a transponder or not.

Unlike most of the other models in InSITE, this model was not estimated only from the household survey data set. Information on whether the household had a transponder was not recorded in the household survey. The alternate data source was a list of transponder owners by zip code provided by E-ZPass administration for the Maryland portion of the model region.[1] What this means is that whether a household in the household survey owned a transponder was not known. What was known was an estimate of the probability of having a transponder given the zip code of the household location, estimated as the number of households in the zip code in the transponder owner database, divided by the total households in the zip code.

Because there is no "choice variable" in the data set, the estimated probabilities were used in defining the likelihood functions for the model estimation. The likelihood function is computed as follows:

1. Compute probabilities of toll transponder ownership for each household in the survey as in any logit model.

2. Take the weighted average probability across each zip code (weighted based on the expansion factors for households).

3. Compute log likelihood = nhhs1 * log(P1) + nhhs2 * log(1-P1)

   Where:

   nhhs1 is the number of households with toll transponders in the zip code

   nhhs2 is the number without (equal to total minus those with) in the zip code

   P1 is the average probability of toll transponder ownership for the zip code from the survey respondents.

[1] Note, however, that since the E-ZPass data does not represent the set of households having a transponder, it does not exactly measure what the model predicts, the probability of having a transponder available to the household's vehicles. Some households may own multiple transponders while others may use transponders from other states' E-ZPass programs. There are also transponders that are used for commercial vehicles, not household vehicles, in E-ZPass's database.

The final log likelihood is then scaled by (nzipcodes/total households). This ensures valid statistics on the coefficient estimates.

Estimation Results

The model estimation results are shown in the companion spreadsheet *E-ZPass 1.xlsx*.

Model Structure/Alternatives

The structure for this model is binary logit, with two alternatives at the household level: having a transponder or not.

Variables

The following variables are used in the toll transponder model.

Alternative Specific Constant

Not having a transponder is the base alternative, and so there is a constant only for the transponder alternative.

Household Characteristics

Several household characteristics were used, including the following:

- Whether there are workers in the household with no regular workplace, who work from home, or who have regular workplaces outside the model region;
- Whether there are workers with a toll path from the home to the workplace (meaning that there is no free path that is faster than all paths that use a tolled facility);
- Vehicle availability and sufficiency (zero vehicles and workers > vehicles); and
- Household income level.

Accessibility Variables

These variables are based on the computed accessibility logsums as described in Section 1.2. The specific accessibility variables used in the tour generation model include the following:

- The difference between the auto and transit-walk access accessibility logsums, with a minimum value of 6.
- The difference between the auto (free path) and auto (toll path) accessibility logsums, with a minimum value of 8.

Another variable uses the mode choice logsums between the home and the regular workplace, summed across all workers in the household. The variable is the difference between the logsums for the auto modes (drive alone, shared ride 2, and shared ride 3+) and the sum of the logsums for the non-auto modes (transit-walk access, walk, and bicycle—note that transit-auto access is not included in either the auto or non-auto modes for this computation). The variable is bounded so that values less than -5 are held at -5 and values greater than 10 are capped at 10.

Estimation Findings

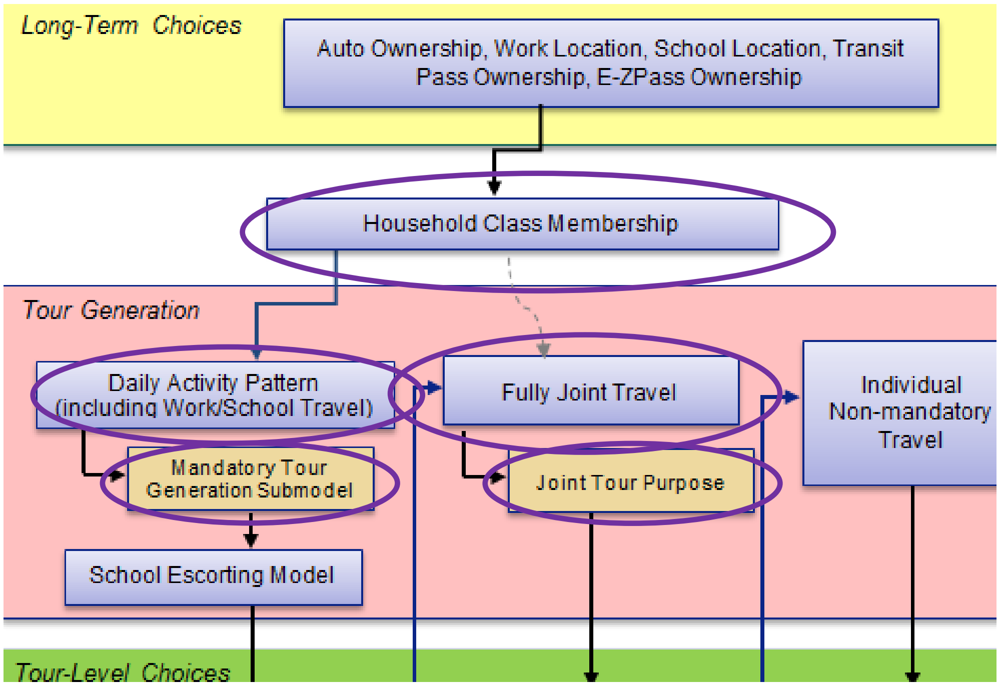
Some of the key findings of the model estimation are presented below. Note that the coefficients for several variables had to be constrained. This is not surprising since there is no information in the dataset available for model estimation about how probability varies other than by location. Therefore, some of these findings are actually assumptions made in constraining these coefficients.

- Lower income households, households with fewer vehicles than workers, and households without vehicles are less likely to have a transponder.
- Having a regular workplace in the region increases the probability of having a transponder.
- Having a toll path to work increases the probability of having a transponder.
- Increasing the auto accessibility relative to transit increases the probability of having a transponder.
- Increasing the auto accessibility via a tolled path relative to free paths increases the probability of having a transponder.

2.6 Daily Activity Pattern and Fully Joint Tour Generation

This section discusses the daily activity pattern (DAP) and fully joint tour generation models. This includes several distinct model components related to DAP and joint travel for the household, including the latent class model structure. The models described in this section are identified in Figure 2.2, which shows a portion of the overall model structure presented in Figure 1.1.

Figure 2.2 Model Components Related to Daily Activity Pattern



Summary

The daily activity pattern (DAP) determines whether individuals travel on the travel day, and the number and purpose of mandatory tours generated for the individual. These two components are split across two separate models: a high-level DAP model and a mandatory tour enumeration model. The fully joint tour generation models consist of three distinct models. The first model determines the number of fully joint tours for the household, the second determines the purpose of each tour generated for the household, and the third determines the members of the household that will participate in the joint tour.

Note that in this case, joint tours are restricted to non-mandatory tours. Examination of the survey data show that few joint mandatory tours are made among household members. The school location choice model (see Section 2.2) considers the probability that children of similar ages attend the same school, and the school escorting model (see Section 2.7) does consider the "bundling" of children in escorting decisions.

In InSITE, each person in the synthetic population is classified as one of eight "person types":

- **CH1** – Child 1 (age 0-4)
- **CH2** – Child 2 (age 5-15)
- **CH3** – Child 3 (age 16-17)
- **FTW** – Full time worker
- **PTW** – Part time worker

- **NWA** – Non-working adult
- **STD** – Adult student (e.g., university)
- **SEN** – Senior (age 65+)

Note that in InSITE, the use of age as a variable is not restricted to the person type definitions. Many model components use the person's specific age, sometimes in connection with a specific age range (e.g., age 5-10 or age greater than 40) to explain travel behavior.

Model Structure

The models detailed in this section include five separate models that were estimated. They are the latent class DAP and joint tour generation model, the adult mandatory tour enumeration model, the child mandatory tour enumeration model, the joint tour purpose model, and the joint tour participation model. The models, as they fit into the overall InSITE model, are shown in Figures 1.1 and 2.2.

Latent Class DAP and Joint Tour Model

The first components of both the DAP and fully joint travel modules were estimated simultaneously in a latent class model structure. The high-level DAP model is a choice model for each individual in the household with three alternatives:

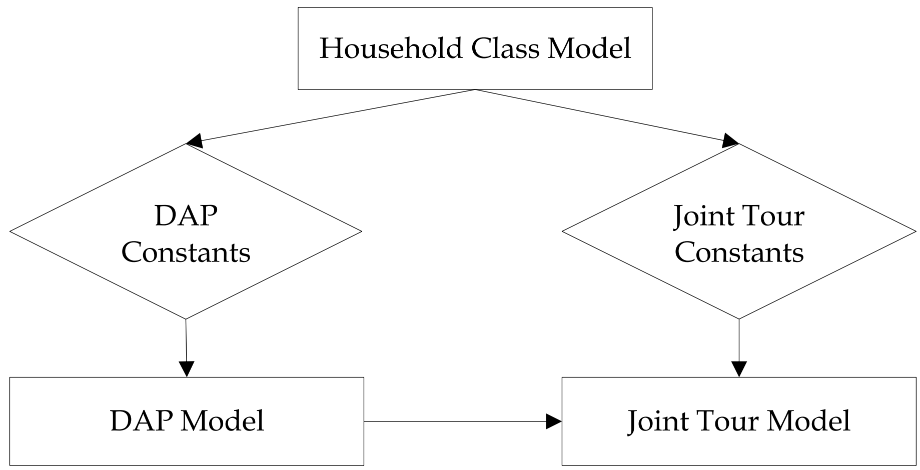
- Mandatory pattern
- Non-mandatory pattern
- Stay home pattern

A mandatory pattern consists of at least one mandatory (work or school) tour, and possibly other non-mandatory tours. A non-mandatory pattern consists of at least one non-mandatory tour and zero mandatory tours. A stay home pattern indicates that the individual did not generate any travel within the model region on the travel day. Note that a person with a "stay home" pattern may not actually be at home all day; he or she might be traveling outside the region with no travel within the region (for example, out of town on a business trip). Basically, the intention is to identify those persons who do not travel within the model region on the travel day.

The first joint tour model is a choice model with three alternatives also: zero, one, or two joint tours.

These two models are estimated simultaneously in a latent class model structure. As part of this model structure, a secondary household class model is also estimated, which is another discrete choice model. Each of these three discrete choice models estimated simultaneously here (i.e., the high-level DAP model, the joint tour generation model, and the household class model) are multinomial logit models. The interaction between these three models is shown in Figure 2.3.

Figure 2.3. Latent Class DAP and Joint Model Interaction



As shown in the figure, the household class model determines only the constants that are used for the DAP and joint tour models. The constants are based on the class selected for the household. If the household selects class 1, the constants used for household members' DAP models are class 1 DAP constants and the constants used for the joint tour model are class 1 joint tour constants. Besides the constants in the DAP and joint tour models, all other variables are generic to the household class. That is, the coefficients for other variables do not depend on the household class. Note that the joint tour model also depends on the outcomes of the DAP model. This is a consequence of the sequencing of these two models (as shown in Figure 2.3), not of the simultaneous model estimation.

There are several reasons for choosing this model structure. First, we are able to accommodate interactions between individual DAP choices and household level joint tour generation choices via the household class model. In some activity based models, DAP is assumed to be independent from joint travel, which is not ideal[2]. Second, interactions between DAP choices of household members are accommodated seamlessly, and without the need to test large numbers of two-way interaction terms in the DAP utility functions. Instead, the DAP constants themselves determine the interactions across household members. This is done by having different constants for each person type. For one class, the constants may show it to be very likely that a young child and full-time worker both stay home, while in another class, the constants may show it to be more likely the young child stays home and the full-time worker goes to work. These sorts of interactions are accommodated through DAP constants for eight mutually exclusive person types. Third, application of this group of models is extremely simple. It is a sequence of three simple

[2] Typically in activity based models, the ordering of the DAP and joint tour models would be the same as shown in Figure 2.3. However, there would be no mechanism to feed joint tour choice information back to the DAP model. Here, the household class model accomplishes this information feedback.

multinomial logit (MNL) models, two of which (the DAP and joint tour model) have only three alternatives and the other has a small number of alternatives also (in this case, six).

Mandatory Tour Generation Sub-Model

The high-level DAP model only determines whether an individual will have a mandatory day, non-mandatory day, or stay home. Within the choice of mandatory DAP, each individual must also select the number and purpose of mandatory tours to engage in. The mandatory tour generation sub-models do just this. Two separate models were estimated, one for adults and the other for children. The main reason for segmenting adults and children is that they have different education purpose options. Children can have school activities while adults can have university activities.

Note the non-mandatory tours for persons with non-mandatory patterns are generated in the individual non-mandatory tour generation model. Non-mandatory tours, if any, made by persons with mandatory DAPs are also generated by this model.

While nested logit model structures were tested, the MNL model structure worked the best. The alternatives are defined by the number of mandatory tours (one or two), the number of stops (zero, or one or more), and the types of tours (work, school, or university). There are 13 alternatives in the model, but only a subset are considered available for any particular person type. Table 2.1 shows the model alternative availability matrix for each person type.

Table 2.1. Mandatory Tour Options by Person Type[3]

Alternative	CH1	CH2	CH3	STD	FTW	PTW	NWA	SEN
1 Work0[4]			X	X	X	X	X	X
1 Work1			X	X	X	X	X	X
2 Work0					X	X		
1 Work0 + 1 Work1					X	X		
2 Work1					X	X		
1 Work0 + 1 Univ.				X	X	X		
1 Work1 + 1 Univ.				X	X	X		
1 Work0 + 1 School			X					
1 Work1 + 1 School			X					
1 Univ.				X	X	X	X	X
2 Univ.				X				
1 School	X	X	X					
2 School	X	X	X					

3. Person types are as follows: CH1 = child less 5 years, CH2 = child 5-15 years, CH3 = child 16+ years, STD = college student, FTW = full-time worker, PTW = part-time worker, NWA = non-working adult < 65 years, SEN = non-working adult 65+ years.

4. Work0 is a work tour with no stops, Work1 is a work tour with 1+ stops.

Joint Tour Purpose Model

The joint tour purpose model determines the tour purpose for each joint tour generated by the household in the joint tour generation model. The alternatives of the model include the following tour purposes:

- Meal
- Shopping
- Personal Business
- Social/Recreation

The tours are modeled in sequence for each household, rather than simultaneously. This reduces the number of alternatives that must be considered in the model from 16 (for two tours with up to four purpose options for each) to four. It also means that the joint distribution of purposes for households with two joint tours may not exactly match the observed distribution (e.g., the models may suggest it is more likely than observed to have households with two joint meal tours). However, we did check the distributions of one- and two-joint tour households and found that the distribution of purposes for two-joint tour households was close to what one would expect if the purposes of each joint tour were independent of one another. Moreover, we tested variables in the model that accounted for the household having two joint tours (rather than just one).

Joint Tour Participation Model

The joint tour participation model determines the household members that will engage in a joint tour that was generated by the joint tour generation model. It does this by sequencing through all household members based on the person type in the following order:

- Child 1 (age 0-4)
- Non-working adult (less than 65 years old)
- Senior
- Child 2 (age 5-15)
- Child 3 (age 16+)
- Part-time worker
- Full-time worker
- Adult student

This order is chosen because it represents an ordering of person types based on their typical availability to take part in joint activities (e.g., workers and college students typically have more limited availability, while non-workers and preschool age children have more flexibility).

The model has only two alternatives—either the person can be part of the joint tour or not. All household members with an active DAP (mandatory or non-mandatory) are eligible to participate in the joint tour. Scheduling of the joint tour is simulated after participation (rather than before), and is based on the time availability overlaps of participating household members. Note that the time of day has already been simulated for mandatory tours (see Section 2.10) and for school escorting activities (see Section 2.7) for every person in the household prior to the application of the joint tour participation model.

No strict requirements are enforced on the estimation to ensure that model application will result in a valid fully joint tour. In other words, application of the model could result in zero or one household members participating. In such cases, the model will be rerun until a valid tour is constructed.

Estimation Results

Model estimation results for the latent class, daily activity pattern and joint tour generation models are presented in the companion spreadsheet *DAP 1.xlsx*. Model estimation results for the mandatory tour enumeration model are presented in the companion spreadsheet *Mand Tour Enum 1.xlsx*. Model estimation results for the joint tour purpose model are presented in the companion spreadsheet *Joint Purp 1.xlsx*. Model estimation results for the joint tour participation model are presented in the companion spreadsheet *Joint Partic 1.xlsx*.

Variables – Latent Class DAP and Joint Tour Generation Model

Latent Class Model Component

The following variables are used in the latent class model. All are household level variables, since the latent class part of the model is simulated at the household level.

- Zero vehicle household: 1 if the household owns no vehicles, 0 if the household owns at least one vehicle.
- Number of vehicles less than number of adults: 1 if the number of vehicles in the household is less than number of adults in the household, 0 otherwise.
- Number of children in the household: including all ages of children.
- Number of workers in the household: including full- and part-time workers.
- Household size: total number of persons in the household.
- Presence of children less than 5 years in the household: 1 if there is one or more children less than 5 years in the household, 0 otherwise.
- Presence of non-working adult less than 65 years in the household: 1 if there is one or more non-working adults less than 65 years in the household, 0 otherwise.

Five annual household income categories are used: $0-$15,000, $15,000-$30,000, $30,000-$50,000, $50,000-$100,000, and over $100,000.

- Income less than $X: 1 if the household income is less than $X, 0 otherwise. $X must represent a breakpoint between two income categories. Note that more than one of these variables may appear in the same model, and so more than one of these variables may have a value of 1 (they are not mutually exclusive).

- Transit pass in household: 1 if the traveler's household has a transit pass, 0 otherwise.

High-Level DAP Model Component

The following variables are used in the high-level daily activity pattern model. Many of the variables are segmented by person type.

- Alternative specific constants: As described above, there are different sets of alternative specific constants for each household class. If a household is simulated to be in class 1, its household members use class 1 constants, if a household is simulated to be in class 2, its household members use class 2 constants, and so on. Each set of alternative specific constants includes two constants for each person type: one for the mandatory DAP alternative and one for the stay home DAP alternative. The non-mandatory DAP alternative is considered to be the base or reference alternative.

- Age: Traveler's age in years.

- Age minus 4 if age is greater than 4: 1 if the number of years older than 4, 0 if the traveler is 4 or younger.

- Age minus 17 if age is greater than 17: 1 if the number of years older than 17, 0 if the traveler is 17 or younger.

- Age minus 40 if age is greater than 40: 1 if the number of years older than 40, 0 if the traveler is 40 or younger.

- Female: 1 if the traveler is a female, 0 if male.

- Accessibility logsum for non-mandatory purpose: This is a logsum at the household zone across all destination choice alternatives in the non-mandatory tour destination choice model. The specifics of the calculation can be found in Section 1.2.

- Accessibility logsum for university purpose: This is a logsum at the household zone across all destination choice alternatives in the university tour destination choice model. The specifics of the calculation can be found in Section 1.2.

- Regular workplace: 1 if the person has a regular workplace, 0 otherwise.

- Works from home: 1 if the person works from home, 0 otherwise.

- External workplace: 1 if the person's regular workplace is external to the region, 0 otherwise.

- Home-to-work mode choice logsum: This is a mode choice logsum between home zone and work zone if the person has a regular workplace location that is internal to the region. The specifics of the calculation can be found in Section 1.2.

Joint Tour Generation Model Component

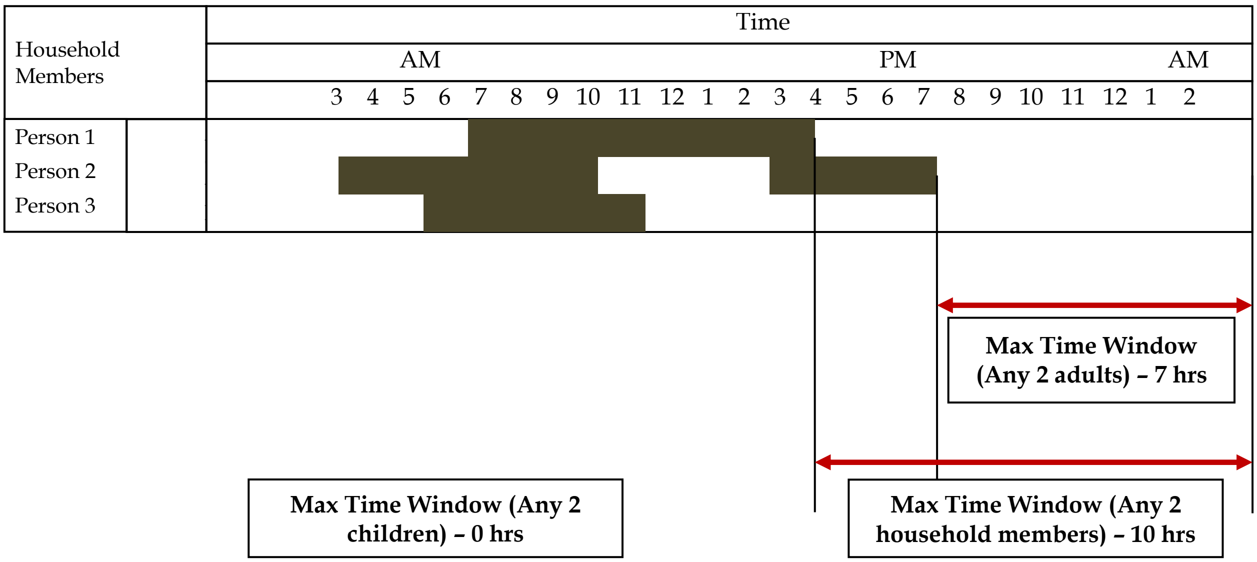
- Alternative specific constants: As described above, there are different sets of alternative specific constants for each household class. If a household is simulated to be in class 1, it uses class 1 constants, if a household is simulated to be in class 2, it uses class 2 constants, and so on. Each set of alternative specific constants includes two constants: one for the 1-joint tour alternative and one for the 2-joint tour alternative. The 0-joint tour alternative is considered to be the base or reference alternative.

- Number of persons by type in the household by DAP pattern choice: For each person type, these represent the number of individuals in the household of that person type that also chose a particular DAP pattern. Of particular importance in the model are individuals that chose the non-mandatory pattern. For instance, one variable in the model is the number of children less than 5 years old with a non-mandatory DAP.

