Model Estimation and Validation Report

2010 Travel Behavior Inventory

Final

Report

prepared for

Metropolitan Council

prepared by

Cambridge Systematics, Inc.

July 30, 2015

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final report

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1.0 Background

The Request for Proposals for the 2010 Travel Behavior Inventory (TBI) issued by the Metropolitan Council (MetCouncil) called for a data collection and modeling effort that would provide an accurate and current picture of personal and commercial travel in the region. In thinking through the approach and developing the approach to data and model design, the following considerations were made:

- The need to provide answers to **policy questions** dictated the approach to modeling and the design and collection of supporting data to build analytical tools.
- During the design process, **tradeoffs** among the level of data detail, sophistication of the analysis approach, and complexity of the model structure were evaluated against the need to obtain results that can inform decision-making.
- The **complexity** of the models that were considered covered the spectrum from a simple four-step model to a full-fledged activity model. Based on policy needs and discussions with MetCouncil staff, a "best practice" approach to model development was selected.

The analytical approach to model development reflected a **customized design** to meet regional needs; a **collaborative effort** between the consulting team and MetCouncil, and a "best practice" activity-based approach to model development. These were considered the key elements to provide the greatest value to MetCouncil for this multi-year data collection and model development project.

1.1 The 2010 Travel Behavior Inventory

The four-step approach to modeling travel in an urban context represented the state of the practice during the 1970s and early 1980s. The state of the art in regional modeling was improved over time as disaggregate analytical methods for various models were adopted. Advances included disaggregate model estimation, the emphasis on market segmentation, the use of stated-preference data, developing linkages among different choices, forecasting using sample enumeration techniques, and the eventual emergence of tour-based models.

Despite advances in best practice modeling, regional models that are rooted in the four-step process are still being applied for forecasting purposes. These modeling approaches are characterized by weaknesses that preclude the estimation and application of a behaviorally based policy sensitive tool for forecasting purposes. These weaknesses most often include the following dimensions:

- The model estimation methods used are often based on aggregate data that treat the traffic zone as the unit of analysis instead of focusing on the behavior of individual travelers or households or the individual traveler as the decision-maker and the unit of analysis;

- The use of aggregate data such as average zonal trip rates and average household income masks differences in travel behavior and sensitivity to policy variables such as travel cost and level of service among households in the same zone and does not allow the development of forecasts for different segments of the market;
- Model development efforts often place considerably more emphasis on replicating the base year travel patterns at the expense of gaining valuable behavioral insights and developing models that are sensitive to important policy considerations such as transportation control measures or the introduction of a new transit service;
- The emphasis of the models on unlinked trips instead of the entire daily travel pattern does not accurately capture the linkages among trips in the daily chain of travel, the interactions among household members with different travel needs and priorities, or the true impact of automobile availability for the second and third trip during the day;
- The reliance on regional models that do not link models of generation, destination choice, and mode choice may lead to inaccurate estimates of travel by mode and by origin-destination limiting the policy relevance of the estimated models; and
- Models that are estimated at the individual traveler level are often applied at the aggregate zonal level effectively limiting the benefits of disaggregate model estimation. A sample enumeration method needs to be used to apply the models at the individual level consistent with model estimation and providing the ability to segment the market.

The methodology for the MetCouncil travel demand model system was built upon the "best practice" model estimation practices to provide a behaviorally based, policy-sensitive activity-based model that is applicable in a regional travel context. In summary, the model system is guided by the following concepts:

- ***Disaggregate Choices –*** The model system consists of choice models estimated and applied with individual and household level data.
- ***Activity Orientation –*** The demand for travel is derived from the demand for participation in activities that require travel. Thus, the activities pursued and the factors that affect activity behavior are represented in the model.
- ***Tours and Trips –*** The ultimate purpose of the model system is to predict volumes of trips. However, the model system explicitly models tours that are sequences of trips beginning and ending at home or work and may have intermediate stops during the tour.

- ***Choice Hierarchy –*** The model system reflects long term decisions such as automobile ownership and short term decisions such as the daily travel behavior that is conditional on longer term decisions.

The premise behind the *activity-based* modeling approaches is that the unit of travel is defined as the tour from home to one or more destinations and then back home instead of the four-step process where the individual trip is the unit of travel. While tour-based models can't give a solution to all the problems of the four-step process, they solve one of the most critical problems which is the treatment of individual trips as independent decisions where the effects of other activity decisions are not considered.

Activity-based modeling treats travel as a derived demand reflecting the desire to participate in activities, has a stronger theoretical basis and does not require data beyond what is needed to develop a four-step travel model system. The activity-based approach explicitly captures interdependencies among linked trips. A pattern of activities can be described as a collection of tours. A person may stay at home and make no tours or may select an activity pattern involving one or more home and non-home activities that are scheduled with one or more stops.

1.2 DATA SOURCES

As part of the 2010 Travel Behavior Inventory, a range of different data sources were analyzed to estimate, implement and validate the MetCouncil model system. These sources included existing travel behavior databases and observed ridership and traffic data sources supplemented by survey data designed and collected specifically to support different aspects of model development and included:

- A regional household survey supplemented by a sample of GPS loggers;
- An extensive on-board survey on regional bus and rail routes;
- Traveler and visitor surveys at the Airport and the Mall of America; and
- An extensive external origin-destination survey.

Each of these data sources is described briefly in this Section. Full free standing reports have been developed for each of these data collection efforts.

Household Travel Survey

The household survey conducted in the Twin Cities region for the Metropolitan Council (Council) was a key part of the 2010 Travel Behavior Inventory. The household survey provides modelers and planners a snapshot of travel behavior in the region and can be used for several purposes including:

- The development of a regional activity-based model;
- Travel patterns by different times of day;
- Geographic distribution of travel among area residents;

- Preferences towards different modes for by purpose; and
- Comparisons and trend analyses to assess how travel patterns have changed over the years by contrasting the 2010 surveys with the 1990 and 2000 Travel Behavior Inventory surveys.

The objective of the household survey was to obtain an inventory of representative travel behavior in the Twin Cities metropolitan area. The sample was distributed to a total of 19 counties including 16 counties in Minnesota and three in Wisconsin.

- The seven **Core counties** include the counties of Ramsey, Hennepin, Carver, Scott, Dakota, Washington and Anoka. These more urbanized areas account for 81.5 percent of the households in the 19-county region.
- The remaining 12 **Ring counties** include nine counties in Minnesota (Chisago, Isanti, Sherburne, Wright, McLeod, Sibley, Le Sueur, Rice, and Goodhue) and three counties in Wisconsin (Pierce, St. Croix and Polk). These counties have much lower densities and account for 18.5 percent of the households in the 19-county region.

Figure 1.1 shows the study area geography for the project. For purposes of sampling the 1.35 million households, the 19 counties were grouped into the seven subregions that are shown in different colors. A sampling rate of about one percent was used for the seven "Core" counties compared to a sampling rate of half a percent for the 12 "Ring" counties. The objective was to obtain a representative sample for the region and to focus more on the travel behavior of travelers in the seven more densely populated Core MPO counties.

The 19 counties were grouped into seven subregions for the sampling plan:

- The City of Minneapolis (green),
- The City of St. Paul (dark green),
- Hennepin and Carver counties (light green),
- Ramsey, Washington and Anoka counties (light red),
- The remainder of the Core counties of Dakota and Scott (yellow).
- Nine Ring Counties in Minnesota (blue), and
- Three Ring Counties Wisconsin (purple).

To obtain a representative sample of the 1.35 million households, the sampling plan took into account household size, automobile ownership and geography. A total of over 26,000 households were recruited for this effort out of the 235,000 households that were contacted. An address-based sample was used along with a multi-modal recruit and retrieval effort to improve response rates. Respondents had the option of filling out their diaries and mailing them back, going on the web to complete their diaries, or providing their travel information over the phone. A total of over 14,000 household surveys were collected with 12,103 surveys deemed complete for purposes of the modeling analysis.

Figure 1.1 Study Area, Counties, and Sampling Subregions

Source: Metropolitan Council and Cambridge Systematics, 2011.

Onboard Travel Survey

The onboard survey was conducted in the Twin Cities metropolitan area between September and November, 2010.

At that time Metro Transit operated over 125 bus routes, the Hiawatha light-rail line, and the Northstar commuter rail line. An additional 90 bus routes were operated by various regional transit partners. All 217 routes in the region were analyzed during the sampling plan development.

The main goal of the 2010 onboard survey was to collect surveys from at least five percent of riders on the most relevant routes to support detailed disaggregate analysis. Total daily boardings on the entire system are in excess of 275,000. As part of regional planning and modeling efforts, it is critical to understand the travel and usage patterns of riders to support transit planning and to improve the sensitivity of the regional travel demand model to the transit market segment.

A total of 26,000 surveys were distributed to passengers during the survey process and 21,078 surveys were handed back. In total, 16,562 records were entered into the database. Traditional pen and paper surveys were handed out and were supplemented by boarding and alighting counts that were recorded with GPS loggers to provide detailed transit usage patterns and rider information to support modeling.

Since these survey data are expected to influence transit policy over the next decade in the Twin Cities region, a careful overview of existing and required data was carried out. Three key points were critical to finalizing the approach:

- First, the focus of the study was to capture the **most current and reliable data** necessary to determine future public transportation needs in the Minneapolis region.
- Second, the study collected detailed transit ridership data for different routes by time of day to develop a disaggregate transit trip table that will **support advanced travel demand modeling**.
- Third, the study was designed to **leverage the existing** 2005 onboard survey and provide the best quality data to update the Travel Behavior Inventory in the Minneapolis/ St. Paul metropolitan region.

Airport Survey

Minneapolis-St. Paul Airport (MSP), the twin cities' primary airport, is one of the busiest in the Midwest. In addition to being a major Delta hub, the airport is served by 12 domestic and international airlines with direct flights to 122 domestic destinations and 26 international destinations serving over 15 million passengers per year. MSP provides a connection to the rest of the country and the world, is a driver of the local economy and impacts the local transportation network with passengers using taxi, limousine, van and shuttle services, rental cars, local bus, light rail and private vehicles to access the airport.

As part of the 2010 Travel Behavior Inventory, a special intercept survey of air passengers was commissioned to capture travel patterns of residents and visitors to and from the airport. The surveys were administered in June 2011.

The main goal of the survey effort was to produce enough survey records to support the development of a stand-alone airport travel behavior model which could include airport trip generation and purpose, mode choice, and time-of-day models. As such, the survey focused on the collecting the information necessary to support such modeling efforts including the nature of the participant's air travel, their local trip origins, and the ground transportation they used to reach the airport.

The survey effort collected information from 1,009 passengers with 556 passengers reported making an outbound trip from MSP.

External Origin-Destination Survey

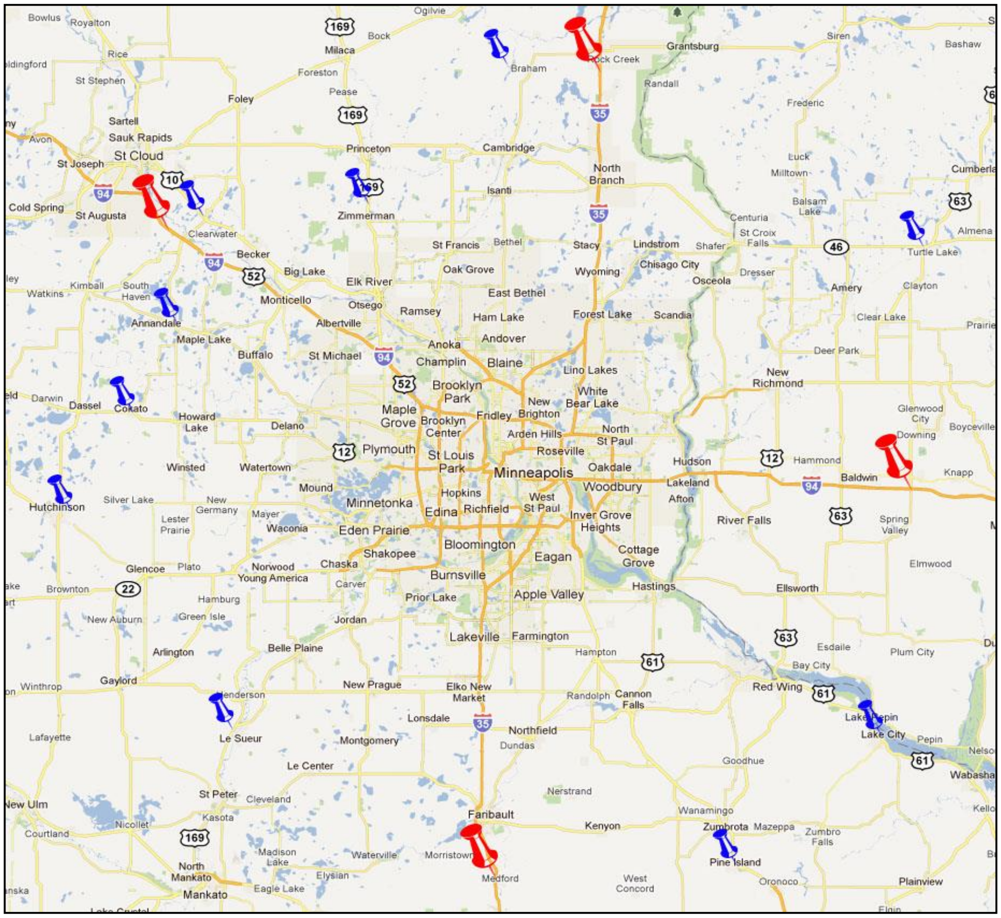
An origin-destination survey was conducted to capture the automobile-based travel patterns of non-residents who travel into, out of, or through the Metropolitan Council Area. This survey was conducted in a two-phase approach. First, license plates were captured via video at several key perimeter roadway locations (**Figure 1.2**). These license plates were matched to vehicle owner addresses. Second, surveys were mailed out to those drivers whose addresses were outside the Metropolitan Council area.

Key steps in the survey process included the following:

- Coordination with Minnesota and Wisconsin State Departments of Transportation to match license-plates with driver address databases;
- Identification of 14 locations to capture the license plate numbers of incoming, outgoing, and through passing automobile traffic;
- Development of a simple survey questionnaire that focused on only the most relevant travel behavior questions; and
- Customization of the questionnaire specific to the location used by each traveler to serve as a prompted recall-based instrument for drivers.

The 14 sites included four Interstate locations and ten non-Interstate locations on major roadway facilities at the perimeter of the Metropolitan Council region. Roadways selected included I-35 North, I-94, US-12, US-10, US-169 North, MN-7, MN-65, and MN-55.

Figure 1.2 Site Location Map for the External Origin-Destination Survey



Source: Site Location Map Developed by Minnesota Traffic Observatory

Data were collected between October 25th and November 10th, 2011 with a total of over 400 hours of video recording. The process yielded a total of 138,217 vehicle events and nearly 100,000 unique license plates.

- Of the 83,373 Minnesota licenses addresses were matched for 78,744 license plates. Similarly, out of the 8,598 Wisconsin license plates, 6,003 addresses were matched.
- Of the 84,747 license plates with an address match, only 24,725 addresses (or about 30 percent) belonged to residents outside the study area. Customized surveys were mailed to these travelers.
- The database consists of a total of 3,377 surveys that were included in our analysis corresponding to a response rate of about 14 percent.

1.3 STRUCTURE OF THE REPORT

Section 2.0 provides a brief overview of how each of the 49 individual model components fits within the overall activity model structure. We discuss the four broad types of models that examine long-term choices, daily activity patterns, tour-level decisions and trip-level decisions. The model structure is shown in detail along with the order in which each model is applied.

Section 3.0 presents in detail the 49 individual model components in 17 sections. We outline the objectives of each model type, its segmentation, and its relative position in the model stream. We discuss the model structure, the alternatives studied, and the variables tested. We present the estimation approach and the results along with key observations about each model.

Section 4.0 describes the model calibration approach. We present the various data sources along with an overview of the comparisons made as part of the calibration effort. The validation of the sociodemographic inputs is addressed first followed by the validation of the activity model system. A representative set of models is used to highlight the comparisons made. The complete set of spreadsheets is provided for the validation of each of the 49 individual model components.

2.0 Activity-based Model Framework

The Metropolitan Council's activity-based modeling (ABM) framework consists of a Population Synthesizer (PopGen) and 48 individual models that effectively describe every individual's travel and their activities within detailed time and space constraints. There are four major categories of models in the ABM framework (**Figure 2.1**):

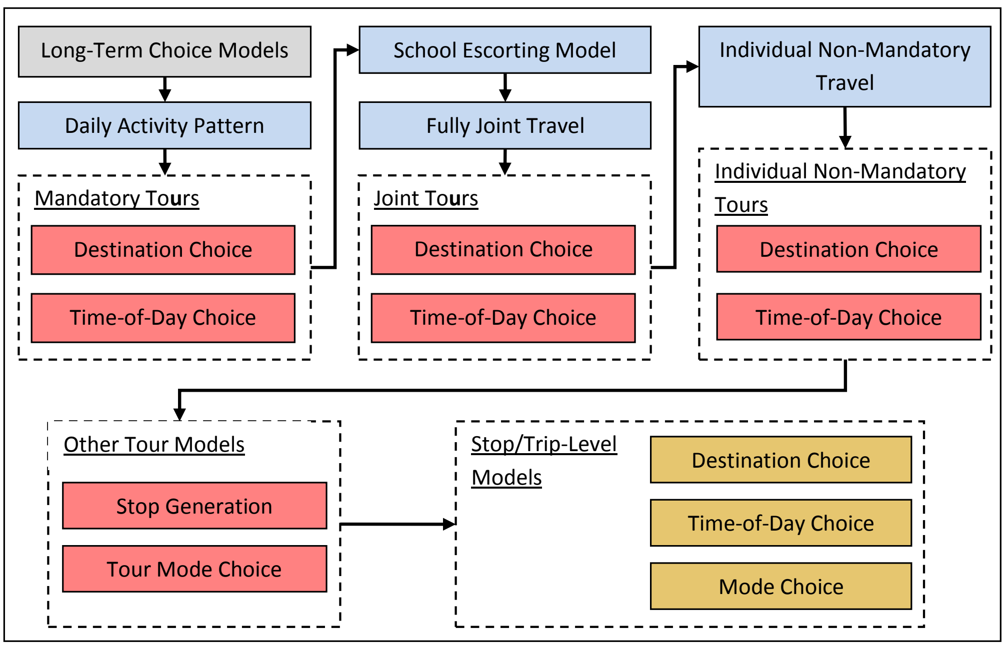
- **Long-term Models.** This category includes models that capture decisions with a longer time horizon including as the location of one's regular workplace, regular school location, vehicle availability, and transit and toll transponder pass ownership models. These decisions are modeled first since the outcome of these decisions influences other components of travel including mode choice and time availability for non-mandatory travel.
- **Daily Activity Patterns**. One key aspect of advanced models is the concept of a daily activity pattern that can be established at the individual level. Related to this concept is the understanding that each individual has a restricted amount of time per day that can be engaged in activities and associated travel. The daily activity patterns are simulated through a series of models, including the following:
  - Daily activity pattern model that determines the number and types of activities in which an individual is expected to participate;
  - Mandatory tour generation (work, university, and school) that is conditional on the "person type";
  - School escorting, which simulates whether children with a school tour are escorted by another family member;
  - Joint non-mandatory tour participation, which simulates the number of tours undertaken jointly by members of the same household; and
  - Individual non-mandatory tour generation that is modeled based on time available for individuals after the mandatory (work and school), escorting, and joint non-mandatory travel have been modeled.
- **Tour Level Models**. Tour-based models incorporate interrelationships among trips that are components of a "tour" which typically departs from home, visits one or more activity locations, and then returns home.

  Hierarchical rules were established to identify the appropriate nature of the tour. For instance, tours that included a mandatory destination such as work (or school) were defined as a work-based tour irrespective of other destinations serviced as part of this tour. These tour-level models provide an improved framework over trip-level models to represent daily travel decisions since they account for previous and subsequent trips within a tour. Overall, tour-based models account for information on modes, time-of-day, group travel, and other characteristics of travel that are clearly interrelated across trips within a tour.

- **Trip/Stop Level Models**. Within each tour, non-primary stops are modeled as intermediate stops. For tours with intermediate stops, separate models that capture the destination of the stop, the mode of travel, and the time-of-day of travel are developed.

  These models are constrained by the choices already made at the tour-level and therefore, allow for a more realistic decision-making process for every individual trip.

Figure 2.1 Activity-based Model Structure



In total, there are 49 different models (some are broken down by purpose) developed for the ABM. **Table 2.1** outlines each of these models and the application sequence of these models. The model design plan describes the modeling framework, and the data used to estimate and validate the models in greater detail.

Table 2.2 outlines the order in which each of the 49 models is estimated. This report focuses on the model estimation results, and the validation of these models to better reflect regional travel patterns. Section 3 describes the model estimation process using the order of the models shown in **Table 2.2**.

Table 2.1 Models in the Activity-based Model by Application Sequence

Model Categories	Model Step Description	Application Sequence
Long-Term Models	Vehicle Availability Usual Work Location (binary, destination choice) School Location Transit Pass Ownership Toll Transponder Ownership	**1-6**
Daily Activity Pattern (DAP)	Child 6-15 Child 16+ Nonworking adults Seniors Part tine workers Full time workers Adult students	**7-13**
Mandatory Tour	Destination Choice – Work Destination Choice – School Time of Day Choice – Work Time of Day Choice – School/University	**14-17**
School Escorting	School Escorting Generation	**18**
Joint Tour	Tour Generation Tour Participation Tour Destination Choice Tour Time of Day Choice	**19-22**
Individual Non-Mandatory Tour	Tour Generation Destination Choice (*Includes non-school escorting)* Time of Day Choice	**23-25**
Intermediate Stop Generation	Home-based Work: Outbound and Return School/University: Outbound and Return Individual Non-mandatory: Outbound and Return Escorting: Combined outbound/return Joint Non-mandatory: Outbound and Return	**26-36**
Tour Mode Choice	Home-based Work School/University Individual Non-mandatory Escorting Joint Non-mandatory	**37-41**
Work-based Sub-tour Choices	Tour Generation Tour Destination Choice Tour Time-of-Day Choice Intermediate Stop Generation Tour Mode Choice	**42-46**
Trip Models	**Stop Destination Choice** **Stop Time of Day Choice** Trip Mode Choice	**47-49**

Table 2.2 Estimation of Models in the Activity-based Model

Model Categories	Model Step Description	Estimation Sequence
Tour Mode Choice	Home-based Work School/University Individual Non-mandatory Escorting Joint Non-mandatory Work Sub-tour	**1-6**
Long-Term Models	Usual Work Location Vehicle Availability School Location Transit Pass Ownership Toll Transponder Ownership	**7-12**
Daily Activity Patterns	Child 6-15 Child 16+ Nonworking adults Seniors Part tine workers Full time workers Adult students	**13-19**
Tour Destination Choice	Home-based Work University Individual Non-mandatory Escorting Work Sub-tour Home-based Joint Non-mandatory	**20-25**
Tour Time of Day Choice	Home-based Work School/University Individual Non-mandatory – nonschool escort Joint Non-mandatory Work Sub-tour	**26-30**
School Escorting	School Escorting	**31**
Joint Tours	Joint Tour Generation Joint Tour Participation	**32-33**
Individual Non-mandatory	Tour generation	**34**
Work Sub-tour	Work-based Sub-tour Generation	**35**
Intermediate Stop Generation	Home-based Work: Outbound and Return School/University: Outbound and Return, Individual Non-mandatory: Outbound & Return Escorting: Combined outbound/return Joint Non-mandatory: Outbound and Return Work Sub-tour: Outbound and Return	**36-46**
Trip Models	**Stop Destination Choice** **Stop Time of Day Choice** Trip Mode Choice	**47-49**

3.0 Model Estimation

This section provides an overview of the model estimation results for the activity-based model. The report presents results from each individual model outlined in **Table 2.1** and in the sequence in which they were estimated.

3.1 TOUR MODE CHOICE MODELS

The first step in the estimation process was the estimation of the tour mode choice models. These models were estimated first because several of the models that follow use the mode choice logsums as an explanatory variable.

A total of six models were estimated, based on travel purpose, and are defined as follows:

- Home based work - Individual,
- Home based school/university - Individual,
- Home based non-mandatory - Individual,
- Home based escort - Individual,
- Joint non-mandatory tours, and
- Work-based sub-tours – Individual.

By definition, all tours begin and end at home, except the work-based sub-tours which begin and end at a work location.

The trip database was converted into tours by using a hierarch for assigning a purpose and mode for each tour. **Table 3.1** lists the purpose-specific and modal hierarchies that were used to build the tour database.

The top hierarchy of mandatory tours such as work and educational tours reflects their relative importance and also individual travelers' lowest degree of flexibility. On the other hand, the low hierarchy of the discretionary tours reflects individual travelers' highest degree of flexibility of scheduling these tours.

School bus has the highest modal hierarchy reflecting student travelers' limited flexibility while the walk and bike modes have the lowest modal hierarchy reflecting travelers' highest degree of flexibility.

- As an example, if an individual makes a trip from home to work, followed by a shopping trip from work before finally returning home from the shopping location, these three trips are combined into one tour and assigned a tour purpose of "home based work" based on the tour purpose hierarchy.
- For this same example, if the first trip from home to work was made using a shared ride mode with two passengers; the shopping trip from work was made

using a walk mode; and the return trip back home from the shopping location was made using transit-walk, then the tour would be assigned a transit-walk mode based on the modal hierarchy.

Table 3.1 Tour Purpose Hierarchy and Modal Hierarchy

	Tour purpose
Higher Priority ↑	Work
	School (K-12)
	Higher Education
	School Escort (Parent's tour)
	Maintenance (Personal Business)
	Shopping
	Eating Out
	Discretionary
	Chauffeur (Escort)
	Home (Work-based only)
	Other

	Mode
Higher Priority ↑	School Bus
	Transit - Drive
	Transit - Walk
	Shared Ride 3
	Shared Ride 2
	Drive alone
	Walk
	Bike

The model specifications were finalized after testing a wide range of explanatory variables, nesting structures, availability conditions and constraints. The variables tested included person-level and household-level attributes, travel characteristics, level-of-service attributes (e.g., travel cost, travel time and number of transfers in transit), and land-use variables. In most models, the cost variable was segmented by household income (quintiles), which allows the segmentation of values of time by household income.

- **Model Structure.** All models were estimated as either nested (NL) or multinomial logit (MNL) structures. **Figure 3.1** to **Figure 3.6** show the final nesting structures for the six tour mode choice models. The home-based escort model and the home-based joint non-mandatory model were the only models with a multinomial model structure.

Figure 3.1 Home-based Work Tour Mode Choice Model

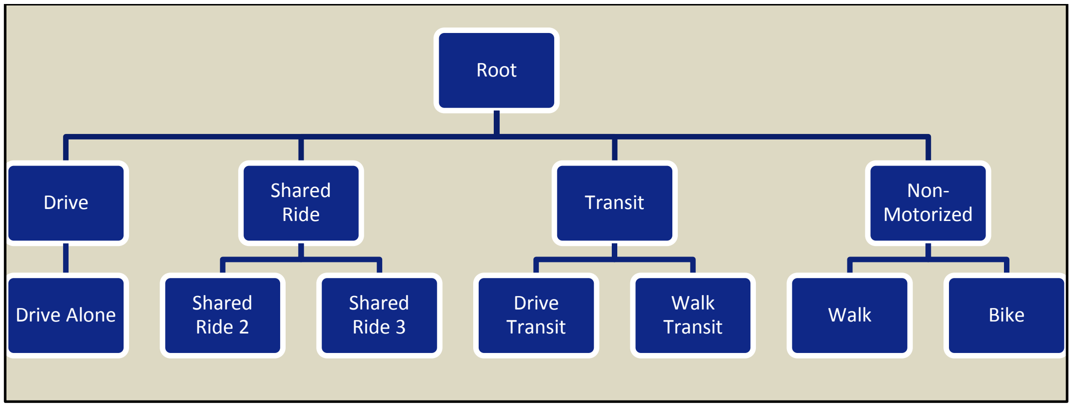


Figure 3.2 Home-based School and University Tour Mode Choice Model

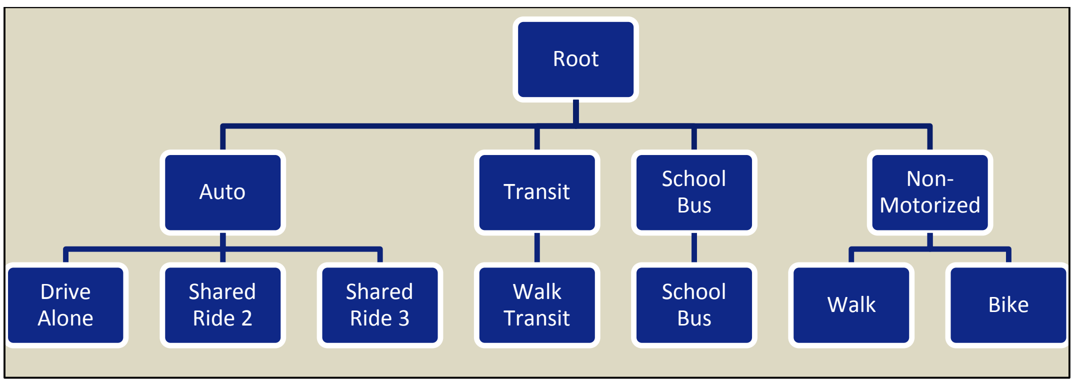


Figure 3.3 Home-based Non-Mandatory Tour Mode Choice Model

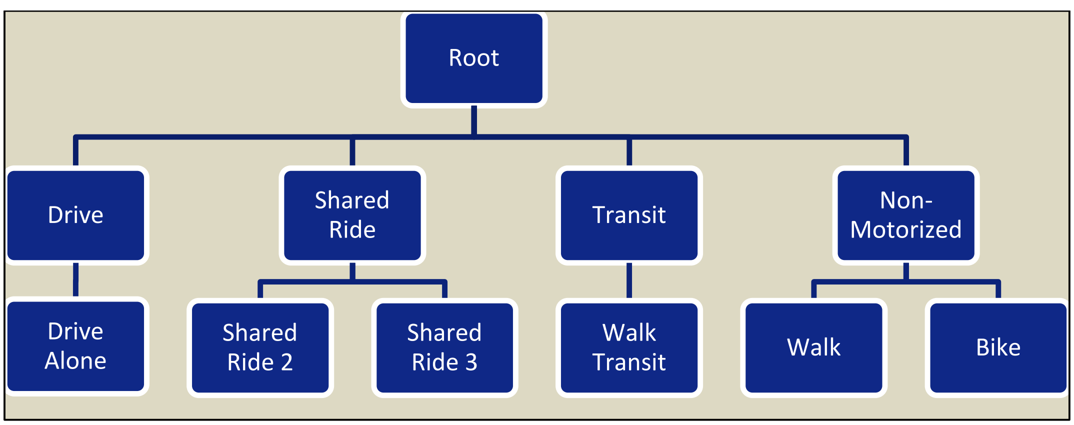


Figure 3.4 Home-based Escort Tour Mode Choice Model

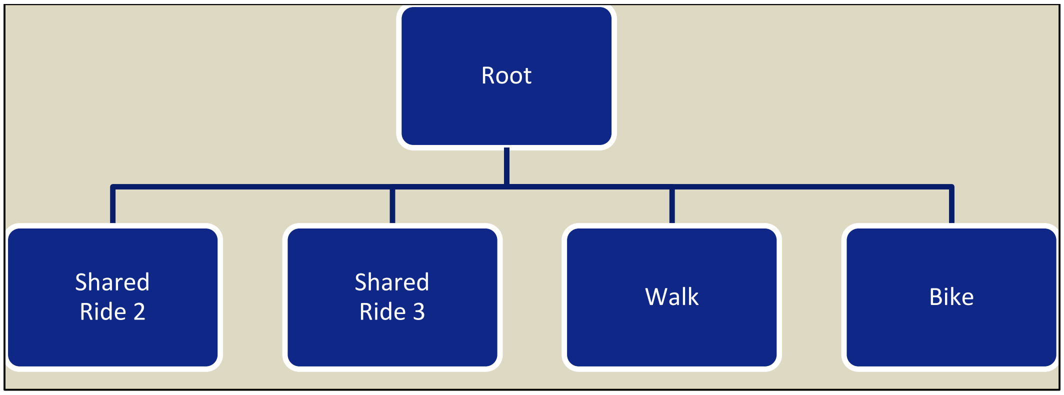


Figure 3.5 Work-based Sub-tour Mode Choice Model

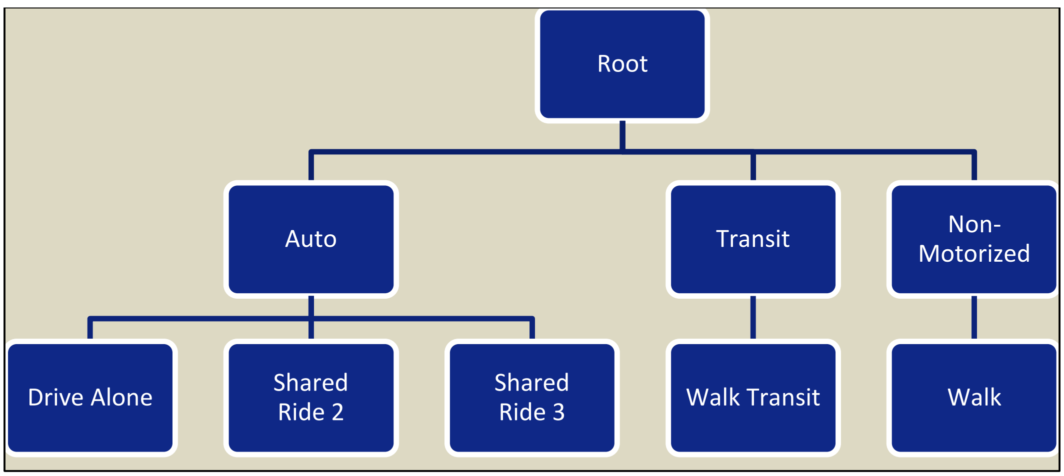
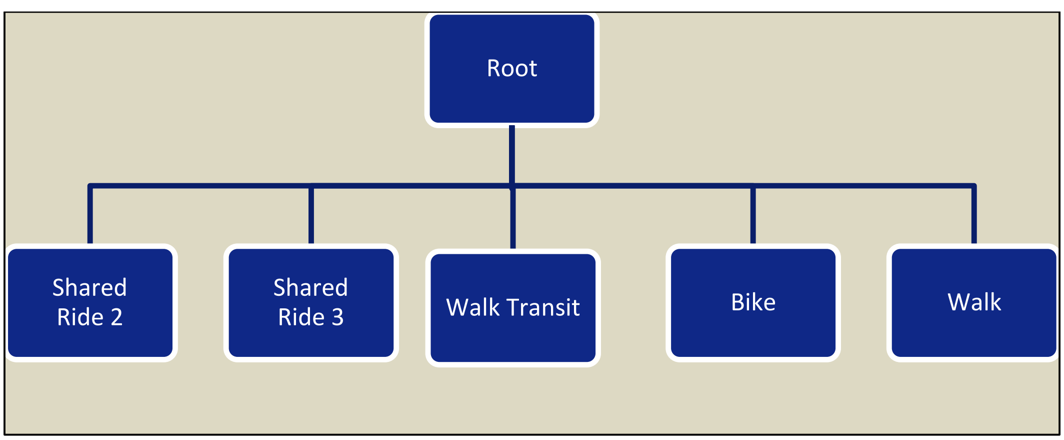


Figure 3.6 Home-based Joint Non-Mandatory Tour Mode Choice Model



- **Alternatives.** The following mode alternatives were defined for the tour mode choice model:
  - Drive alone;
  - Shared Ride broken down into two categories based on the number of occupants:
    - Shared ride 2 and
    - Shared ride 3+;
  - Transit broken down into two categories based on mode of access:
    - Transit Walk Access and
    - Transit Auto Access;
  - Non-Motorized broken down into two distinct categories:
    - Bike;
    - Walk; and
  - School bus.
- **Availability Criteria for the Choice Set**. The first step in the model estimation process was to analyze the household survey data and determine whether enough observations existed to model the availability of a particular mode for each of the six distinct tour mode choice models. **Table 3.2** outlines the distribution of the survey data by mode and purpose.
  - **School Bus**. School bus was an available mode only for the home-based school tour purpose. It was not available for any other purpose.
  - **Walk to Transit**. Travel demand models are used to assess transit investments. Therefore, it is critical that transit be included as an alternative in all tour and trip purposes. Therefore, even though there are limited observations for transit in escort, joint and work-based tours, the modeling team decided to include walk to transit as a viable alternative for these models.
  - **Drive to Transit**. Drive to transit had a limited number of observations for most tour purposes. Therefore, it was determined to include drive to transit as a modal option only for the home-based work tour purpose.
  - **Drive Alone**. By definition, drive alone was not provided as an option for escorting and for joint travel tours.
  - **Bike**. Bike was dropped from the work-based sub-tour models due to a limited number of observations.
  - **Shared Ride and Walk**. These modes were included in each of the tour mode choice models since enough records were available to support the preferences for these modes.

Table 3.2 Distribution of Survey Data by Mode and Purpose

		Shared Ride		Transit		Non-Motorized			
Tour Purpose	**Drive Alone**	**Shared Ride 2**	**Shared Ride 3+**	**Walk to Transit**	**Drive to Transit**	**Bike**	**Walk**	**School Bus**	**Total**
Home-Based Work Tours	5,587	779	887	422	102	144	129	-	**8,050**
Home-based School/University Tours	245	75	543	66	12	34	85	1,164	**2,224**
Home-based Non-Mandatory Tours	5,524	1,364	2,074	185	4	161	518	-	**9,830**
Home-based Escort Tours	-	693	568	11	3	12	59	-	**1,346**
Work-based Sub-Tours	410	81	108	6	1		174	-	**780**
Joint Non-Mandatory Tours	-	671	987	9	-	16	70	-	**1,753**
Total	**11,766**	**3,663**	**5,167**	**699**	**122**	**367**	**1,035**	**1,164**	**23,983**

- **Availability Criteria by Purpose**. **Table 3.3** summarizes the modal availability matrix that was used during tour mode choice model estimation.
  - The full complement of modal alternatives is available for the home-based work tours. Options include drive alone, shared ride 2, shared ride 3+, walk, bike, transit with walk access and transit with auto access.
  - The home-based school and university tours do not include transit with drive access as an option, but include school bus.
  - Home based non-mandatory (excluding escort) tours include all modes except transit with drive access. Options include drive alone, shared ride 2, shared ride 3+, bike, walk and transit with walk access.
  - Home based escort tours are the most restrictive and only include shared ride 2, shared ride 3+, bike and walk as options.
  - Home based joint non-mandatory tours do not include drive alone or transit with drive access as options, but include shared ride 2, shared ride 3+, bike, walk, and transit with walk access.
  - Work-based sub-tours include drive alone, shared ride 2, shared ride 3+, transit with walk access, and walk as options.
- **Additional Availability Criteria**. In addition to data-driven availability criteria, additional restrictions were applied to preclude certain "illogical" mode choice behavior during estimation. The full set of availability criteria is listed below:
  - **Drive Alone Mode**
    - » The drive alone mode is unavailable to all persons under age 16 for all tour purposes.
    - » The drive alone mode is unavailable to all persons who make escort stops on return and outbound tours.
  - **Shared Ride Mode.** Shared ride 2 is not available for fully joint tours with three or more participants.
  - **Transit Mode.** Transit is available only if transit in-vehicle time is non-zero/non-null in the skim matrix for the zone pair between home and the primary activity location. The same rule applies for zone pairs between the work location and the sub-tour destination. The same criteria are applied for transit walk access and transit drive access modes.
  - **Bike and Walk Mode.** Bicycle is not available for half-tours longer than 15 miles. Walk is not available for half-tours longer than 5 miles. These criteria are used to reflect that people are not likely to travel longer distances when riding a bike or walking respectively.

Table 3.3 Modal Availability Matrix used in Model Estimation

		Shared Ride		Transit		Non-Motorized		
Tour Purpose	Drive Alone	Shared Ride 2	Shared Ride 3+	Walk to Transit	Drive to Transit	Bike	Walk	School Bus
Home-Based Work Tours	✓	✓	✓	✓	✓	✓	✓	✗
Home-based School/University Tours	✓	✓	✓	✓	✗	✓	✓	✓
Home-based Non-Mandatory Tours	✓	✓	✓	✓	✗	✓	✓	✗
Home-based Escort Tours	✗	✓	✓	✗	✗	✓	✓	✗
Work-based Sub-Tours	✓	✓	✓	✓	✗	✗	✓	✗
Joint Non-Mandatory Tours	✗	✓	✓	✓	✗	✓	✓	✗

- **Explanatory Variables.** The variables used in tour mode choice include:

  Travel costs and **transportation level-of-service characteristics**. The values for the level of service variables are obtained from network skims. Because this is a tour level model, costs and levels of service represent the times and costs for the entire tour including the origin to destination half-tour (outbound half-tour) and the destination to origin half-tour (return half-tour).

  » Cost represents the total travel cost per person for the tour.

  i. **Auto Cost** per person for drive alone mode includes 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+ is calculated by assuming an average occupancy of 2 and 3.5 respectively.

  ii. **Transit Cost** per person for transit with walk access and transit with auto access includes the total fare paid for the outbound and return half-tours.

  iii. **Cost segmentation** by income is defined as follows:

     a. Income less than $25,000: Cost variable as defined above if income is less than $25,000.

     b. Cost income between $25,000 and $50,000: Cost variable as defined above if income is between $25,000 and $50,000.

     c. Cost income between $50,000 and $75,000: Cost variable as defined if income is between $50,000 and $75,000.

     d. Cost income between $75,000 and $100,000: Cost variable as defined above if income is between $75,000 and $100,000.

     e. Cost income greater than $100,000: Cost variable as defined above if income is greater than $100,000.

  » **In-vehicle travel time**: This variable is obtained directly from the in-vehicle skims specific to each mode both for the outbound and return half-tours. For the transit with auto access mode, this includes the auto access time.

  » **Out-of-vehicle travel time**: For auto modes, this variable includes the origin and destination terminal time. Terminal time is the time spent to travel from the car to the final destination and vice versa. For transit modes, it includes walk access and egress times, transfer time and wait times for the outbound and return half-tours. Access time is the time spent to travel to the transit stop from the origin and egress time is the time spent to travel to the destination from the transit stop. Wait times include the time spent to transfer from one transit line to another (which includes both walk travel time and wait time for the transfer).

» **Total generalized time**: This variable is the sum of in-vehicle travel time and two and one and a half times the out-of-vehicle travel time.

» **Distance**: This variable is defined as the sum of the distances traveled during the outbound and the return half-tours.

» **Transit Frequency**: This variable is used to differentiate between high frequency service with a wait time less than 10 minutes; medium frequency service with a wait time between 10 and 20 minutes; and low frequency service with a wait time of 30 or more minutes.

Traveler/household characteristics. Variables that fall in this category are the number of members in the traveler's household, the number of full-time and part-time workers, adults, and children aged 0-5, 6-15, and 16+ in the household, household income level, and the number of vehicles. Characteristics of the traveler include age, gender, and whether the traveler is a worker or a school or university student. The following is a complete list of variables in the final models:

» **Zero vehicle household**: one if the household owns no cars and zero otherwise.

» **Children younger than five years old**: one if the person's age is between 0 and 5 and zero otherwise.

» **Children between six and 15 years old**: one if the person's age is between 6 and 15 and zero otherwise.

» **Children of age 16 and over**: one if the person's age is 16 and over and zero otherwise.

» **Male**: one if the person is male and zero otherwise.

» **Age greater than 35 years**: one if the person's age is greater than 35 years and zero otherwise.

» **Age greater than 55 years**: one if the person's age is greater than 55 years and zero otherwise.

» **Senior**: one if the person is non-worker, non-student and his/her age is greater than or equal to 65 years and zero otherwise.

» **Full-time worker**: one if the person is a full-time worker and zero otherwise.

» **Adult student**: one if the person is an adult and a student and zero otherwise.

» **One person household**: one if the number of household members is 1 and zero otherwise.

» **Two person household**: one if the number of household members is 2 and zero otherwise.

  - » **Income less than $50,000**: one if the household income is less than $50,000 and zero otherwise.
  - » **Income greater than $75,000**: one if the household income is greater than $75,000 and zero otherwise.
  - » **Number of vehicles**: Total number of vehicles in the household.
  - » **Number of children**: Total number of children in the household.
  - » **Number of children younger than 5 years old**: Total number of children in a household less than 5 years old.
  - » **Number of workers**: Total number of workers in the household.

- **Land Use Variables**
  - » **Mixed use density at origin zone**: This variable is a measure of the mix of retail employment and households in all zones within a walking distance of 1.5 miles of the zone of interest. It is defined as follows:
  - » **Residential density** is the number of households in the origin zone, divided by the total area (in sq. mi) of that zone.
  - » **Retail employment density** is the retail employment in the origin zone, divided by the total area (in sq. mi) of that zone.
  - » **Origin mixed use density** is then defined as:

    (Residential density)*(Retail employment density) / max (0.001, Residential Density + Retail Employment Density).
  - » **Mixed use density at destination zone**: This is defined the same way as the mixed use density at origin zone, but for the destination zone.
  - » **Total population and total employment density at origin zone**: These variables are defined as the sum of total population/employment, divided by the total area (in sq. mi) of that zone.
  - » **Total population and total employment density at destination zone**: These variables are defined the same way but for the destination zone.

- **Tour Variables**
  - » **AM Peak arrival time**: one if arrival time at destination is between 7 AM and 9 AM, and zero otherwise.
  - » **Mid-day arrival time:** one if arrival time at destination is between 10 AM and 2 PM, and zero otherwise.
  - » **PM Peak arrival time**: one if arrival time at destination is between 4 PM and 6 PM, and zero otherwise.
  - » **Evening arrival time**: one if arrival time at destination is between 6 PM and 12 AM, and zero otherwise.