- Time window overlaps across household members: The term "time windows" refers to the portions of the day for which an individual has not already had a tour simulated and are therefore available for other activities to take place. For the joint tour model, the tours that have already been simulated, including their start and end times, include the mandatory and school escorting tours. The time windows available for joint tours are therefore the times when neither mandatory nor school escorting tours are made.

  Time window variables are critical in defining the amount of time available for two or more household members to actually engage in joint activities. For instance, in a household with two workers that have different work shifts, the overlapping available time for engaging in joint activities would be rather small. On the other hand, a household with one part-time worker and one non-worker may have a rather large overlapping window in which joint activities could be scheduled. Figure 2.4 illustrates how these time window overlaps are computed in a simple case with two adults and one child, each having a mandatory tour and one of the adults having a second mandatory tour.

Figure 2.4. Time Window Example



In addition to using different time window overlap variables for different pairs of person types, we also introduce different time window overlap variables for different periods during the day. Three different periods are considered:

- The entire day, 3:00 a.m. to 3:00 a.m.
- The PM window, noon to 3:00 a.m.
- The evening window, 5:00 p.m. to 11:00 p.m.

- Relative transit accessibility logsum: This is the difference between two accessibility logsums. The accessibility logsums are the drive alone specific logsum in the home zone across all destination zones and the walk-transit specific logsum in the home zone across all destination zones. The logsum calculations can be found in Section 1.2. The difference variable here is computed as follows:

$$RLS_{tr} = \min(6, LS_{da} - LS_{tr})$$

Variables – Mandatory Tour Enumeration Model

The following variables are used in the mandatory tour enumeration models.

- Number of vehicles less than number of workers: 1 if the number of vehicles in the household is less than number of full and part-time workers in the household, 0 otherwise.

- Number of vehicles less than number of adults: 1 if the number of vehicles in the household is less than number of adults in the household, 0 otherwise.

- Number of children in the household: including all ages of children.

- Number of children less than 5 years in the household

- Number of STD, NWA, & SEN in the household: the number of college students plus the number of non-working adults less than 65 years plus the number of non-working adults 65+ years in the household.

- Number of FTW & PTW in the household: the number of full-time workers plus the number of part-time workers in the household.

- Household size of 1: 1 if the household size is equal to one, 0 otherwise.

- Income less than $X: 1 if the household income is less than $X, 0 otherwise. $X must represent a breakpoint between two income categories. Note that more than one of these variables may appear in the same model, and so more than one of these variables may have a value of 1 (they are not mutually exclusive).

- Transit pass in household: 1 if the traveler's household has a transit pass, 0 otherwise.

- Relative transit accessibility logsum: This is the difference between two accessibility logsums. The accessibility logsums are the drive alone specific logsum in the home zone across all destination zones and the walk-transit specific logsum in the home zone across all destination zones. The logsum calculations can be found in Section 1.2. The difference variable here is computed as follows:

$$RLS_{tr} = \min(6, LS_{da} - LS_{tr})$$

- Age minus 4 if age is greater than 4: 1 if the number of years older than 4, 0 if the traveler is 4 or younger.

- Age minus 17 if age is greater than 17: 1 if the number of years older than 17, 0 if the traveler is 17 or younger.

- Age minus 40 if age is greater than 40: 1 if the number of years older than 40, 0 if the traveler is 40 or younger.

- Female: 1 if the person is female, 0 if male.

- Accessibility logsum for university purpose: This is a logsum at the household zone across all destination choice alternatives in the university tour destination choice model. The specifics of the calculation can be found in Section 1.2.

- Regular workplace: 1 if the person has a regular workplace, 0 otherwise.

- Works from home: 1 if the person works from home, 0 otherwise.

- External workplace: 1 if the person's regular workplace is external to the region, 0 otherwise.

- Home-to-work mode choice logsum: This is a mode choice logsum between home zone and work zone if the person has a regular workplace location that is internal to the region. The specifics of the calculation can be found in Section 1.2.

Variables – Joint Tour Purpose Model

The following variables are used in the joint tour purpose model.

- Number of persons by type in the household by DAP pattern choice: For each person type, these represent the number of individuals in the household of that person type that also chose a particular DAP pattern. Of particular importance in the model are individuals that chose the non-mandatory pattern. For instance, one variable in the model is the number of children less than 5 years with non-mandatory DAP.

- Income less/greater than $X: 1 if the household income is less than $X, 0 otherwise: $X must represent a breakpoint between two income categories. Note that more than one of these variables may appear in the same model, and so more than one of these variables may have a value of 1 (they are not mutually exclusive).

- Transit pass in household: 1 if the traveler's household has a transit pass, 0 otherwise.

- Time window overlaps across household members: These are similar to the variables described previously for the joint tour generation model component above.

- Household with two joint tours: 1 if the household was simulated to have 2 joint tours, 0 otherwise.

Variables – Joint Tour Participation Model

The following variables are used in the joint tour participation model. Most variables in the model are segmented by person type. That is, different person types will use different sets of coefficients for the same variables. For some variables, the coefficients are segmented by whether the person has a mandatory DAP or non-mandatory DAP.

- Meal tour: 1 if the tour purpose is meal, 0 otherwise.

- Shopping tour: 1 if the tour purpose is shopping, 0 otherwise.

- Social/recreation tour: 1 if the tour purpose is social/recreation, 0 otherwise.

- Number of vehicles less than number of workers: 1 if the number of vehicles in the household is less than number of full and part-time workers in the household, 0 otherwise.

- Household size: total number of household members.

- Income less/greater than $X: 1 if the household income is less than $X, 0 otherwise. $X must represent a breakpoint between two income categories. Note that more than one of these variables may appear in the same model, and so more than one of these variables may have a value of 1 (they are not mutually exclusive).

- Age minus 4 if age is greater than 4: 1 if the number of years older than 4, 0 if the traveler is 4 or younger.

- Female: 1 if the person is female, 0 if male.

- School escort tours: number of school escort tours made by the person.

- Accessibility logsum for joint tours: This is a logsum at the household zone across all destination choice alternatives in the joint tour destination choice model. The logsum depends on the joint tour purpose. That is, if the tour purpose is meal, the meal logsum is used. If the tour purpose is shopping, the shopping logsum is used. Likewise, personal business and social/recreation logsums are used for those tour purposes. The specifics of the calculations can be found in Section 1.2.

- Number and presence of persons (by person type) already assigned to the joint tour: This is the number of persons already assigned to the tour or presence of persons already assigned to the tour (1 if one or more persons of the specified type are assigned to tour). Different variables are used for different person types already assigned to the tour. These variables are important to ensure we end up with joint tour compositions (e.g., the mix of person types) that are reasonable.

- Presence of CH1 assigned to the tour & no adults assigned to tour: 1 if a child less than 5 years has been assigned to the tour and no adults have been assigned to the tour, 0 otherwise.

- Number of remaining adult candidates if presence of CH1 assigned to the tour and no adults assigned to the tour: This is equal to the number of remaining adult candidates multiplied by the variable directly above.

- Relative transit accessibility logsum: This is the difference between two accessibility logsums. The accessibility logsums are the drive alone specific logsum in the home zone across all destination zones and the walk-transit specific logsum in the home zone across all destination zones. The logsum calculations can be found in Section 1.2. The difference variable here is computed as follows:

$$RLS_{tr} = \min(6, LS_{da} - LS_{tr})$$

- Joint tour size ratio: This variable encourages participation the closer the simulation gets to last individual in household, if the tour does not have at least 2 members set to participate already. It is computed as follows:

$$SizeRatio = \max\left(0, \frac{2 - \text{joint tour size before simulated person}}{\text{Number of remaining candidates in household}}\right)$$

- Time window overlaps if simulated person participates: These are similar to the variables described previously but are computed only across the members of the household that have already been simulated to participate in the joint tour, along with the person currently being simulated.

- Reduction in time window overlap if simulated person participates: This is computed in the difference in time window overlaps across household members. Specifically, it is 1) the time window overlap if the simulated person participates minus 2) the time window overlap computed across only the members of the household that have already been simulated to participate.

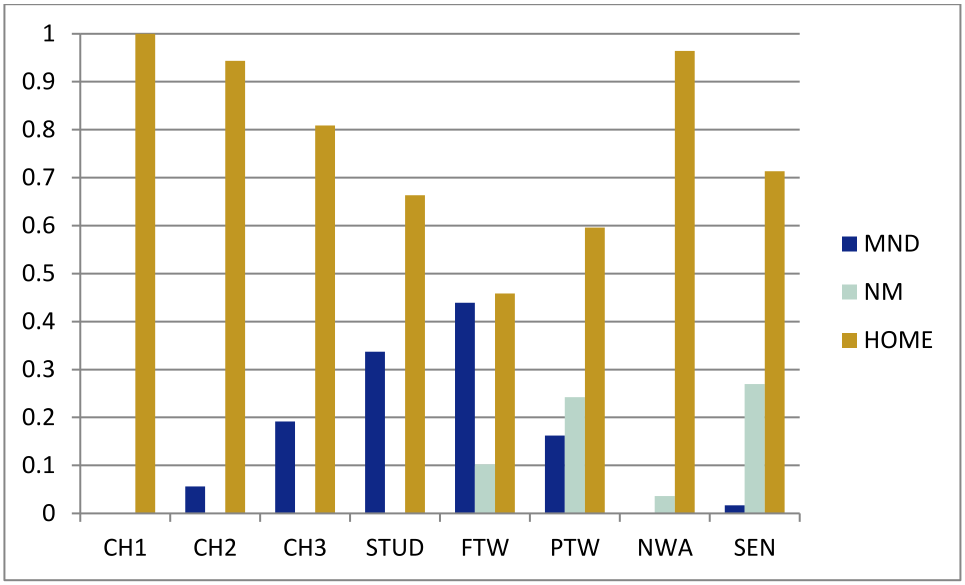
Estimation Findings

Some of the key findings of the model estimation are discussed below.

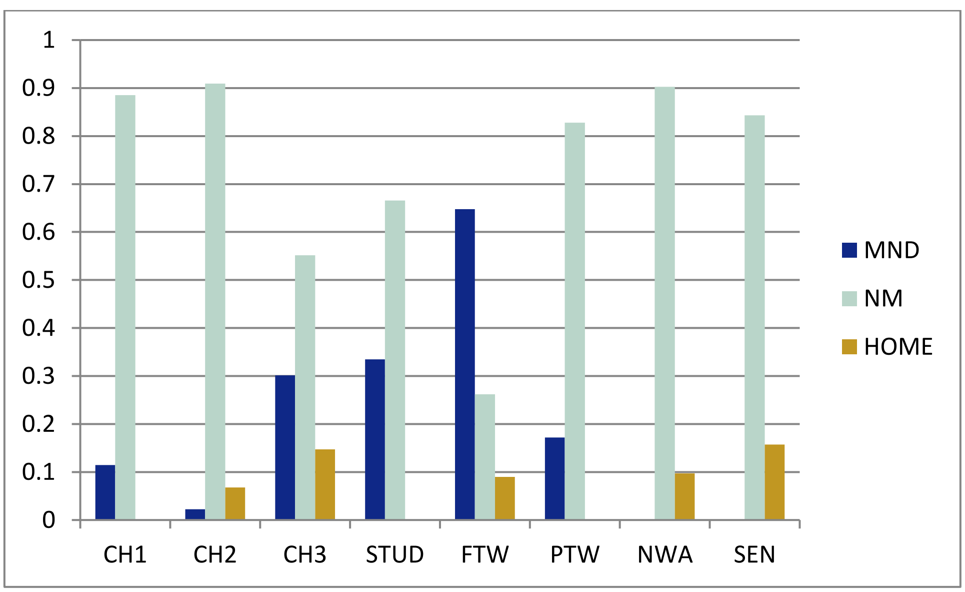
Latent Class Model

- **Household Class** was found to be an important variable in the DAP and joint tour generation models, particularly the DAP model. The findings of the model can best be conveyed by describing the characteristics of the underlying household classes, both in terms of sociodemographics and in terms of DAP and joint tour choices particular to each class. These are described below, along with figures of average DAP choices by person type associated with each class, which result from the mix of person type specific, DAP constants estimated that are estimated distinctly for each class.

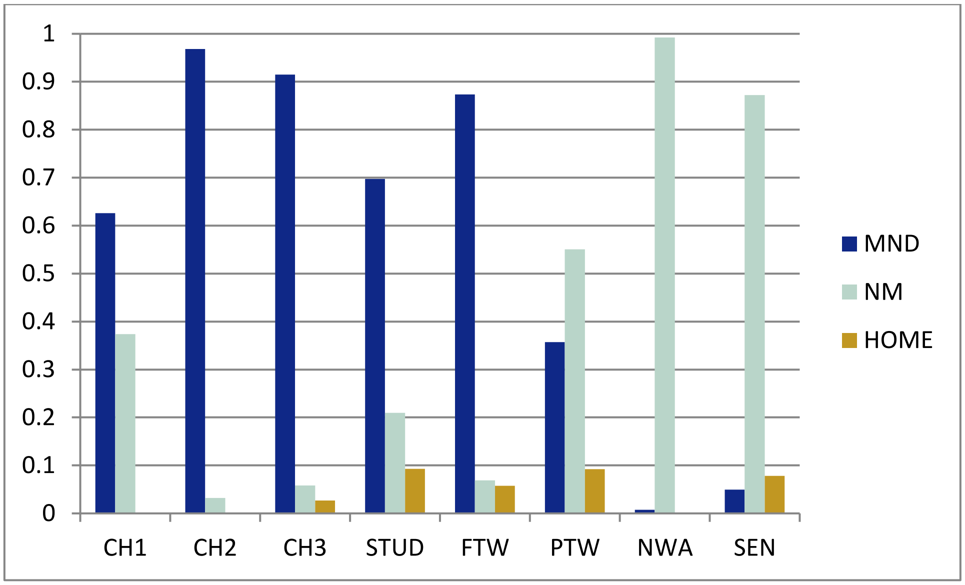
  - **The "homebodies" class**. Persons from households in this class tend to select the stay home DAP, regardless of person type. These households almost never have transit passes, typically have lower incomes, and have the highest number of children < 5 yrs.



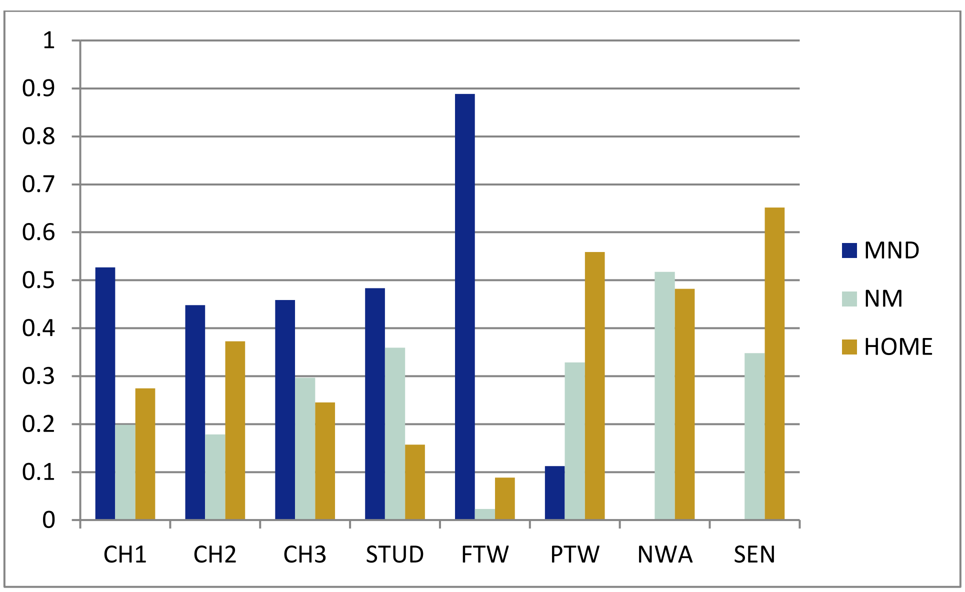
- **The "family activities" class**. Persons from households in this class tend to select the non-mandatory DAP, regardless of person type (with the exception of FTWs). These households tend to engage in a lot of joint activities and other out-of-home non-mandatory activities. These households have the largest number of children, overall, and tend to be from higher incomes.



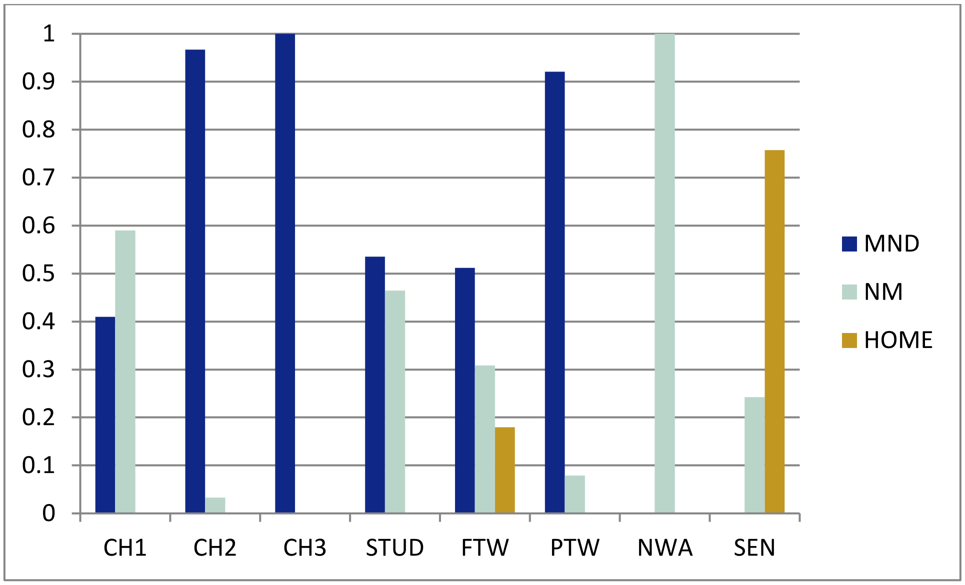
- **The "standard day 1" class**. One can imagine members of this class having a typical day, children going to school, workers going to work. Children younger than age 5 tend to go to daycare/school in this class. These households tend to be smaller, on average, typically not more than 1 child, if any, and are lower income.



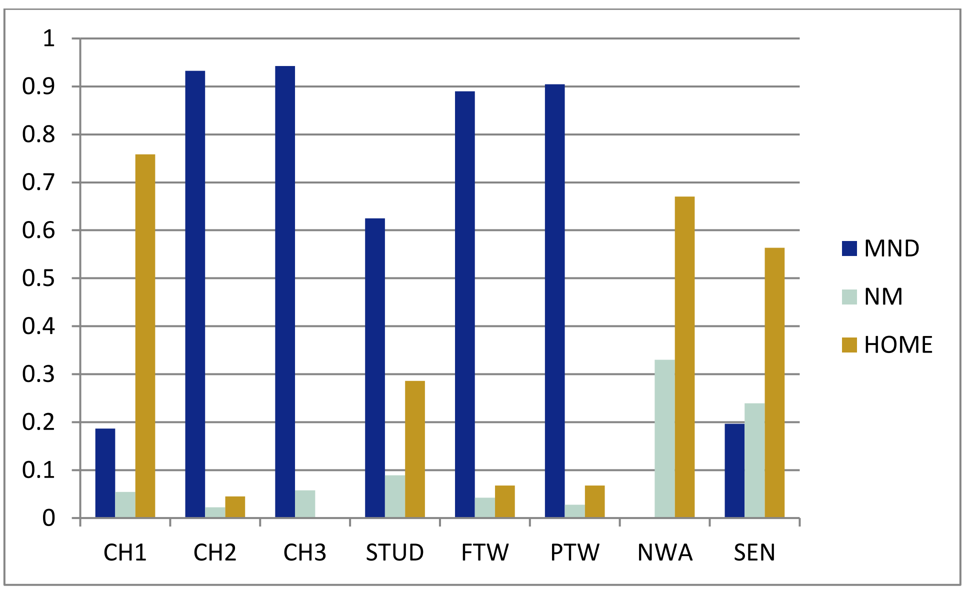
- **The "mixed-bag" class**. FTWs from households in this class tend to work, but for other person types, DAP options tend to be balanced. This could be consistent with a household with sick child staying home, other children going to school, and PTW and non-workers either staying home also or running errands (though this isn't necessarily the case). These households tend to have a lot of non-workers, but higher income (suggesting a single bread winner with high paying job).



- **The "worker vacation" class**. Children from this class tend to go to school and PTWs work, but FTWs only work about 50% of the time in such households (hence, worker vacation day). These households seem to have everyone in the household worrying only about themselves for the day, and they have very few joint tours in these households. These households also almost never have transit passes and are typically lower income.



- **The "standard day 2" class**. Like the first standard day class, one can imagine members of this class having a typical day, school-age children going to school, workers going to work. Unlike the other standard day class, children younger than 5 years of age tend to stay home in this class, and household sizes are closer to average household sizes. These households also have the highest occurrence of transit pass ownership and are typically higher income.



- **Age** was found to be important for DAP choice of several person types. Children over 4 years are more likely to go to school then young children while older college students and full time workers are more likely to have non-mandatory patterns. The oldest non-workers, on the other hand, are more likely to stay home.

- **Gender** was a key factor influencing choice of DAP. Female college students and workers are more likely to have non-mandatory days, while female non-workers are more likely to stay home than male non-workers.

- **Regular workplace** was observed to have an effect for workers. Workers that had a regular workplace were more likely to work and less likely to stay home, while workers that work from home or have a workplace external to the region boundaries are less likely to go to work. The effect of the home-to-work accessibility (as measured by the mode choice logsum) was constrained to have an appropriate effect, since the estimated effect was not significant.

- **Number of persons by type with non-mandatory DAPs** was found to have important, positive effects on the generation of fully joint tours for the household. This effect was observed for all eight person types. These people do not have mandatory activities, and thus, have better schedule flexibility to participate in joint tours.

- **Time window overlap variables** were also found to have important impacts on joint tour generation. The greater the amount of shared free time between household members, the more likely joint tours are to be generated. The strongest effects were found for the time window overlap over the entire day for any two household members, and the time window overlap between 5:00 p.m. and 11:00 p.m. for any two household members.

Mandatory Tour Enumeration

Adults

- **Low income** adults tend to make more work tours than high income workers. However, low income workers tend to make fewer work tours with stops. Low income, non-college students are more likely to make university tours than other non-college students. The reverse is true for higher income non-college students.