- **Presence of stops on outbound or return half-tours**: one if the number of stops between origin and destination, or between destination and origin are greater than zero, and zero otherwise.
- **Presence of stops on outbound half-tour**: one if the number of stops between origin and destination are greater than zero, and zero otherwise.
- **Presence of stops on return half-tour**: one if the number of stops between destination and origin are greater than zero, and zero otherwise.
- **School escort tour**: one if escort tour is to or from a school, and zero otherwise.
- **Discretionary tour**: one if tour is to or from a discretionary tour purpose, and zero otherwise.
- **Meal tour**: one if tour is to or from a meal tour purpose, and zero otherwise.
- **Shopping tour**: one if tour is to or from shopping tour purpose, and zero otherwise.
- **Number of fully joint tours**: Total number of fully joint tours for the individual.
- **Shopping stops on tour**: one if total number of stops which are shopping related on the outbound or in-bound half-tours is greater than zero and zero otherwise.
- **Meal stops on tour**: one if total number of stops which are meal tour purpose related on the outbound or in-bound half-tours are greater than zero, and zero otherwise.
- **Chauffeur stops on tour**: one if total number of stops which are chauffeur tour purpose related on the outbound or in-bound half-tours is greater than zero, and zero otherwise.
- **Discretionary stops on tour**: one if total number of stops which are discretionary tour purpose related on the outbound or in-bound half-tours is greater than zero, and zero otherwise.
- **Number of mandatory stops on tour:** Total number of stops which are work or school related on outbound and return tours.
- **Number of non-mandatory stops on tour**: Total number of stops which are not work or school related on outbound and return tours.

- **Estimation Approach.** Estimation was carried out using an iterative approach.
  - First, variables were introduced into the model in an incremental manner.
  - At every intermediate stage, the resulting models were evaluated for: (a) explanatory power, (b) statistical significance of each coefficient, and (c) relative magnitude and sign of each coefficient within the models.
  - Third, the models were evaluated under different nesting structures to assess the most suitable nesting structure for the model.
  - Fourth, coefficients that were dropped during an earlier iteration, were re-tested once a draft final specification had been determined to assess whether their explanatory power and relative magnitudes had improved within this draft final specification. If so, they were re-introduced back into the model.
  - Once each of these steps had been carried out and the resulting models had been assessed, the model estimation was determined complete. Results from these completed models are included in this memorandum.
- **Model Estimation Results.** All estimation results for the six tour mode choice models are presented in the spreadsheet called ***"TBI ABM–Tour Mode Choice Models.xlsx"***.

  Key findings of the model estimation are discussed below:
  - **Level of Service Variables**. Since the effect of level-of-service variables in the models is critical for policy testing, these variables required special attention to ensure that coefficient estimates had correct signs and fell within reasonable ranges. Because the estimates do not always meet these requirements, some or all the level-of-service coefficients had to be constrained to a specific value.
  - **Out-of-vehicle Travel Time vs. In-vehicle Travel Time**. For all models, the relative weights of out-of-vehicle travel time (OVTT) to in-vehicle travel time (IVTT) were constrained. Traditionally in a modeling framework the relative weight of out-of-vehicle travel time (OVTT) to in-vehicle travel time (IVTT) lies in the range of 2 to 3. The Federal Transit Administration (FTA) also suggests the same range. For this study, before finalizing a ratio of IVTT to OVTT, a sensitivity test was run to determine an optimal ratio. By varying the ratio between 2 and 3, it was observed that none of the coefficients in the models experienced a change in their estimates or directionality. Hence, we used a ratio of 2.5, which is the midpoint of the generally accepted 2 to 3 range.
  - **Vehicle Availability**. Vehicle availability was found to be very important for work and non-mandatory tours. As expected, drive alone was least likely in households with a low vehicle availability, while transit and non-motorized modes were most likely to be chosen.

- **Household Income**. Household income was found to be an important explanatory variable. For home based work tours, low income households were found to associate less utility for "transit with auto access" while high income households attributed lower utility to the walk mode. For non-mandatory tours, transit with walk access mode was more often preferred by low income households.
- **Household Size**. Household size was a key factor influencing the choice of shared ride modes. Shared ride modes were less likely to be chosen when there was only one household member and shared ride 3+ mode was unlikely to be chosen when there were two or fewer household members. Both findings suggest that shared travel is mostly limited to members of the same household.
- **Number and Age of Children**. The age of children had an effect on school and individual non-mandatory tours while the number of children had an impact on home based work tours. Children between five and 15 years old were more likely to bike and share a ride for individual non-mandatory travel purposes. Households with children under six years old were more likely to share a ride to school.
- **Gender**. Gender had an important impact on walk and bike modes across several mode choice models with males more likely to choose these modes than females.
- **Mixed Use Density and Employment Density**. These variables had a positive effect on the utility for transit and walk modes in several models. This is an important finding that suggests that the propensity to use non-motorized modes is highest in dense urban settings.
- **Tour Stops**. The presence, number and types of stops made on a tour were found to be a significant indicator in several models. The presence of any stops (other than the primary activity) typically increases the likelihood of any auto mode being chosen. Similarly, the presence of stops indicated a lower preference towards transit and non-motorized modes.
- **"Parent Tour" Influence on Sub-Tour**. The "parent" work tour mode was a key indicator for work-based sub-tour mode choice. In particular, when an individual chooses a non-auto mode for a work tour, any work-based sub-tours generated by these individuals associate higher utility values to non-auto modes. Similarly, when the work tour mode is shared ride 2 or 3+, both shared ride modes and walk mode utilities increase in work-based sub-tour mode choice.

3.2 LONG-TERM CHOICE MODELS

There are five long-term choice models in the Metropolitan Council's model system. These include the usual workplace location, school location, vehicle availability, transit pass ownership model, and a toll transponder model.

Usual Workplace Location Model

The choice of the usual workplace location is modeled as a two-step process consisting of two models:

- **'Usual' versus 'No Usual' Workplace Location Binary Choice Model**. The 'usual' versus 'no usual' binary model is essential to determine if a worker opts for the 'no usual' workplace location choice. These individuals are then subjected to the tour-level home-based work destination choice; and
- **'Usual' Workplace Location Choice Model**. The 'usual' workplace location choice model captures the usual location to which a person commutes for work and work-related purposes.

The final specification for both of these models was reached by testing a wide range of model variables.

- For the binary choice model, the variables used include person attributes such as age and part-/full-time worker, and household attributes such as income and lifecycle stage.
- For the location choice model, the variables used were similar to a typical destination choice model, such as level of service, socio-economic and demographic, and land use variables. This model also includes size functions, which are additive logarithmic functions of attractions in a zone such as employment, households and enrollment. This model has a very similar structure to that of the home-based work destination choice model.
- All estimation results for this model are presented in the spreadsheet called ***"TBI ABM – Workplace Location Models.xlsx"*.**

Usual vs. No Usual Workplace Location Binary Choice Model

- **Model structure**. This model has a binary logit form, and predicts the probability of each individual having a usual workplace location. This is typically dictated by individual characteristics and household attributes.
- **Alternatives**. There are only two alternatives for this model – having a usual workplace and not having a usual workplace.
- **Explanatory Variables.** The following variables were used:
  - **Person and Household Attributes**
    - » **Worker status** differentiated between full-time and part-time workers.
    - » **Gender** distinguished between male and female commuters.

   - » **Age** was used as a continuous variable.
   - » **Household composition** included information about the number of children, workers and non-workers in a household.
 - **Vehicle Availability** was obtained from the 'vehicle availability' model which is another long-term choice model that predicts the number of vehicles to which a household has access.

- **Estimation Results.** Key findings of the model estimation were as follows:
  - Part-time workers have a higher propensity of not having a usual workplace location choice than full-time workers. This is probably because they either work multiple jobs at different locations or work on a temporary basis and therefore, do not have a fixed long-term workplace location. This effect was stronger for high income residents.
  - Full time workers younger than 65 were more likely to have a workplace. However, this result did not hold for those over 65 indicating that older individuals were more likely to work part-time and may have a greater flexibility in choosing their work location.
  - Both full-time and part-time workers were more likely to have a usual workplace location if there were many non-workers in the household.
  - Workers in zero vehicle households were much less likely to have a usual workplace than workers in households with autos.
  - Women were (slightly) more likely than men to have a fixed workplace.

Usual Workplace Location Choice Model

- **Model Structure**. This model has a multinomial logit form (MNL), and predicts the probability of choosing a TAZ for the usual workplace location. The probability of choosing a particular TAZ is based on the relative ease to get to the destination, the availability of modes to reach the destination, the employment opportunities in the zone, and the household and personal attributes of the commuter.
- **Alternatives**. Every internal TAZ in the modeling area is a possible workplace location. Therefore, the alternatives in the model are all internal TAZs numbered from 1 to 3,030. The logit structure is shown below where TAZs 1, 2, through N (N=3,030) are the alternatives under the main root.

- **Size Function.** Size functions are used to measure the amount of activity that occurs at each destination zone and incorporate it 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 size and employment levels. The **size variables** tested in the estimation of the usual workplace location model include:

- **Employment by type**: retail and non-retail
- **College enrollment**, and
- **Number of households** (since the usual workplace could be the home for some workers).
- The size function is included in the utility equation of each destination choice (TAZ) using a simple example:

  *Size function = LSM * ln {(non-retail employment) + exp (coeff$_{22}$) * retail employment + exp (coeff$_{33}$) * households}*

  Where:

  The first size variable, non-retail employment, is the base variable;

  Size variables 2 and 3 are retail employment and number of households;

  Coeff$_{22}$ and Coeff$_{33}$ are coefficients for size variables 2 and 3; and

  LSM is log size multiplier which is a coefficient that is multiplied by the entire size function.

- **Explanatory Variables.** The following variables were used in the usual workplace location choice model:
  - **Transportation levels of service**. Distance was measured as the **round-trip (RT) distance** from origin to destination and from destination to origin. It was derived from the network skims and was expressed in miles.
    - » To provide a non-linear relationship with distance, a logarithmic function of distance was used.
    - » The logarithm of distance was expressed as ln(RT distance + 1) to ensure that the estimation process does not attempt to compute the logarithm of zero.
    - » The logarithm of distance was segmented by income categories to capture differences in decision-making among different income levels.
  - **Mode choice logsum** – The disaggregate mode choice logsum is derived from the estimated home-based work tour-level mode choice models. This variable captures the accessibility and performance of each mode available to make the trip to the desired workplace location.
  - **Land use/zonal variables** computed at the zone level.
    - » **Intrazonal** indicator – it takes the value of one if the destination zone is the same as the home zone, and zero otherwise.

  - » **Destination mixed use density** within 1.5 miles of the destination zone. This variable is defined as the sum of employment multiplied by the sum of households. It is divided by the sum of employment plus the sum of households plus 1.0. These sums include the employment or number of households from any zone, including the zone for which the value is being calculated, which is less than 1.5 miles by walking distance.
  - » The **Central Business District**, is introduced as a separate variable to capture the attractiveness of the region's core in attracting workers.
- – **Size function** – The coefficients of the employment variables in the size function are estimated specific to market segments defined by household income level and worker status.

- **Estimation Results.** Key findings of the model estimation were as follows:
  - – **Distance** is the key level of service variable with a strong impact on utility. TAZs that are further away from the home location are less likely to be as a usual workplace location than nearby zones all else being equal.
  - – Distance has a stronger impact on **part-time workers** who are more negatively influenced by distance than full-time workers.
  - – The **mode choice logsums**, which indicate accessibility of a zone by highway and by transit, are more important to full-time workers.
  - – The **intrazonal** dummy variable is positive for both types of workers but it is much higher for full-time workers than part-time workers.
  - – The size function has **non-retail employment** as the base variable. **Retail employment** has a much greater effect on part-time workers and workers from **low income** households. This suggests the greater attraction of zones with high retail employment to the lower income market segment of the population that is more likely to have part-time jobs.

Vehicle Availability Model

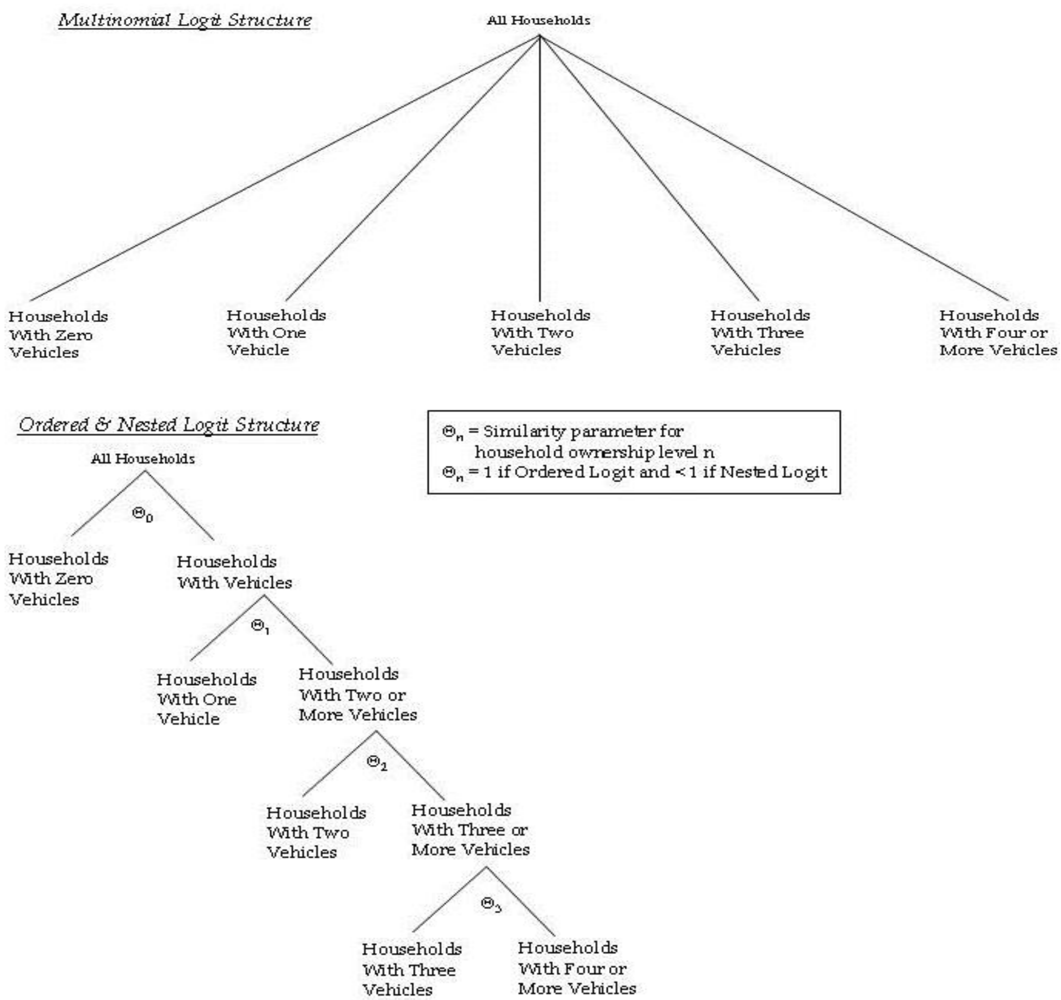
The number of motor <u>vehicles available</u> to a household has a major impact on the travel behavior of the members of the household. Many MPOs have incorporated models of household vehicle "availability" or vehicle "ownership" into their travel forecasting model systems.

For the Metropolitan Council's model, the decision was made to model vehicle availability rather than vehicle ownership for two reasons:

- Household vehicle availability, a measure of the total number of vehicles available for use by household members (including both passenger cars and trucks owned, leased, and/or provided by employers), is more closely related with the level of household mobility than the more limited household vehicle ownership measure.

- In addition, data on vehicle availability are collected in the ACS decennial U.S. Census, and therefore are available in the Census Transportation Planning Products (CTPP) and PUMS datasets in the 2010 Census.
- **Model Structure**. There are three possible discrete choice model formulations or structures for the vehicle availability model: 1) the multinomial logit (MNL) model, 2) the ordered response logit (ORL) model, and 3) the nested logit (NL) model. The structural differences among these discrete choice model formulations are depicted in **Figure 3.7**.

Figure 3.7 Alternative Modeling Structures for the Vehicle Availability Model



The first structure shows the simpler multinomial model approach.

The second structure implies a sequential choice by households, first determining whether to have any vehicles at all, and then how many to have. This structure requires an ordered model approach. The ORL structure also assumes that the similarity between the two choices available at each level of the choice structure (as reflected in the theta coefficient) is equal.

The NL structure also assumes a sequential choice process, but does not assume that the choices at each level of the structure are considered equally. Instead, the theta coefficients of this model structure can vary to provide the best model fit to the available data.

Past experience in vehicle availability modeling has shown that the ORL model usually provides a slightly better statistical fit than the MNL model while the NL structure generally shows no advantage over the ORL model. Therefore, an ORL modeling structure was chosen.

- **Model Alternatives**

Seven alternatives were chosen for this model and are as follows:

- zero vehicles available
- One vehicle available
- Two vehicles available
- Three vehicles available
- Four vehicles available
- Five vehicles available
- Six or more vehicles available

- **Explanatory Variables.** Several variables were tested and included in the final specification of the vehicle availability model (***TBI ABM – Vehicle Availability Models.xlsx***). These include:
  - **Theta Values** were specified for six alternatives with the zero vehicle alternative as the base. These theta values are intercepts but work in the opposite direction and they measure the difficulty of moving from one alternative to another. Having access to six or more vehicles is the most difficult option (8.58) compared to any other alternatives as shown in **Table 3.4**. Also shown here is the relative difference across any two successive theta values, which actually get added to the utility equation of each alternative. Therefore, as the availability of vehicles goes up from 1 to 6+, the utility decreases as it becomes too onerous to own many vehicles.

Table 3.4 Vehicle Availability Model Results

Alternatives	Variable	Coefficient	Relative Difference
0-Vehicle	Base	0	
1-Vehicle	Theta1	-3.06	3.06
2-Vehicles	Theta2	0.79	3.85
3-Vehicles	Theta3	3.97	3.19
4-Vehicles	Theta4	5.92	1.95
5-Vehicles	Theta5	7.43	1.51
6 or more Vehicles	Theta6	8.58	1.15

Source: Model Estimation Results.

- **Household characteristics**. Several household characteristics were used, including the following:
  - Number of **children of driving age** (16+ yrs) segmented by household income;
  - Number of **adult students** (i.e., adults who go to school) segmented by household income;
  - Number of **full time and part time workers** segmented by household income;
  - Number of **non-working adults** and **seniors** segmented by household income;
  - **Household income**;
  - **Household size** and **household composition** indicators (e.g., one person in the household, one adult and one child, etc.)
- **Location attributes** of the household zone include highway and transit accessibility variables and zonal density variables:
  - **Presence of transit stops** within walking distance of the home zone;
  - **Household density**;
  - **Highway accessibility** and **transit accessibility** to employment. These accessibility measures are computed as follows:

    A_i = Accessibility for TAZ_i

    $$A_i = \ln\left(1 + \sum_j \mathrm{TotEmp}_j \cdot \exp\left[\frac{-C \cdot T_{ij}}{\bar{T}}\right]\right)$$

    Where:

    TotEmp_j = Total employment in TAZ_j.

T_{ij} = Peak non-HOV auto travel time or transit time from TAZ_i to TAZ_j.

$$\overline{T} = \frac{\sum_j \sum_i T_{ij}}{\text{Number of zone pairs}}$$

Note: For transit, only pairs with transit connection are counted

$$C = \begin{cases} 10 \text{ for auto accessibility} \\ 15 \text{ for transit accessibility} \end{cases}$$

Acc_i = Ratio of auto accessibility during the peak hours to transit accessibility during the peak hours

$$Acc_i = {}^{A_{i,Auto}}\!\Big/_{1 + A_{i,Transit}}$$

- **Estimation Results.** Some of the key findings of the model estimation are as follows:
  - The theta values increase with the number indicating the lower likelihood of a large number of vehicles available in a household. The increasing thetas decrease the utility of households having access to many vehicles.
  - Higher income households are more likely to have more vehicles.
  - Number of children who are in the driving age group has a positive impact on vehicle availability for households with higher income.
  - The number of part-time or full-time workers correlates to more vehicles. The effect is less pronounced in higher income households suggesting that for the incremental addition of another worker has a smaller impact on auto availability compared to a lower income household.
  - The number or non-workers and driving-age children had a greater impact among higher income households as they have the resources to provide vehicles for household members who do not work.
  - The ratio of transit accessibility to auto (highway) accessibility has the expected effect on the utility. As the transit accessibility increases, the vehicle availability utility decreases.

School Location Model

The school location model assigns children to one of three types of schools – elementary, middle, and high school depending on their age.

Children in the 5–12 year age group were assigned to elementary schools.

Children in the 13-15 year age group could go either to middle or high schools.

Children who are 16 years or older were assigned to high schools only.

- **Explanatory Variables.** The model inputs were the child's age, the home location, and the location of schools in the region. School location data were provided by Metropolitan Council staff. The dataset included location information, as well as the type of school. Schools were assigned to the appropriate model TAZs based on their location. This database does not include information about private schools.

- **Model Structure.** A child's school location was restricted to a set of TAZs within the same school district that contain a school for the appropriate age level. As part of the analysis, TAZs were assigned to school districts based on existing school boundaries. In the future, this information must be updated if the school boundaries are to change. Two methodologies were tested:
  - In the first round of model development, students were assigned to the closest (appropriate) school. When the results of the model were compared with the survey reported distribution of travel distances, it was observed that this simplified model under-reports travel. Therefore, this approach was not used.
  - A more involved methodology was then tested. Under this approach, a list of up to ten of the closest TAZs with "in-district" schools were made available for each student. A 30 percent chance was given to the closest school and the remaining 70 percent was divided among the remaining nine TAZs. The school location was then chosen using a simulation approach based on these pre-determined probabilities. This framework was more suited to replicate observed behavior and was retained within the modeling framework.
- **Alternatives.** Each child has ten TAZs within their school district (with a school appropriate for their age group) as potential alternatives.
- **Estimation Results**. Application of this method resulted in a distance distribution comparable to the one observed in the survey. Overall, elementary students traveled the shortest distance while high school students traveled the farthest.

Pass Models

There are two separate pass models – one each for transit pass ownership and toll transponder ownership.

- During model application, only those individuals who own the toll transponder will be able to use the express lanes when driving in a single occupancy vehicle.
- Similarly, transit pass holders are assigned a zero dollar fare during the tour mode choice model to account for the fact that they have already made the investment to purchase the transit pass.

Model estimation results for both models are discussed below:

- **Model structure**. Both pass models were estimated independently. The structure used for both was a binary logit. "No pass owned" is the base alternative and coefficients estimate the effect of variables on the choice to own a pass. All estimation results for both pass models are presented in the spreadsheet named ***"TBI ABM – Pass Models.xlsx"*.**

- **Alternatives.** As discussed above, the alternatives for these models are –
  - No (do not own a pass)
  - Yes (own a pass)
- **Explanatory Variables** for vehicle availability model included the following:
  - **Household characteristics**. Several household characteristics were used, including the following:
    - » Number of **full time and part time workers**;
    - » **Household income**;
    - » Household has **two or more vehicles**;
    - » Household has **usual workplace(s) in CBD**;
    - » Household has **usual workplace(s) in the suburbs**;
    - » Home is located in the **outer suburbs** (based on TAZ terminal time);
    - » **Presence of transit stops** within walking distance of the home zone;
    - » **Mixed use density** at the home zone which is captured in the form of LN[1 + Mixed Use Density] segmented by household income;
    - » **Automobile accessibility** to employment;
    - » **Transit accessibility** to employment;
    - » **Accessibility** to employment on **MnPASS (tolled) routes:**

      A_i = Accessibility for TAZ_i

      $$A_i = \ln\left(1 + \sum_j \text{TotEmp}_j \cdot \exp\left[\frac{-C \cdot T_{ij}}{\overline{T}}\right]\right)$$

      Where:

      TotEmp_j = Total employment in TAZ_j.

      T_{ij} = Peak non-HOV auto travel time or transit time from TAZ_i to TAZ_j.

      $$\overline{T} = \frac{\sum_j \sum_i T_{ij}}{\text{Number of zone pairs}}$$

      $$C = \begin{cases} 10 \text{ for auto accessibility} \\ 15 \text{ for transit accessibility} \end{cases}$$

      Note: For transit, only pairs with transit connection are counted

      Note: For toll transponder accessibility, the employment in TAZ_j is counted if and only if there is a toll-based roadway connection between TAZ_i and TAZ_j.

- **Estimation Results** for the MnPass model included the following:
  - Transit accessibility to employment negatively correlates to MnPASS ownership.
  - As expected, the impact on MnPass is positive and very strong for a higher degree of automobile accessibility, and even more positive for access to roads that allow the use of toll transponders.
  - Toll transponder ownership is heavily dependent on home and work locations. Households in far-off suburbs with workplaces in the CBD are more likely to have the pass. Those with workplaces in the suburbs are less likely.
  - Higher income and a larger number of workers correlated to higher toll transponder ownership. However, having more than two vehicles, which is more prevalent in wealthier households, dampened this effect.
- **Estimation Results** for the transit pass model included the following:
  - Transit pass ownership is more common among households living in TAZs with higher transit accessibility.
  - The coefficient for automobile accessibility is also positive. While may seem counterintuitive, auto accessibility is highest in areas near the CBD.
  - A home in the outer suburbs also has a positive effect on transit pass ownership.
  - The number of workers in a household increased the likelihood of transit pass ownership especially if those workers were employed part-time.
  - The number of vehicles in the household had a strong impact on transit pass ownership with zero vehicle households being more likely to own a transit pass and households that own 2 or more vehicles were least likely.

3.3 Daily Activity Pattern Models

These models create a differentiation between mandatory tour and non-mandatory travel only for each person type in a household. Seven different person types were modeled, using the sequence listed below, in the daily activity pattern models (DAP).

- Children between six and 15 years old,
- Children 16 years or older,
- Non-working adults,
- Seniors (all individuals 65 years and above),
- Part-time workers,

- Full-time workers, and
- Adult students.

It must be noted that in the DAP model, the patterns of individuals within a household are interrelated. The models are sequenced strategically in application, and each model is applied conditional on the activity patterns of previously simulated household members.

Children are simulated first, since they are dependent on other individuals within the household for travel needs.

Adults are simulated in an order that is most likely responsible for taking care of children.

The model estimation results are shown in the spreadsheet ***"TBI ABM - DAP Models.xlsx"***. The final model specifications were reached by testing a wide range of model variables, nesting structures, availability conditions and model constraints. The types of variables tested included personal and household attributes, travel characteristics, and activity patterns of other persons within a household.

The DAP is a broad characterization of the types of travel an individual undertakes in the day. The choice set includes alternatives defined by the number and the type of mandatory tours in which an individual participates. For individuals who do not have mandatory travel, the only possible alternatives include non-mandatory travel only, stay-at-home, and external travel only. The full set of model alternatives is shown in **Table 3.5**. As one can expect, some alternatives are not available to particular person types.

The last two alternatives (stay-at-home and external travel only) represent options that will generate zero tours in model application. They are modeled explicitly because of the dependencies generated across household members of different person types, particularly the stay-at-home pattern. The non-mandatory travel pattern is basically a separate classification for individuals who do not engage in mandatory tours, but do take non-mandatory tours (e.g., meal, shopping, etc.). For these individuals, this includes the possibility of fully joint tours and/or school escorting tours.

Table 3.5 Alternatives Available by Person Type – DAP Model

DAP Choices	DAP Availability						
	Child 6-15 yrs	Child 16+ yrs	Non-Worker	Senior	Part-Time Worker	Full-Time Worker	College Student
1 Work Tour - No Stops	No	Yes	Yes	Yes	Yes	Yes	Yes
1 Work Tour - 1+ Stops	No	Yes	Yes	Yes	Yes	Yes	Yes
2 Work Tours - No Stops	No	No	No	No	Yes	Yes	No
2 Work Tours - 1+ Stops on one, no stops on other	No	No	No	No	Yes	Yes	No
2 Work Tours - 1+ Stops on both	No	No	No	No	Yes	Yes	No
1 University Tour & 1 Work Tour - No Stops	No	No	No	No	Yes	Yes	No
1 University Tour & 1 Work Tour - 1+ Stops	No	No	No	No	Yes	Yes	No
1 School Tour & 1 Work Tour - No Stops	No	Yes	No	No	No	No	No
1 School Tour & 1 Work Tour - 1+ Stops	No	Yes	No	No	No	No	No
1 University Tour	No	No	Yes	Yes	Yes	Yes	Yes
2 University Tours	No	No	No	No	No	No	Yes
1 School Tour	Yes	Yes	No	No	No	No	No
2 School Tours	Yes	Yes	No	No	No	No	No
Non-Mandatory Travel Only	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Stay-at-Home	Yes	Yes	Yes	Yes	Yes	Yes	Yes
External Travel Only	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Table 3.6 presents the total number of observations available in the survey data set by alternatives available and person type. Key observations include:

- Children who are six to 15 years old had mostly school (mandatory) patterns in comparison to other possible patterns.
- Children how are 16 years or older had a wider variety of possible travel patterns, including work-related travel and more complex tours involving both work and school.
- Non-workers and seniors predominantly had non-mandatory patterns.
- The travel patterns of part-time and full-time workers revolved around work (mandatory) patterns.

Table 3.6 Distribution of Survey by Person Type – DAP Model

DAP Choices	Survey Incidence						
	Child 6-15 yrs	Child 16+ yrs	Non-Worker	Senior	Part-Time Worker	Full-Time Worker	College Student
1 Work Tour - No Stops		4%	7%	1%	25%	36%	2%
1 Work Tour - 1+ Stops		4%	10%	2%	24%	39%	7%
2 Work Tours - No Stops					1%	2%	
2 Work Tours - 1+ Stops on one, no stops on other					1%	1%	
2 Work Tours - 1+ Stops on both						1%	
1 University Tour & 1 Work Tour - No Stops							
1 University Tour & 1 Work Tour - 1+ Stops							
1 School Tour & 1 Work Tour - No Stops		2%					
1 School Tour & 1 Work Tour - 1+ Stops		1%					
1 University Tour					3%	0%	43%
2 University Tours							2%
1 School Tour	68%	44%					
2 School Tours	3%	3%					
Non-Mandatory Travel Only	19%	23%	60%	67%	34%	13%	35%
Stay-at-Home	9%	17%	21%	27%	10%	7%	11%
External Travel Only	1%	2%	1%	2%	2%	2%	1%
Total	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**

Explanatory Variables. Most of these activity pattern models use a multinomial logit structure, with the exception of the model for full-time worker, which uses a nested logit structure. The following variables were used to explain daily activity patterns:

- **Household and person characteristics**
  - Number of household members by person type;
  - Household income;
  - Number of vehicles and vehicle availability for the household;
  - Gender; and
  - Age.

- **Work-location related attributes**
  - Presence of a regular workplace location and
  - Mode choice logsum to regular workplace.
- **Location related attributes of the home**
  - Mixed use density = $\frac{\text{(HH density)}*\text{(Employment Density)}}{\max\left(1,\text{(HH density)}+\text{(Employment Density)}\right)}$
  - Highway accessibility to total employment (A_i), $A_i = \ln\left(1 + \sum_j \text{TotEmp}_j * \exp\left[\frac{-10*T_{ij}}{\overline{T}_i}\right]\right)$, $\text{TotEmp}_j =$ Total employment in zone j, $T_{ij} =$ Travel time from zone i to zone j, $\overline{T}_i = \frac{\sum_j \sum_j T_{ij}}{(\text{number of zones})^2} = 44.2\ (\textit{average value})$
  - Transit accessibility to total employment. (B_i), $B_i = \ln\left(1 + \sum_j \text{TotEmp}_j * \exp\left[\frac{-15*T_{ij}}{\overline{T}_i}\right]\right)$, $\text{TotEmp}_j =$ Total employment in zone j, $T_{ij} =$ Travel time from zone i to zone j, $\overline{T}_i = \frac{\sum_j \sum_j T_{ij}}{(\text{number of zones})^2} = 38.65\ (\textit{average value})$
  - Distance to the nearest external zone.
- **Activity patterns of previously modeled household members.** These variables are critical to the individual's activity patterns, particularly for those household members who are simulated toward the end of the sequence.
  - The activity patterns of children 6 to 15 years old, appear as explanatory variables for each other person type. For children 16 years or older, the activity patterns of children younger than 5 years old appear as explanatory variables, but the activity patterns of other household members do not.
  - At the other end of the spectrum, college students are simulated last, so their activity patterns depend on the activity patterns of all other household members. However, the activity patterns of college students do not affect the choices of other household members.
  - Of particular importance are the activity patterns of children 6 to 15 years old since they are most dependent on adults to meet their travel needs. In addition, these children, particularly the younger ones, must be under constant supervision. Thus, a simulated stay-at-home pattern for young children is very important to understanding the choice of a stay-at-home pattern among adults in the household.

- **Estimation Results**. Key findings of the estimation were as follows:
  - Children 6 to 15 years old were more likely to go to school if there were other children present in the household.
  - Children 16+ years old were less likely to go to school, if there was already a child 6-15 years that had a stay at home or non-mandatory pattern.
  - A child with a stay-at-home pattern increases the propensity for adults to choose the stay-at-home pattern. This effect is even more pronounced for adult working females than for adult working males.
  - The presence of children with non-mandatory or mandatory activity patterns increases the propensity of adults choosing these patterns as well.
  - If any household member has external travel-only patterns, the propensity for subsequent individuals in the household to make external travel-only patterns increases.
  - Absence of a regular workplace was found to significantly decrease the likelihood of work tour generation for part-time and full-time workers.

3.4 TOUR DESTINATION CHOICE MODELS

Destination choice models are developed for each tour purpose except school location and school escorting because school locations were estimated separately using the long-term school location choice model. There are a total of six models, based on travel purpose, defined as follows:

- Individual home-based work;
- Individual home-based university;
- Individual home-based non-mandatory (except escort purpose);
- Individual home-based escorting (except school escort purpose);
- Individual work-based sub-tours; and
- Fully joint home-based non-mandatory tours.

For all the tour destination models, each zone is a candidate destination. The models calculate the probability of choosing a destination TAZ for the primary tour activity given the household location (or work location for the work-based sub-tours).

All of these models are disaggregate multinomial logit models estimated at the individual level. The utility of each destination reflects the attractiveness and density of each zone, its accessibility via different modes, and the level of service. The relative ease to get to the destination, necessity to engage in activities at the destination, and availability of different modes to reach the destination are used as explanatory variables.

Table 3.7 presents the distribution of tours by distance between the home TAZ (or work TAZ) and the primary destination TAZ in the household survey database.

- Tours which are work-based have the shortest distance, since they reflect travel from the workplace to an activity. Nearly 75 percent of the tours are five miles or less.
- Home-based escort and non-mandatory tours also have a majority of primary destinations within 5 miles from home.
- Home-based mandatory tours – work and university – are the most likely to have destinations further from home. Around half of the chosen destinations are more than 10 miles apart.

Table 3.8 presents the distribution of destination choice in the household survey dataset. It shows how many of the 3,030 zones were not visited, visited once, or visited twice. It shows how concentrated destination choice is, not by general area type, but by how many zones get several tours while others get none.

- University tours stand out as having the most zones with no activity. This makes sense as destinations are limited to the areas near the region's universities.
- Home based work and non-mandatory purposes, which have far more tours than the others, have many repeatedly visited zones. Home based work has the most zones with more than 20 visits and these zones probably reflect zones with high employment activity.

Table 3.8 helps illustrate the structure of the choice set, especially in comparison to models like mode choice which have a small number of choices.

Table 3.7 Tour-Length Distribution in the Household Survey

	Drive Alone Distance between Tour Origin and Primary Destination (mi)										
Tour Purpose	**0-5**	**5-10**	**10-15**	**15-20**	**20-25**	**25-30**	**30-35**	**35-40**	**40-45**	**45-50**	**Over 50**
Home-Based Work Tours	25%	23%	18%	13%	9%	5%	3%	1%	1%		1%
Home-based University Tours	35%	21%	14%	10%	9%	4%	2%	2%	1%		2%
Home-based Non-Mandatory Tours	57%	23%	9%	4%	2%	1%	1%				2%
Home-based Escort Tours (No school escorting)	65%	22%	7%	3%	1%						1%
Work-based Sub-Tours	72%	15%	6%	3%	2%						1%
Joint Non-Mandatory Tours	50%	24%	10%	5%	3%	2%	1%	1%			3%

Table 3.8 Frequency of Zone Selection in the Household Survey

	Drive Alone Distance between Tour Origin and Primary Destination (mi)										
Tour Purpose	**0**	**1**	**2**	**3**	**4**	**5**	**6-10**	**10-15**	**16-20**	**Over 20**	**Total**
Home-Based Work Tours	1,293	510	323	207	151	103	244	91	45	63	3,030
Home-based University Tours	2,932	58	16	8	0	6	6	3		1	3,030
Home-based Non-Mandatory Tours	1,004	557	356	244	192	134	218	118	53	54	3,030
Home-based Escort Tours (No school escorting)	2,260	414	201	75	36	24	19		1		3,030
Work-based Sub-Tours	2,549	332	88	31	15	5	6	3	1		3,030
Joint Non-Mandatory Tours	2,088	550	219	81	42	14	31	4		1	3,030

- **Model Structure and Alternatives.** As discussed previously, **e**very internal TAZ in the modeling area is a possible destination choice location. Therefore, the alternatives in the disaggregate MNL-based model are all internal TAZs. The logit structure is shown below where TAZs range from 1 to N (N=3,030) and represent the alternatives under the main root.

- **Explanatory Variables.** The following variables are used in the tour-level destination choice models.
  - **Transportation level of service**
    - **Distance** – This is the round trip (RT) distance from origin to destination plus from destination to origin, derived from the network skims and expressed in miles. To provide a non-linear relationship with distance, logarithmic, square (d2), and cubed (d3) functions of distance are used. The logarithm of distance was calculated as ln(RT distance + 1) to ensure that the program does not attempt to compute the logarithm of zero. The three functions allow for a flexible fitting of distance and were checked to ensure that the resulting utility was negative at all inter-zonal distances.
    - **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 of each zone by different modes and the performance of each mode available to make the trip to the desired destination.
    - **Parking cost**. This reflects the disutility of CBD locations with higher parking cost.
    - **Transit accessibility**. This is a binary variable that indicates the existence of a transit service from the base zone to each zone in the region.
  - **Land use/zonal variables.** Land use variables are computed at the zone level and reflect the attractiveness and level of activity in each zone.
    - **Destination mixed use density**. This variable is defined as the sum of all employment types in the zone, multiplied by the number of households in the zone. It is divided by the sum of all employment types in the zone plus the number of households in the zone plus 1.0.
    - **Intrazonal** indicator. A value of one is used if the destination zone is the same as the home zone, zero otherwise.
    - **CBD** indicator. A value of one is used if the destination zone is in the Central Business District.

   - » **Rural** indicator. A value of one is used if the destination zone is rural.
   - » **University enrollment** within a specified distance of a destination zone.
   - » **Number of households** in the destination zone.
   - » **Retail employment** in the destination zone.
   - » **Non-retail employment** in the destination zone.

- – **Usual work zone location indicator**. A value of one is used if the destination zone is the usual work zone that is obtained from the usual work zone destination choice model, zero otherwise.
- – **Household and person characteristics. C**haracteristics of the household or person/persons taking the tour can be used to segment the zonal and level of service variables. These include worker status, age, household income, household size, vehicle availability, (joint) party composition, and (joint) party size.
- – **Size Function**. Size functions are used to measure the amount of activity that occurs at each destination zone and incorporate it into the utility of each zone. This is similar to the way in which trip attractions are used as a variable in conventional trip distribution models. The size variable is frequently used in destination choice models to account for differences in zone sizes and levels of activity within each zone. The size variables used in these models include: employment (retail and non-retail), area, and number of households. The size function is included in the utility equation of each destination choice (TAZ). A sample functions is shown below:

  Size function = LSM * ln {(non-retail employment) + exp ($coeff_{22}$) * retail employment + exp ($coeff_{33}$) * households}

  where:

  The first size variable, non-retail employment, is the base variable;

  Size variables 2 and 3 are retail employment and number of households;

  $Coeff_{22}$ and $Coeff_{33}$ are coefficients for size variables 2 and 3; and

  LSM is log size multiplier which is a coefficient that is multiplied by the entire size function.

- **Estimation Results**. Key findings include:
  - – Distance is the key level of service variable and has the expected negative effect on the choice of a TAZ as a destination. As the distance between the origin and the primary destination increases, the utility declines gradually.
  - – The distance variable is segmented by a variety of characteristics. In escort tours, household size and age are used as these relate strongly to this activity. In joint tours party size and presence of a child made a difference to how the far the traveler was likely to go.

- In the work model, the "usual workplace" given in the survey is the primary determinant of the choice.
- The mode choice logsums for all models have coefficients that range between 0.5 and 1. This underscores the importance of the level of service that different modes offer in the selection of a particular destination zone.
- The intrazonal dummy variable is negative for all destination choice models in which it is used indicating that for most travel purposes, people tend to travel outside the origin zone probably reflecting the land use patterns in the region.
- Parking cost which is higher in the urban areas and in the CBD was negative counteracting the positive attractions of the high employment in those areas.
- Transit accessibility, which indicates transit-based connectivity of a destination zone, has a positive effect on destination choice.
- The retail employment types were segmented by income (and purpose in the non-mandatory tour purpose) in some models, to account for the relative impact on destination choice.
- The number of households had a weaker effect than employment in the model estimation results.

3.5 Tour Time-of-Day Choice Models

The time of day choice is predicted in 30-minute intervals beginning and ending at 3:00 AM for a total of 48 periods across the day. The models predict, jointly, the time interval an individual arrives at and the time interval an individual departs from (returns from) the primary activity location of the tour. Thus, for each arrival period alternative, there are multiple departure (or return) period options.

For instance, for an arrival in the 8:00-8:30 AM period, one could potentially return at any time interval thereafter up until the last period of the day. Each "arrival/departure" pair represents an alternative. In total, there are 1,176 arrival/departure alternatives for time-of-day choice.

A total of five time-of-day choice models were estimated, based on tour purpose. All tours begin and end at home, except the work-based sub-tours which begin and end at a work location. The modeled tour purposes are defined as follows:

- Home-based work,
- Home-based school/university,
- Home-based non-mandatory and home-based non-school escort,
- Joint non-mandatory tours, and
- Work-based sub-tours.

Table 3.9 and **Table 3.10** present the total number of observations available in the survey data set by time-of-day and by tour purpose.

- As expected, a majority of home-based work tours arrive at their primary destination between 7:00 AM and 9:00 AM and a majority of work tours depart their primary work place between 3:00 PM and 5:00 PM.
- Similarly, most of the home-based school/university tours arrive at their primary destination between 7:00 AM and 8:00 AM while a majority of school/university tours depart between 3:00 PM and 5:00 PM.
- A majority of work-based tours arrive at their destination between noon and 3:00 PM and also depart from their destination between noon and 3:00 PM.
- Home-based non-mandatory and non-school escort tours have a wide spread of arrival times. For example, 9:00-10:00 AM, 12:00 PM-3:00 PM and 5:00-7:00 PM account for most of the arrivals for these tours. Similarly, most of the home-based non-mandatory and non-school escort tours depart between noon and 3:00 PM and between 7:00 and 9:00 PM.

Table 3.9 Distribution of Arrival Times in the Household Survey

Tour Purpose	DAP Availability									
	3-7 AM	7-8 AM	8-9 AM	9-11 AM	11 AM - 12 PM	12-3 PM	3-5 PM	5-7 PM	7-9 PM	9 PM –3 AM
Home-based work	1,726	2,473	2,011	1,153	242	796	248	172	53	65
Home-based school & university	67	886	633	406	30	97	41	78	10	3
Home-based non-mandatory & non-school escort	259	401	606	1,655	890	2,228	1,462	2,029	1,108	201
Joint non-mandatory	22	31	40	209	103	305	219	547	255	24
Work-based	5	9	18	82	216	405	34	10	4	1

- **Model Structure.** The departure and arrival times are modeled jointly using a multinomial logit modeling structure. The modeling approach chosen for these models is as follows:
  - Alternative specific constants are used for combinations of arrival periods, departure periods, and durations. Particularly important periods (such as arrival at work in the AM peak) have constants for specific 30-minute intervals.
  - "Shift effect" variables are used to push arrival times earlier or later and to account for longer or shorter durations of stay. As a result, the departure time period is also shifted accordingly.

Table 3.10 Distribution of Departure Times in the Household Survey

Tour Purpose	DAP Availability									
	3-7 AM	7-8 AM	8-9 AM	9-11 AM	11 AM - 12 PM	12-3 PM	3-5 PM	5-7 PM	7-9 PM	9 PM – 3 AM
Home-based work	58	67	66	189	308	1,265	3,506	2,571	448	461
Home-based school & university	5	2	8	42	57	724	1,115	186	67	45
Home-based non-mandatory & non-school escort	101	231	334	1,253	816	2,399	1,635	1,455	1,704	911
Joint non-mandatory	8	12	30	116	120	300	215	313	470	171
Work-based	4	4	13	45	85	555	52	19	6	1

  - The concept of available time windows for scheduling tours is extensively used. As each tour is simulated, the periods that are used by the tour are made either fully or partially unavailable for any subsequent lower priority tours. At every step of the process, the length of available time windows is calculated and reduced accordingly.
  - Generalized time variables are included to estimate the effects of traffic congestion on time of day choice. It must be noted that the values of time used to convert costs into equivalent minutes are obtained from the tour mode choice models, thereby ensuring consistency in the modeling framework.

- **Alternatives.** The tour arrival and departure time model predicts the time period for arrival at the primary destination of the tour and the time period for departure from the primary destination. There are a total of 48 half-hour intervals for arrival and departure, starting with the 3:00 - 3:30 AM period and ending with the 2:30 - 3:00 AM period the following day. As discussed above, there are 48 x (48+1)/2 = 1,176 possible alternatives.
- **Explanatory Variables.** A series of different variables were tested and used:
  - **Alternative Specific Constants**.
    - » Most arrival and departure time intervals do not have a constant associated specifically to that interval. Instead, groups of 30-minute intervals share arrival and departure constants.
    - » Constants specific to individual time periods are only developed for peak travel periods for each purpose.
    - » Duration constants were included in these models to measure the duration of the primary activity. Based on the activity purpose, the

base duration is the most common duration and it is different for different tour purposes.