- Adults from households with **fewer vehicles** make fewer work tours and fewer university tours than others.

- **Females** tend to make fewer work tours than men. Female non-college students are less likely to make university tours than male non-college students.

- **Older** non-college students are less likely to make university tours than younger non-college students.

- **Mode choice logsum to workplace**. Better accessibility to one's workplace (if one has a regular workplace) is correlated with making more work tours. It is also correlated with making university tours (probably because it is easier to make both a work tour and a university tour in such cases). Workers that work from home are also more likely to make university tours than work tours. This makes sense since this model already presumes that the worker has at least one mandatory tour.

- **Better zonal accessibility logsum to university employment** is associated with more university tours, both for college and non-college students alike.

Children

- **Low income** children make fewer school tours, while high income children make more school tours.
- Children from households with **fewer vehicles** make fewer work tours and fewer school tours than others.
- **Older children** tend to make more school tours than young ones.
- **Transit pass ownership** by a household increases the propensity of children (16 years or more) to generate work tours.
- **Relative drive accessibility to transit accessibility** increases the propensity to make work and school tours for children.

Joint Tour Purpose

- The **number of children less than 5 years** in the household tends to increase the likelihood of the shopping purpose and reduce the likelihood of the meal purpose if those children have mandatory DAPs.
- The **number of children 5-15 years** in the household decreases the likelihood of shopping and especially meal purposes. The meal effect is more exaggerated if the children have mandatory DAPs.
- The **number of children 16+ years** in the household decreases the chances of meal and social/recreation purposes and slightly decreases the utility of shopping purpose if the children have mandatory DAPs. If they have non-mandatory DAPs, the likelihood of shopping or social/recreation purposes drop.
- The **number of college students** in the household decreases the chances of meal and social/recreation purposes. If the college students have mandatory DAPs, shopping purpose utility drops also, but not by as large an amount as meal and social/recreation purposes.
- The **number of full-time workers** in the household tends to make the personal business purpose less likely.
- The **number of part-time workers** in the household makes the meal and social/recreation purposes less likely. If the part-time worker has a mandatory pattern, shopping utility is also decreased.

- **The number of non-workers** in the household (senior and non-senior) with non-mandatory patterns (very few of such individuals have mandatory patterns anyhow) make meal and social/recreation purposes less likely.

- **High income** households are relatively most likely to select the meal purpose. The personal business purpose is least likely for such households.

- **Transit pass ownership** decreases the meal purpose utility, while it increases the utilities for both shopping and social/recreation purposes.

- The greater the **maximum time window overlap** across any two individuals in the household, the more likely is the social/recreation purpose. This is probably the case because social/recreation tours are often longer than other purposes.

- If the household has **two joint tours**, the shopping purpose is more likely for either of them and meal purpose is least likely. These variables are important to control for the different marginal distribution of tour purposes for households with one versus two joint tours.

Joint Tour Participation

- Workers and children 5-15 years are more likely to participate if the tour is a **meal** tour. Children less than 16 years are more likely to participate if the tour is a **social/recreation** tour, while children 16+ years are less likely to participate.

- **College students and workers** are less likely to participate in joint tours when the **household size** is larger.

- **Females** are more likely to participate than males, particularly college student females.

- As a **child's age** increases, a child becomes less likely to participate, reflecting older children's increased mobility independence.

- If **a child less than 5 is assigned to a joint tour already** and no adults are assigned to it, the likelihood of a non-worker (both senior and non-senior) participating in the tour is higher. If another adult is already assigned to the tour, then the likelihood of a non-worker (both senior and non-senior) participating is reduced.

- A child is more likely to participate in the tour if the **relative accessibility of transit** is higher and there is at least one other child already participating and no adults. This makes sense, since children are more likely to rely on transit for their mobility needs, particularly absent an adult.

- A worker or college student is more likely to participate in the tour if the **relative accessibility of transit** is low and there is at least 2 children already participating and no adults. This makes sense, since an adult may be needed to drive the children if transit accessibility is poor.

- The likelihood of participation increases when the **joint tour size ratio** is large. The joint tour size ratio becomes large when there are relatively few eligible participants left to be simulated and the joint tour has less than two participants. This variable essentially encourages the joint tour to become valid.
- The **maximum time window remaining** if the person participates in the tour has a positive effect on participation. This variable measures the amount of time overlap across all members already set to participate in the tour and the person being simulated. The more time available to engage in the joint activity, the higher the participation rate, which makes sense.
- The **reduction in the maximum time window overlap**, likewise, has a negative impact on participation for adults.

2.7 School Escorting

Summary

The school escorting model captures the choice of whether a child is escorted to/from school or not, and if so, by whom. The school escorting model is sequenced after mandatory tour destination choice, but before mandatory tour time of day choice. By sequencing the model in this way, the model is independent of timing constraints (instead, timing considerations are conditional on whether there is school escorting).

For each child having a school activity, the escorting model simulates escorting for both the outbound half-tour (travel to school) and the return half-tour (travel home from school).

The alternatives in the model include the no escort alternative, and up to three adults (if they exist in the household). For each adult, two alternatives are specified. The first is a mandatory tour option, where the adult would escort the child as a stop on the adult's mandatory tour (typically work). If the adult does not have a mandatory tour, then the mandatory option is not available as an alternative in the model. The second is a stand-alone school escorting tour option, where the adult generates a new tour for the specific purpose of escorting the child to/from school.

Since each school tour has two travel components (outbound and return), there are two choice dimensions, handled simultaneously in the model. In other words, each alternative represents the joint choice for outbound half-tour escort choice and return half-tour escort choice.

One issue in modeling school escorting behavior is how to handle multiple children in the same household traveling together to or from school. We call this bundling of the escort decision, since it suggests the escort choices of each child are not independent. To accommodate this behavior, child bundles were considered in the escorting model. Child bundle formation consists of two parts. First, the school tours for each child must share a common school location (school locations are predicted by the school location choice model). If this condition is not met, the children will not be bundled. Second, a probability distribution based on observed household survey data is used to simulate whether two children form a bundle or not (if the first condition is met also). The probability distribution depends on the ages of the children being considered. The distributions for outbound and return half tours are shown in Table 2.2.

Table 2.2. Percentages of Children from Same Household Having Same Escort Decision

Outbound Half Tours

Age Range	0 to 4	5 to 10	11 to 13	14 to 18
0 to 4	98%			
5 to 10	76%	98%		
11 to 13	71%	84%	85%	
14 to 18	0%[1]	19%	62%	70%

Return Half Tours

Age Range	0 to 4	5 to 10	11 to 13	14 to 18
0 to 4	98%			
5 to 10	68%	93%		
11 to 13	43%	75%	75%	
14 to 18	0%	19%	56%	56%

Source: Baltimore/Washington region household survey data set.

[1] In the household survey, there were only two child pairs in this category (who happened to have the same escort decision). It is asserted that this value should be 0% for application purposes.

Pairs of children are simulated from youngest to oldest. For instance, in the case of a 3-year old, 8-year old, and 15-year old, the 3-year old and 8-year old would be compared first. From the table, we see the probability of bundling among these two children on the outbound half tour is 76%. Second, the 8-year old and 15-year old would be compared, having a probability of bundling of 19%. This probability holds regardless of whether the 3-year old and 8-year old were already bundled or not. In total for this case, there are four possible outcomes, each with the following probabilities:

- No bundling: P = (1-0.76) * (1-0.19) = 0.194
- 3 years, 8 years Bundled: P = (0.76) * (1-0.19) = 0.616
- 8 years, 15 years Bundled: P = (1-0.76) * (0.19) = 0.046
- All bundled: P = (0.76) * (0.19) = 0.144

Note that it is not possible for the 3- and 15-year old to be bundled without the 8-year old; this is by design. Also note that bundling on the outbound half tour and on the return half tour are handled independently from one another. Children need not be bundled on both half tours.

Since children are bundled for the purposes of the school escorting choice, the decision-maker is the child bundle.

Estimation Results Spreadsheet

All estimation results for this model are presented in the companion spreadsheet *School Escort 1.xlsm*.

Alternatives

The alternatives of the model are shown in Table 2.3.

Table 2.3. Alternatives in the School Escorting Model

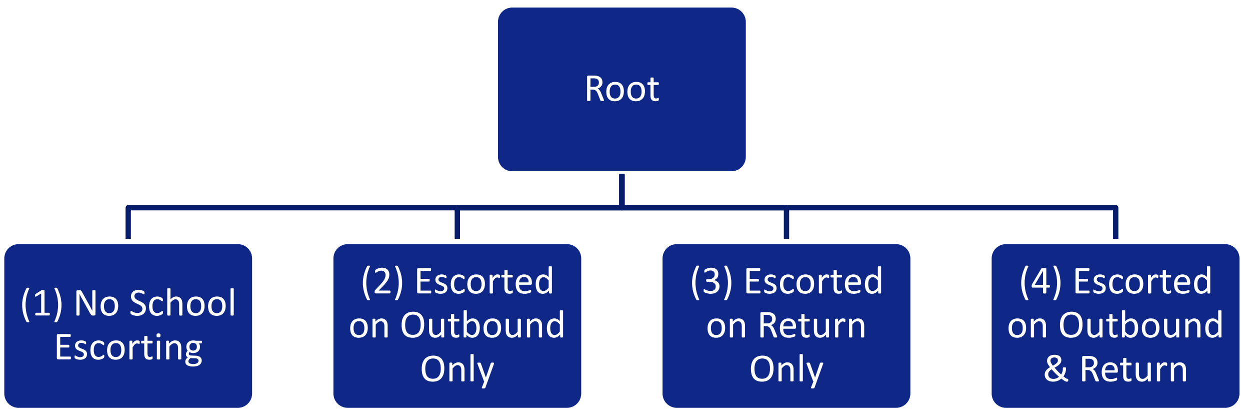
Alternative Number	Joint Choice ID	Outbound	Return
1	1,1	1 – Adult 1, Mandatory	1 – Adult 1, Mandatory
2	1,2	1 – Adult 1, Mandatory	2 – Adult 1, Standalone
3	1,3	1 – Adult 1, Mandatory	3 – Adult 2, Mandatory
4	1,4	1 – Adult 1, Mandatory	4 – Adult 2, Standalone
5	1,5	1 – Adult 1, Mandatory	5 – Adult 3, Mandatory
6	1,6	1 – Adult 1, Mandatory	6 – Adult 3, Standalone
7	1,7	1 – Adult 1, Mandatory	7 – Not escorted
8	2,1	2 – Adult 1, Standalone	1 – Adult 1, Mandatory
↓	↓	↓	↓
14	2,7	2 – Adult 1, Standalone	7 – Not escorted
15	3,1	3 – Adult 2, Mandatory	1 – Adult 1, Mandatory
↓	↓	↓	↓
21	3,7	3 – Adult 2, Mandatory	7 – Not escorted
22	4,1	4 – Adult 2, Standalone	1 – Adult 1, Mandatory
↓	↓	↓	↓
28	4,7	4 – Adult 2, Standalone	7 – Not escorted
29	5,1	5 – Adult 3, Mandatory	1 – Adult 1, Mandatory
↓	↓	↓	↓
35	5,7	5 – Adult 3, Mandatory	7 – Not escorted
36	6,1	6 – Adult 3, Standalone	1 – Adult 1, Mandatory
↓	↓	↓	↓
42	6,7	6 – Adult 3, Standalone	7 – Not escorted
43	7,1	7 – Not escorted	1 – Adult 1, Mandatory
↓	↓	↓	↓
49	7,7	7 – Not escorted	7 – Not escorted

Note that up to three adults appear as alternatives on each half tour, and each adult will appear twice, as long as the adult has a mandatory tour. Adults that do not have mandatory tours will only appear as standalone escort options. In most cases, there will be far fewer than 49 alternatives because typically there will be fewer than three adult candidates that exist in the household. (Adults are not candidates if they have a stay at home DAP.)

Model Structure

The model uses a nested logit structure, as shown in Figure 2.5. The first nest includes only alternative 49 – not escorted on outbound, not escorted on return. The second nest includes alternatives 7, 14, 21, 28, 35, and 42 – escorted on outbound, not escorted on return. The third nest includes alternatives 43 to 48 – not escorted on outbound, escorted on return. The last nest includes all other alternatives with escorting on both outbound and return.

Figure 2.5. Alternatives for the School Escorting Model



Variables

The following variables are used in the school escorting model.

Alternative Specific Constants

Alternative specific constants are defined for each alternative escorting type combination. As discussed above, there are three escorting types: mandatory, standalone escort, and not escorted. With two choice dimensions, there are a total of nine escorting type combinations. The "not escorted on either half-tour" alternative serves as the base.

Escort Characteristics

Several characteristics of the adult escort were used, including the following:

- Gender
- Person type (full-time worker, part-time worker, non-working senior, adult student)

- Indicator taking value of 1 if a worker typically works from home
- Daily activity pattern of the adult
- Indicator taking value of 1 if the alternative uses the same adult on outbound and return half-tours

Level-of-Service and Zonal Attributes

Several level-of-service attributes were used, including the following:

- Indicator taking a value of 1 if the child bundle's school location is in a different county than the household location.

- Generalized time[3] between home and school

- Detour generalized time for mandatory escort alternatives. Detour generalized time is computed as the sum of generalized time from home to school and school to work, minus the generalized time from home to work.

School Tour Characteristics

- Presence of child less than 5 years in the child bundle
- Presence of child 16 years or more in the child bundle
- Age of the youngest child in the child bundle
- Indicator taking value of 1 if the child bundle is of size 2 or more

Household Characteristics

- Presence of child less than 5 years in household with stay-at-home daily activity pattern
- Indicator for zero-car household
- Indicator taking value of 1 if workers > cars and cars > zero
- Household income indicators

Estimation Findings

Some of the key findings of the model estimation are as follows:

- Younger children are more likely to be escorted while older children are less likely to be escorted.

[3] Generalized time is equal to the utility contribution of all travel time components, computed from the tour mode choice model coefficients. Mandatory escort alternatives use the coefficients from the work tour model, and stand-alone escort alternatives use the coefficients from the non-work tour model. See Section 2.14 for a description of the tour mode choice models.

- Generalized time to/from school and detour generalized time to/from school for mandatory alternatives have a positive effect on utility for all escorting alternatives.
- For mandatory escorting alternatives, child group size has a negative effect on utility for being escorted on either outbound or return half-tours, but little effect on being escorted on both outbound and return half-tours.
- For standalone escorting alternatives, child group size has no effect on utility for being escorted on either outbound or return half-tours, but positive effect on being escorted on both outbound and return half-tours.
- Adults are more likely to escort children to school if the child goes to school in a different county from the household's county. Many of these children would be going to private schools, and so it makes sense they would have higher rates of school escorting.
- Households with poor vehicle sufficiency are less likely to escort children to/from school.
- Higher income households are more likely to escort children to/from school.
- Females are more likely to escort children to/from school.
- Full-time workers are less likely to escort as standalone escort tours. However, both full- and part-time workers are more likely to escort as part of mandatory tours, especially on the outbound half-tour or both half-tours.
- Higher utilities are associated with alternatives where the same adult escorts the child to/from school on both outbound and return half-tours.
- Adults with mandatory tours are much less likely to generate standalone escort tours for escorting children to/from school.
- Adults are much less likely to escort children to school if the household has another child less than 5 years that stays home for the day.

2.8 Tour Destination Choice

Summary

The purpose of this model is to simulate the location of each primary activity on a tour. A destination choice model was estimated for each tour purpose[4]. A total of five models were estimated, defined as follows:

- Individual work;
- Individual university;
- Individual non-mandatory (including escort purpose);
- Individual work-based subtours; and
- Fully joint non-mandatory tours.

Note that by definition all tours begin and end at home, except work-based subtours.

Estimation Results

The estimation results for the five models are presented in the companion spreadsheet *Tour Dest Choice 1.xlsx*.

Model Structure

All of these models are structured as multinomial logit (MNL). These models predict the probabilities of choosing a destination TAZ for the primary tour activity given the household location, based on the relative ease to get to the destination, necessity to engage in activities in the destination, and availability of modes to reach the destination.

Note that later in the modeling process a point (parcel) location will be simulated for each activity location, within the zone chosen in this tour destination choice model.

Alternatives

Every internal TAZ in the BMC modeling area is a possible destination choice location. Therefore, the alternatives in the MNL-based model are all internal TAZs. The logit structure is shown below where TAZs 1, 2, …, 2,934 are the alternatives under the main root. (Note that there are no TAZs numbered from 1388 to 1399.)

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[4] A school tour purpose model was not estimated. A regular school place location model will be among the long term choice models, and each child person type will have a school place assigned. When a child generates a school tour, it will automatically be assigned to the regular school place location; thus, no tour-level model is needed.

Variables

The following variables are used in the tour-level destination choice models.

Size function

Size functions are used to measure the amount of activity that occurs at each destination zone and incorporate this into the utility of alternative variables. This is similar to the way in which the number of trip attractions is used as a variable in conventional trip distribution models. This type of variable is frequently used in destination choice models to account for differences in zone sizes and employment levels. The size variables used in these models include as components employment by type (office, industrial, retail, medical, education, restaurant, other), and number of households. The size function is included in the utility equation of each destination choice (TAZ) as follows:

U = Coeff1 * Var1
+ Coeff2 * Var2
+ Coeff3 * Var3
+ ……..
+ Size function

Where:

Var1, Var2, Var3 are explanatory variables (e.g., distance, intrazonal, mixed density, etc.);

Coeff1, Coeff2, Coeff3 are coefficients for Var1, Var2, Var3;

Size function = LSM * ln {(Size variable1)
+ exp (coeff22) * Size variable2
+ exp (coeff33) * Size variable3
+ …….}

Where:

Size variable1 is the base variable (e.g., office employment);
Size variables 2 and 3 are other explanatory variables (e.g., retail employment);
Coeff22 and Coeff33 are coefficients for size variables 2 and 3; and
LSM is log size multiplier, which is multiplied by the entire size function.

Distance – This is the round trip (RT) distance, from origin to destination PLUS destination to origin, derived from the network skims and expressed in miles. To provide a non-linear relationship with distance, a piecewise linear formulation is used. The following example, from the individual non-mandatory model, shows how this works:

Distance	-0.0745
Max(0, Distance - 5)	-0.1056
Max(0, Distance - 10)	0.0630

Max(0, Distance - 20)	0.0481
Max(0, Distance - 45)	0.0550

For example:

- For 2 miles, the utility contribution of the distance variables is (-0.0745 * 2).
- For 7 miles, the utility contribution of the distance variables is:

  (-0.0745 * 7) + (-0.1056 * (7-5)).

- For 12 miles, the utility contribution of the distance variables is:

  (-0.0745 * 12) + (-0.1056 * (12-5)) + (0.0630 * (12-10))

Mode choice logsum – The disaggregate mode choice logsum for the same tour purpose is derived from the estimated tour-level mode choice models. This variable captures the accessibility and performance of each mode available to make the trip to the desired destination.

Land use/zonal variables

Land use variables are computed at the zone level and are stored as zone variables in the model database. These have already been computed for the base year and should be in the zone database. Land use variables included in the tour destination choice models include the following.

Intrazonal dummy – 1 if the destination zone is the same as the home zone, zero otherwise

University zone dummy – 1 if the destination zone has a university, zero otherwise

Transit-walk access dummy - 1 if the destination zone is accessible from the origin zone via transit with walk access, zero otherwise

Usual work zone location dummy – In the work tour model, 1 if the destination zone is the usual work zone (from the usual work zone destination choice model), zero otherwise

Variable segmentation

In some cases, the variables have been estimated with values specific to particular market segments. These segments may be defined by:

- Person type (full-time worker, part-time worker, adult student, non-working adult, child);
- Income level;
- Whether the traveler's household has fewer vehicles than workers;

- Daily activity pattern characteristics (whether the traveler has a mandatory tour, more than one tour, or more than two tours);
- Specific tour purpose for individual non-mandatory tours, fully joint tours, and work based subtours;
- Group size for joint tours;
- Group composition for joint tours (children only, adults and children); and
- Parent tour mode, for work based subtours.

Estimation Findings

Some of the key findings of the model estimation are as follows:

- The key level of service variable, distance, effects utility of choosing a TAZ inversely. That is, if the distance increases, the utility declines gradually. This can be further examined by plotting the effects of distances against utility derived.
- The mode choice logsums for all models except the university model are constrained to be 0.5.
- The intrazonal dummy variable is positive for all models.
- The size function always has a base variable which is different across the tour purposes. For the work model, office employment made most sense while for the university model, education employment was the base variable. For all other tour purposes, total employment was used as the base variable.
- Having a university in the zone, not surprisingly, increases the probability of a university tour destination. This has a negative effect in the fully joint tour and work based subtour models.
- Being transit-walk access accessible has a small positive effect on the probability of choosing a destination zone.

2.9 Individual Non-Mandatory Tour Generation

Summary

The individual non-mandatory tour generation model predicts the number and type of individual non-mandatory tours (as opposed to joint tours among household members, which are modeled separately) for each individual in the simulated population. This model is a function of the number of available time windows, activity patterns of other household members, transportation accessibility, and other household and person attributes.

Estimation Results

The model estimation results are shown in the companion spreadsheet *NM Tour Gen 1.xlsx*.

Model Structure

The structure for this model is multinomial logit.

Alternatives

There are a total of 56 possible alternatives for this model as shown below. These include a combination of the five non-mandatory activity purposes: meal, shop, personal business, escort and social recreation tours. The possibilities are 0, 1, 2, or 3 tours of each type.

- 0 tours
- 1 meal tour
- 1 shopping tour
- 1 personal business tour
- 1 social/recreation tour
- 1 escort tour
- 2 meal tours
- 1 meal & 1 shopping tours
- 1 meal & 1 personal business tours
- 1 meal & 1 social-recreation tours
- 1 meal & 1 escort tours
- 2 shopping tours
- 1 shopping & 1 personal business tours
- 1 shopping & 1 social-recreation tours
- 1 shopping & 1 escort tours
- 2 personal business tours
- 1 personal business & 1 social-recreation tours
- 1 personal business & 1 escort tours
- 2 social/recreation tours
- 1 social-recreation & 1 escort tours
- 2 escort tours
- 3 meal tours
- 2 meal & 1 shopping tours
- 2 meal & 1 personal business tours
- 2 meal & 1 social-recreation tours
- 2 meal & 1 escort tours
- 1 meal & 2 shopping tours
- 1 meal, 1 shopping, & 1 personal business tours
- 1 meal, 1 shopping, & 1 social-recreation tours
- 1 meal, 1 shopping, & 1 escort tours
- 1 meal & 2 personal business tours

- 1 meal, 1 personal business, & 1 social-recreation tours
- 1 meal, 1 personal business, & 1 escort tours
- 1 meal & 2 social-recreation tours
- 1 meal, 1 social-recreation, & 1 escort tours
- 1 meal & 2 escort tours
- 3 shopping tours
- 2 shopping & 1 personal business tours
- 2 shopping & 1 social-recreation tours
- 2 shopping & 1 escort tours
- 1 shopping & 2 personal business tours
- 1 shopping, 1 personal business, & 1 social-recreation tours
- 1 shopping, 1 personal business, & 1 escort tours
- 1 shopping & 2 social-recreation tours
- 1 shopping, 1 social-recreation, & 1 escort tours
- 1 shopping & 2 escort tours
- 3 personal business tours
- 2 personal business & 1 social-recreation tours
- 2 personal business & 1 escort tours
- 1 personal business & 2 social-recreation tours
- 1 personal business, 1 social-recreation, & 1 escort tours
- 1 personal business & 2 escort tours
- 3 social/recreation tours
- 2 social-recreation & 1 escort tours
- 1 social-recreation & 2 escort tours
- 3 escort tours

Variables

Most of the variables in the tour generation model are interacted with the number of tours by tour purpose for the alternative. This is because there are a relatively large number of alternatives (56 in total, making it awkward to estimate distinct coefficient for a variable for each alternative), and those alternatives share important attributes (namely, that each represents a number of tours). Therefore, most coefficients are applied to a variable on a per tour basis. For example, *beta1* might apply to 0-car households per meal tour. Then for any 0-car household, the contribution of this variable to utility functions would be given by the following equation:

$$U_{i,mspre} = \beta_i \times X_{0car} \times (m)$$

Here, m refers to the number of meal tours represented by the particular alternative (s, p, r, and e refer to the number of shopping, personal business, social/recreation, and escort tours, respectively). For an alternative with 0 meal tours, the utility contribution would be 0, since m would equal 0. For an alternative with 2 meal tours, the utility contribution would be multiplied by 2, since m would equal 2.

The following variables are used in the individual non-mandatory tour generation model.

Alternative Specific and Other Constants

In all there are 56 alternatives, and so the maximum number of constants allowed is (56-1) = 55. However, due to the low number of observations for some alternatives (particularly those that have three tours), only 38 constants were estimated, many of which apply to more than one alternative. At least one constant applies to each alternative with one or more tours, where the "0 individual non-mandatory tours" is held as the base alternative.

The constants were defined as follows:

1. One constant for each of the five single tour alternatives, defined by activity purpose

2. One constant for each of the 15 possible two tour alternatives, defined by pairs of activity purposes

3. A constant that applies to any three-tour alternative

4. Four constants that apply to three-tour alternatives that have at least one tour for a particular purpose (there is no constant for personal business)

5. Five constants that apply to three-tour alternatives that have at least two tours for a particular purpose

6. Eight constants that apply to three-tour alternatives that have at least one tour for a particular purpose and one for another purpose. The eight combinations are:

   - Meal/shopping
   - Meal/personal business
   - Meal/social-recreation
   - Meal/escorting
   - Shopping/personal business
   - Shopping/social-recreation
   - Shopping/escorting
   - Social-recreation/escorting

The three-tour constants (#3 through #6) are additive, and so more than one constant may apply to a particular alternative. For example, the alternative with three tours for meal, shopping, and escorting would include in its utility function the following constants:

- Any three-tour alternative
- Any three-tour alternative
- Any three-tour alternative with at least one meal tour
- Any three-tour alternative with at least one shopping tour
- Any three-tour alternative with at least one escorting tour
- Any three-tour alternative with at least one meal tour and one shopping tour
- Any three-tour alternative with at least one meal tour and one escorting tour
- Any three-tour alternative with at least one shopping tour and one escorting tour

Several household and person level characteristics were used, including the following:

- Person type (child by age group, full-time worker, part-time worker, senior);
- Whether there are children in the household;
- Whether the traveler is the only person in his/her household;
- Age (piecewise linear effects);
- Gender (whether the traveler is an adult female);
- Vehicle availability and sufficiency (zero vehicles, adults > vehicles, and workers > vehicles); and
- Household income level.

There are also variables related to the daily activity pattern of the traveler or other household members. Some of these are interacted with each other or with person characteristics.

- Whether there are one or more children in the household with a stay at home pattern
- Whether there are one or more adults in the household with a stay at home pattern
- Whether the traveler is an adult with a non-mandatory daily activity pattern
- Whether the traveler is an adult with a non-mandatory daily activity pattern
- Number of mandatory, fully joint, and school escorting tours in day

Accessibility Variables

These variables are based on the computed accessibility logsums as described in Section 1.2. The specific accessibility variables used in the tour generation model include the following:

- Accessibility logsums for social-recreation activities (applied for alternatives with social-recreation tours, on a per social-recreation tour basis)

- Accessibility logsums for personal business activities (applied for alternatives with personal business tours, on a per personal business tour basis)

- The difference between the drive alone and transit-walk access accessibility logsums, with a minimum value of 6. A separate value for the parameter of this variable is used for travelers in households with transit passes. These variables are applied on a per tour basis.

- The difference between the drive alone and walk mode accessibility logsums, with a minimum value of 9. These variables are applied on a per tour basis. Separate parameters are used for meal tours and escorting tours.

Time Availability Variables

These variables account for the effects of previously scheduled tours (mandatory and full joint) on the time available to make non-mandatory tours. A time window is defined as the number of consecutive half hour periods in which no previously scheduled tour takes place. Note that "partially used periods," in which a previously scheduled activity begins or ends, is considered to be available. The following variables are used:

- Natural logarithm of the total number of available half hour periods in the day. Additional variables dampen the effect for tours of certain purposes.

- Natural logarithm of the number of available periods between 5:00 p.m. and 11:00 p.m., applied (with separate parameters) for shopping and personal business tours.

- Natural logarithm of the maximum available time window, measured in half hour periods. The effects are different for meal and escort tours than for other tour purposes.

Estimation Findings

Some of the key findings of the model estimation are as follows:

- Household income plays a significant role in generating non-mandatory tours. Individuals from higher income households tend to generate more tours in total, especially meal, escorting, and social-recreation tours.

- Lower vehicle availability or sufficiency results in fewer non-mandatory tours.

- Households without children make more meal and social-recreation tours and fewer escorting and personal business tours.

- Presence of others in the household who stay at home reduces the number of non-mandatory tours. Presence of another adult in the household with a non-mandatory activity pattern increases the number of non-mandatory tours that a person makes.

- Single person households tend to make more tours of all types except escorting.

- Children generally tend to make more escorting tours (note that these escort tours would include going along with adults to escort their siblings).

- Full-time workers make fewer tours in general.

- As they get older, children over the age of 4 tend to make more social-recreation and personal business tours and fewer escorting tours. After the age of 10, they tend to make more shopping tours as they age.

- Up to age 40, adults tend to make more tours as they age, but fewer meal and personal business tours. This effect flattens out after age 40.

- Not surprisingly, better accessibility leads to more non-mandatory tours.

- Not surprisingly, more time availability leads to more non-mandatory tour making. The effect is dampened for discretionary and escorting tours. The number of available time periods in the evening dampens the effect for shopping and personal business tours. Some of the locations where these activities take place may not be open in the evenings.

2.10 Tour Time of Day Choice

Summary

The tour level time of day choice models are estimated for the following tour purposes:

- Work
- University/school
- Individual non-mandatory
- Joint non-mandatory
- Work-based subtour

Note that by definition all tours begin and end at home, except work-based subtours.

Time of day choice is predicted in 30-minute intervals (48 periods across the day) beginning and ending at 3:00 AM. The models predict, jointly, the time interval an individual arrives at and the time interval an individual leaves from the tour primary activity location. Thus, for each arrival period alternative, there are multiple return period options. For instance, for an arrival in the 8-8:30 AM period, one could return potentially return at any time interval thereafter (up until the last period of the day). Each arrival/return pair represents an alternative, for a total of 1,176 alternatives.

The main approach is to use alternative specific constants for various groupings of arrival periods, departure periods, and durations, plus shift effects that push arrivals earlier or later and durations of stay longer or shorter (as a result, shifting the departure period as well). The models also make extensive use of the concept of available time windows for scheduling tours. As each tour is simulated, the periods that are used by the tour are made either fully or partially unavailable for any other tours, and the length of remaining time windows available during the day is calculated.

Finally, a logsum variable from the mode choice model is used to estimate the effects of transportation level of service, including road congestion and tolling, on time of day choice.

Estimation Results Spreadsheet

The model estimation results are provided in five separate companion spreadsheets:

- Work – *Tour TOD Work 1.xlsm*
- University/school – *Tour TOD Sch Univ 1.xlsm*
- Individual non-mandatory – *Tour TOD NM 1.xlsm*
- Joint non-mandatory – *Tour TOD Joint 1.xlsm*
- Work-based subtour – *Tour TOD WB Subtour 1.xlsm*

Model Structure

The models for all five tour purposes are multinomial logit.

Alternatives

The tour arrival and departure time model predicts the time arriving at the primary destination of the tour and the time leaving the primary destination. There are a total of 48 half-hour intervals for arrival and return, starting with the 3:00-3:30 AM period and ending with the 2:30-3:00 AM period. In all, there are 48x(48+1)/2 = 1,176 alternatives.

Variables

The following variables are used in the tour time of day choice models.

Alternative Specific and Other Constants

Most individual arrival and return time intervals do not have a constant associated specifically with that interval. Instead, groups of 30-minute intervals share arrival and return constants. Only during peak periods are constants associated with specific arrival/return intervals.

Other constants included in these models are "duration" constants, which measure the duration of the primary activity. Depending on the activity purpose, the base duration is different for different models. It is longer for work and university/school purposes (9 and 7 hours respectively), 1.5 hours for non-mandatory activities (individual and joint), and one half hour for work-based activities. Like the arrival and return constants, some duration constants are associated with multiple durations. Table 2.4 shows the duration constants for each tour purpose.

Table 2.4. Duration Constants for Each Tour Purpose

Work	University/School	Individual Non-Mandatory	Joint Non-Mandatory	Work-Based Subtour
[0-3)	[0-3)	0	0	0
[3-6)	[3-6)	0.5	0.5	0.5 (BASE)
[6-7)	[6-7)	1	1	1
[7-8)	7 (BASE)	1.5 (BASE)	1.5 (BASE)	1.5
8	7.5	2	2	[2-4)
8.5	8	2.5	2.5	[4-8)
9 (BASE)	8.5	[3-4)	[3-4)	
9.5	9	[4-5)	[4-5)	
10	9.5	[5-6)	[5-6)	
10.5	[10-11)	[6-9)	[6-9)	
[11-12)	[11-12)	[9-12)	[9-12)	
[12-13)	[12-16)	[12-24)	[12-24)	
[13-16)	[16-24)			
[16-24)				

Shift variables

Two kinds of "Shift" variables are computed, namely "Shift Early" and "Shift Later," which measure the difference between the time period indicator (on a scale from 1 through 24 with 0.5 increments) and the pivot point. "Shift Early" is used when the time period indicator is less than the pivot point whereas "Shift Later" is used when it is greater. The shift variables are defined as follows:

"Shift Early" for AM = max(P–T, 0)
"Shift Later" for AM = max(T–P, 0)
T = Hour – 1, 2, 3, …, 24
P = Pivot point

For work tours, P was set at 7.5 and for non-mandatory tours, P was set at 10 in defining the arrival shift variables.

Duration "shift" variables were also defined for the work tour model, since the distribution of work tour duration peaks near 9 hours. In this case, the pivot point was set at 9 hours in computing duration "Shift Shorter" and "Shift Longer" variables. During model estimation, these "Shift" variables are multiplied by household and person attributes to see the effects of individual attributes on time-of-day choice.

Household, Person, and Daily Activity Pattern Characteristics

Several household, person, and daily activity pattern characteristics were used to interact with the shift variables. These include:

- Person type (full-time worker, part-time worker, adult student, senior, non-working adult, child by age group)
- Worker age 50-64
- Gender (female)
- Household income category
- Only one mandatory tour in the person's daily activity pattern
- Only one tour (of any type) in the person's daily activity pattern
- Whether there is an intermediate stop on the tour
- Whether there is a child in the household with a stay at home daily activity pattern
- Whether the household has one adult plus child(ren)
- Whether there is escorting on the outbound or return half tour (and for school tours, whether the group of children being escorted has at least two students)
- Presence of a person in the household with mandatory tour
- Purpose of non-mandatory tour or work based subtour (meal, shop, personal business, social recreation, or escort, plus work or university for work based subtours)
- For joint non-mandatory tours, composition of the group (only adults or children, only females, size of the group)

Dummy Variables

Duration dummy variables are used in the individual and joint non-mandatory tour models that vary by purpose:

- Meal with different durations (0.5, 1, 1.5, 2 hours)
- Shop with different durations (0.5, 1, 1.5, 2 hours)
- Social/recreation with different durations (0.5, 1, 1.5, 2, >3 hours)
- Personal business (>3 hours)
- Escort with different durations (0.5, 1, 1.5, 2 hours)

Delay variables

The delay variable represents the level of congestion that is computed as a function of the time traveled in the chosen period and the free flow travel time. This variable is used to estimate the propensity for peak spreading since the peak periods are the most congested. The greater the difference between the congested and free flow time travel times, the greater the congestion effect:

Delay = max(30 - max(congested TT - free flow TT, 0), 0) / 30

This variable ranges from 0 to 1, with the variable taking value 1 if congested time = free flow time, and 0 if congested time is 30 minutes or more greater than free flow time.

The Delay variable is then interacted with two shift variables to estimate the propensity for persons to shift AM peak arrivals and PM peak departures away from the peak of the peak. Four variants of this variable are used in the models:

- Congestion arrival - am peak period time interval - earlier than AM peak (7:30 am)
- Congestion arrival - am peak period time interval - later than AM peak (7:30 am)
- Congestion departure - pm peak period time interval - earlier than PM peak (5:00 pm)
- Congestion departure - pm peak period time interval - later than PM peak (5:00 pm)

These variables are not used for work-based subtours, and the variable is segmented by person type (full time worker vs. all others) for work tours.

Table 2.5 shows the values of these shift variables for each period.

Table 2.5. Shift Variable Values for Delay Variables

Arrival Period	Clock Time	AM Peak Early Arrival Shift	AM Peak Late Arrival Shift	Departure Period	Clock Time	PM Peak Early Departure Shift	AM Peak Late Departure Shift
1	3:00 a.m.	0	0	1	3:00 a.m.	0	0
↓	↓	↓	↓	↓	↓	↓	↓

7	6:00 a.m.	0	0	25	3:00 p.m.	0	0
8	6:30 a.m.	0.5	0	26	3:30 p.m.	0.5	0
9	7:00 a.m.	1	0	27	4:00 p.m.	1	0
10	7:30 a.m.	1.5	0	28	4:30 p.m.	1.5	0
11	8:00 a.m.	0	1.5	29	5:00 p.m.	0	1.5
12	8:30 a.m.	0	1	30	5:30 p.m.	0	1
13	9:00 a.m.	0	0.5	31	6:00 p.m.	0	0.5
14	9:30 a.m.	0	0	32	6:30 p.m.	0	0
↓	↓	↓	↓	↓	↓	↓	↓
48	2:30 a.m.	0	0	48	26.5	0	0

Time Window Variables

These variables are derived from the amount of time available after the person's daily activity pattern is simulated. This gives an indication of time available to indulge in other activities and the propensity to either arrive/depart late or early from/to primary destinations.

- Total available time remaining
- Available time remaining if other mandatory tours have yet to be scheduled (applies to mandatory tours only)
- Available time remaining if other non-mandatory tours have yet to be scheduled (applies to individual non-mandatory tours only)
- Arrival period partially used (person has another tour scheduled to depart during this period)
- Departure period partially used (person has another tour scheduled to arrive during this period)

Transportation level of service

Mode choice logsum – Logsum computed from the tour mode choice model, for the round trip between the origin and destination.

Distance-duration interaction – Designed to capture the time of day effects of longer trips and longer activity durations, the following variables are used:

- ln(1 + distance in miles) * ln(1+ duration in hours)
- ln(1 + distance in miles) * ln(1+ duration in hours)

Estimation Findings

Some of the key findings of the model estimation are as follows:

- The coefficients of the mode choice logsum are positive, indicating that people prefer to travel when multimodal accessibility is better. Note that in some cases, the positive coefficient was asserted. This was necessary because of the conflicting effects between time of day choice and travel demand. People prefer to travel when travel times are better, but more travelers mean more congestion and higher travel times.

- The positive distance–duration coefficient indicates that the farther the activity location, the longer the tour duration. This is reasonable because people want to spend more time doing activities than traveling; and the farther they travel the longer they typically spend doing the activity.

- The higher the level of congestion, the greater the likelihood of either arriving early or later than the peak of the peak period, when the congestion is the highest, as indicated by the positive coefficients of the delay variables. These "peak spreading" effects are as expected.

- The available time window remaining is correlated with longer activity durations. This makes sense since more time spent engaging in one activity limits the time remaining for other activities (including at-home activities such as eating and sleeping).

- In the work tour model, the shorter duration shift variables interacted with non-full time workers have positive coefficients, indicating that, all else being equal, these persons are more likely to stay at work for shorter durations. Similarly, the longer duration shift variables for these groups have negative coefficients.

- Work activity durations tend to be shorter when there is escorting on the return half tour (for example, when a child is being picked up), when there are children in the household with stay at home patterns, and when the traveler is female, as shown by the negative coefficients of the longer duration shift variables when interacted with these indicators.

- Most of the shift variables are negative except when interacted with low income travelers, adult students, and workers in the age group 50-64 years in the work tour model. This indicates that commuters in these groups seem to prefer earlier arrivals.

- The indicator variables for partially used periods have negative coefficients, due to the lesser availability for activities in these periods that are already partially in use for other activities.

2.11 Tour Destination Choice

Summary

The purpose of this model is to simulate the location of each primary activity on a tour. A destination choice model was developed for each tour purpose[5]. This is analogous to having gravity models for each trip purpose in a four-step model. A total of five models are estimated, based on travel purpose, defined as follows:

- Individual work;
- Individual university;
- Individual non-mandatory (including escort purpose);
- Individual work-based subtours; and
- Fully joint non-mandatory tours.

Note that by definition all tours begin and end at home, except work-based subtours.

Estimation Results Spreadsheet

All the estimation results for the five models are presented in Appendix A.

Model Structure

All of these models are structured as multinomial logit (MNL). These models predict the probabilities of choosing a destination TAZ for the primary tour activity given the household location, based on the relative ease to get to the destination, necessity to engage in activities in the destination, and availability of modes to reach the destination.

Note that later in the modeling process, a point (parcel) location will be simulated for each activity location, within the zone chosen in this tour destination choice model.

Alternatives

Every internal TAZ in the BMC modeling area is a possible destination choice location. Therefore, the alternatives in the MNL-based model are all internal TAZs. The logit structure is shown in Figure 2.1, where TAZs 1, 2, …, 2,934 are the alternatives under the main root. (Note that there are no TAZs numbered from 1388 to 1399.)

[5] A school tour purpose model was not estimated. A regular school place location model will be among the long term choice models, and each child person type will have a school place assigned. When a child generates a school tour, it will automatically be assigned to the regular school place location; thus, no tour-level model is needed.

Variables

The following variables are used in the tour destination choice models.

Size function

Size functions are used to measure the amount of activity that occurs at each destination zone and incorporate this into the utility of alternative variables. This is similar to the way in which the number of trip attractions is used as a variable in conventional trip distribution models. This type of variable is frequently used in destination choice models to account for differences in zone sizes and employment levels. The size variables used in these models include as components employment by type (office, industrial, retail, medical, education, restaurant, other), and number of households. The size function is included in the utility equation of each destination choice (TAZ) as follows:

U = Coeff1 * Var1
+ Coeff2 * Var2
+ Coeff3 * Var3
+ ……..
+ Size function

Where:

Var1, Var2, Var3 are explanatory variables (e.g., distance, intrazonal, mixed density, etc.);
Coeff1, Coeff2, Coeff3 are coefficients for Var1, Var2, Var3;
Size function[6] = LSM * ln {(Size variable1)
+ exp (coeff22) * Size variable2
+ exp (coeff33) * Size variable3
+ …….}

Where:

Size variable1 is the base variable (e.g., office employment);
Size variables 2 and 3 are other explanatory variables (e.g., retail employment);
Coeff22 and Coeff33 are coefficients for size variables 2 and 3; and
LSM is log size multiplier, which is multiplied by the entire size function.

---

[6] Note that the exponent of all size coefficients is taken. This is to ensure that the effect of each size variable is not negative. However, this also means that an estimated coefficient value of zero could be an important variable in the model, and model statistics based on the coefficient value, such as the t-statistic, are meaningless as a result.

Transportation level of service

Distance – This is the round trip (RT) distance, from origin to destination PLUS destination to origin, derived from the network skims and expressed in miles. To provide a non-linear relationship with distance, a piecewise linear formulation is used. The following example, from the individual non-mandatory model, shows how this works:

Distance	-0.0745
Max(0, Distance - 5)	-0.1056
Max(0, Distance - 10)	0.0630
Max(0, Distance - 20)	0.0481
Max(0, Distance - 45)	0.0550

For example:

- For 2 miles, the utility contribution of the distance variables is (-0.0745 * 2).
- For 7 miles, the utility contribution of the distance variables is:

  (-0.0745 * 7) + (-0.1056 * (7-5)).

- For 12 miles, the utility contribution of the distance variables is:

  (-0.0745 * 12) + (-0.1056 * (12-5)) + (0.0630 * (12-10))

Mode choice logsum – The disaggregate mode choice logsum for the same tour purpose is derived from the estimated tour-level mode choice models. This variable captures the accessibility and performance of each mode available to make the trip to the desired destination.