- Duration is longer for work and university/school purposes with 9 and 8 hours respectively.
- Non-mandatory activities (individual and joint) have a base duration of 2.5 hours, and work-based activities have a base duration of 30 minutes.
- The bases for each tour purpose were data driven and reflect the category that contained the maximum number of observations.
- Like the arrival and departure constants, some duration constants are combined.
- **Table 3.11** shows how the duration was segmented into multiple categories for each tour purpose.

Table 3.11 Model Segmentation by Duration for different Purposes

Constants	Duration in Hours				
	Home-based Work	Home-based School and University	Home-based Non-Mandatory and School Escort	Joint Non-Mandatory	Work-based
Category 1	[0-3)	[0-3)	0.5	0.5	**0.5 (Base)**
Category 2	[3-6)	[3-6)	1	1	1
Category 3	[6-7)	[6-7)	2	2	1.5
Category 4	[7-8)	7	**2.5 (Base)**	**2.5 (Base)**	[2-4)
Category 5	8	7.5	3	[3-4)	[4-8)
Category 6	8.5	**8 (base)**	3.5	[4-5)	[8-24)
Category 7	**9 (base)**	8.5	[4-5)	[5-6)	
Category 8	9.5	9	[5-6)	[6-9)	
Category 9	10	9.5	[6-8)	[9-12)	
Category 10	10.5	[10-11)	[8-10)	[12-18)	
Category 11	[11-12)	[11-12)	[10-16)	[18-24)	
Category 12	[12-13)	[12-16)	[16-24)		
Category 13	[13-16)	[16-24)			
Category 14	[16-24)				

- **Arrival, Departure and Duration Shift variables.** Two types of "shift" variables were computed:
  - » "Shift earlier" and "shift later" variables measure the difference between the time period indicator (on a scale from 1 through 24 with half hour increments) and the pivot-point.
    - The pivot point for each purpose represents the most likely arrival time period. Similarly, the pivot point for each tour purposes represents the most likely departure time period.
    - "Shift earlier" 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 Earlier" for AM = max(P – T, 0)

    "Shift Later" for AM = max(T – P, 0)

    T = Hour – 1, 2, 3, ……, 24

    P = Pivot-point
  - » Pivot points were chosen by picking the time period that contained the maximum number of observations in the arrival and departure time periods.
  - » For work and school-university tours, P for arrivals was set at 7:30 AM; and the pivot point for non-mandatory tours was set at 10:00 AM.
  - » 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 early", and "shift late" variables. During model estimation, these 'shift' variables were modeled jointly with household and person attributes to assess the effects of individual attributes on time-of-day choice.
  - » Shift variables were interacted with a number of indicator attributes of the tour, person, and household allowing the model to capture the effect of these attributes on time-of-day choice.
    - "Shift earlier" arrival variable with a positive coefficient would indicate that individuals of that type are more likely to arrive earlier, all else being equal.
    - Similarly, "shift later" arrival variable with a positive coefficient would indicate that individuals of that type are more likely to arrive later, all else being equal.
- **Congestion Delay Variables**. The delay variable represents the level of congestion computed as a function of the time traveled in the chosen period and the free flow travel time. The greater the difference between

the congested travel time (AM, PM Peak) and free flow travel time (Off-peak), the greater the congestion effect:

» Delay Ratio = (30 - minimum(Congested time – Free flow time, 30))/30

» The delay variable is then interacted (multiplied) with the "shift earlier" and "shift later" variables to estimate the propensity for persons to shift AM peak arrivals and PM peak departures away from the peak of the peak.

"Shift Earlier" than Peak of Peak = max(P – T, 0)

"Shift Later" than Peak of Peak = max(T – P, 0)

AM Peak: T = Hour – 6.5, 7, …, 8.5; P = 7.5

PM Peak: T = Hour – 15.5, 16, …, 18; P = 17

» 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)

– **Time Window Variables.** These variables were derived from the amount of time available after the person's daily activity pattern is simulated. This gives an indication of the time available to participate in other activities and the propensity to either arrive at or depart late from primary destinations. Variables related to time window characteristics include:

» Total available time remaining;

» Available time remaining if other non-mandatory tours have yet to be scheduled (applies to individual non-mandatory tours only);

» Arrival period partially used; and

» Departure period partially used.

– **Auto Generalized Time.** This is the drive-alone generalized travel time. Costs are converted to travel time using values of time that differ by tour purpose and are consistent with the mode choice model from origin to destination and back.

– **Household and Person Characteristics.** Several household and person characteristics were used to interact with the shift variables. The reason is that different types of area residents are more likely to arrive earlier or later based on their characteristics. Market segments reflect these variables:

   - » Full-time workers;
   - » Part-time workers;
   - » Adult students;
   - » Seniors;
   - » Non-workers;
   - » Household income;
   - » More than one mandatory tour in the person's daily activity pattern;
   - » Gender; and
   - » Number of children in the household.

  - Different types of dummy variables were used related to arrival time, departure time and duration in the individual and joint non-mandatory tour models to capture differences by tour purpose. The reason for including these variables is that longer or shorter activity duration affects the time-of-day choice decision. These include:
    - » 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 hours), and
    - » Escort with different durations (0.5, 1, 1.5, 2 hours).

- **Estimation Results.** Key findings from the tour time-of-day choice models are listed here. A detailed output of the model estimation results is available in the spreadsheet titled ***"TBI ABM – Tour Time-of-Day Choice Models.xlsx".***
  - » The duration "shift earlier" variable interacted with full-time worker had a large negative value, indicating that, all else being equal, full-time workers are less likely to stay at work for shorter durations.
  - » The arrival shift variables for workers 35 years or older was positive in the work time of day choice model. This indicates that commuters in this age group seemed to prefer earlier arrivals.
  - » The available time window remaining had a large positive and significant effect on time-of-day choice for individual non-mandatory and non-school escort tours. Respondents with more time available preferred to choose alternatives with greater duration. This also suggests that more time spent engaging in one activity limits the time remaining for other activities including at-home activities such as eating and sleeping. Individuals adjust their arrival and departure times accordingly.
  - » The higher the level of congestion, the greater was the likelihood of either arriving earlier or later than the peak of the peak period, when the congestion is the highest.

- » Similarly, on the return half-tour, there was a strong propensity to depart later than the peak of the peak period. These patterns reflect the "peak spreading" effects and are as expected.
- » As expected, the generalized times for auto were negative. This indicates that as travel times increase for certain arrival and departure time period combinations, the preference to choose that alternative decreases.
- » The arrival and departure variables specific to children with school tours were all positive for the 7:30 - 8:30 AM and 2:30 - 3:30 PM time periods. These variables were introduced to provide levers during validation to match adults' work tours with children school tours.

3.6 SCHOOL ESCORTING

The school escorting model captures the choice of whether a child taking a school tour is escorted to school by other members in the household (or not), and if so, by whom.

- The alternatives in the model include the no escort alternative, and each "available" adult in the household.
- Adults are split into two groups:
  - Adults who could perform the escorting task as a stop on a previously generated mandatory tour (e.g., drop child off at school on the way to work).
  - Adults who could perform the escorting task as a stand-alone tour.

There are a number of availability conditions that must be processed in order to generate the choice set for each school tour. For adults with mandatory tours, the timing of the mandatory tour (which is simulated prior to school escorting) must meet two conditions for the adult to be considered available for escorting as part of the mandatory tour.

- First, the adult's mandatory activity must begin after the school activity (on outbound journey to school) or end before the school activity ends (on return journey from school). If this condition is not met, the adult is not considered a viable escort candidate.
- Second, the adult's mandatory activity must begin or end within 3 half-hour periods of the start or end of the school tour. If this condition is not met, the adult can still be considered a viable escort candidate, but only in the stand-alone school escorting category, not as part of the adult's mandatory tour.
- Only if both conditions are met is the adult considered a candidate for school escorting as part of the mandatory tour.

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 escort choice and return escort choice.

- **Alternatives.** Modeled alternatives include:

  (a) "not escorted" alternative,

  (b) up to three escort alternatives by an adult as part of a mandatory tour, and

  (c) Up to three escort alternatives by an adult as part of a stand-alone school escort tour.

  There are a total of up to seven potential alternatives for both the outbound and return escort choice, for a total of 49 joint alternatives, as shown in **Table 3.12** below.

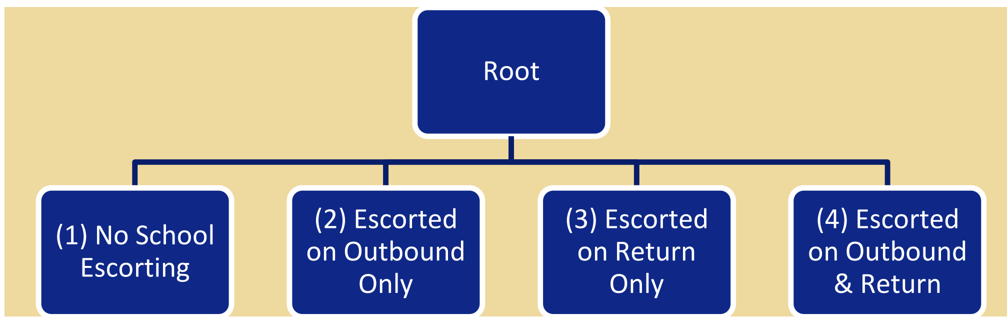
- In most cases, there will be far fewer than 49 alternatives because fewer than three adult candidates exist in the household for either escorting type.

Table 3.12 School Escorting Model Alternatives

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

- **Model Structure**. The model uses a nested logit structure.
  - The first nest includes only alternative 49 – not escorted on either half-tour.
  - The second nest includes alternatives 7, 14, 21, 28, 35, and 42 – escorted on outbound but not escorted on return.
  - The third nest includes alternatives 43 to 48 – not escorted on outbound but escorted on return.
  - The last nest includes all other alternatives with escorting on both the outbound and return half-tours.

Figure 3.8 School Escorting Model Structure



- **Explanatory Variables** used in the school escorting model included:
  - **Alternative Specific Constants.** Alternative specific constants were defined for each alternative escorting type combination. As noted above, there are three escorting types: mandatory tour, stand-alone escort tour, 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 were used, including the following:
    - » Gender;
    - » Person type (full-time worker, part-time worker, senior);
    - » Full- or part-time worker over 50 years (but less than 65 years);
    - » Daily activity pattern of the adult; and
    - » Indicator variable with a value of 1 if the alternative uses the same adult on outbound and return half-tours.
  - **Level-of-Service Attributes.**
    - » Transit accessibility indicator between home and school.

- **Child Characteristics**
  - » Age of child taking the school tour.
- **Household and Land Use Characteristics** included**:**
  - » Mixed use density = $\frac{(\text{HH density})*(\text{Employment Density})}{\max(1,(\text{HH density})+(\text{Employment Density}))}$;
  - » Presence of child less than 5 years in household with stay-at-home daily activity pattern;
  - » Household vehicle sufficiency indicators; and
  - » Income.

- **Model Estimation Results** were as follows:
  - Younger children are more likely to be escorted while older children are less likely to be escorted.
  - Travel time for home to school or as a detour on the route to work were not a factor in the choice of whether to escort. Detour times were small for nearly all adults who were available to escort on the way to work and as such this deviation in travel time had a low impact on the model estimation results. Similar findings hold true for stand-alone escorting tours.
  - Households with fewer vehicles than workers are less likely to take a trip solely to escort children to/from school.
  - Females were more likely to escort children to/from school than males.
  - Full- and part-time workers were more likely to escort children, especially as part of mandatory tours. Seniors are less likely to escort children.
  - Higher utilities were associated with alternatives where the same adult escorted the child to/from school on both outbound and return half-tours than all other alternatives.

3.7 FULLY JOINT TOUR MODELS

Fully joint tours are tours made jointly by two or more individuals from the same household. Each facet of the tour is common to all participating individuals including tour purpose, number of stops, the purpose of each stop, activity location for each stop, timing of each stop, and mode choice for each trip made on the tour. The fully joint tour model consists of two submodels:

- Tour generation at the household level which simulates the number and purpose of joint tours for a household; and
- Tour participation at the individual level which simulates which household members will participate in each joint tour.

- For purposes of the Metropolitan Council activity based model system, only joint tours with non-mandatory purposes are modeled. **Table 3.13** presents the total number of observations available in the survey data set by alternatives available.
  - There were 5,395 non-mandatory tour records that come from the set of households that have two or more persons with active daily activity patterns (i.e., mandatory and/or non-mandatory).
  - A majority of the households report no joint tours (74 percent). The households that do report joint ravel (26 percent) do so across several different tour types. The data suggest that one joint tour is more common among households than two or more joint tours. This is a function of the time budget that every individual in a household has available.

Table 3.13 Fully Joint Tour Participation Alternatives Observed in Household Survey Dataset

Constants	Availability				
	Maintenance Tour	Shopping Tour	Meal Tour	Discretionary Tour	Survey Frequency
No Joint Tour	0	0	0	0	4,035
1 Maintenance Tour	1	0	0	0	196
1 Shopping Tour	0	1	0	0	317
1 Meal Tour	0	0	1	0	195
1 Discretionary Tour	0	0	0	1	450
2 Maintenance Tours	2	0	0	0	11
2 Shopping Tours	0	2	0	0	14
2 Meal Tours	0	0	2	0	4
2 Discretionary Tours	0	0	0	2	46
1 Maintenance, 1 Shopping Tour	1	1	0	0	16
1 Maintenance, 1 Meal Tour	1	0	1	0	6
1 Maintenance, 1 Discretionary Tour	1	0	0	1	21
1 Shopping, 1 Meal Tour	0	1	1	0	19
1 Shopping, 1 Discretionary Tour	0	1	0	1	46
1 Meal, 1 Discretionary Tour	0	0	1	1	19

- **Model Structure.** The modeling framework is only applied to households with at least two members. Model estimation results can be accessed using the spreadsheet "*TBI ABM – Fully Joint Tour Models.xlsx*".
  - Household members were sequenced strategically for estimation and application based on person type. The sequence was based on which individual would be most likely be willing to participate in a joint tour. Hence, adult students and workers come towards the end of the sequence.
    - » Non-working adult (most likely to participate in joint tours);
    - » Senior;
    - » Child 6-15 years;
    - » Child 16 or more years;
    - » Part-time worker;
    - » Full-time worker; and
    - » Adult student (least likely to participate in joint tours).
  - The joint tour generation model is estimated on and applied for all households where two or more household members have an active daily activity pattern choice (i.e., a mandatory or non-mandatory travel pattern from the activity patterns model).
  - The participation model follows the following principles:
    - » It includes two alternatives for each household member: participate in a joint tour and not participate in a joint tour.
    - » The participation model is estimated and applied for all members of households where the household consists of three or more household members with active daily activity pattern choices. For households with only two members, the joint travel is assigned to both members automatically.
    - » No strict requirements were enforced to ensure that the model application results 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 is re-run until a valid tour is constructed.
- **Explanatory Variables -** ***Fully Joint Tour Generation*** include the following:
  - **Household and Person Characteristics**
    - » Number of household members by person type and activity pattern;
    - » Household income;
    - » Number of vehicles and vehicle availability for the household; and
    - » Household composition (i.e., number of children in household).

– **Location Attributes of the Household Zone.** These variables include highway and transit accessibility variables and zonal density variables:

» Highway accessibility to total employment (Ai):

$A_i = \ln\left(1 + \sum_j TotEmp_j * \exp\left[\frac{-10*T_{ij}}{\overline{T}_i}\right]\right)$

$TotEmp_j$ =Total employment in zone j

T_{ij} = Travel time from zone i to zone j

$\overline{T}_i = \frac{\sum_j \sum_j T_{ij}}{(\text{number of zones})^2} = 44.2$ (average value).

» Transit accessibility to total employment (B_i):

$$B_i = \ln\left(1 + \sum_j TotEmp_j * \exp\left[\frac{-15 * T_{ij}}{\overline{T}_i}\right]\right)$$

$TotEmp_j$ =Total employment in zone j,

T_{ij} = Travel time from zone i to zone j

$\overline{T}_i = \frac{\sum_j \sum_j T_{ij}}{(\text{number of zones})^2} = 38.65$ (average value).

» Distance to the nearest external zone.

– **Time Window Overlaps across Household Members.** These variables are critical in defining the amount of time available for two or more household members to 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.

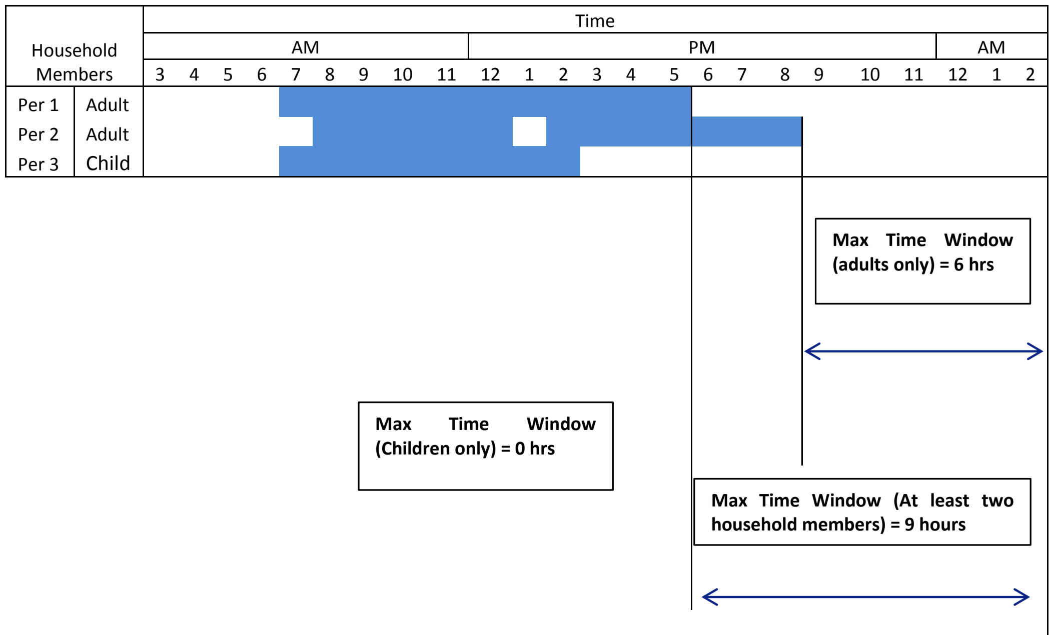
» **Figure 3.9** below illustrates how these time window overlaps are computed in a simple case with two adults and one child with each adult having a mandatory tour and one of the adults having a second mandatory tour. Maximum time over adults is computed by comparing the free available time between any two adults.

- In this example the time window is 6 hours from 8:30 PM to 2:30 AM. Because person 2 is busy from 5:30 PM to 8:30 PM in another activity the common available time is from 8:30 PM to 2:30 PM.

» Since there is only one child in the household, the maximum time window overlap across children is zero hours. The third time window component is computed by comparing two individuals within a household.

- In the example below, the maximum time window between any two individual occurs between person 1 and person 3 who are free to participate in joint tours from 5:30 PM to 2:30 AM.

Figure 3.9 Maximum Time Window Example



- **Explanatory Variables -** ***Fully Joint Tour Participation*** include the following:
  - **Household and person characteristics**
    - » Number of household members by person type;
    - » Household income;
    - » Number of vehicles and vehicle availability for the household; and
    - » Household composition (i.e., number of children in household).
  - **Joint Tour Composition.** Several variables defining the composition of the joint tour and its attributes were also defined, including the following:
    - » Number and type of household members already simulated to participate in joint tour;
    - » Indicators for whether the joint tour members include only household members having mandatory patterns or only household members having non-mandatory patterns;
    - » Maximum time window remaining if the person chooses to participate in the joint tour;

A "joint tour size ratio" variable. The purpose of this variable is to encourage participation the closer the simulation gets to last individual in household, in cases where the tour does not have at least two members set to participate already. It is expressed as follows:

max(0, [2 – joint tour size before simulated person] /

[Number of remaining candidates in household]).

- **Estimation Results - *Fully Joint Tour Generation.*** Some of the key findings of the joint tour generation model estimation are as follows:
  - » Zero-car households are less likely to generate joint tours.
  - » As the number of household members with no scheduled tours increases, there is a greater propensity for that household to generate joint tours.
  - » As the number of full-time and part-time workers with non-mandatory patterns increases, the likelihood of joint tour generation also increases.
  - » Transit accessibility had a positive correlation with generation of joint tours.
  - » Highway accessibility had a positive correlation with generation of meal-based joint tours.
  - » Maximum time window overlaps had a positive correlation on the generation of joint tours. This result is intuitive as it increases the propensity to go on joint tours as more time becomes available during the day.
- **Estimation Results - *Fully Joint Tour Participation.*** Some of the key findings of the joint tour participation model estimation are as follows:
  - » Individuals with mandatory daily activity patterns are less likely to participate in joint tours.
  - » Individuals with two mandatory tours are even less likely to participate in joint tours.
  - » Children between 6 and 15 years are more likely to participate in a joint tour as long as other children within the household have already been assigned to the tour.
  - » Participation is less likely for individuals with mandatory patterns if the joint tour composition includes 1 or more individuals with non-mandatory patterns and no individuals with mandatory patterns.

3.8 Individual Non-Mandatory Tour Generation Model

The individual non-mandatory tour generation model predicts the number and type of individual non-mandatory tours for each individual in the population. This model is a function of the number of available time windows, number of mandatory and joint tours already simulated, whether there was only one partially coordinated tour simulated implying the need to pick-up or drop-off through an escort tour, accessibility to various types of employment, and other household and person attributes. There are a total of 56 possible alternatives for this model. These include a combination of tours described hierarchically:

- Meal tours;
- Shopping tours;
- Maintenance tours;
- Escort tours; and
- Discretionary tours.

The possibilities are zero, one, two, or three tours of each type. In the survey dataset, the following selections shown in **Table 3.14** were observed. Three key elements worth noting include the following:

- Many individuals report no non-mandatory travel during the day (42 percent). Of the remaining, a significant number report one non-mandatory tour (40 percent). Two non-mandatory tours (13 percent) and three non-mandatory tours (four percent) are considerably less likely.
- The one-tour alternatives are either discretionary, maintenance of shopping purpose related with very few meal and escort tours.
- Most of the two-tour alternatives are shopping and discretionary related.