Land use/zonal variables

Land use variables are computed at the zone level and are stored as zone variables in the model database. These have already been computed for the base year and should be in the zone database. Land use variables included in the tour destination choice models include the following.

Intrazonal dummy – 1 if the destination zone is the same as the home zone, zero otherwise

University zone dummy – 1 if the destination zone has a university, zero otherwise

Transit-walk access dummy - 1 if the destination zone is accessible from the origin zone via transit with walk access, zero otherwise

Usual work zone location dummy – In the work tour model, 1 if the destination zone is the usual work zone (from the usual work zone destination choice model), zero otherwise

Variable segmentation

In some cases, the variables have been estimated with values specific to particular market segments. These segments may be defined by:

- Person type (full-time worker, part-time worker, adult student, non-working adult, child);
- Income level;
- Whether the traveler's household has fewer vehicles than workers;
- Daily activity pattern characteristics (whether the traveler has a mandatory tour, more than one tour, or more than two tours);
- Specific tour purpose for individual non-mandatory tours, fully joint tours, and work based subtours;
- Group size for joint tours;
- Group composition for joint tours (children only, adults and children); and
- Parent tour mode, for work based subtours.

Estimation Findings

Some of the key findings of the model estimation are as follows:

- The key level of service variable, distance, effects utility of choosing a TAZ inversely. That is, if the distance increases, the utility declines gradually. This can be further examined by plotting the effects of distances against utility derived.
- The mode choice logsums for all models except the university model are constrained to be 0.5.
- The intrazonal dummy variable is positive for all models.
- The size function always has a base variable which is different across the tour purposes. For the work model, office employment made most sense while for the university model, education employment was the base variable. For all other tour purposes, total employment was used as the base variable.
- Having a university in the zone, not surprisingly, increases the probability of a university tour destination. This has a negative effect in the fully joint tour and work based subtour models.
- Being transit-walk access accessible has a small positive effect on the probability of choosing a destination zone.

2.12 Stop Generation

Summary

These models estimate the number of intermediate stops (i.e., excluding the primary activity for the tour) for each tour in the simulated daily activity patterns, and the purpose for each stop. These models estimate the number of stops on each half tour, to a maximum of three.

Separate models are estimated for different tour purposes. Note that school escorting stops are not modeled here since these are modeled earlier in the model chain. Nor are "change mode" stops, such as transit transfers or park-and-ride and kiss-and-ride stops (although the stop for the person driving a transit rider to a stop is modeled as an escort stop, if it is not the primary activity of the (escort) tour).

Stop generation is modeled for the tour purposes listed below:

- Work
- School/university
- Individual non-mandatory (including escort and fully joint tours)
- Work-based subtours

Therefore, there are a total of eight models, a number of stops model and a stop purpose model for each of the four purposes listed above.

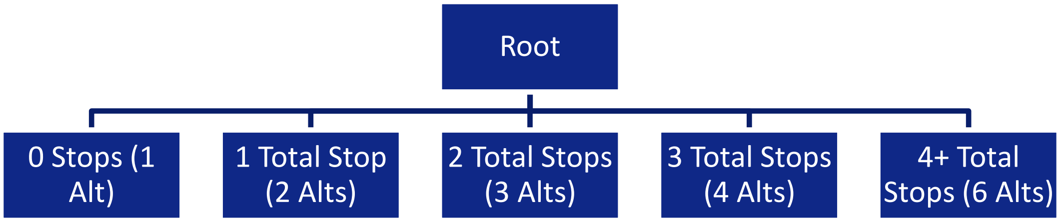
Estimation Results

Estimation results for this model are presented in the companion spreadsheet *Stop Gen 1.xlsx*.

Model Structure

The alternatives for the number of stops models are defined by the number of stops on each half tour. A nested logit structure is used, with the upper level alternatives defined by the number of total stops on both half tours, and the lower level alternatives defined as the specific number of stops on each half tour. The nesting structure is illustrated in Figure 2.6.

Figure 2.6 Nesting Structure for Stop Generation Model



The stop purposes models are multinomial logit.

Alternatives

There can be 0, 1, 2, or 3 stops on each half tour. This means that the number of stops model has 16 alternatives—the combination of the four possible numbers of stops on each half tour. Some of the alternatives are not available or are combined, depending on tour purpose:

- For the work tour model, the daily activity pattern model specifies whether the tour has stops or not, and the stop generation models are run only for work tours that have stops. The alternative with zero stops on both half tours is therefore invalid, and so there are 15 alternatives for this tour purpose.

- For the school tour model, the alternatives with 3 stops on the outbound half-tour and 1, 2, and 3 stops on the return half-tour share an alternative specific constant. This is because the data was not robust enough to estimate distinct constants for each alternative. However, each of these alternatives is treated as being a distinct alternative in the model, even though the constant is shared.

- For the work based subtour model, the four alternatives with two or more stops on both half tours share an alternative specific constant. Like the school model above, the alternatives were not collapsed; they remain distinct alternatives, but the constant is the same for each of the alternatives.

- For the non-mandatory tour model, the data was robust and constants were estimated for all 16 alternatives.

For the stop purpose models, there are up to seven alternatives defined by stop purpose:

- Work
- School/University
- Meal
- Shopping
- Personal business
- Social/Recreation
- Escort

Since non-mandatory tours cannot have mandatory stops, the non-mandatory tour model has only five stop purposes. Work based subtours do not have school stops, and so that model has only six alternatives.

Variables

Most of the variables in the stop number model are interacted with the number of stops or number of stops by purpose for the alternative. This is because there are a relatively large number of alternatives (16 in total, making it awkward to estimate distinct coefficient for a variable for each alternative), and those alternatives share important attributes (namely, that each represents a number of stops). Therefore, most coefficients are applied to a variable on a per stop basis. For example, *beta1* might apply to 0-car households per stop. Then for any 0-car household, the contribution of this variable to utility functions would be given by the following equation:

$$U_{i,mn} = \beta_i \times X_{0car} \times (m + n)$$

Here, *m* and *n* refer to the number of stops on half tour 1 and half tour 2, respectively, represented by the particular alternative. For the 0 stops on both half tours alternative, the utility contribution would be 0, since *m*=0 and *n*=0. For the 2 stop on half tour 1 and 1 stop on half tour 2 alternative, the utility contribution would be multiplied by 3, since *m*=2 and *n*=1.

Many of the variables in the models are constants and indicator variables of *characteristics of the traveler or his/her household*, or interactions among them, including:

- Vehicle availability and sufficiency (compared to workers or adults in household)
- Income level
- Number of persons or children in the household, and related combinations (e.g., 1 adult and 1 or more children)
- Age related, gender, or combination of the two (e.g., adult female)
- Whether the household has a transit pass (from the transit pass ownership model)

The model uses the *person type* definitions used in other model components. If otherwise unspecified, variables related to "child" or "children" refer to any of the child person types.

Variables related to *transportation level of service* are also included. These include:

- Logsum from the mode choice model
- Difference between the logsums for the combined auto and combined transit modes (limited to a range of 5 to +12)
- Indicator of the availability of the transit walk-access mode (0/1)

Other variables include:

- For the non-mandatory tour and work based subtour models, the specific purpose of the tour (e.g., meal, escort)
- Round trip auto travel distance
- Parent tour mode (for work based subtours)
- Employment density within ½ mile of tour primary activity
- Arrival time (for the outbound half-tour) or departure time (for the return half-tour)—These variables represent the number of half hour periods that the primary activity begins or ends in various time periods (before 6:30 a.m., 9:00 a.m. to noon, etc.)
- Duration of primary activity
- Various daily activity pattern variables, including presence of non-mandatory tours, number of other tours by purpose and joint tours, whether there are multiple work tours, whether there is school escorting on each half-tour, and the types of daily activity patterns for other household members. Some of these variables are specific to specific person types/age groups (e.g., child where 1+ children in the household stays home, child's number of mandatory tours).
- Number of available periods – For the outbound half-tour, these variables indicate the number of 30-minute intervals between the start of the primary work activity and either the end of a previous tour's primary activity or the start of the day (3:00

a.m.). For the return half-tour, these variables indicate the number of 30-minute intervals between the end of the primary work activity and either the start of a subsequent tour's primary activity or the end of the day (3:00 a.m.). These variables are used to measure the opportunity to make stops, since it would be unlikely or infeasible to make stops when two tours' primary activities are temporally adjacent to one another.

- Number and purpose of stops on the half-tour, or on the other half-tour
- For the non-mandatory tour models, characteristics of the tour if it is fully joint (e.g., number of persons on the tour, number of children, whether any of the persons on the tour has a mandatory daily activity pattern, etc.)

Some variables are specific to the half tour (outbound or return) on which the stop occurs or to the stop purpose.

Estimation Findings

Some of the key findings of the model estimation are as follows:

- In the work tour model, there are more stops on the return half-tour than on the outbound half-tour (note the more negative constants on alternatives with more stops on the outbound half-tour).
- Longer travel distances to the primary activity mean more stops.
- A longer primary work activity durations means fewer stops.
- Having more available periods means more stops.
- Having more tours in the daily activity pattern means fewer stops.
- Non-workers and seniors are less likely to stop on work tours.
- Adult females are more likely to make stops on non-work tours.
- Among non-mandatory tours, more stops are likely on meal, shopping, and social-recreational tours and less likely on escort tours.
- Tours made for the purpose of school escorting are more likely to have stops than other non-mandatory tours.
- Fully joint tours are less likely to have stops than individual non-mandatory tours.
- Being without a car decreases the number of stops on non-mandatory tours.
- Having fewer cars than workers makes it more likely to make stops on work tours, which makes sense since whoever has the car is likely to have to perform other household maintenance and escorting activities.

- Seniors are less likely to stop in general.
- On work tours, the most likely stop purposes on the outbound half-tour include escorting, university, and meal. The least likely stop purpose is shopping, which makes sense since many stores may not be open during typical morning commute periods.
- On work tours, university and social-recreation stops are less likely when there are other stops on either half-tour. Escort stops are more likely in these cases.
- Not surprisingly, having zero vehicles and/or zero children in the household makes escorting a less likely stop purpose. Having fewer cars than workers, though, makes escort stops more likely, which may indicate that the person with the car needs to perform the drop-off/pickup duties.

2.13 Work-Based Subtour Generation

Summary

The work-based subtour generation model predicts the number and type of work-based subtours for each home-based work tour (referred to as the "parent tour") that is simulated in the daily activity pattern model. This model is a function of characteristics of the parent work tour, other activities the traveler has during the day, the distance from the home to the workplace, highway and transit accessibility, and other household and person attributes.

Estimation Results

The model estimation results are shown in the companion spreadsheet *WB Subtour Gen 1.xlsx*.

Model Structure

The structure for this model is multinomial logit.

Alternatives

The alternatives for this model have the following characteristics:

- Subtour purposes include work, meal, shop, personal business, social/recreation, and escort.
- A maximum of two work based subtours per parent tour are permitted.

- All 2-subtour formations have at least one meal or one work subtour and no escort subtours. The 2-meal subtour alternative is not permitted.

Table 2.6 enumerates the 15 alternatives that fulfill these requirements.

Table 2.6. Alternatives for Work Based Subtour Generation Model

Number of Work-Based Subtours by Tour Purpose							
Alternative	Work	Meal	Shop	Personal Business	Social/Recreation	Escort	Number of tours
1	0	0	0	0	0	0	0
2	1	0	0	0	0	0	1
3	0	1	0	0	0	0	1
4	0	0	1	0	0	0	1
5	0	0	0	1	0	0	1
6	0	0	0	0	1	0	1
7	0	0	0	0	0	1	1
8	2	0	0	0	0	0	2
9	1	1	0	0	0	0	2
10	1	0	1	0	0	0	2
11	1	0	0	1	0	0	2
12	1	0	0	0	1	0	2
13	0	1	1	0	0	0	2
14	0	1	0	1	0	0	2
15	0	1	0	0	1	0	2

Variables

The following variables are used in the work based subtour generation model. Other than the constants, variables are applied on a per subtour basis. Some variables apply only to subtours of certain purposes, or only to the two work subtour alternative.

Alternative Specific Constants

There is one constant for each alternative except the base alternative, which is the zero-subtour alternative.

Household, Person, and Daily Activity Pattern Characteristics

Several household and person level characteristics were used, including the following:

- Whether the traveler is a part-time worker;
- Age (formulated as the natural logarithm of the age plus one);
- Gender; and

- Household income level.

There are also variables related to the daily activity pattern of the traveler:

- Whether the traveler has two mandatory tours; and
- The number of fully joint tours the traveler participates in.

Accessibility and Land Use Variables

The accessibility variables are based on the computed accessibility logsums as described in Section 1.2. The specific accessibility variable used in the subtour generation model is the difference between the drive alone and transit accessibility logsums, with a minimum value of 6. This variable is applied on a per subtour basis to escort, personal business, and social-recreation tours. A separate parameter, applied on a per subtour basis to all subtours, is included for all travelers whose parent tour mode is non-auto.

Employment density is used as a variable, in the form of the natural logarithm of the employment density within ½ mile of the workplace plus one.

Parent Tour Characteristics

These variables include the following:

- Whether there is school escorting on either the outbound or return half tour, or on both half tours;
- Presence of stops on either half tour;
- Parent tour mode (drive alone, transit, or non-motorized);
- Home to work distance (in logarithmic form);
- Parent tour duration (number of half hour periods);
- Number of half hour periods before noon that the tour leaves work; and
- Number of half hour periods after noon that the tour arrives at work.

Estimation Findings

Some of the key findings of the model estimation are as follows:

- The propensity to make meal subtours is higher for high income travelers and for males and seniors.

- Females make more subtours in general but are less likely to make work and meal subtours.

- Part-time workers are more likely to make two work subtours or to make escorting tours.

- As age increases, the likelihood of making work, escorting, and/or personal business subtours increases (though the likelihood of making two work subtours decreases), and the likelihood of making shopping or meal subtours decreases. This is probably due to the increasing responsibilities and changing social and household dynamics of older people compared to their younger counterparts.

- As the travel distance increases from home to work, the propensity to make subtours goes down. This is due to the fact that there is less time left to participate in subtours with increasing commute distances (or times).
- A person with two mandatory tours in the day is much less likely to have meal subtours.
- Participating in fully joint tours makes it more likely that the traveler will also have work based subtours of all types except work and shopping.
- Meal and shopping subtours are more likely if the primary mode for the parent work tour is drive alone relative to shared ride. Subtours of most types are more likely if the parent tour mode is transit though work and escorting subtours are less likely. Subtours of all types except work subtours are more likely if the parent tour mode is non-motorized.
- Subtours of all types are more likely if there is school escorting on either half tour of the parent tour, and shopping subtours are even more likely. Subtours of most types (except work and meal) are even more likely if there is school escorting on both half tours.
- Longer work tour durations make subtours more likely; this reflects more available time to make subtours within the duration of the work activity. Social-recreation and personal business subtours are most likely.
- Greater accessibility generally means more subtours for personal business, social-recreation, or escorting if the parent tour mode is auto.
- Greater employment density near the workplace increases subtours.
- The number of half-hour periods before noon from the time the parent tour departs from work has a negative effect on the generation of subtours. The same is true for the number of half-hour periods after noon that the parent tour arrives at work. This suggests that individuals with more regular 8:00 a.m. to 5:00 p.m. workdays are the ones that are most likely to generate work-based subtours. Those leaving from work before noon or arriving at work after noon are less likely to have work-based subtours.
- The presence of stops on the return and outbound half-tours increases the likelihood of making work-based subtours. This seems a bit counterintuitive, since we may expect fewer subtours when an individual already has a number of other activities. However, we found similar trends in earlier models, suggesting that individuals with multiple activities actually may tend to group all of these extra activities into a single day during the week, for instance, and on other days may have only a single

work activity (perhaps because they are already "out and about"). It may also have something to do with the roles and responsibilities of specific household members, and perhaps there is often a single household member that typically takes care of many of the maintenance type out-of-home activities needed for the household, which would allow other household members to have none.

2.14 Tour Mode Choice

Summary

Four tour mode choice models were estimated, based on tour purposes or groups of purposes (the first three models represent home based tours):

- Work;
- School/university;
- Non-mandatory, individual and joint (including shopping, meal, personal business, social/recreation, and escort tours); and
- Work-based subtours.

The final model specifications were reached by testing a range of model variables, nesting structures, and model constraints though we were guided by our experience with similar models in other activity based model systems. Types of variables included attributes of the traveler and his or her household, tour characteristics, level-of-service attributes (e.g., travel cost and travel time), and land-use variables. In each model, the cost variable was segmented by household income level.

Estimation Results

The model estimation results are shown in the companion spreadsheet *Tour Mode Choice 1.xlsx*.

Model Structure

All models were estimated using mixed logit structures. This was required to estimate the models with distributed values of time. Distributed values of time are achieved by assuming a lognormal distribution for the in-vehicle travel time parameters. (All travel times are converted to equivalent in-vehicle times using out-of-vehicle time ratios.)

Due to the computational advantages of estimating mixed logit models of the MNL form, nested logit error structures were not pursued. However, mixed logit models can approximate any nested logit error structure, using random error components in the utility functions. Specifically, the utility functions are written as follows:

$$U_{ik} = [Scale] \times \left[\beta_1 X_{ik} + \beta_{ivt,i}(IVT_{ik} + \alpha \times OVT_{ik})\right] + \sigma \times \eta_{ip} + \varepsilon_{ik}$$

Here, i indexes the person and k indexes the alternative. $\beta_1 X_{ik}$ is the component of the utility function that is deterministic (like a simple MNL model), $\beta_{ivt,i}$ is a parameter that is distributed according to a lognormal distribution, a is the out-of-vehicle time to in-vehicle time ratio, ε_{ik} is an iid, Gumbel-distributed error term (like one would see in a simple MNL model). Finally, η_{ip} is a random error term with a standard normal distribution; however, it is indexed by p rather than k. Here, p represents the nest that alternative k belongs to. So all alternatives in a given nest have the same error component, η_{ip}, which induces correlation among alternatives in a common nest. This is very similar to the structure of the nested logit model. For normalization purposes, the error component associated with each nest is assumed to have the same standard deviation, σ. This is done so that the utility function of each alternative has the same scale.

The systematic portion of the utility function is also scaled by the term *[Scale]*. This was done to ensure the error components did not affect the relative scale of the utility function parameters. Instead, the values of utility function parameters are independent of the size of σ.

$$[Scale] = \left(\frac{\tau^2 + \sigma^2}{\tau^2}\right)^{0.5}$$

The error component structure is equivalent to a nested logit model. Figures 2.7 through 2.9 show the three equivalent nesting structures for the four models (the work and non-mandatory tour models use the same nesting structure).

Figure 2.7 Work and Non-Mandatory Tour Models

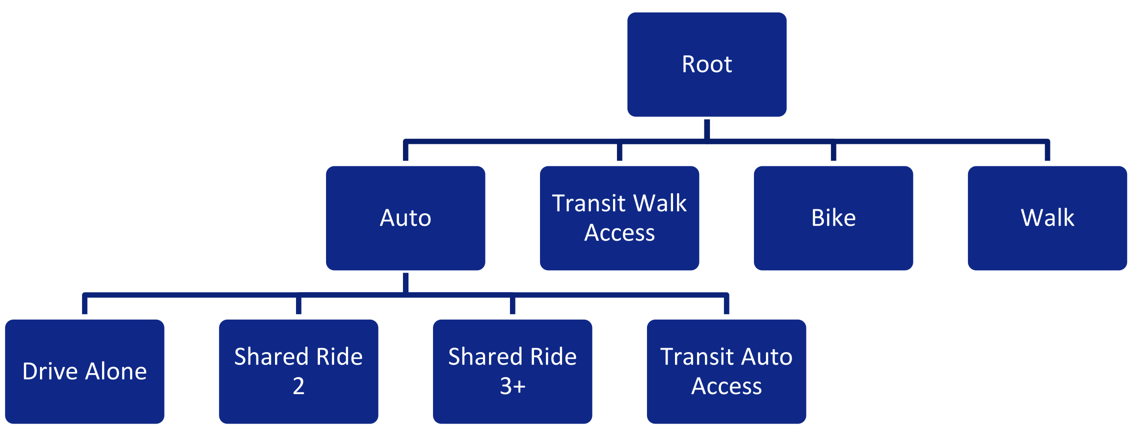


Figure 1.8 School/University Tour Model

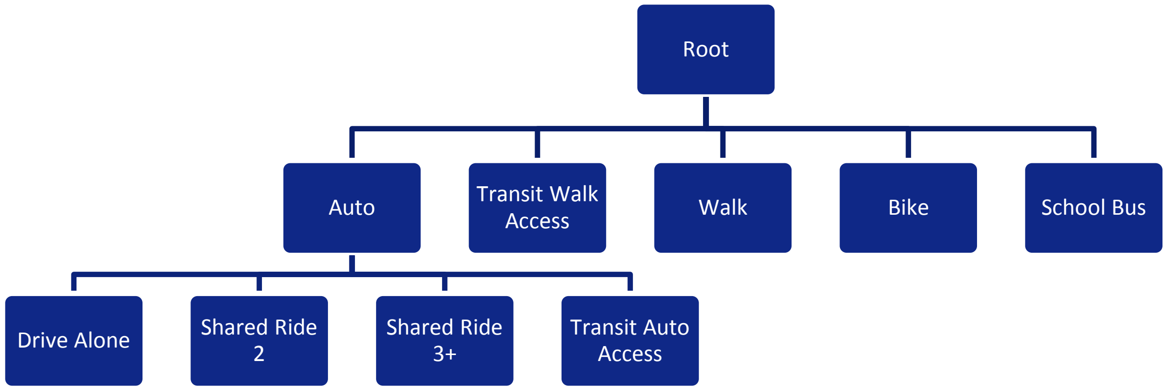
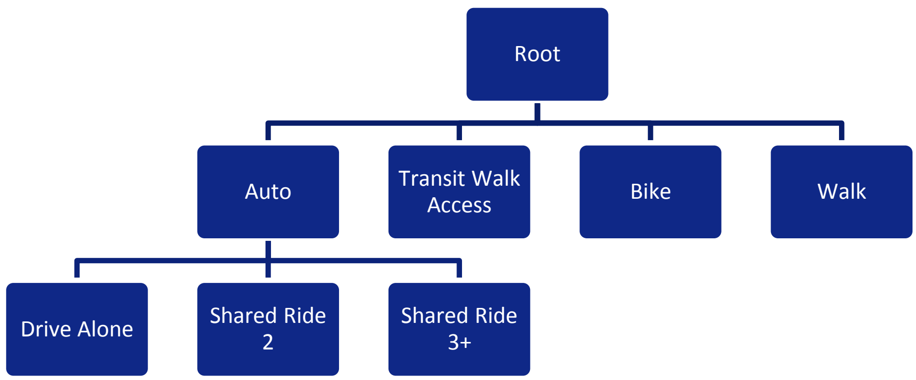


Figure 2.9 Work-Based Subtour Model



Alternatives

The following alternatives are defined for the tour mode choice model:

- Transit Auto Access
- Transit Walk Access
- School bus
- Shared ride 3+
- Shared ride 2
- Drive alone
- Bike
- Walk

The available alternatives vary by tour purpose, as shown in Table 2.7.

Table 2.7 Mode Availability by Tour Purpose/Type

Tour Purpose/Type	Drive Alone	Shared Ride 2	Shared Ride 3+	Walk	Bike	Transit Walk Access	Transit Auto Access	School Bus
Work	●	●	●	●	●	●	●	
School	●	●	●	●	●	●		●
University	●	●	●	●	●	●	●	
Escort		●	●	●				
Other Individual Non-Mandatory	●	●	●	●	●	●	●	
Joint Non-Mandatory		●	●	●		●		
Work Based Subtours	●	●	●	●	●	●		

While there are only four tour mode choice models, the more detailed tour purposes will be known prior to application of tour mode choice, and so the appropriate mode alternatives can be excluded.

The following mode availability rules were used:

- The drive alone mode is unavailable to all persons under age 16 for all tour purposes. Transit auto access is unavailable to all persons under age 16 for all tour purposes. For fully joint tours in cases where the eldest member of the tour is under age 16, shared ride 2 is unavailable. Shared ride 3+ is always available in such cases, since there can always potentially be a non-household member as part of such tours that could be of driving age.

- Each transit mode (auto access, walk access) is available only if there is an in-vehicle time value (non-zero, non-null) in the skim matrix for the zone pair corresponding to the home (work for work-based subtours) and primary activity location for the tour for that access mode.

- School bus is available only for school tours. School bus is unavailable in the Baltimore City jurisdiction if the distance is less than 1 mile or the student's age is over 11.

- Drive alone is not available for fully joint tours, and shared ride 2 is not available for fully joint tours with three or more participants (the participants for each fully joint tour is known as the fully joint tour model is run prior to tour mode choice).

- Drive alone, transit walk access, transit auto access, and bike are not available if there are any school escorting stops on the tour, and shared ride 2 is not available for tours with more than one child student being escorted per half tour.

- Drive alone is not available if there are any escorting stops on the tour (including non-school escort).

- Transit auto access is not available for fully joint, school, or escort tours, or for work-based subtours.

- Transit walk access is not available for escort tours.
- Bicycle is not available for tours longer than 30 miles round trip, and walk is not available for half-tours longer than 10 miles round trip, as measured without stops between the home and the primary activity location.
- While not expressly a mode availability rule, school tours in which the child is escorted are not modeled in tour mode choice at all. This applies in cases when the child is escorted on both half tours (outbound to and return from school) and in cases where the child is escorted on only one half tour. In case of the latter, trips on the non-escorted half tour will select a mode via trip mode choice model.

Variables

The following variables are used in the tour mode choice models.

Traveler/household characteristics

Household composition:

- Household size = 1: 1 if the number of household members is equal to one (i.e., the traveler is the only person in his or her household), 0 otherwise.
- Household size = 2: 1 if the number of household members is equal to two, 0 otherwise.

Income:

Five annual household income categories are used: $0-$15,000, $15,000-$30,000, $30,000-$50,000, $50,000-$100,000, and over $100,000.

- Income less than $X: 1 if the household income is less than $X, 0 otherwise. $X must represent a breakpoint between two income categories. Note that more than one of these variables may appear in the same model, and so more than one of these variables may have a value of 1 (they are not mutually exclusive).
- Income between $X and $Y: 1 if the household income is greater than $X and less than $Y, 0 otherwise. $X and $Y must represent breakpoints between two income categories though they need not represent breakpoints between consecutive categories.
- Income less than $X, escort: 1 if the household income is less than $X and the tour purpose is escort, 0 otherwise. $X must represent the breakpoint between two income categories. Note that more than one of these variables may appear in the same model, and more than one of these variables may have a value of 1 (they are not mutually exclusive).

- Income between $X and $Y, escort: 1 if the household income is greater than $X and less than $Y and the tour purpose is escort, 0 otherwise. $X and $Y must represent breakpoints between two income categories though they need not represent breakpoints between consecutive categories.

Traveler personal characteristics:

- Full time worker: 1 if the traveler is a full time worker, 0 otherwise.
- Part time worker: 1 if the traveler is a full time worker, 0 otherwise.
- Non-senior adult non-worker: 1 if the traveler is neither a full time nor a part time worker and is between the ages of 18 and 64 inclusive, 0 otherwise.
- Senior non-worker: 1 if the traveler is neither a full time or part time worker and is age 65 or older, 0 otherwise.
- College student: 1 if the traveler is a college student (adult student), 0 otherwise.
- Full time worker, escort: 1 if the traveler is a full time worker and the tour purpose is escort, 0 otherwise.
- Senior non-worker, escort: 1 if the traveler is neither a full time or part time worker and is age 65 or older and the tour purpose is escort, 0 otherwise.
- Age: Traveler's age in years.
- Child of age 4 and under: 1 if the traveler's age is less than 5, 0 if older.
- Child of age 4 and under, escort: 1 if the traveler's age is less than 5 and the tour purpose is escort, 0 otherwise.
- Child of age 5-15: 1 if the traveler's age is between 5 and 15 inclusive, 0 if not.
- Child of age 5-15, escort: 1 if the traveler's age is between 5 and 15 inclusive and the tour purpose is escort, 0 otherwise.
- Child of age 16 and over: 1 if the traveler's age is 16 or 17, 0 if not.
- Age minus 17 if age is greater than 17: 1 if the number of years older than 17, 0 if the traveler is 17 or younger.
- Age minus 40 if age is greater than 40: 1 if the number of years older than 40, 0 if the traveler is 40 or younger.
- Male: 1 if the traveler is a male, 0 if female.

Transportation Level of Service Characteristics

The values for the level of service variables come from network skims. Because this is a tour level model, the transportation level of service variables represent the times and costs for the entire tour i.e., the round trip from origin to destination (outbound) and destination to origin (return).

For short trips (less than 3.75 miles one way), the orthogonal distance was used in place of the skimmed network distance, including for the walk component of transit walk access. Orthogonal distance equals the east-west distance plus the north-south distance based on the coordinates of the home and the primary activity location (or between home/activity location and the transit stop, for transit walk access).

Note: The units for all time variables are minutes; the units for cost variables are dollars; and the units for distance variables are miles.

- Cost: This represents the total travel cost per person for the tour.
  - **Auto**: Cost per person for drive alone mode include the outbound and return toll cost, total parking cost and operating cost (set at $0.15 per mile). Cost per person for shared ride 2 and 3+ are calculated by assuming an average vehicle occupancy of 2 and 3.5, respectively.
  - **Transit**: Cost per person for transit walk access and transit auto access includes the total fare paid for the outbound and return half-tours.
- Cost for household income less than $15,000: Cost variable as defined above segmented by household income if income is less than $15,000.
- Cost for household income less than $30,000: Cost variable as defined above segmented by household income if income is less than $30,000.
- Cost for household income less than $50,000: Cost variable as defined above segmented by household income if income is less than $50,000.
- Cost for household income greater than $100,000: Cost variable as defined above segmented by household income if income is greater than $100,000.
- Bicycle time: Skim distance multiplied by 5 (implying 12 mph speed).
- Walk time: Skim distance multiplied by 20 (implying 3 mph speed).
- In-vehicle time: This variable is obtained directly from the in-vehicle time skims specific for each mode both for outbound and return half-tours. For the transit auto access, this also includes the auto access time.
- Ratio of out-of-vehicle time to in-vehicle: This variable represents the ratio of the out-of-vehicle time coefficient to the in-vehicle time coefficient. For auto modes,

out-of-vehicle time includes the home and primary activity location terminal times. Terminal time represents the time spent to travel between the vehicle location (parking space or pickup/dropoff location) and the activity location. For transit modes, out-of-vehicle time includes walk access and egress times, transfer times, and wait times for the outbound and return half-tours. Access time is the time spent to travel between the transit stop and the home, and egress time is the time spent to travel between the activity location and the transit stop. Transfer time is the time spent to transfer from one transit line to another (which includes both walk travel time and wait time for the transfer).

- Wait time greater than seven minutes: Defined as max(0, Initial Wait Time - 7).
- Number of transit transfers. The number of transfers required in one direction on the tour.
- Local bus used. This is a 0/1 indicator of whether local bus is used as part of the transit path between the home and the primary activity location.
- School bus distance: This variable is defined as the round trip distance between home and the school location.
- Time standard deviation parameter: The standard deviation of the log-normal distribution for the distributed values of time. See the section below ("Distributed Values of Time") for further details.

Other

- Transit pass in household: 1 if the traveler's household has a transit pass, 0 otherwise.
- Intersection density at home: Defined as the number of intersections with three or more legs within a ½ mile buffer of the home.
- Log of employment density plus one at destination: The natural logarithm of the employment density within a ½ mile buffer of the tour's primary activity location.

Tour (or subtour) purpose variables:

- Work tour: 1 if the tour purpose is work, 0 otherwise.
- University tour: 1 if the tour purpose is university, 0 otherwise.
- Shopping tour: 1 if the tour purpose is shopping, 0 otherwise.
- Meal tour: 1 if the tour purpose is meal, 0 otherwise.
- Escort tour: 1 if the tour purpose is escort, 0 otherwise.

- Social/recreation tour: 1 if the tour purpose is social/recreation, 0 otherwise.
- Personal business tour: 1 if the tour purpose is personal business, 0 otherwise.

Tour pattern variables:

- Fully joint tour: 1 if the tour is fully joint, 0 otherwise.
- Number of mandatory stops on tour: Total number of stops for work, school, and university purposes on the tour.
- Number of maintenance stops on tour: Total number of stops for shopping and personal business purposes on the tour.
- Number of maintenance stops on tour, escort: Total number of stops for shopping and personal business purposes on the tour if the tour purpose is escort, 0 otherwise.
- Number of discretionary stops on tour: Total number of stops for meal and social/recreation purposes on the tour.
- Number of escort stops on tour: Total number of stops for the escort purpose on the tour.
- Number of escort stops on tour, escort: Total number of stops for the escort purpose on the tour if the tour purpose is also escort, 0 otherwise.
- Number of escort stops on tour, fully joint: Total number of stops for the escort purpose on the tour if the tour is fully joint, 0 otherwise.
- Number of total stops on tour: Total number of stops for all purposes on the tour.
- Presence of stops on outbound (return) half-tour: 1 if the number of stops on the outbound (return) half tour is greater than zero, 0 if there are no stops on the outbound (return) half tour.
- School escort episodes on outbound (return) half-tour equals 1: 1 if there is exactly one stop on the outbound (return) half tour to drop off or pick up children at school, 0 otherwise.
- School escort episodes on outbound (return) half-tour greater than 1: 1 if there is more than one stop on the outbound (return) half tour to drop off or pick up children at school, 0 otherwise.
- School escort episodes on tour greater than 1: 1 if the number of stops on the tour to drop off or pick up children at school if there are two or more such stops, 0 if there are zero or one such stops.
- University tour: 1 if the tour purpose is university, 0 otherwise.

- Activity duration less than or equal to 30 minutes: 1 if the activity duration is 30 minutes or less, 0 if it is longer.

- Activity duration greater than or equal to 3 hours: 1 if the activity duration is three hours or longer, 0 if it is shorter.

- Arrival time between 11:00 a.m. and 1:00 p.m.: 1 if the arrival time at the activity location for the work based subtour (from the tour time of day choice model) is between 11:00 a.m. and 1:00 p.m., 0 otherwise.

- Arrival time between 11:00 a.m. and 1:00 p.m., meal: 1 if the arrival time at the activity location for the work based subtour (from the tour time of day choice model) is between 11:00 a.m. and 1:00 p.m. and the subtour purpose is meal, 0 otherwise.

- No children on fully joint tour: 1 if the tour is fully joint and all of the participants are age 18 or older, 0 otherwise.

- No adults on fully joint tour: 1 if the tour is fully joint and all of the participants are age 17 or younger, 0 otherwise.

Parent tour mode variables (for work based subtours):

For work based subtours, the parent tour mode is the mode for the tour that brought the traveler to and from work.

- Parent mode non-auto: 1 if the parent tour mode is a transit or non-motorized mode, 0 if the parent tour mode is an auto mode.

- Parent mode drive alone: 1 if the parent tour mode is drive alone, 0 otherwise.

- Parent mode bike: 1 if the parent tour mode is bike, 0 otherwise.

Cost Coefficients

The cost coefficients for different income levels are computed as combinations of a base coefficient and parameters specific to various income levels. The companion spreadsheet shows both the actual constrained cost coefficients and the "effective cost coefficients." The effective cost coefficient is computed as follows:

Effective cost coefficient =
-1 * exp[ln(-1*base cost coefficient)
+ exp (first cost coefficient specific to individual income level)
+ exp (second cost coefficient specific to individual income level)
+ exp (third cost coefficient specific to individual income level)]

From the companion spreadsheet, the cost coefficients are:

Base Cost	-0.100
1. Cost for income less than $15,000	-0.600
2. Cost for income less than $30,000	-1.200
3. Cost for income less than $50,000	-1.200
4. Cost for income greater than $100,000	-1.000

There may not be three cost coefficients for every income level. For incomes less than $15,000, there are three coefficients (1, 2, and 3), for income between $15,000 and $30,000 there are two (2 and 3), for income between $30,000 and $50,000 there is one (3), and for income greater than $100,000 there is one (5). Because the income level between $50,000 and $100,000 is the base, the formula is slightly different, to achieve a logical ordering of the values of time:

Effective cost coefficient =
-1 * exp[ln(-1*base cost coefficient)
+ exp (cost coefficient specific to income level)

Distributed Values of Time

Variable value of time is achieved in the tour mode choice models by specifying a distribution for the in-vehicle time coefficient, in this case a log-normal distribution. With a fixed cost coefficient, the value of time distribution can be described easily.

Instead of using a coefficient for out-of-vehicle time in the new models, the ratio of out-of-vehicle time to in-vehicle time was constrained to equal 2.5. This means the coefficient for out-of-vehicle time also follows a log-normal distribution but is determined by the in-vehicle time distribution and the ratio of 2.5.

Cost coefficients for the various household income levels were constrained to produce reasonable average values of time. Table 2.8 shows the median values of time for each model for each income level (note that mean values of time will be higher). The median time coefficients are -0.018 for home-based work tours and -0.012 for all other tours.

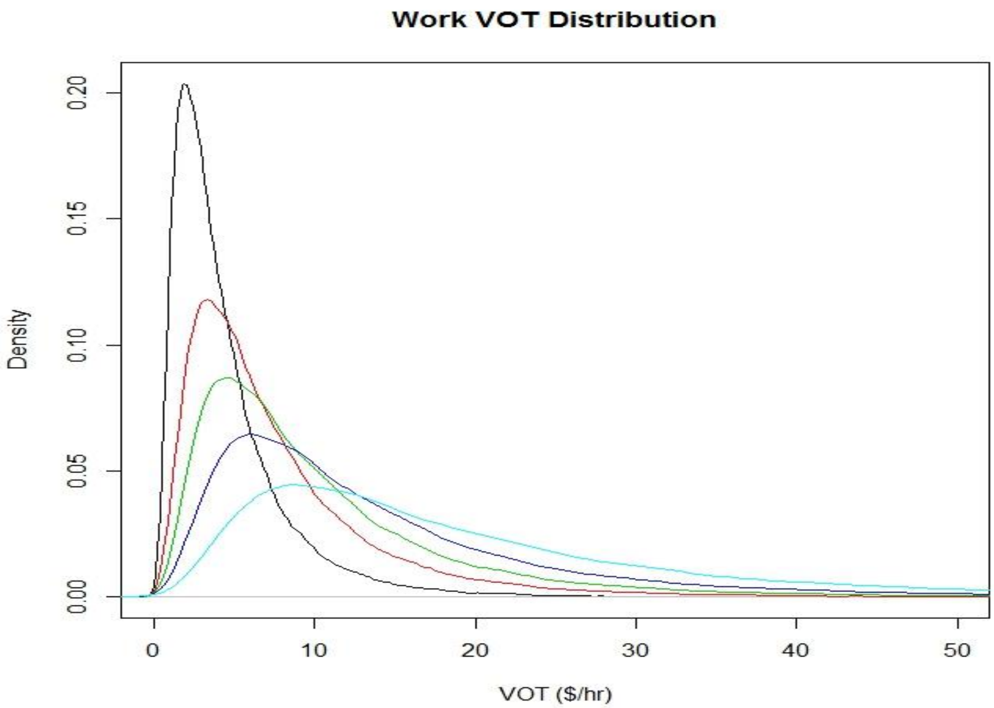
Table 2.8 Values of In-Vehicle Travel Time

Tour Purpose	Values of Time ($/hour)				
	Income < $15K	Income $15-$30K	Income $30-$50K	Income $50-$100K	Income > $100K
Work	$3.42	$5.91	$7.99	$10.80	$15.60
School/university	$2.28	$3.94	$5.33	$7.20	$10.40
Non-mandatory	$2.28	$3.94	$5.33	$7.20	$10.40
Work-based subtour	$2.28	$3.94	$5.33	$7.20	$10.40

Besides the median value for the in-vehicle time coefficient, the other parameter for the log-normal distribution is the standard deviation. This parameter was constrained to equal 0.75

to produce reasonable shapes for the value of time distributions. The distributions are shown in Figures 2.8 and 2.9.

Figure 2.8 Value of Time Distributions



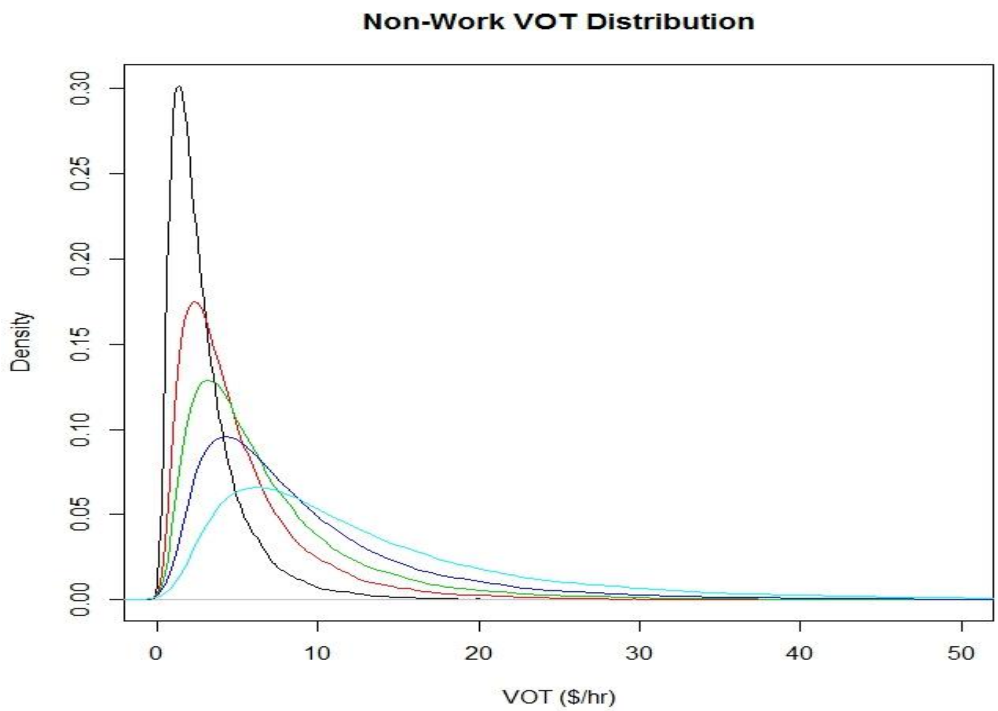
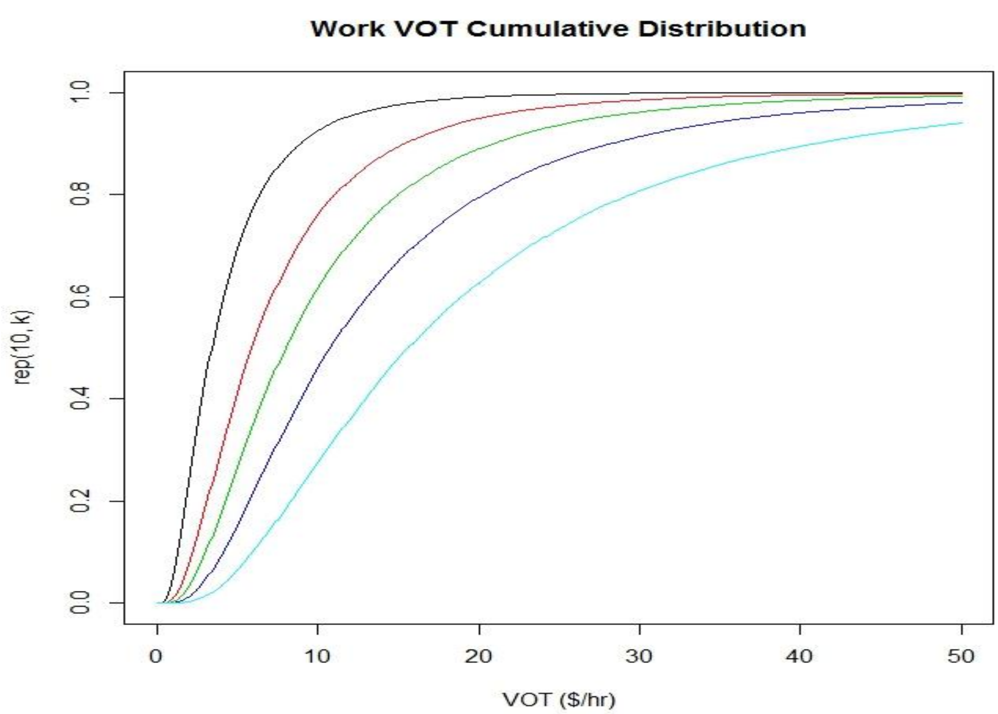
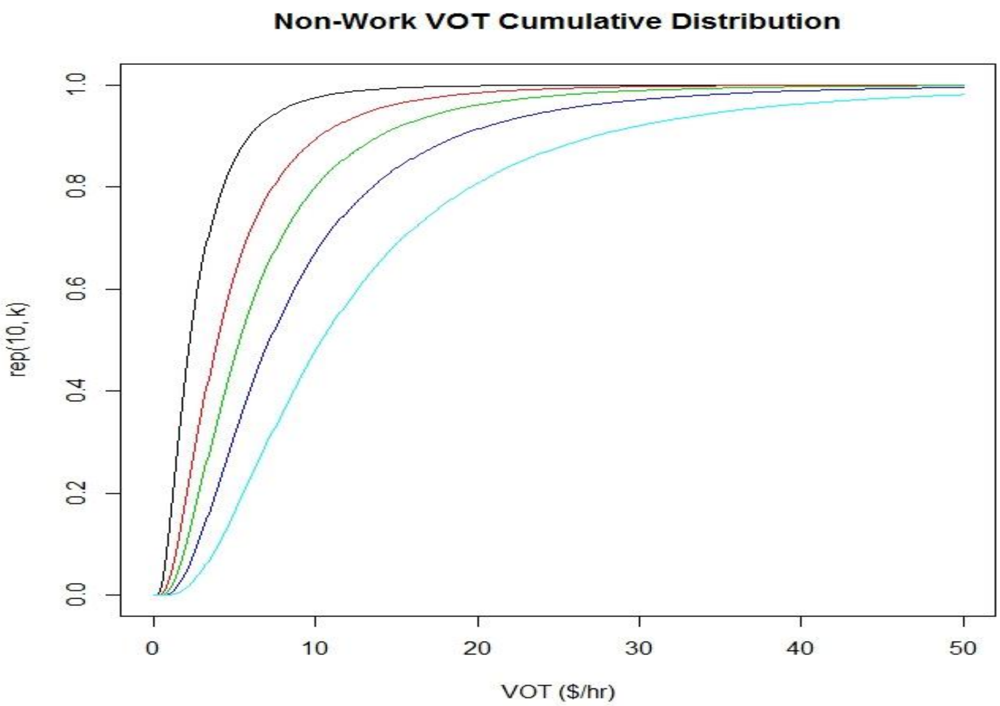


Figure 2.9 Cumulative Value of Time Distributions





Estimation Findings

Some of the key findings of the model estimation are discussed below.