Table 3.14 Distribution of Survey Data by Alternatives

No Tours	7,603
1 Maintenance Tour	1,628
1 Shopping Tour	1,868
1 Meal Tour	727
1 Discretionary Tour	2,616
1 Escort Tour	385
2 Maintenance Tours	140
2 Shopping Tours	142
2 Meal Tours	29
2 Discretionary Tours	311
2 Escort Tours	86
1 Maintenance & 1 Shopping Tour	213
1 Maintenance & 1 Meal Tours	116
1 Maintenance & 1 Discretionary Tours	325
1 Maintenance & 1 Escort Tours	72
1 Shopping & 1 Meal Tour	126
1 Shopping & 1 Discretionary Tour	449
1 Shopping & 1 Escort Tour	113
1 Meal & 1 Discretionary Tour	150
1 Meal & 1 Escort Tour	30
1 Discretionary & 1 Escort Tour	102
3 Maintenance Tours	15
3 Shopping Tours	11
3 Meal Tours	1
3 Discretionary Tours	32
3 Escort Tours	14
2 Maintenance & 1 Shopping Tour	25
1 Maintenance & 2 Shopping Tours	20
2 Maintenance & 1 Meal Tours	14
1 Maintenance & 2 Meal Tours	6
2 Maintenance & 1 Discretionary Tours	32
1 Maintenance & 2 Discretionary Tours	44
2 Maintenance & 1 Escort Tours	12
1 Maintenance & 2 Escort Tours	17
2 Shopping & 1 Meal Tours	19
1 Shopping & 2 Meal Tours	15
2 Shopping & 1 discretionary Tours	47
1 Shopping & 2 Discretionary Tours	67
2 Shopping & 1 Escort Tours	21
1 Shopping & 2 Escort Tours	22
2 Meal & 1 Discretionary Tours	7

No Tours	7,603
1 Meal & 2 discretionary Tours	37
2 Meal & 1 Escort Tours	3
1 Meal & 2 Escort Tours	5
2 Discretionary & 1 Escort Tours	33
1 Discretionary & 2 Escort Tours	18
1 Maintenance, 1 Shopping & 1 Meal Tours	14
1 Maintenance, 1 Shopping & 1 Discretionary Tours	46
1 Maintenance, 1 Shopping & 1 Escort Tours	14
1 Meal, 1 Shopping & 1 Discretionary Tours	40
1 Meal, 1 Shopping & 1 Discretionary Tours	11
1 Meal, 1 Escort & 1 Discretionary Tours	12
1 Meal, 1 Escort & 1 Maintenance Tours	5
1 Maintenance, 1 Meal & 1 Discretionary Tours	18
1 Maintenance, 1 Escort & 1 Discretionary Tours	46
1 Shopping, 1 Escort & 1 Discretionary Tours	43

- **Explanatory Variables.**
  - **Household and person characteristics**
    - Number of household members by person type;
    - Household income;
    - Number of vehicles and vehicle availability for the household;
    - Gender;
    - Age; and
    - Presence of children.
  - **Location Attributes of the Household Zone.** These variables include highway and transit accessibility variables and zonal density variables:
    - Mixed use density that includes information from both activity zone as well as adjacent zones = $\frac{(\mathbf{HH\ density})*(\mathbf{Employment\ Density})}{\max(\mathbf{1},(\mathbf{HH\ density})+(\mathbf{Employment\ Density}))}$;
    - Highway accessibility to total employment (A_i):

      $A_i = \ln\left(1 + \sum_j TotEmp_j * \exp\left[\frac{-10*T_{ij}}{\overline{T}_i}\right]\right)$

      $TotEmp_j$ =Total employment in zone j,

      T_{ij} = Travel time from zone i to zone j

      $\overline{T}_i = \frac{\sum_j \sum_j T_{ij}}{(\text{number of zones})^2}$ = 44.2 (average value).

» Transit accessibility to total employment (B_i):

$$B_i = \ln\left(1 + \sum_j \text{TotEmp}_j * \exp\left[\frac{-15 * T_{ij}}{\overline{T}_i}\right]\right),$$

TotEmp_j =Total employment in zone j,

T_{ij} = Travel time from zone i to zone j

$$\overline{T}_i = \frac{\sum_j \sum_j T_{ij}}{(\text{number of zones})^2} = 38.65 \text{ (average value)}.$$

– **Tour Level Attributes.** A number of tour-level attributes and outputs from the daily activity patterns model and tour-level models are used in this model. These variables affect the propensity to make individual non-mandatory tours:

» Number of available (half-hour) time periods left in the day;

» Presence of school escorting tours;

» Number of workers and non-workers with non-mandatory daily activity patterns;

» Number of fully joint tours; and

» Number of work tour with stops.

- **Estimation Results**. Key findings of the model are as follows:

– Household income plays a significant role in the generation of non-mandatory tours with higher income households more likely to generate non-mandatory tours.

– As the number of children in the household with mandatory patterns increase, there are more escort tours, but fewer shopping and meal tours. This probably is due to the fact that there is not much time left to make such tours or someone else in the household (e.g., non-workers) are making such tours.

– As the number of workers with non-mandatory patterns increase, there is increased generation of non-mandatory tours.

– One person households have a greater propensity to make discretionary tours.

– Zero-children households make more non-mandatory tours overall, but far fewer escort and discretionary tours.

– Zero car households make fewer non-mandatory tours than households with cars.

– Mixed use density at the home zone has a positive influence in the generation of individual non-mandatory tours due the availability of opportunities to shop and eat closer to home.

  - As the total number of half-hour time periods left in the day increase, there is a higher chance of generating more non-mandatory tours.
  - As the maximum time window available increases, there is a greater propensity for one or more non-mandatory tours.

3.9 Work-Based Sub-Tour Generation Models

The work-based generation model predicts the number and type of work-based sub-tours for each home-based work tour (referred to as the "parent tour") simulated in the daily activity pattern model.

- This model is only estimated and applied for workers that make at least one mandatory work tour during the day.
- This model is a function of several "parent tour" attributes including:
  - The timing and duration of the parent work tour and the number of stops made on the parent tour;
  - The distance from the home to the workplace;
  - The number of other tours that have been previously simulated for the person;
  - Accessibility and household measures also impact the sub-tour generation model including:
    - » Highway accessibility;
    - » Worker type (full-time or part-time); and
  - Other household and person attributes.
- The type of sub-tours include work-based shop, work-based maintenance, work-based meal and work-based discretionary. In total, there are 20 alternatives for this model and up to two tours by purpose are permitted. The selection of feasible alternatives was driven by the findings from the household survey (**Table 3.15**).
- Key findings include:
  - Most survey data were in the zero tours category (86 percent) suggesting that a majority of workers make no work-based tours during the day.
  - Most work based sub-tours were meal based.
  - One work-based sub-tour was observed among 13 percent of workers while two work-based sub-tours are extremely uncommon (1 percent).

- **Explanatory Variables**. The following variables were used in the work-based tour generation model:
  - **Household and Person-level Characteristics.**
    - » Full-time worker/part-time worker;
    - » Household income;
    - » Gender; and
    - » Presence of children.

Table 3.15 Distribution of Survey Data by Alternatives

Choices	Availability						
	Maintenance Tour	Work Tour	Shopping Tour	Escort Tour	Meal Tour	Discretionary Tour	Survey Frequency
0 Tours							4,489
1 Maintenance Tour	1						90
1 Discretionary Tour						1	80
1 Meal Tour					1		301
1 Shopping Tour			1				89
1 Work Related Tour		1					112
1 Escort Tour				1			9
1 Meal, 1 Maintenance Tour	1				1		6
2 Work Tours	0	2					9
2 Maintenance Tours	2						1
1 Meal, 1 Escort Tour				1	1		2
1 Meal, 1 Work Related Tour		1			1		6
1 Shopping, 1 Meal Tour			1		1		8
2 Shopping Tours			2				2
2 Meal Tours					2		2
1 Meal, 1 Discretionary Tour					1	1	3
1 Work, 1 Maintenance Tour	1	1					3
1 Maintenance, 1 Discretionary						1	3
1 Work, 1 Discretionary Tour		1				1	2
1 Work, 1 Escort Tour		1		1			2

  - **Location Attributes of the Household Zone.** These variables include highway and transit accessibility variables and zonal density variables:
    - » Distance from home to work; and

  » Highway accessibility to total employment (Ai):

  $$A_i = \ln\left(1 + \sum_j \text{TotEmp}_j * \exp\left[\frac{-10 * T_{ij}}{\bar{T}_i}\right]\right)$$

  TotEmp_j =Total employment in zone j

  T_{ij} = Travel time from zone i to zone j

  $$\bar{T}_i = \frac{\sum_j \sum_j T_{ij}}{(\text{number of zones})^2} = 44.2 \text{ (average value).}$$

- **Tour Level Attributes.** These variables affect the propensity to make work based tours:
  - » Indicator variable for persons who have two mandatory tours in a day;
  - » Number of school escorting tours and work tours already simulated;
  - » Number of half-hour periods earlier than noon that the parent tour (home-based work) departs;
  - » Number of half-hour periods later than noon that the parent tour (home-based work) arrives;
  - » Indicator variable for a drive alone mode in the parent tour (home-based work); and
  - » Indicator variable for parent tour (home-based work) mode as shared ride 2 or 3+.

- **Estimation Findings**. Key findings from the model are as follows:
  - The propensity to make shopping related sub-tours was much less for full time workers when compared to part-time workers;
  - The propensity to make shopping related sub-tours was much less for men when compared to women.
  - Individuals from high income households were more likely to make work based sub-tours than lower income workers. This was especially true for work-related sub-tours.
  - As the travel distance increases from home to work, the propensity to make work based sub-tours goes down. This could be due to the fact that there is less time left to participate in sub-tours with increasing commute distances (or times).
  - The number of meal and maintenance sub-tours increases with improved auto accessibility to retail and non-retail employment.
  - The number of half-hour periods before noon from the time the parent tour departs has an adverse effect on the generation of sub-tours. The same is true for the number of half-hour periods after noon that the parent tour arrives. This suggests that individuals with regular 8:00 a.m. to 5:00 p.m. workdays are the ones that are most likely to generate work-based sub-

tours. Those leaving from work before noon or arriving at work after noon are less likely to have work-based sub-tours.

- The number of shopping and meal based sub-tours increases when the primary mode is drive alone.

3.10 Intermediate Stop Generation Models

The intermediate stop generation models estimate the number of intermediate stops by purpose (i.e., excluding the primary activity for the tour) for each tour in the simulated daily activity patterns.

- For all home based tours, separate models were estimated for the home to the primary activity half-tour and for the primary activity to home half-tour.
- For the non-school escort model, we have a joint model for modeling stops on the entire tour due to data constraints.
- A total of eleven stop generation models were estimated, based on tour purpose, and are defined as follows:
- Home based work - Individual,
  - Outbound tour
  - Return tour
- Home based school/university - Individual,
  - Outbound tour
  - Return tour
- Home based non-mandatory and home based school escort - Individual,
  - Outbound tour
  - Return tour
- Home based non-school escort - Individual,
  - Outbound and return tour
- Joint non-mandatory tours,
  - Outbound tour
  - Return tour
- Work-based sub-tours – Individual
  - Outbound tour
  - Return tour

It must be noted that in the tour mode choice models, the school escort and non-school escort tours were modeled together. However, in the stop generation models, the school escorting models were combined with the non-mandatory tours to be consistent with the tour hierarchy discussed in **Table 3.16**, especially given that intermediate stops are generated based on this hierarchy.

Table 3.16 Tour Purpose Hierarchy

	Tour purpose
Higher Priority	Work
	School (K-12)
	Higher Education
	School Escort (Parent's tour)
	Joint Non-Mandatory
	Maintenance (Personal Business)
	Shopping
	Eating Out
	Discretionary (Social/Recreational)
	Chauffeur (Escort)
	Work-based

A majority of observations in the household survey fall in the zero-stop alternative. **Table 3.17** presents the frequency distribution of the number of stops in the household survey. There are two key elements worth noting:

- **Home-based Work Tours**. Home based work stop generation models take into account only those records where number of stops are greater than zero on the outbound and return half-tours. The stop generation models for other tour purposes take into account all half-tours regardless of whether stops are being made. This is done because the daily activity pattern model estimates the probability of zero stops being made on either half-tour in a home based work tour. This is why the number of observations available for model estimation in home based work stop generation model is much lower than the data available for model estimation in home based work mode choice model.
- **Differences in Usable Records for Outbound vs. Return Half-Tours**. The availability criteria for all tour purposes (by direction) assumes that the number of stops being made in the outbound or return tour directions cannot be greater than the number of periods available for travel in that direction. This results in slightly different numbers of usable records for the outbound and return directions for the same tour purpose.

Table 3.17 Frequency Distribution of Number of Stops in Survey Data

Tour Purpose	Direction	Number of stops 0	1	2	3	Total
Home based work	Outbound tour	2,382	1,417	454	245	4,498
	Return tour	1,053	2,023	811	613	4,500
Home based school & university	Outbound tour	1,944	211	56	0	2,211
	Return tour	1,715	307	191	0	2,213
Home based non-mandatory & school escort	Outbound tour	7,025	1,954	651	401	10,031
	Return tour	6,919	1,957	678	479	10,033
Home based non-school escort	Outbound & Return tour	872	106	32	0	1,010
Joint non-mandatory	Outbound tour	1,335	306	111	0	1,752
	Return tour	1,365	261	123	0	1,749
Work based	Outbound tour	697	87	0	0	784
	Return tour	695	89	0	0	784

- **Explanatory Variables**. Several different variables were used in the model estimation procedures:
  - **Alternative Specific Constants**. Most of the variables in the models are alternative specific constants. The constants should be viewed differently than they would be in a model with fewer alternatives, such as a mode choice model.
    - » Rather than estimate different alternative-specific constants for each alternative, we took advantage of the fact that the alternatives are combinations of stop types. This procedure is extremely helpful when there are limited observations for certain alternatives.
    - » The constants reflect characteristics of multiple alternatives such as the number of total stops and the presence of specific combinations of stop purposes (for example, "2+ Meal Stops," "1+ Shopping & 1+ Chauffeur Stop"). This allows the model to reflect the commonalities among the alternatives. Each alternative, therefore, can have several constants associated with it.
    - » For example, the utility for the alternative with one work stop, one meal stop, and one shopping stop includes all the following constants:
    - » 3 Stops, 3 Stops - 3 Different Stop Purposes, 1 Work Stop, 1+ Work & 1+ Meal Stop, 1+ Work & 1+ Shopping Stop, 1 Meal Stop, 1+ Meal & 1+ Shopping Stop and 1 Shopping Stop.
  - Household and Person Characteristics. Many socio-demographic variables describing the characteristics of the traveler or his/her household

were included. Examples of such variables include vehicle availability, income, worker status, age characteristics and gender.

- Other variables used in model estimation included:
  - Round Trip Auto Travel Distance;
  - Mixed-Use Density at Destination;
  - Employment Density at Destination;
  - Arrival time (for the outbound half-tour) or departure time (for the return half-tour) – These variables are indicator variables for whether the primary activity begins or ends in various time periods (before 9:00 a.m., 9:00 a.m. to noon, etc.);
  - Duration of primary activity;
  - Daily activity pattern variables such as presence of non-mandatory tours, number of other tours by purpose and joint tours, and whether there is school escorting on each half-tour; and
  - 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 the end of a previous tour's primary activity or the start of the day (3 am). For the return half-tour, these variables indicate the number of 30-minute intervals between the end of the primary work activity and the start of a subsequent tour's primary activity or the end of the day (3 am). 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.
  - For the return half-tour, we also used the number and purpose of stops on the outbound half-tour.

Table 3.18 Variables Used in the Different Stops Models

	Round Trip Auto Travel Distance	Mixed Density	Employment Density	Arrival Time *(outbound)* Departure Time *(return)*	Duration of Primary Activity	Daily Activity Pattern Variables	Available Periods	# of stops and Purpose of stops on outbound tour *(return tour only)*
Home-based Work Tour	✓	✓	✓	✓	✓	✓	✓	✓
Home-based School & University Tour	✓	✓	✓	✓	✓	✓	✓	
Home-based Non-Mandatory & School Escort Tour	✓	✓	✓	✓	✓	✓	✓	
Home-based Non-School Escort Tour	✓	✓			✓	✓	✓	
Joint Non-Mandatory Tour	✓	✓	✓	✓	✓	✓	✓	
Work-based Tour	✓	✓			✓	✓	✓	

- **Structure -** ***Home-based Work Tour Stop Generation.*** There are seven types of stop purposes including work, meal, shopping, maintenance, discretionary, escort, and University (no school). Based on a careful examination of the household survey data, the number of stops on each half-tour was limited to three. There are potentially 120 alternatives available for stop generation:
  - One with zero stops;
  - Seven with one stop (one for each purpose);
  - 28 with two stops (21 of each possible two-purpose combination, plus seven with two stops of the same purpose);
  - 84 with three stops (42 with two stops of one purpose and one of another, 28 with three stops all with different purposes, and seven with three stops of the same purpose);
  - A total of 32 of these potential alternatives were eliminated due to no records or very low incidence in the household survey data set:
    - » Any tour with 3 stops, at least one of which is University (28 alternatives);
    - » Three Meal stops (1 alternative);
    - » Three Social/Recreation stops (1 alternative);
    - » One Work stop, one University stop (1 alternative); and
    - » Two University stops (1 alternative).

  Figure 3.10 shows the final model structure of the home based work stop generation model.

- **Structure -** ***Home Based School-University Tour Stop Generation.*** The alternatives for this model are defined by the number of stops by available activity purpose. There are seven types of stop purposes for the School-University purpose. These include school, meal, shopping, maintenance, discretionary, escort, and University. Based on the analysis of the household survey data, the number of stops on each half-tour was limited to two. There are potentially 35 alternatives available for the stop generation model:
  - One with zero stops;
  - Seven with one stop (one for each purpose); and
  - 27 with two stops (20 of each possible two-purpose combination, plus seven with two stops of the same purpose).

  Figure 3.11 shows the final model structure of the home based school & university stop generation model.

Figure 3.10 Home-based Work Tour Stop Generation Model Structure

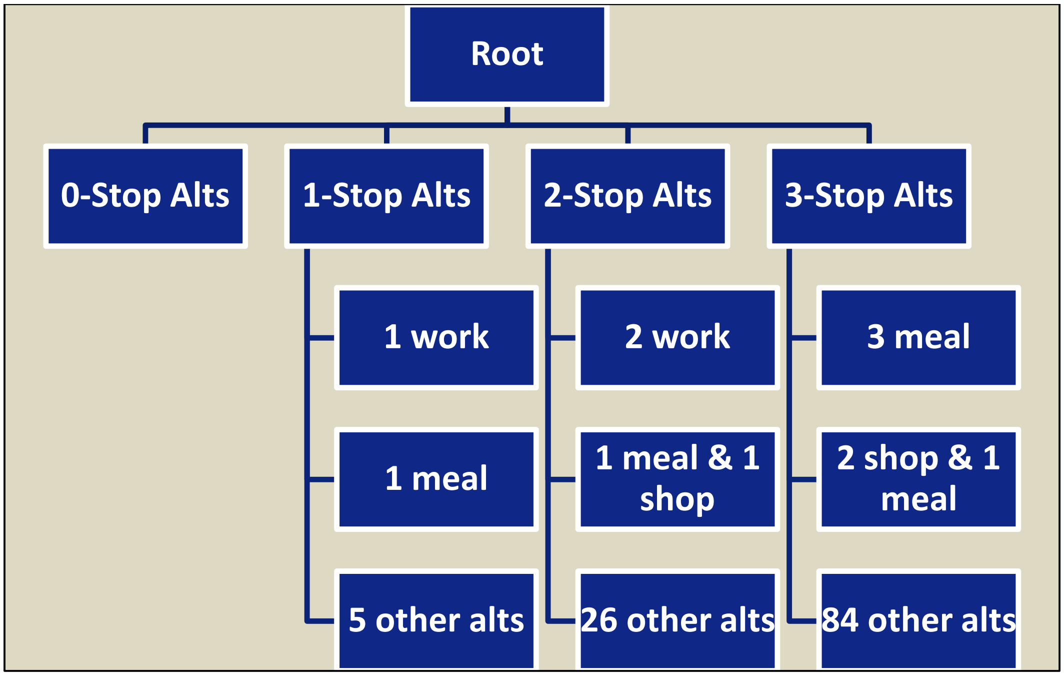
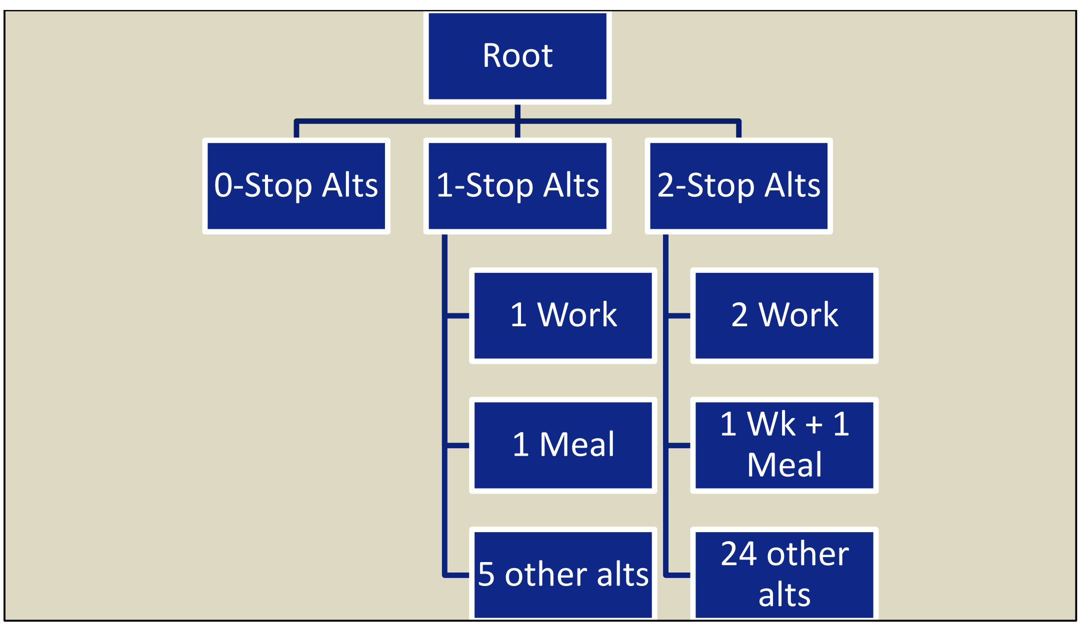


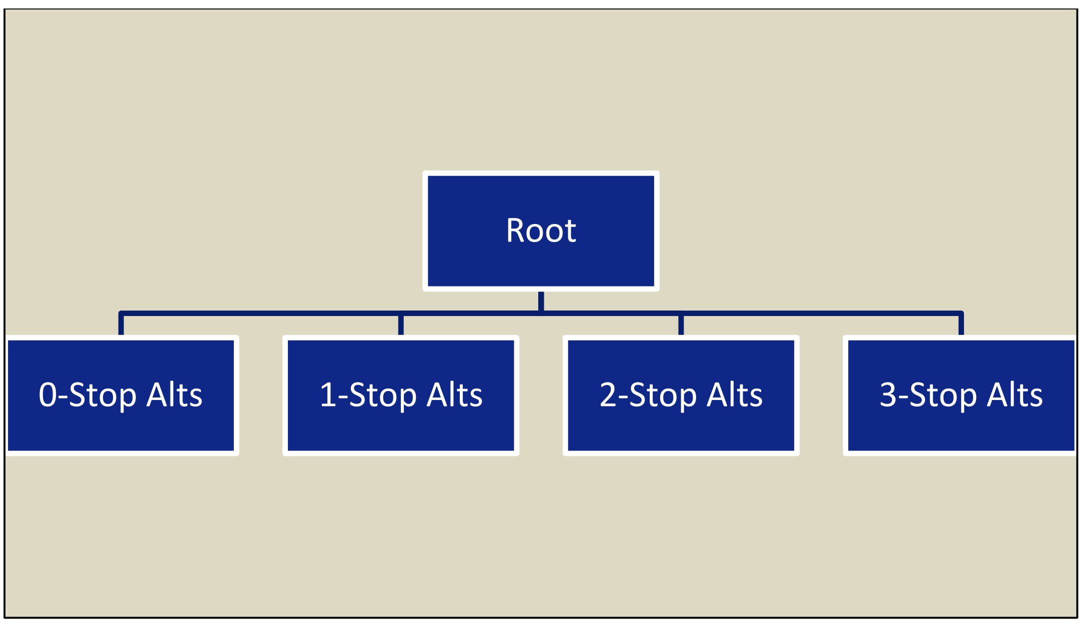
Figure 3.11 Home Based School & University Tour Stop Generation Model Structure



- **Structure -** ***Home Based Non-Mandatory & School Escort Tour Stop Generation.*** As before, the alternatives for this model are defined by the number of stops by available activity purpose. There are five types of stop purposes for the non-mandatory and school escorting purposes. These include meal, shopping, maintenance, discretionary and escort stops. Based on a careful examination of the household survey data, the number of stops on each half-tour was limited to three. There are potentially 55 alternatives available for stop generation:
  - One with zero stops;
  - Five with one stop (one for each purpose);
  - 15 with two stops (10 of each possible two-purpose combination, plus 5 with two stops of the same purpose);
  - 34 with three stops (30 of each possible two-purpose combination, plus 4 with two stops of the same purpose); and

  Figure 3.12 shows the final model structure of the home based non-mandatory & school escort tour stop generation model.