Since the effects of level-of-service variables in the models are critical for policy testing, it is important that coefficient estimates have correct signs and fall within reasonable ranges. Because the unconstrained estimates did not meet these requirements in some cases, the level-of-service coefficients had to be constrained (to specific values). The specific coefficient constraints are shown in the companion spreadsheet *Tour Mode Choice 1.xlsx*, and the implied average values of time are those shown in Table 2.8.

A number of other variables were found to have significant effects in tour mode choice:

- **Vehicle availability** was found to be important for home based tours. Together, the vehicle availability variables suggest that drive alone is least likely in cases where the number of household vehicles is low while transit and non-motorized modes are most likely to be chosen in such cases. For school tours, school bus is more likely when the number of vehicles is low.

- **Household income** was found to be important for home based tours. The probability of using transit with walk access tends to decrease as income increases. For work and non-mandatory tours, bicycle is more likely for travelers from higher income households. For school tours, school bus is less likely for students from the highest income households.

- **Household size** was a key factor influencing choice of shared ride modes. These modes are less likely to be chosen when there are only one or two household members.

- **Age** was observed to have an effect for school and non-mandatory tours. The probability of using school bus increases with age though much more slowly for children over 4 years old. For non-mandatory tours, children are more likely to use 3+ person carpools, especially children under 5 years old. This effect is most pronounced for escort tours. For adults over the age of 40, the probability of walking and bicycling decreases with age, more so for the bike mode.

- **Gender** was found to have an impact on mode choice. Males are more likely to walk or bicycle to work or school and less likely to use transit with walk access.

- **Full time workers** are more likely to use transit with auto access or bicycle to travel to work than other person types. Part time workers are more likely to carpool to work. For non-mandatory tours, non-workers are more likely to use transit with walk access and less likely to carpool or bicycle. Senior non-workers are less likely to use transit with walk access for non-mandatory tours while college students are less likely to walk for these tours. Full time workers are less likely to use 3+ person carpools or to walk for escort tours.

- **School escorting** is associated with higher probabilities for carpool modes.

- The **presence, number, and types of stops** made on a tour were found to be significant indicators. Stops increase the probability of auto modes and decrease the probability of non-auto modes, more for non-motorized than transit modes. This effect is most pronounced when the stops are for the escort purpose. Stops typically increase the utility for choosing shared ride modes compared to the drive alone mode.

- Not surprisingly, **having a transit pass** strongly and positively affects the probability of choosing transit.

- The **parent work tour mode** has a strong effect on work based subtour mode choice. In particular, when an individual chooses a non-auto mode for a work tour, any work-based subtours made by these individuals are more likely to use non-auto modes. Workers who drive alone or bicycle to work are more likely to use the same mode for work based subtours.

- Work based subtours made **between 11:00 a.m. and 1:00 p.m.** are more likely to use the walk mode and are also more likely to carpool if the subtour is for the meal purpose.

- **Intersection density** and **employment density** increase the probability of choosing transit and walk modes in several models.

2.15 Stop Location Choice

Summary

The purpose of this model is to simulate the location of each activity that is not the primary activity on a tour (and is not a school escorting activity). Prior to the application of the stop location choice model, the following information is known about the tour:

- The home location of the traveler
- All information about the primary activity (purpose, location, start and end time periods)
- The chosen tour mode
- The number and purpose of stops generated on each half tour (outbound and return)

The objective of the stop location choice model is to simulate the location of each of these stops. If the stop is the only stop on a half tour, the stop location is simulated based on the locations of the home and the primary activity. In cases where multiple stops exist on a single half tour, the stops are modeled in sequence starting with the one closest in temporal proximity to the primary activity. For outbound stops (first half tour), this means stops are modeled in reverse chronological order, and for return stops (second half tour), this means stops are modeled in chronological order. In such cases, a second stop's location is simulated based on the locations of the first stop's simulated location (rather than that of the primary activity) and the home location, and a third stop's location is simulated based on the location of the second stop's simulated location and the home location.

The main approach of the model is similar to that used for tour destination choice. Size variables, defined similarly to those used in tour destination choice, reflect the amount of activity and therefore attractiveness of destinations. The main differences are that 1) the "detour generalized accessibility" and "detour distance," rather than the direct home-to-activity location time and distance, are used as the impedance measures, and 2) a single model is used for stop location choice, rather than separate models by activity purpose (although some model parameters vary by stop and/or tour activity purpose).

Estimation Results

The model estimation results are shown in the companion spreadsheet *Stop Dest 1.xlsx*.

Model Structure

The model is structured as multinomial logit. The model predicts the probability of choosing each TAZ as the location for the stop activity given both the household location and the location of the previously simulated activity, which could be either the primary activity of the tour or another stop activity occurring on the same half tour between the primary activity and the stop activity currently being simulated.

Note that later in the modeling process a point (parcel) location will be simulated for each simulated school location, within the zone chosen in this school location choice model.

Alternatives

Every internal TAZ in the BMC model region is a possible stop location. Therefore, the alternatives are all internal TAZs. The logit structure is shown in Figure 2.1, where TAZs 1, 2, …, 2,934 are the alternatives under the main root. (Note that there are no TAZs numbered from 1388 to 1399.)

Variables

The following variables are used in the stop location choice models.

Size function

Size functions are used to measure the amount of activity that occurs at each destination zone and incorporate this into the utility of alternative variables. They are defined in the same way as for the tour level destination choice models. The size variables used in these models are: employment by type (office, government, industrial, retail, medical (type 1 and 2), education, restaurant, entertainment), college enrollment, and number of households. The size function is included in the utility equation of each destination choice (TAZ) as shown below:

U = Coeff1 * Var1
+ Coeff2 * Var2
+ Coeff3 * Var3
+ ……..
+ Size function

Where:

Var1, Var2, Var3 are explanatory variables (e.g., distance, intrazonal, mixed density, etc.);

Coeff1, Coeff2, Coeff3 are coefficients for Var1, Var2, Var3;

Size function = LSM * ln {(Size variable1)
+ exp (coeff22) * Size variable2
+ exp (coeff33) * Size variable3
+ …….}

Where:

Size variable1 is the base variable (e.g., office employment);
Size variables 2 and 3 are other explanatory variables (e.g., retail employment);
Coeff22 and Coeff33 are coefficients for size variables 2 and 3; and
LSM is log size multiplier, which is multiplied by the entire size function.

Transportation Level of Service

Detour distance – For first half tour stops, this is the distance from the home location to the destination, PLUS the distance from destination to subsequent activity location (either the primary activity location or a subsequent half tour 1 stop location, if it exists), MINUS the distance direct from the home to the subsequent activity location. For second half tour stops, this is the distance from the previous activity location (either the primary activity location or a previous half tour 2 stop location, if it exists) to the destination, PLUS the distance from the destination to the home location, MINUS the distance direct from the previous activity location to the home. The distance is derived from the highway network skims and expressed in miles.

To provide a non-linear relationship with distance, a piecewise linear formulation is used, with breakpoints at 5, 10, 20, and 45 miles. The following estimation results show how this works if tour mode is auto (each tour mode uses a different base value, but they share the piecewise linear coefficients):

Distance - Auto	-0.302
Max(0, Distance - 5)	0.035
Max(0, Distance - 10)	0.029
Max(0, Distance - 20)	0.066
Max(0, Distance - 45)	0.061

For example:

- For 2 miles, the utility contribution of the distance variables is (-0.302 * 2).
- For 7 miles, the utility contribution of the distance variables is:

  (-0.302* 7) + (0.035 * (7-5)).

- For 22 miles, the utility contribution of the distance variables is:

  (-0.302 * 22) + (0.035 * (22-5)) + (0.029 * (22-10)) + (0.066 * (22-20))

Distance variables are also segmented by a number of other variables, including the following:

- Tour mode
- Stop purpose
- Tour purpose/type (including home-based work, work-based, and fully joint)
- Income
- Time period availability

Detour generalized accessibility – The detour generalized accessibility variable is used only for tours whose mode is auto or transit, not for walk and bicycle tours. This variable is equal to the utility contribution of detour time and cost attributes, based on the estimated tour mode choice models. Detour time and cost variables are measured in the same way as detour distance variables described above, except they use time and cost network skims instead of skims of network distance.

Since the utility contributions of time and cost vary by tour purpose, they also vary here based on tour purpose. For instance, if the stop is part of a home-based work tour, the generalized accessibility calculation uses the coefficients from the home-based work tour mode choice model. Since this variable is the represents the utility contribution of time and cost in the tour mode choice model, the variable itself is always negative, since both time and cost have a negative impact on one's utility. The variable will be lower when the accessibility is poorer and will be higher when the accessibility is better. Therefore, we expect a positive coefficient to be estimated for this variable in the stop location choice model. Indeed, that is what we find.

Household and Person Characteristics

Income is the only household or personal characteristic used in the model. Household income level is used to segment the size variable for work tours (for full-time workers) and also the detour distance.

Tour and Stop Characteristics

The following tour and stop characteristics are used in segmentation for such variables as detour distance and generalized time, size variables, and the "other" variables described below:

- **Tour purpose** (work or non-work, fully joint or not, work-based or not), for detour distance and intrazonal indicators
- **Stop purpose**, for detour distance and size variables
- **Tour mode**, for detour generalized time and detour distance
- **Presence of additional stops to be modeled**, for detour distance
- **Number of available time of day periods to make stop**, for detour distance

Other

Some intrazonal indicator variables, reflecting whether the stop location is in the same zone as the home (or workplace for a work-based subtour), previously simulated activity, or primary activity were tested, sometimes segmented by work versus non-work tour and, for work tours, whether the half tour is outbound or return. In some cases, additional segmentation reflects whether the stop being modeled is the last on the half tour to be simulated.

Another indicator variable used when the tour mode is transit is an indicator whether there is a valid transit path to and from the zone given the anchor locations. And finally, an indicator for whether there is a university in the destination zone is used for stops made on home-based university tours.

Estimation Findings

Some of the key findings of the model estimation are as follows:

- The detour generalized accessibility coefficients are positive for all tour purposes, indicating that stop locations with detour accessibilities closer to zero are more likely (note again that accessibility variables are always negative). The sensitivity to detour generalized accessibility is greatest for work-based tours and lowest for home-based work tours.

- The detour distance coefficients are negative for all tour modes, indicating that stop locations with lower detour distances are more likely. The effects are dampened somewhat for some stop purposes (such as work and school) and slightly greater for other stop purposes (such as shopping, meal, and escort). Individuals from lower income households tend to be more sensitive to detour distance, while the opposite is true individuals from of high income households.

- Individuals with four or more tours in the day are more sensitive to detour distance than others, due to the additional scheduling constraints placed on them due to having many activities. Individuals with more available time to make stops on the half tour are less sensitive to detour distance, again due to scheduling considerations.

- The intrazonal indicator variables (stop activity same as base or subsequent activity) have positive coefficients, indicating a greater likelihood of having a stop in the same zone as either the base or subsequent activity zones. (The values of these coefficients by themselves may understate the intrazonal effects since the detour distance will be lower for such trips than for nearly all alternatives.)

- The coefficients for the intrazonal indicator variables for both base and subsequent activity zones are negative, partially offsetting the effect noted above. The overall effect is still positive, however, since the intrazonal effects are additive and given that the detour distance for trips intrazonal to both the base and activity zones is close to zero.

- The coefficients for the intrazonal indicators with the base zone when there are additional stops to model are negative, indicating that the intrazonal effects are reduced if there are additional stops to be simulated.

- The base size variable for all work stops was chosen to be total employment. The relative weights for different types of employment in the size variable depend on whether the traveler comes from a low income household (less than $50,000 per year) or high income household (greater than $50,000 per year). Relative to high income households, low income households are more likely to make work stops based on restaurant, office, and industrial employment.

- The base size variable for university stops is education employment, with retail and restaurant employment increasing the likelihood of a university stop.
- The base size variable for meal stops is restaurant employment, with all other employment types having smaller effects.
- The base size variable for shopping stops is retail employment, with all other employment types having smaller effects.
- The base size variable for personal business stops is total employment, with medical, restaurant, and retail employment types and households contributing further to a greater likelihood of personal business stops.
- The base size variable for social/recreational stops is total employment, with restaurant employment type and households contributing further to a greater likelihood of social/recreational stops.
- The base size variable for escort stops is total employment, with the education and retail employment types and households contributing further to a greater likelihood of escort stops.

2.16 Stop Time of Day Choice

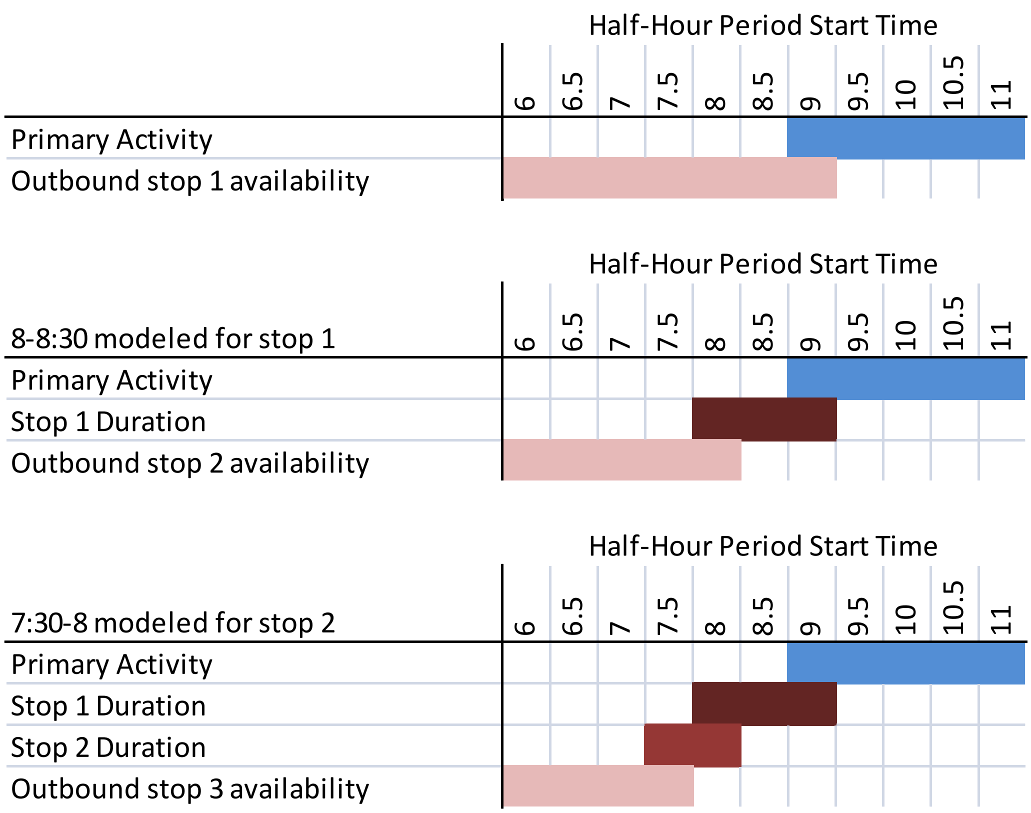
Summary

Time of day choice is predicted in 30-minute intervals (48 periods across the day) beginning and ending at 3:00 a.m. Unlike the tour time of day choice models, the stop time of day choice model predicts only a single time period for each stop activity. This time period corresponds to the activity start time if the stop occurs on an outbound half-tour or the activity end time if the stop occurs on a return half-tour.

At the point in which stop time of day choice is applied in the model chain, the start and end times of a tour's primary activity have already been simulated. Thus, the difference between stop start time and primary activity start time (outbound half-tour) or stop end time and primary activity end time (return half-tour) represents the duration of that stop (inclusive of the travel time between activity locations). Of course, an outbound half-tour stop must occur earlier than the primary activity start time and a return half-tour stop must occur later than the primary activity end time.

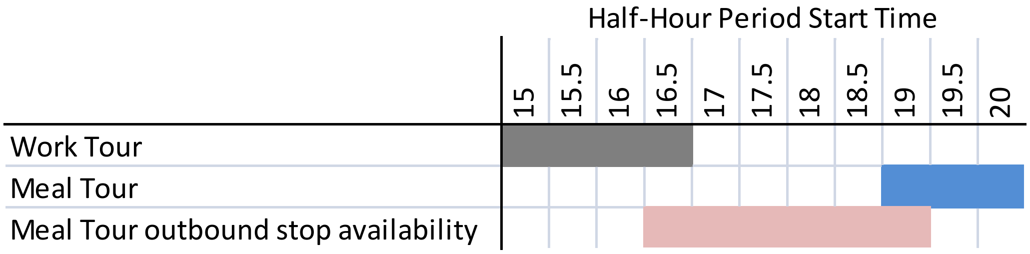
In cases where multiple stops exist on a single half-tour, the stops are modeled in sequence starting with the one closest in temporal proximity to the primary activity (the stop location choice model sequences stops the same way). For outbound half-tour stops, this means stops are modeled in reverse chronological order, and for return half-tour stops, this means stops are modeled in chronological order. In such cases, the second stop's timing would be bounded by the start/end time of the first stop's simulated time period (rather than that of the primary activity), and a third stop's timing would be bounded by the start/end time of the second stop's simulated time period. As an example, the modeling sequence and timing bounds of three outbound half-tour stops to a primary activity that begins in the 9:00-9:30 a.m. period are shown in Figure 2.10.

Figure 2.10 Example of Stop Modeling Sequence



In addition to knowing the primary activity's start and end time, the start and end times of other tours for an individual are also known when stop time of day choice is applied. The timing of these other tours bound the available timing of stops from the opposite direction. For instance, if an individual has a work tour that ends in the 4:30-5:00 p.m. time period and a meal tour that begins in the 7:00-7:30 p.m. time period and that meal tour has an outbound half-tour stop, the timing of that stop is bounded between 4:30 and 7:30 p.m., as shown in Figure 2.11.

Figure 2.11 Example of Time of Day Constraints with Multiple Tours



As indicated above, the difference in stop time of day and the time of day of the subsequent or previous activity represents the duration of that stop. This duration includes both the actual stop activity's duration and the travel time between the stop activity and subsequent/previous activity. It is worth noting here that no specific requirements are placed on the stop time of day choice to ensure consistency between activity timing choices and travel times. In other words, it would be possible (though unlikely) for the stop time choice to be such that there is insufficient time to travel between activity locations and engage in the stop activity (e.g., tour ends in 4:00-4:30 period, stop choice is the 4:30-5:00 period, and travel time between locations is 60 min). There are several reasons for this. First, the 30-minute time periods are a bit fuzzy, in that choice of a specific time period could indicate an exact time at the beginning of that 30-minute period or the end. In the case of activities that lie one period apart (e.g., 4:00-4:30 and 4:30-5:00), the exact times chosen could be as little as 1 minute apart or as large as 59 minutes apart. This means any restrictions would have to be very broad anyway. Second, while tour mode would be known when the model is applied, trip modes may be different than tour modes. Choice of a specific mode's skims to use in such cases is unclear. Third, given these first two considerations, implementation of such requirements could be rather complicated. Last, we felt these inconsistencies would be rather rare, in general, and we were able to include some variables in the model specification that work to discourage these potential inconsistencies.

The main approach of the model is similar to that used for tour time of day choice. Alternative specific constants are used for various durations (segmented by half-tour) and shift effects can encourage longer or shorter stop durations. The models also use the concept of available time windows.

Estimation Results

Estimation results for this model are presented in the companion spreadsheet *Stop TOD 1.xlsm*.

Model Structure

The model is structured as multinomial logit.

Alternatives

The model predicts the time period the stop arrives at an outbound half-tour stop activity or the time period the stop departs from a return half-tour stop activity. With 30-minute time period lengths, there are 48 intervals across the day. However, there will usually be substantially fewer time periods actually eligible for any given stop. For instance, on a work tour that starts at 9:00 a.m. and ends at 5:00 p.m., a stop on the return half-tour is limited to half-hour periods after 5:00 p.m.

Variables

The following variables are used in the stop time of day choice models.

Stop Duration Constants

Constants are defined by the implied duration of the stop time period, measured in number of half-hour intervals. Since it is possible for stop time of day to share the same period as the subsequent/previous activity's arrival/return period, the smallest implied duration is zero, which serves as the reference category.

Different constants are specified based on the whether the stop is on the outbound or return half-tour. On the outbound half-tour, nine constants are specified. The first five relate specific durations of 1, 2, 3, 4, or 5 half-hour periods. The last four consider groups of durations: 6-7 periods, 8-10 periods, 11-15 periods, or 16 or more periods. On the return half-tour, 10 constants are specified.

Shift variables

Most of the non-constant variables in the model are interacted with duration shift variables. These variables increase as the implied duration of the alternative increases. Table 2.9 details two examples. The first example shows the duration shifts for a return half-tour stop with primary activity ending in the 4:00-4:30 p.m. period. The second example shows the duration shifts for a return half-tour stop with primary activity ending in the 5:30-6:00 p.m. period.

Table 2.9 Example Shift Variables

Alternative	Example 1 Shift	Example 2 Shift
3:30-4:00 p.m.	0	0
4:00-4:30 p.m.	0	0
4:30-5:00 p.m.	1	0
5:00-5:30 p.m.	2	0
5:30-6:00 p.m.	3	0
6:00-6:30 p.m.	4	1
6:30-7:00 p.m.	5	2
7:00-7:30 p.m.	6	3
↓	↓	↓
2:30-3:00 am.	21	18

A second type of shift variable is also used, which offsets the base shift variable by some amount. This enables non-linear effects to be captured, essentially by including a "spline" effect. If we use example 1 above, a second shift variable could be offset by 2 or 4, for instance, as shown in the Table 2.10.

Table 2.10 Examples of Shift Variable Offsets

Alternative	Example 1 Shift	Example 1 "Shift – offset by 2"	Example 1 "Shift – offset by 4"
3:30-4:00 p.m.	0	0	0
4:00-4:30 p.m.	0	0	0
4:30-5:00 p.m.	1	0	0
5:00-5:30 p.m.	2	0	0
5:30-6:00 p.m.	3	1	0
6:00-6:30 p.m.	4	2	0
6:30-7:00 p.m.	5	3	1
7:00-7:30 p.m.	6	4	2
↓	↓	↓	↓
2:30-3:00 a.m.	21	19	17

Finally, a third shift variable indicates the remaining number of available periods if the time period was chosen (excluding the chosen period itself). This is essentially the inverse of the duration shift. In the example 1 above, the duration shift variable increases from 0 to 21 as stop period changes from 4:00-4:30 period to the 2:30-3:00 a.m. period. The remaining number of available periods would decrease from 21 to 0 over these same alternatives. In other words, if the stop ended in the 2:30-3:00 a.m. period, there would be 0 remaining available alternatives in the day (since the day ends at 3:00 a.m.).

Household, Person, Tour, and Stop Characteristics

Several household, person, and tour characteristics were used to interact with the shift variables, with tour attributes having the most significant effects. These include:

- Tour purpose
- Stop purpose
- Tour arrival period (if stop is on outbound half-tour)
- Tour return period (if stop is on return half-tour)
- Tour duration
- Tour mode
- Person type

Other variables are interacted with the number of available periods shift variables. These include:

- Presence of an earlier tour in day (if outbound half-tour)
- Presence of a later tour in day (if return half-tour)
- Presence of additional stops to be modeled (if outbound half-tour)
- Presence of additional stops to be modeled (if return half-tour)

Time Overlap Variables

Two variables are used to indicate if the stop time of day alternative is shared with a previous tour's end time or a subsequent tour's arrival time. This is referred to as the period being partially used. Similar variables were utilized in the tour time of day choice models.

Travel Distance and Time

Two impedance measures were introduced in the model specification. The first measures the distance between the stop location and either the subsequent activity location (if outbound half-tour) or the previous activity location (if return half-tour). This variable is applied to alternatives that imply stop durations of 0 or 1 periods. The idea is that if a stop location is very far from the subsequent/previous activity, it will require longer travel times. And, since the modeled stop durations implicitly include travel time, it makes sense for these variables to have a negative effect on choice of very short durations.

The second impedance variable measures the detour time. On the outbound half-tour, this is measured as the home-to-stop-to-subsequent activity time, minus the home-to-subsequent activity time. On the return half-tour, this is measured as the previous activity-to-stop-to-home time, minus the previous activity-to-home time. This variable is applied incrementally to alternatives that imply durations of 2+, 4+, 6+, 8+, and 10+ half-hour periods. The idea with these variables is that the further out of the way the stop location is, the higher the fixed cost to engage in that activity in the first place, but the marginal cost of engaging in an incremental increase of that activity is very low. In other words, we would expect individuals to stay longer at activities that are far out of the way.

Note that detour time is measured in utility units, not units of time (i.e., minutes). This means that increased activity duration for higher detour times would be indicated by negative coefficients on this variable.

Variables Related to School Escorting

Several indicator variables were included that indicate whether the stop period implies that the stop was made jointly with a child escorted to/from school. These variables apply to work tours with a school escort component and a stop. When stop time of day is applied, the time of the school escorting occasion is known, but whether the other stop is made before or after the school escorting occasion is unknown. If it is made before the school escorting occasion on the outbound half-tour or after the school escorting occasion on the return half-tour, it is implied that the adult and child actually made the stop jointly. The variables introduced here take a value of 1 if the alternative implies that the stop would be made individually by the adult, and 0 if the alternative implies that the stop would be made jointly with the child.

Estimation Findings

Some of the key findings of the model estimation are as follows:

- Stop durations on work and university tours were found to be significantly different from stops made on non-mandatory tours. In particular, they tend to be a bit longer (of course, the primary activities for these tour purposes also tend to be longer).

- The distance between the stop location and subsequent/previous activity was found to decrease the utility for very short duration stops, which makes sense when considering that stop duration implicitly includes travel time.

- Detour time was found to have an incrementally positive effect on utilities as stop duration increases.

- Very short duration tours (less than 0.5 hours at primary activity for the outbound half-tour and less than 2.5 hours at primary activity for the return half-tour) were found to have negative effects on stop duration. Activity duration was used as a tie-breaker of sorts for choosing which activity was the primary tour activity. Thus, the primary activity is more often the longest duration activity on a tour, and very short duration tours will be less likely to have longer duration stops.

- Stop durations on the outbound half-tour tend to be longer when the primary tour activity starts later in the day, and return half-tour stop durations tend to be longer when the primary activity ends earlier in the day.

- When there are tours earlier in the day for outbound half-tour stops or later in the day for return half-tour stops or if there are other stops to be modeled, utilities are higher for stop periods that offer a larger available window (of unused time periods).

- Stop duration tends to be shortest for walk/bike tours and longest for transit tours.
- Work and university stops are most likely to be made without children when school escorting is involved on either half-tour. When there is school escorting on the outbound half-tour, meal, shopping, personal business, and social/recreation stops also tend to be made without children. The reverse is true for the return half-tour. Escort stops tend to be made with children, however, which is most likely a result of adults picking up or dropping off children from other households at their homes (or perhaps other members of the same household at different locations) as part of the escorting activities.

2.17 Trip Mode Choice

Summary

A single trip mode choice model was estimated for all tour/trip purposes. There are indicator variables for tour purpose that in effect create different constants by mode for each tour purpose.

Note that by definition all tours begin and end at home, except work-based subtours, which begin and end at work. There may be trips of different purpose than the tour purpose.

The final model specifications were reached by testing a range of model variables, nesting structures, and model constraints though we were guided by our experience with similar models in other activity based model systems. Types of variables included attributes of the traveler and his or her household, tour characteristics, transportation level of service (represented by the generalized accessibility from the tour mode choice model), land use variables, tour mode related variables, and previous trip purpose variables related to escort activities.

Estimation Results

The model estimation results are shown in the companion spreadsheet *Trip Mode Choice 1.xlsm*.

Model Structure

The model was estimated using a multinomial logit structure.

Alternatives

The alternatives for the trip mode choice model arte the same as those for the tour mode choice model:

- Transit Auto Access
- Transit Walk Access
- School bus
- Shared ride 3+
- Shared ride 2
- Drive alone
- Bike
- Walk

Mode availability for trip mode choice depends on the chosen tour mode, as shown in Figure 2.12.

Figure 2.12 Mode Availability by Tour Mode

	Tour Mode							
Available Trip Modes	**Transit Auto Access**	**Transit Walk Access**	**School Bus**	**Shared Ride 3+**	**Shared Ride 2**	**Drive Alone**	**Bike**	**Walk**
Transit Auto Access	●							
Transit Walk Access	●	●						
School bus			●					
Shared ride 3+	●	●	●	●				
Shared ride 2	●	●	●	●	●			
Drive alone	●	●		●	●	●		
Bike		●					●	
Walk	●	●	●	●	●	●		●

The trip mode choice model is not applied for walk mode tours since all trips are known to be walk trips. The same restriction is imposed for bike tours, since the survey data showed that nearly all trips on bike tours are bike trips.

In model application, when the last trip is being simulated, if the tour mode is not the simulated outcome for any of the previously simulated trips on the tour, then the trip mode choice model will not be applied for this last trip, and the mode for this trip will be assumed to be the tour mode.

Note that there is a tour mode for school tours only if there is no school escorting on either half tour. In cases where there is escorting on both half tours, the tour mode and all trip modes are given by the mode choices of the escort. When there is escorting on only one half tour, the trip mode choice model is run for the trips on the other half tour, with all modes assumed available except drive alone and transit with auto access, and without any restrictions based on tour mode (though there might be other mode availability rules as discussed below).

The available alternatives vary by tour purpose and type are shown in Table 2.11. The availability rules are based on examination of the household survey data.

Table 2.11 Mode Availability by Tour Purpose/Type

Tour Purpose/Type	Drive Alone	Shared Ride 2	Shared Ride 3+	Walk	Bike	Transit Walk Access	Transit Auto Access	School Bus
Work	●	●	●	●	●	●	●	
School	●	●	●	●	●	●		●
University	●	●	●	●	●	●	●	
Escort		●	●	●				
Other Individual Non-Mandatory	●	●	●	●	●	●	●	
Joint Non-Mandatory		●	●	●		●		
Work Based Subtours	●	●	●	●	●	●		

Besides the restrictions required by the tour mode choice, the following trip mode availability rules were used:

- **Drive alone**: Tour must not be fully joint, age must be 16 or greater. Not allowed on a school half tour when the other half tour is escorted.
- **Shared ride 2**: Not available when tour is fully joint and the eldest member of the tour is under age 16. Also not available for a fully joint tour with three or more participants.
- **Shared ride 3+**: No additional availability rules.
- **Walk**: Not available for trips longer than 5 miles one way.
- **Bike**: Not available for trips longer than 15 miles one way.
- **Transit walk access**: Available only if there is an in-vehicle time value (non-zero, non-null) in the skim matrix for the zone pair corresponding to the origin and destination for the trip.
- **Transit auto access**: Available only if there is an in-vehicle time value (non-zero, non-null) in the skim matrix for the zone pair corresponding to the origin and destination for the trip. Also unavailable to persons under 16 years of age. Not allowed on a school half tour when the other half tour is escorted.
- **School bus**: No additional availability rules.

Variables

The following variables are used in the trip mode choice models.

Traveler/household characteristics

Vehicle availability:

- Zero vehicle household: 1 if the household owns no vehicles, 0 if the household owns at least one vehicle.

- Number of vehicles less than number of adults: 1 if the number of vehicles in the household is less than number of adults in the household, 0 otherwise.

Household composition:

- Household size = 1: 1 if the number of household members is equal to one (i.e., the traveler is the only person in his or her household), 0 otherwise.

Income:

Five annual household income categories are used: $0-$15,000, $15,000-$30,000, $30,000-$50,000, $50,000-$100,000, and over $100,000.

- Income less than $X: 1 if the household income is less than $X, 0 otherwise. $X must represent a breakpoint between two income categories. Note that more than one of these variables may appear in the same model, and so more than one of these variables may have a value of 1 (they are not mutually exclusive).

- Income greater than $Y: 1 if the household income is greater than $Y, 0 otherwise. $Y must represent a breakpoint between two income categories. Note that more than one of these variables may appear in the same model, and so more than one of these variables may have a value of 1 (they are not mutually exclusive).

Traveler personal characteristics:

- Part time worker: 1 if the traveler is a part time worker, 0 otherwise.

- Non-senior adult non-worker: 1 if the traveler is neither a full time nor a part time worker and is between the ages of 18 and 64 inclusive, 0 otherwise.

- Senior non-worker: 1 if the traveler is neither a full time or part time worker and is age 65 or older, 0 otherwise.

- College student: 1 if the traveler is a college student, 0 otherwise.

- Child of age 4 and under: 1 if the traveler's age is less than 5, 0 if older.

- Child of age 15 and under: 1 if the traveler's age is less than 16, 0 if older.

- Child of age 5-15: 1 if the traveler's age is between 5 and 15 inclusive, 0 if not.

- Child of age 16 and over: 1 if the traveler's age is 16 or 17, 0 if not.

Transportation level of service characteristics

Generalized accessibility – The generalized accessibility variable includes the weighted effects of in-vehicle time, out-of-vehicle time, and cost in a single term. These components are weighted based on the tour mode choice coefficients; therefore, they vary by tour purpose and income level (note that the tour mode choice model imposed constraints on the in-vehicle time, out-of-vehicle time, and cost coefficients, which are preserved for the trip mode choice model). Note that while the tour mode choice model uses distributed values of time, the trip mode choice model uses a single value of time, based on the median value of time from the tour mode choice model for each tour purpose.

The generalized accessibility variable is an accessibility measure because it is in units of tour mode choice utility (as opposed to units of time or cost). Higher values, therefore, reflect a better level of accessibility. Overall, we translate cost and out-of-vehicle time into in-vehicle time units using the value of time and out-of-vehicle time weights from the tour mode choice model and then multiply the resulting value by the in-vehicle time coefficient from tour mode choice. For example, for work tours for a traveler whose household income is greater than $100,000, the generalized accessibility is given by:

0.018 * (in-vehicle time + 2.5*out-of-vehicle time + 3.846*cost)

The coefficient of cost in this formula (3.846) is the effective cost coefficient in the tour mode choice utility function for travelers with household incomes greater than $100,000 (-0.069) divided by the in-vehicle time coefficient (-0.018). The effective cost coefficient is computed as follows:

Effective cost coefficient =
-1 * exp[ln(-1*base cost coefficient)
+ exp (first cost coefficient specific to individual income level)
+ exp (second cost coefficient specific to individual income level)
+ exp (third cost coefficient specific to individual income level)]

From the tour mode choice model documentation, the cost coefficients are:

Base Cost	-0.100
1. Cost for income < $15,000	-0.600
2. Cost for income between $15,000 and $30,000	-1.200
3. Cost for income between $30,000 and $50,000	-1.200
4. Cost for income > $100,000	-1.000

There may not be three cost coefficients for every income level. For incomes less than $15,000, there are three coefficients (1, 2, and 3), for income between $15,000 and $30,000 there are two (2 and 3), for income between $30,000 and $50,000 there is one (3), and for income greater than $100,000 there is one (5). Because the income level between $50,000 and $100,000 is the base, the formula is slightly different, to achieve a logical ordering of the values of time:

Effective cost coefficient =

-1 * exp[ln(-1*base cost coefficient)

+ exp (cost coefficient specific to income level)

Note that there is only one time variable and no cost variables for the non-motorized modes (walk and bike), and the generalized accessibility does not vary by income level. The generalized accessibilities for these two modes are given by:

Bike generalized accessibility = -0.018 * (2.5 * bike time)

Walk generalized accessibility = -0.018 * (3.0 * walk time)

The values for the individual level of service variables come from network skims.

For short trips (less than 3.75 miles one way), the orthogonal distance was used in place of the skimmed network distance, including for the walk component of transit walk access. Orthogonal distance equals the east-west distance plus the north-south distance based on the coordinates of the home and the primary activity location (or between home/activity location and the transit stop, for transit walk access).

The units for all time variables are minutes; the units for cost variables are dollars; and the units for distance variables are miles.

Tour purpose/type

- Tour purpose = XXX: 1 if the tour purpose is XXX, 0 otherwise. Values of XXX for tour purpose are tour purpose = meal, school, university, shopping, personal business, social/recreation, escort, and work based subtour.
- Fully joint 2 person: 1 if the tour is fully joint with two participants, 0 otherwise.
- Fully joint 3+ person: 1 if the tour is fully joint with three or more participants, 0 otherwise.
- Fully joint tour with only adults: 1 if the tour is fully joint and all participants are adults, 0 otherwise.

Tour mode

- Tour mode = Trip mode: 1 if the trip mode is the same as the tour mode, 0 if it is not.
- Tour mode = Trip mode, outbound (return) half tour, 1 trip on half tour: 1 if the trip mode is the same as the tour mode AND the trip is on the outbound (return) half tour AND there is only one trip on the half tour, 0 otherwise.
- Tour mode = Trip mode, outbound (return) half tour, >1 trip on half tour, first (last) trip on half tour: 1 if the trip mode is the same as the tour mode AND the trip is on

the outbound (return) half tour AND there is more than one trip on the half tour AND the trip is the first (last) trip on the half tour, 0 otherwise.

- Tour mode = YYY: 1 if the tour mode is YYY (where YYY may be transit with auto access, transit with auto access, drive alone, shared ride 2, shared ride 3+, or school bus). These variables allow for correlations between tour and trip mode besides the two being the same mode to be considered.

The following variables are included to consider likely auto occupancy levels on trips after another passenger has been picked up or dropped off on the tour. Note that the escort activity (pickup or dropoff) is only known for school escort trip purposes. The trip time of day model is used to simulate non-school escort trip purposes, e.g., dropoff in the a.m., pickup in the p.m.

- Previous trip purpose escort, previous trip mode drive alone: 1 if the purpose of the previous trip is escort AND the mode of the previous trip is drive alone, 0 otherwise.

- Previous trip purpose escort, a.m. peak (p.m. peak), previous trip mode shared ride 2 (shared ride 3+): 1 if the purpose of the previous trip is escort AND the trip takes place in the a.m. peak period (p.m. peak period) AND the mode of the previous trip is shared ride 2 (shared ride 3+), 0 otherwise.

- Previous trip purpose dropoff (pickup), previous trip mode shared ride 2 (shared ride 3+): 1 if the purpose of the previous trip is to drop off (pick up) another passenger AND the mode of the previous trip is shared ride 2 (shared ride 3+), 0 otherwise. Dropoff (pickup) trip purposes are school escort activities, as opposed to non-school escorting, which has a trip purpose "escort."

Other

- Intersection density at home: Defined as the number of intersections with three or more legs within a ½ mile buffer of the home.

- Log of employment density plus one at destination: The natural logarithm of one plus the employment density within a ½ mile buffer of the tour's primary activity location.

Estimation Findings

Some of the key findings of the model estimation are discussed below. It is important to remember that the tour mode imposes restrictions on the available trip mode alternatives, and this affects the interpretation of the parameter estimates. For example, the meal tour purpose indicator variable has a positive coefficient estimate for transit with walk access; however, it is important to note that this mode is available only on tours that have already been assigned one of the two transit tour modes. So the correct interpretation of this coefficient estimate is *not* that persons on meal tours are more likely to use transit than other modes in general, but rather that the likelihood of a person making a meal tour *with a transit mode* to use transit for a particular trip is greater than for other tour purposes.

Household and person variables

- Low household income decreases the probability of driving alone. Higher vehicle availability increases the probability of driving alone.
- The presence of young children in the household increases the probability of the shared ride modes.
- People who live alone are less likely to use shared ride modes.
- Children have a higher probability of walking or using transit with walk access than other person types. Children age 5 to 15 have a higher propensity to walk than other age groups.
- Adults generally have a higher probability of drive alone than other modes.

Tour purpose/type

- Joint tours with at least three participants are most likely to use the shared ride 3+ mode and least likely to use transit with auto access.
- Although the coefficient estimate for the shared ride 2 mode is negative for joint tours with two participants, most of these tours probably have the shared ride 2 tour mode. The negative coefficient estimate reflects the fact that when shared ride 3+ is available for the trip mode, a tour mode other than shared ride 2 must have been chosen, most likely shared ride 3+, reducing the likelihood of a trip mode of shared ride 2 for such trips.
- On all non-work tours, travelers have a higher propensity for 3+ person shared ride than 2-person shared ride (note that shared ride 3+ is unavailable when the tour mode is shared ride 2, and so this effect is limited to those tours where the tour mode is already assigned as shared ride 3+).
- Walk utilities are highest for school tours and lowest for escort tours.

Escort trip effects

- Because escort tours require shared ride modes, the tour mode cannot be drive alone. However, these tours may have drive alone trips, before the escortee is picked up or after he/she is dropped off. A set of variables indicating the mode of the previous escort trip, segmented by the trip mode for that escort trip, were tested. Examination of the household survey data revealed the following patterns:
    - When the previous trip is an escort trip, a previous trip mode of drive alone is usually followed by a shared ride mode.

  - When the previous trip is a dropoff trip, shared ride is likely followed by drive alone, and shared ride 3+ is often followed by shared ride 2.
  - When the previous trip is a pickup trip, shared ride 2 is likely followed by shared ride 3+, and shared ride 3+ is unlikely to be followed by shared ride 2.
  - Escort trips in the morning peak period are likely to be followed by trips of lower vehicle occupancy.
  - Escort trips in the afternoon peak period are likely to be followed by trips of higher vehicle occupancy.

Tour mode effects

- The survey data indicate that the trip mode is usually the same as the tour mode, and so the positive coefficient estimate for the "tour mode = trip mode" variable is expected.

- Additional variables reflect the differing likelihoods of the tour and trip modes being the same depending on which half-tour the trip is on and its sequence among multiple trips on a half-tour.

- There are several variables that reflect the likelihood of particular trip modes that differ from the tour mode being selected, given the tour mode.

Other

- The coefficients for employment density for the transit and walk modes are positive, indicating a higher propensity for transit use in more densely developed areas.