Figure 3.12 Home Based Non-Mandatory & School Escort Tour Stop Generation Model Structure

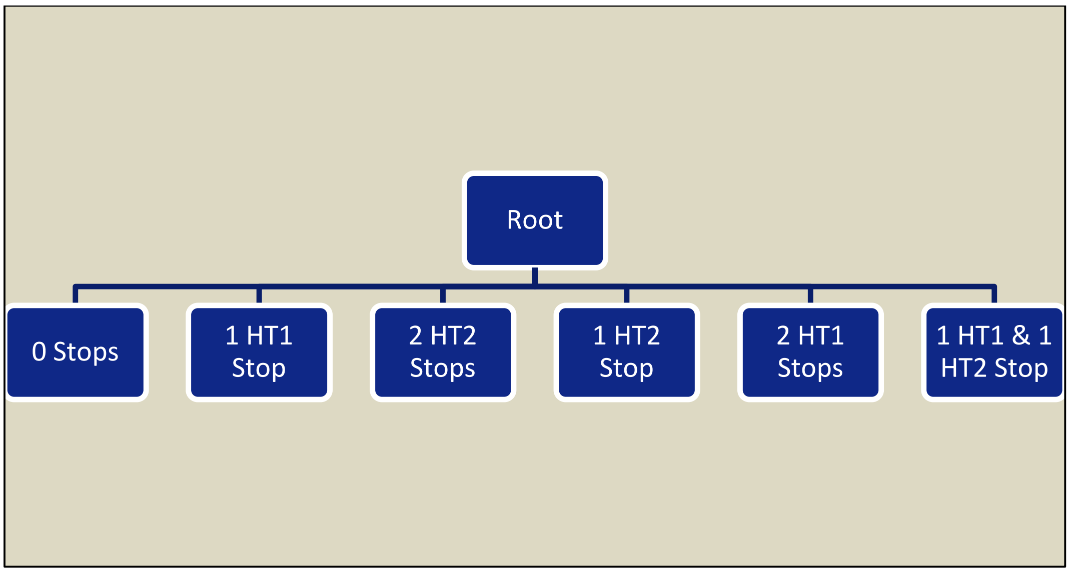


- **Structure -** ***Home Based Non School Escort Tour Stop Generation.*** As before, the alternatives for this model are defined by the number of stops by available activity purpose. There is just one available stop purpose (escorting) for this model. Based on an analysis of the household survey data, the number of stops on each half-tour was limited to two. There are potentially six alternatives available for stop generation:

- One with zero stops;
- Two with one stop (outbound/return); and
- Three with two stops.

Figure 3.13 shows the final model structure of the home based non-school escort tour stop generation model.

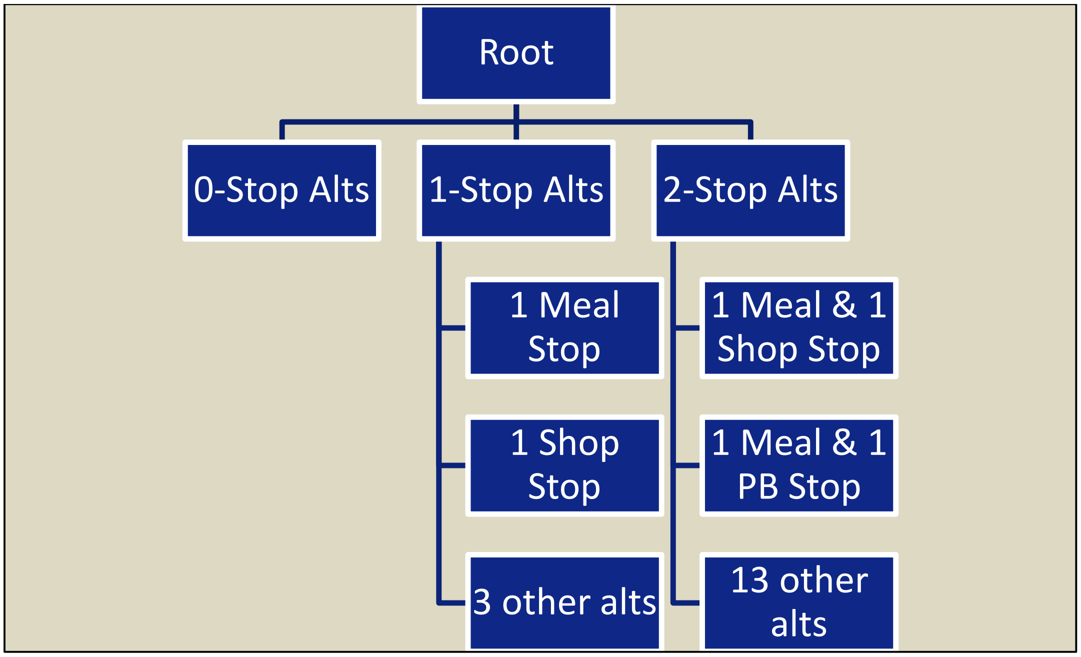
Figure 3.13 Home Based Non School Escort Tour Stop Generation Model Structure



- **Structure - *Joint Non-Mandatory Tour Stop Generation.*** As before, the alternatives for this model are defined by the number of stops by available activity purpose.
  - There are five available stop purposes for this model. These include: meals, shopping, maintenance, discretionary and escort. Based on the household survey data, the number of stops on each half-tour was limited to two.
  - There are potentially 21 alternatives available for stop generation:
    - One with zero stops;
    - Five with one stop (for each stop purpose); and
    - 15 with two stops (10 of each possible two-purpose combination, plus 5 with two stops of the same purpose).
  - One variable unique to the joint tours was traveling party size. This variable was not used in any other stop generation model.

  Figure 3.14 shows the final model structure of the joint non-mandatory tour stop generation model.

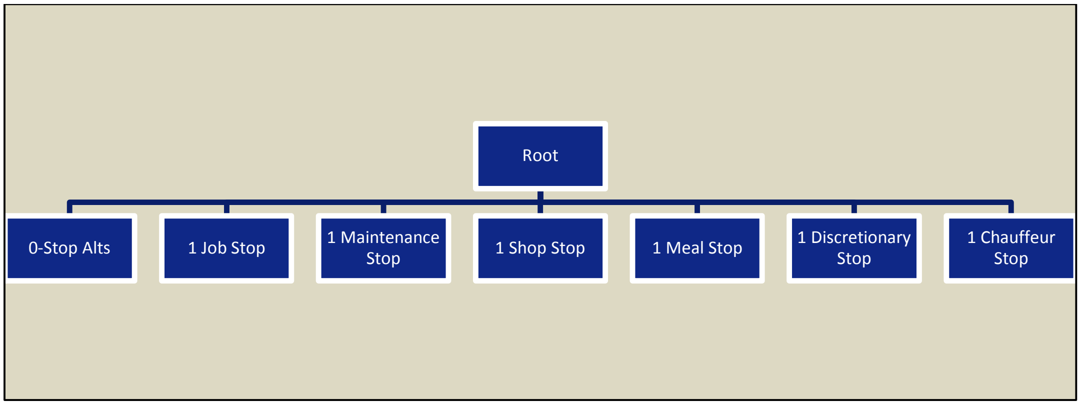
Figure 3.14 Home Based Joint Non-Mandatory Tour Stop Generation Model Structure



- **Structure - Work Based Sub-Tour Stop Generation.** As before, the alternatives for this model are defined by the number of stops by available activity purpose. There are six available stop purposes for this model. These include: work, maintenance, shop, meal, discretionary and escort. Based on a careful examination of the household survey data, the number of stops on each half-tour was limited to one. There are potentially seven alternatives available for stop generation:
  - One with zero stops and
  - Six with one stop (for each stop purpose).

  Figure 3.15 shows the final model structure of the work based sub-tour stop generation model.

Figure 3.15 Work Based Sub-Tour Stop Generation Model Structure



- **Estimation Results** for each tour stop generation model are presented below**.** Detailed estimation results may be obtained from the spreadsheet titled ***"TBI ABM – Stop Generation Models.xlsx"***.
- **Estimation - *Home-based Work Tour Stop Generation.*** There are many differences between the travel behavior on the outbound and return half-tours. Many variables appear for only one half-tour although for most variables that appear in both half-tours, the signs of the coefficients are the same reflecting the observed behavior from the survey. Key findings include:
  - » There were more stops on the return half-tour than on the outbound half-tour as reflected in the larger negative constants on the outbound half-tour for one stop, two stops and three stops.
  - » Longer travel distances to the primary destination usually resulted in more stops.
  - » A larger number of available time periods also resulted in more stops.
  - » Longer primary work activities resulted in tours with fewer stops.
  - » Being without a car increased the number of stops for the outbound and return half-tours. Limited auto availability most likely forces travelers to combine their stops when they leave the house.
  - » Men were less likely to make stops compared to women.
  - » Presence of stops on the outbound tour made individuals less likely to make additional stops on the return tour.
- **Estimation - *Home-based School and University Tour Stop Generation.*** There are many differences between the travel behavior on the outbound and return half-tours. Many variables appear for only one half-tour although for most variables that appear in both half-tours, the signs of the coefficients are the same. Other key findings include:

  - » There were more stops on the return half-tour than on the outbound half-tour as reflected in the larger negative constants on the outbound half-tour for one stops and two stops.
  - » Longer travel distances to the primary destination usually resulted in more stops.
  - » More available time periods also resulted in more stops.
  - » Individuals on a university tour were less likely to make stops overall, but were more like to make meal and discretionary stops.
  - » Men were less likely to make stops compared to women.
  - » Individuals were more likely to make stops if their departure time was before 9 AM.
  - » Presence of stops on the outbound tour made individuals less likely to make additional stops on the return tour.

- **Estimation - *Home-based Non-Mandatory and School Escort Tour Stop Generation.*** Again, there were more stops on the return half-tour than on the outbound half-tour as reflected in the larger negative constants on the outbound half-tour for one, two, and three stops.
  - » Limited car availability decreased the number of non-mandatory stops for the outbound and return half-tours.
  - » Longer travel distances to the primary destination generated more non-mandatory stops as did a larger number of available time periods.
  - » Men were less likely to make all kinds of non-mandatory stops.
  - » Seniors were less likely to make stops on discretionary and maintenance tours.
  - » Individuals were less likely to make stops if their arrival times were before 9 AM.
  - » Presence of stops on the outbound tour made individuals less likely to make additional stops on the return tour.
  - » It should be noted that the coefficients should be viewed differently than they would be in previous models. In this case, they reflect characteristics of *multiple tour purposes and stop types* such as "1+ Shopping Stops on Maintenance Tours" or "1+ Maintenance Stops on Discretionary Tours".

- **Estimation - *Home-based Joint Non-Mandatory Stop Generation.*** Some of the key findings of the model are as follows:
  - » There were more stops on the return half-tour than on the outbound half-tour as reflected in the larger negative constants on the outbound half-tour for one or more stops constants.

- » As the tour party size increases, the group is less likely to make stops.
- » Longer travel distances to the primary destination were likely to result in additional stops.
- » A larger number of available time periods was likely to result in a larger number of stops.
- » If a group is made up only of men, then it was less likely to make stops.
- » A group made up only of seniors was less likely to make stops.
- » Groups were less likely to make stops in zones with a lower employment density.
- » Presence of stops on the outbound tour made individuals less likely to make additional stops on the return tour.

– **Estimation - *Work-based Sub-Tour Stop Generation Models*.** Unlike the home-based tours, this model one focused on stops generated during the sub-tours originating at work. Key findings include the following:

- » There were more stops on the return half-tour than on the outbound half-tour as reflected in the stop constants.
- » Lower income households were less likely to make stops.
- » Longer travel distances to the primary destination were likely to result in more stops.
- » More available periods were likely to result in more stops.
- » If a group was made up only of men, it was less likely to make stops.
- » If a group was made up only of seniors, it was less likely to make stops.
- » Groups were less likely to make stops as the employment density in a zone decreased.
- » Presence of stops on the outbound tour made individuals less likely to make additional stops on the return tour.

3.11 Stop Destination Choice Model

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 destination choice model, the following information is known about the tour:

- The home location of the traveler;
- Tour-level information about the primary activity including tour purpose, tour location, tour start, and tour end time periods;
- The chosen tour mode; and

- The number and purpose of stops generated on each half-tour including both the outbound and return ones.

The objective of the stop destination choice model is to simulate the location of each of the stops generated as part of the stop generation model.

- 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, this means that stops are modeled in reverse chronological order.
  - For return stops, this means that stops are modeled in chronological order.
  - In sub-tours with multiple stops, the location of a second stop is simulated based on the simulated location of the first stop (rather than the location of the primary activity) and the home location. The location of the third stop is simulated based on the simulated location of the second stop and the home location.
- The main approach is similar to that used for tour destination choice. Size variables are defined similarly to those used in tour destination choice to reflect the amount of activity within a zone and the attractiveness of the zonal destinations. The main differences are the following:
  - The ***"detour generalized accessibility"*** and ***"detour distance"*** represent new concepts. They are used instead of the direct home-to-activity location time and distance and serve impedance measures. They reflect the additional distance caused by a detour to visit an additional stop.
  - A single model is used for stop destination choice, rather than separate models by activity purpose although some model parameters vary by stop activity purpose.
- **Model Structure.** The model is structured as a 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. The last simulated activity could be either the primary tour activity or another stop on the same half-tour between the primary activity and the stop activity currently being simulated. Every internal TAZ in the modeling area is a possible stop destination choice location. Therefore, the set of alternatives consists of all internal 3,030 TAZs.
- **Explanatory Variables.** The following variables are used in the stop destination choice models:
  - **Size Functions.** 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 include 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 such as distance, intrazonal indicator, and mixed density;

Coeff1, Coeff2, Coeff3 are their coefficients;

Size function = LSM * ln {(non-retail employment) + exp ($coeff_{22}$) * retail employment + exp ($coeff_{33}$) * households}

where:

The size variables include non-retail employment as the base variable, retail employment, and number of households;

$Coeff_{22}$ and $Coeff_{33}$ are coefficients for size variables 2 and 3; and

LSM is log size multiplier which is a coefficient that is multiplied by the entire size function.

– **Transportation Levels of Service.** Several variables describing accessibility and impedance measures are used in the models.

  » **Detour Distance**. The objective of this variable is to calculate the *additional* distance due to an intermediate stop compared to the original distance between the origin and the destination of a tour. This is calculated as:

  - the distance from the home location to the destination
  - <u>Plus</u> the distance from destination to primary activity location
  - <u>Minus</u> the direct distance from home to primary activity location.

  The distance is derived from the highway network skims and expressed in miles. To provide a non-linear relationship with distance, a logarithmic function of distance is used. The logarithm of distance was calculated as ln(detour distance + 1), to ensure that the program does not attempt to compute the logarithm of zero. The detour distance variable is segmented by tour mode. Additional additive detour distance segmentation variables were introduced based on half-tour (outbound or return), stop purpose, tour purpose, and person/household characteristics.

  - **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. We call this an accessibility measure because we multiplied the travel time components by corresponding travel time coefficients.

    For the home-based school and university tours and the individual escort tours, this variable is the sum of in-vehicle travel time and twice the out-of-vehicle travel time, multiplied by the in-vehicle time coefficient from the tour mode choice model.

    For home-based work, individual non-mandatory (non-escort), and work-based tours, this variable is the sum of in-vehicle travel time and two and half times the out-of-vehicle travel time multiplied by the in-vehicle time coefficient from the tour mode choice model.

    Since the in-vehicle time coefficients are negative, the values of the detour generalized accessibility are always negative. The times are derived from the highway and transit network skims.

  - **Transit Availability**. This variable is binary and takes a value of one if transit is available to get to/from destination zone, and zero otherwise.

- **Household and Person Characteristics.** A few household and person characteristics were tested, sometimes as segmentation variables. The worker type (full-time, part-time, or non-worker) was used to segment the size variable and also detour distance for work tours. Household income level was used to segment the size variable for work tours (for full-time workers) and also the detour distance.

- **Land use/Zonal Variables.** Land use variables were computed at the zone level.

  - **Intrazonal Indicator**. A binary intrazonal indicator was used. This variable has a value of one if the destination zone is the same as the previously modeled zone (following the order described above), and zero otherwise.

  - **Base Zone Indicator**. This binary indicator had a value of one if the destination zone was the same as the base zone, and zero otherwise.

  - **University Enrollment** in a zone.

  - **Employment by Type**. Employment at the workplace zone was broken down by retail and non-retail. The coefficients of the employment variables were estimated specific to market segments defined by household income level and worker status.

- **Tour and Stop Characteristics.** The following tour and stop characteristics are used in segmentation for detour distance and generalized time, size variables, and the "other" variables described below:

  - » Tour purpose (work or non-work, fully joint or not), for detour distance and intrazonal indicators;
  - » Stop purpose for the detour distance and size variables;
  - » Tour mode for the detour generalized time and distance;
  - » Presence of additional stops to be modeled for the detour distance; and
  - » The stop purpose that was used to further segment the detour distance and size variables.

- – **Other Variables.**
  - » Some intrazonal indicator variables were used, reflecting whether the stop location is in the same zone as the tour's base (home or workplace for a work-based sub-tour). In some cases, additional segmentation reflects whether the stop being modeled was the last on the half-tour to be simulated.
  - » When the tour mode is transit, an indicator variable was used to indicate whether there is a valid transit path to and from the zone given the anchor locations.

- **Estimation Findings.** Some of the key estimation findings are as follows:
  - – The detour distance coefficients were negative for all tour modes, indicating that stop locations with longer detour distances were less likely. These effects were expected and were similar across most stop purposes. University stops were less affected by detour distance compared to meal and shopping stops.
  - – The detour generalized accessibility coefficients were (additively) positive for all tour purposes. This indicates that stop locations with better detour accessibilities were more likely. The work and fully joint tours were less sensitive, as indicated by their coefficients, which reduce the positive effect of stop accessibility.
  - – On work tour stops, the detour distance tends to be a greater deterrent, suggesting that the stops on the way to and from work were planned around the work location.
  - – The intrazonal variables indicate that shopping stops were likely to occur in the same TAZ as the other activities on the tour. The base size variable for all work stops was chosen to be zonal population.
  - – Employment had a more positive effect on the work stops of full-time workers than part-time workers. The effect was stronger for full-time workers from higher income households.
  - – Retail employment predictably had the greatest effect on shopping stops, with meal stops close behind and maintenance above the rest.

- University enrollment contributed to the choice of location for stops on a university tour or for a university purpose. Neither employment type had much effect on university stops.
- Escort stop location had a fairly low relationship to retail and non-retail employment. The contribution of zonal population was more of a factor than for other purposes.

3.12 STOP TIME-OF-DAY CHOICE

Time of day choice is predicted in 30-minute intervals (48 periods across the day) beginning and ending at 3:00 AM. 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 (arrival time) if the stop occurs on an outbound half-tour. The time period corresponds to the activity end time (departure time) if the stop occurs on a return half-tour.

The arrival and departure times of the tour's primary activity would have already been modeled when the stop time of day choice is applied in the model chain. Thus, the difference between stop start time and primary activity start time (outbound tour) or between stop end time and primary activity end time (return tour) represents the duration of that stop including the travel time between activity locations. An outbound stop must occur earlier than the primary activity arrival time and a return stop must occur later than the primary activity departure 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. For outbound stops, this means that stops are modeled in reverse chronological order. For return stops, this means that stops are modeled in chronological order. In such cases, the timing of the second stop would be bounded by the arrival/departure time of the time period of the first stop (rather than that of the primary activity). Also, the timing of the third stop would be bounded by the arrival/departure time of the time period of the second stop.

In addition to knowing the primary activity's start and end times, the start and end times of other tours for an individual are also known when the stop time-of-day choice is applied. The timing of these other tours bound the available timing of stops from the opposite direction.

The difference between the 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 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 somewhat aggregate, 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. The choice of a specific mode's skims to use in such cases is yet unknown.
- Third, given the first two items, implementation of such requirements could be rather complicated.
- Finally, inconsistencies would be rather rare, in general, and there are a few variables in the model specification that work to discourage these potential inconsistencies.

Table 3.19 presents summaries from the household survey dataset by time periods A majority of the outbound stops occur in the AM periods (7:00 AM to 11:00 AM) while a majority of the return stops occur in the PM (Noon to 7:00 PM).

Table 3.19 Trip Time-of-Day Choice Data Statistics

Tour Purpose	DAP Availability									
	3-7 AM	7-8 AM	8-9 AM	9-11 AM	11 AM - 12 PM	12-3 PM	3-5 PM	5-7 PM	7-9 PM	9 PM – 3 AM
Outbound Stops	629	1,197	1,102	1,760	809	1,700	662	741	254	31
Return Stops	14	32	81	550	616	2,527	2,991	2,947	1,555	801
Total	643	1,229	1,183	2,310	1,425	4,227	3,653	3,688	1,809	832

- **Explanatory Variables** used in the Stop Time-of-Day choice models include:
  - **Stop Duration Constants**. The constants are defined by the implied duration of the stop time period, measured in 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.
    - » For all half-tour stops, nine constants are specified. The first five relate specific durations of one, two, three, four or five half-hour periods. The

last four consider groups of durations: six to seven periods, eight to 10 periods, 11-15 periods, and 16 or more periods.

» 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 3.20** 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 pm period.
- The second example shows the duration shifts for a return half-tour stop with primary activity ending in the 5:30-6:00 pm period.

» Finally, a second shift variable indicates the remaining number of available periods if the time period was chosen. This is essentially the inverse of the duration shift.

- In the first example above, the duration shift variable increases from zero to 21 as the stop period changes from the 4:00-4:30 period to the 2:30-3:00 am period. The remaining number of available periods would decrease from 21 to zero over these same alternatives. In other words, if the stop ended in the 2:30-3:00 am period, there would be no remaining available alternatives in the day (since the day ends at 3:00 am).

– **Tour Characteristics.** Several tour characteristics were used to interact with the stop duration variables. These include:

» Tour purpose;

» Stop purpose;

» Tour arrival period (if stop is on half-tour 1);

» Tour return period (if stop is on half-tour 2);

» Tour duration;

» Tour mode;

» Travel distance; and

» School escorting.

– **"Period Partially Used" Variables.** Two variables were used to indicate if the stop time of day alternative was shared with a previous tour's end time or a subsequent tour's arrival time. In cases where this occurs, it is referred to as the period being partially used.

Table 3.20 Duration Shift Examples

Alternative	Example 1 Shift	Example 2 Shift
3:30 PM – 4:00 PM	0	0
4:00 PM – 4:30 PM	0	0
4:30 PM – 5:00 PM	1	0
5:00 PM – 5:30 PM	2	0
5:30 PM – 6:00 PM	3	0
6:00 PM – 6:30 PM	4	1
6:30 PM – 7:00 PM	5	2
7:00 PM – 7:30 PM	6	3
↓↓		
2:30 AM – 3:00 AM	21	18

- **Estimation Results.** Key findings of the model estimation are as follows:
  - Stop durations on work and university (mandatory) tours were longer than stops made on non-mandatory tours.
  - The distance between the stop location and subsequent/previous activity decreased the utility for very short duration stops, which makes sense when considering that stop duration implicitly includes travel time.
  - Detour distance was found to have an incrementally positive effect on utilities as stop duration increases.
  - Very short duration tours (less than 1.5 hours at primary activity) and very long duration tours (over 8 hours at primary activity) had a negative effect on stop duration. Both make sense for different reasons. 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. However, a very long duration tour means that a large chunk of the day has already been used up.
  - 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.
  - 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 first half-tour, meal, shopping, maintenance, and discretionary stops tend to be made without children.

- However, non-school escort stops tend to be made with children which is most likely a result of adults picking up or dropping off children from other households at their homes as part of the escorting activities.

3.13 Trip Mode Choice

Prior to the application of the trip mode choice model, the following information is known about the tour:

- Home location of the traveler;
- All information about the primary activity including tour purpose, primary destination location, tour start and end time periods and chosen tour mode;
- Information about intermediate stop activities including number of stops, purpose of stops, location of the stops, and the start and end time periods for activities at each stop; and
- Number of children escorted on each trip.

The objective of the trip mode choice model is to simulate the mode for each trip between the home (the workplace for work-based sub-tours), the primary activity, and intermediate stops.

- The tour mode choice determines the available trip mode alternatives. A single model is used for trip mode choice, rather than separate models by activity purpose.
- For school escorting tours, tour mode choice is not run. No tour mode is assigned for children that are escorted on either half-tour. For these tours, trip mode choice is applied only for half-tours that are not escorted. For the trips on the non-escorted half-tour, all modes are available, subject to the general mode availability requirements (walk access to transit within the required distance, drive alone available only for those 16 or older, etc.).
- Mode availability for trip mode choice depends on the chosen tour mode, as shown in **Table 3.21**.

Table 3.21 Trip Mode Alternatives Available by Tour Mode

Available Trip Mode	Tour Mode							
	Drive to Transit	Walk to Transit	School Bus	Shared Ride 3+	Shared Ride 2	Drive Alone	Bike	Walk
Drive to Transit	✓							
Walk to Transit	✓	✓						
School Bus		✓	✓					
Shared Ride 3+	✓	✓	✓	✓				
Shared Ride 2	✓	✓	✓	✓	✓			
Drive Alone	✓	✓		✓	✓	✓		
Bike	✓	✓	✓	✓	✓		✓	
Walk	✓	✓	✓	✓	✓			✓

Some key trip mode choice application rules include the following:

- If the tour mode is not simulated for any trip on a tour during model application, then the mode for this trip will be assumed to be the tour mode and the trip mode choice model will not be applied for this last trip.
- Drive alone mode is not available to persons under age 16 for all tour purposes.
- 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 are known as the fully joint tour model has been run prior to trip mode choice.
- Transit walk access is not available for escort tours.
- Each transit mode (auto access, walk access) is available only if there is an in-vehicle time (non-zero, non-null) in the skim matrix for the zone pair corresponding to the trip for that access mode.
- Transit auto access is not available for work-based sub-tours or joint, school or escort tours.
- School bus is available only for trips with one end at school that are part of a school tour.
- Bike is not available for trips longer than 15 miles and walk is not available for trips longer than 5 miles.
- Bike is not available for work-based sub-tours.
- The survey dataset is summarized in **Table 3.22** for trip mode selection. As is the case for the tour mode choice dataset, nearly 90 percent of all trips are made using auto (DA, SR2, and SR3+). Transit makes up about 2.3 percent of all trips, with walk and bike together accounting for about 5.5 percent of all trips.

Table 3.22 Distribution of Survey Data by Trip Mode

Total Trips	70,834	100%
Drive to Transit	229	0.3%
Walk to Transit	1,419	2.0%
School Bus	2,216	3.1%
Shared Ride 2	14,851	21.0%
Shared Ride 3+	9,689	13.7%
Drive Alone	38,552	54.4%
Bike	993	1.4%
Walk	2,885	4.1%

- **Explanatory Variables.** The following variables were used in the model:
  - **Household and Person Characteristics.** Indicator variables were tested for selected household and person characteristics expected to influence mode choice. These include:
    - » Number of household members by person type;
    - » Household income;
    - » Vehicles and vehicle availability for the household;
    - » Gender; and
    - » Age.
  - **Tour and Stop Characteristics.** The following tour and stop characteristics were found to affect trip mode choice during the estimation process:
    - » Tour purpose;
    - » Number of trips on half-tour;
    - » Sequence of the trip on the half-tour (first or last trip);
    - » Whether the previous trip purpose is escort; and
    - » Group size of fully joint tour.
  - **Transportation Level of Service Variables.** The generalized accessibility variable that includes the weighted effects of in-vehicle time, out-of-vehicle time, and cost were included 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 relationship between the in-vehicle time and out-of-vehicle time coefficients, which are preserved for the trip mode choice model.

» This 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 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 between $50,000 and $75,000, the generalized accessibility is given by:

*0.0088 * (in-vehicle time + 2.5*out-of-vehicle time + 5.58*cost)*

The coefficient of cost in this formula (5.58) is the cost coefficient in the tour mode choice utility function (-0.0491) divided by the travel time coefficient (-0.0088).

- **Model Estimation Results**. The model structure used a multinomial logit model with a choice set that was constrained by modal selection at the tour level. 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 discretionary tour purpose indicator variable has a relatively high coefficient estimate (1.390) for walk to transit. However, it is important to note that this mode is available only on tours that have already been assigned a transit tour mode. The interpretation of this coefficient estimate is not that persons on discretionary tours are more likely to use transit than other modes in general; but rather that the likelihood of a person using transit for a particular trip is greater among discretionary tours with a transit tour mode than other tour purposes with a transit tour mode.
  - The coefficients for employment density for the transit modes are positive, indicating a higher propensity for transit use in dense urban areas.
  - Low household income increases the propensity to choose bike and transit.
  - Vehicle unavailability decreases the probability of driving alone and increases the probabilities of using shared ride, walk and walk to transit.
  - The number of children in the household increases the probability of the shared ride 3+ mode.
  - Children 6-15 years old (Type 2) and children older than 16 (Type 3) have a higher propensity to use bicycle or walk than other person types.
  - On all non-work tours, travelers have a higher propensity for 3+ person shared ride than 2-person shared ride. We should 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+.

- Fully joint tours with at least three participants were most likely to use shared ride 3+ mode (note that shared ride 2 and drive alone are unavailable modes for such tours).
- Because escort tours require shared ride modes, the tour mode cannot be drive alone. However, these tours may have a few drive-alone trips, before the person being escorted is picked up or after he/she has been 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: Previous trip mode of SR3+ is often followed by SR2 or SR3+. Drop-offs are evident in the morning (SR3 - SR2) and pickups in the afternoon (SR3 - SR3).
- The survey data indicate that the trip mode is usually the same as the tour mode, and so the highly positive coefficient estimate for the "tour mode = trip mode" was 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. These results were relatively minor adjustments to the strongly positive correlation between tour and trip modes

3.14 Airport Model

The airport special generator model was developed using the airport survey. This model had three components – trip generation, mode choice, and time-of-day factors. This airport model captures only "trips to the airport" made by local residents since there is no visitor model (*Airport Model.xlsx*). A brief description of the model components follows:

Trip Generation

The weighted airport survey data were geocoded at the non-airport end to identify where people were traveling from. These geocoded trip data were then assigned to both TAZ and planning districts.

- In total, there are 28 planning districts for the region, and the survey data report trips in 23 of these districts.
- A linear regression model was then run to identify the best predictor of airport trips.
- It was found that using households as a predictor provided a model with the best performance.
- The model suggests that, on average, there 0.199 airport trips per day per household in the region.

Mode Choice Model

A multinomial logit model was estimated using the airport survey data.

- In total, the estimation dataset had 166 usable records.
- A majority of respondents reported using some form of auto to commute to the airport. Transit was also a chosen mode.
- In total, the model was estimated using four possible modal options – drive alone, shared ride with two members, shared ride with three or more members, and walk to transit.
- The model has two explanatory variables – time and cost along with modal constants.

Time-of-Day Distribution

The airport survey was also analyzed to capture movements during different times-of-day. Due to relatively small size of the dataset, the survey data were broken down into four time periods – AM peak, Mid-day, PM peak, and Overnight. The distribution is listed below:

- AM Peak: 28.2%
- Mid-Day: 35.2%
- PM Peak: 16.5%
- Overnight: 20.1%

Trips From the Airport

Since the airport survey only captures trips "to the airport", there is a need to capture the return travel as well. This was done in two stages:

- **Drive Alone and Walk to Transit**. It was assumed that for every one-way trip into the airport that uses this mode, there is a second one-way trip from the airport that uses these modes. So, the trip tables for these modes were transposed and added to the overall trip table.
  - *Final Trip Auto = Auto to Airport + Transpose of Auto to Airport*
  - *Final Trip Transit = Transit to Airport + Transpose of Transit to Airport*
- Shared Ride Trips. Many of the trips using these modes are escort trips. So, in addition to simply adding the transpose back, the survey data was also studied to see how many of trips using these modes actually had a return trip minus the passenger(s). It was observed that 94 percent of all SR2 trips had a return trip while 63 percent of all SR3+ trips had a return trip
  - *Final SR2 Trip = SR2 to Airport + Transpose of SR2 to Airport + 0.63*SR2 to Airport + 0.63*Transpose of SR2 to Airport*

– *Final SR3 Trip = SR3 to Airport + Transpose of SR3 to Airport + 0.94*SR3 to Airport + 0.94*Transpose of SR2 to Airport)*

3.15 External Models

The external models were estimated using the external O-D survey. Auto and truck trips through the externals are divided into 3 main categories:

- External-external (EE);
- External-internal (EI); and
- Internal-external (IE).

The model takes as input a database file containing the daily volumes at each external station (zone 3031 – 3061) as a total (AADT) and truck-only (HCAADT). Note that these are not directional volumes, but the directional split is assumed to be 50/50.

The following sections describe how these volumes are allocated to EE, EI and IE categories.

Auto External-External (EE)

EE trips are asserted to only occur between the external stations on the two Interstate facilities. All other locations are expected to only have EI or IE travel.

- According to the license plate survey data, the percentage of EE traffic at these locations is approximately 1.12 percent of the total traffic. The model segments 1.12 percent of vehicles from these external zones and distributes it to the other Interstate external stations.
- The distribution pattern uses the observed distribution pattern. For forecast years, an iterative proportional fitting (IPF) process fits the new target EE volumes to the current distribution pattern.
- All EE trips are considered to be drive-alone with no transponder, meaning that the managed lanes are not available to them.
- The EE trips are split into the 11 time periods for model assignment according to the person trip distribution from the most current iteration of the activity-based model.

Table 3.23 External Zone Locations

Interstate	Location	Zone
I-35	South	3046
	North	3032
I-94	East	3057
	West	3038

Truck External-External (EE)

Truck EE trips were built from a separate list of truck EE-only targets at each external station and a seed matrix with the observed distribution between the external stations. These two files are defined in the user guide manual. The resulting truck distribution was then split into single and combination unit trucks using a pre-determined split of 72.7 percent for single trucks and 27.3 percent for combination trucks.

Auto External-Internal (EI) / Internal-External (IE)

The remaining auto volumes at each external station were divided into EI / IE trips by three auto modes according to a fixed set of factors, defined in the lookup file referenced in the "External Auto splits and mode shares" scenario key in the model. The trips were then distributed to a specific internal zone using a destination choice model described in **Table 3.24**.

Table 3.24 External Destination Choice Model

Variable Description	Coefficient Values
Converged	TRUE
Observations	2220
Final log (L)	-14887.4
Degrees of Freedom	5
$Rho^2(0)$	0.163
$Rho^2(c)$	-0.384
Scaling	1
Destination in Zones where Terminal Time equals 5 minutes (Downtown areas)	1.32 (24.0)
Travel Time	-0.116 (-22.3)
Travel Time Squared	5.9e-4 (7.8)
Travel Time Cubed	-3.6e-7 (-1.2)
L_S_M	1.00 (*)
Total Employment	3.96 (25.1)

4.0 Model Calibration

The model calibration and validation process was conducted in a sequential fashion with each model (and purpose) being calibrated. The entire model was then re-run up to that point before moving on to the next model. The model calibration sequence was consistent with the model application sequence in order to ensure that the calibrated results did not change with the adjustment of subsequent models.

4.1 Data Sources Used for Calibration

Five separate data sources were used for the validation of the MetCouncil model:

- The **American Community Survey** (ACS) was used only for the calibration/validation of the population synthesizer model.
- The **Household Travel Survey** served as the primary dataset for calibration of all the activity-based model components.
- The **Transit On-board Survey** data served as a key secondary dataset for the calibration of the tour and trip mode choice with a special emphasis on the calibration of the transit components of the model.
- Regional **Traffic Counts**, provided by Minnesota DOT, served as the primary dataset for the calibration/validation of the highway assignment procedures.
- Data pertaining to the physical location of **Public Schools** in the study region were used in the calibration of the school location models.

4.2 Model Calibration Overview

A customized reporting template was developed for the validation of the activity-based model. This reporting template allowed comparison of the model results against survey data across several different dimensions including:

- **Comparisons at a Regional and Sub-Regional level**
  - The sub-regional level of comparison includes seven different areas including Minneapolis, St. Paul, Suburban Minneapolis, Suburban St. Paul, Rest of Core Counties, Rest of Minnesota, and Rest of Wisconsin.
  - **Table 4.1** presents an example of regional summaries from the Daily Activity Pattern (DAP) model.

Table 4.1 Regional Summaries of the Daily Activity Patterns Model

Daily Activity Patterns Type	Expanded Household Survey Data		Model Results	
	Weighted Count	Percentage	Count	Percentage
None	0	0.0%	0	0.0%
One-Work Tour - No Stops	480,836	35.3%	479,316	35.4%
One-Work Tour - With Stops	520,931	38.2%	518,932	38.3%
Two-Work Tours - No Stops	25,872	1.9%	25,743	1.9%
Two-Work Tours - Stops on One	15,627	1.1%	15,622	1.2%
Two-Work Tours - Stops on Both	7,487	0.5%	7,498	0.6%
One University - One Work Tour-No Stops	1,542	0.1%	1,456	0.1%
One University Tour - One Work Tour - Stops On Work Tour	118	0.0%	118	0.0%
One School Tour - One Work Tour - No Stops	0	0.0%	0	0.0%
One School Tour - One Work Tour-Stops On Work Tour	0	0.0%	0	0.0%
One University Tour	3,678	0.3%	3,553	0.3%
Two University Tours	0	0.0%	0	0.0%
One School Tour	1,135	0.1%	0	0.0%
Two School Tours	0	0.0%	0	0.0%
Non-Mandatory Travel	167,202	12.3%	165,943	12.2%
Stay-At-Home	106,541	7.8%	107,460	7.9%
Out-Of-Area	1,640	0.1%	0	0.0%
External-Travel-Only	29,672	2.2%	29,884	2.2%

- **Comparisons Using Different Socio-Demographic Data**. Since the ABM includes detailed individual and household-level demographics all the way until the assignment procedures, it is possible and necessary to calibrate the model across several different socio-demographic data. This is a key difference from the calibration/validation of trip-based models and showcases the effectiveness of the ABM in effectively representing travel patterns of key market segments. During the model calibration, we included comparisons across several key socio-demographics including, but not limited to:
  - **Household and Person-Level Demographics**
    - » Household Size;
    - » Household Income;

  - » Household Auto Availability;
  - » Household Size*Household Income;
  - » Household Size*Auto Availability;
  - » Gender;
  - » Age; and
  - » Worker Status (part-time, full-time).

- **Comparisons using Network-Level Characteristics.** Several network and level of service characteristics were used to calibrate the models – especially the ones related to destination choice and related models such as the usual workplace location models.
  - – Travel times (and distributions);
  - – Travel distances (and distributions);
  - – Intrazonal travel patterns; and
  - – District-district flows – especially for transit.
- **Comparisons using Activity/Tour Patterns**. For the lower level models, such as stop generation, and trip-level models, tour-level model information was used in the calibration. This ensures that survey-reported trip-level travel patterns are appropriately linked to their tours and this information is translated accurately in the ABM. Comparisons that were made included:
  - – Number of stops;
  - – Travel time window availability;
  - – Stops in outbound vs. return directions;
  - – Time of day distributions; and
  - – Influence of tours on trip-level decisions.

In this Section we present the validation efforts for four different types of models:

- The Population Synthesizer outputs since they use socio-demographic control totals from the ACS survey;
- The school location model that uses school location datasets for validation;
- One example each from all of the major activity-based model families – including generation, time-of-day, destination, and mode choice.
- Highway assignments which use traffic counts and screenline information.

4.3 VALIDATION OF SOCIO-DEMOGRAPHIC INPUTS

Synthesized households and individual members of the region's population are an essential element of the activity-based model framework. We describe both the application of the model as well as the key validation checks that were conducted as part of the model calibration process.

The synthetic population generation process for the Metropolitan Council TBI model was conducted using a population synthesizer called 'PopGen' which was developed by the Arizona State University. This synthesizer was selected for a few reasons:

- The software uses a series of open-source and free software to run the model.
- The synthesizer was developed by academics using rigorous testing and had been used to generate synthetic populations successfully in other regions.
- The procedural files describing the synthesizer are well documented and can be used by an analyst to understand the methodology relatively quickly.
- The software can be adjusted to develop synthetic populations at several different levels of geography using public sources of household and population data supplemented with data developed by the Metropolitan Council.

PopGen Framework

'PopGen' helps generate disaggregate synthetic population data for a region at a user-selected level of geography. It uses distributions of household and person-level variables and a sample of household data compiled from national data sources such as the 2005-2009 five percent Public Use Micro Sampled data (PUMS).

- The data inputs to PopGen are the following:
  - First, from an activity-based modeling perspective, households and population need to be synthesized at a TAZ level. Therefore, a geographic correspondence file that relates TAZs to county and PUMA information was developed at the outset.
  - Second, a file that outlines household and person level TAZ control totals for all variables of interest was also developed using information generated by Metropolitan Council staff.
  - Third, a sample file that contains sample household and person level information was generated from the PUMS database. This file becomes the synthetic population database from which PopGen draws households using selection probabilities to match the marginal distributions.
- The software utilizes a standard iterative proportional fitting (IPF) algorithm to draw households from the sample data such that marginal distributions

from the selected households match the distribution of the control data at a TAZ level for the variables under consideration.

PopGen Categories

PopGen uses an iterative proportional updating algorithm for estimating household weights. The algorithm estimates sample household weights so that both household and person-level distributions are matched. Based on a household's composition and the marginal totals that are provided as input, PopGen develops weights for households defined in the sample data. The following variables were defined as control targets at a household and person level:

- **Household Characteristics**
  - Household Income Categories[1]
    - Category 1: Less than $25,000;
    - Category 2: Between $25,000 and $50,000;
    - Category 3: Between $50,000 and $75,000;
    - Category 4: Between $75,000 and $100,000; and
    - Category 5: Greater than $100,000.
  - **Household Size**: Originally, only five household size categories were used. Following a careful assessment, it was determined that limiting larger household sizes to a 5+ category was adversely impacting the population matching that is conducted as part of PopGen. In the final run, household size was broken down to eight categories that accounts for households with 1, 2, 3, 4, 5, 6, 7 and 8 or more members. The household size variable in the marginal totals file for PopGen is also capped at eight.
- **Person Level Characteristics**. Several person-level characteristics were used in PopGen:
  - **Employment Status**. This was broken down into three categories to be consistent with the variables used in modeling.
    - Full-time worker;
    - Part-time worker; and
    - Unemployed.

---

[1] Metropolitan Council's land use model forecasts four income categories which are as follows: less than $35,000, between $35,000 and $59,999, between $60,000 and $99,999, and greater than $100,000. However, for purposes of model application, it was necessary to convert these four categories into five income categories to make the income categories in the synthesized population consistent with model estimation results. County-level factors were created using the 2007-2011 ACS data to convert the four income categories provided by Metropolitan Council into five distinct income categories.

- **Student Status**
  - » Student and
  - » Non student.
- **Gender**
  - » Male and
  - » Female.
- **Age.** Age was broken down into categories that are consistent with the model estimation results as well as the person types used to generate daily activity patterns in the activity-based model.
  - » Less than 6 years;
  - » 6 to 12 years;
  - » 13 to 15 years;
  - » 16 to 17 years;
  - » 18 to 24 years;
  - » 25 to 34 years;
  - » 35 to 44 years;
  - » 45 to 54 years;
  - » 55 to 64 years; and
  - » 65 years and over.

PopGen Application Results

The results from PopGen were compared to the marginal totals provided by Metropolitan Council at a TAZ level. In this report, we compare the population and household totals generated by PopGen with the control data at a regional level.

Table 4.2 compares the synthetic household distribution by income categories to the TAZ level marginal totals provided by Metropolitan Council.

- Synthetic household outputs match the TAZ marginal totals almost perfectly.
- **Table 4.2** shows that household income of the synthetic population matches the marginal totals for three different geographic comparisons: (a) the entire study area, (b) Minnesota counties only and (c) Wisconsin counties only.
- The difference between the synthetic population totals and the original control totals does not exceed 700 households in any one cell.

Table 4.2 Household Income Comparison – Synthetic Households vs. Metropolitan Council Control Totals

Region	Household Income	Synthetic Households		Metropolitan Council TAZ Marginal Totals	
		Count	Percentage	Count	Percentage
Study Area	Less than $25,000	228,089	16.7%	228,589	16.8%
	$25,000-$50,000	286,486	21.0%	286,481	21.0%
	$50,000-$75,000	261,494	19.2%	261,496	19.2%
	$75,000-$99,999	203,938	15.0%	204,081	15.0%
	$100,000+	383,148	28.1%	382,510	28.1%
	Total	**1,363,155**	**100.0%**	**1,363,157**	**100.0%**
Minnesota	Less than $25,000	217,064	16.70%	217,527	16.80%
	$25,000-$50,000	271,794	20.90%	271,804	20.90%
	$50,000-$75,000	247,866	19.10%	247,876	19.10%
	$75,000-$99,999	193,502	14.90%	193,640	14.90%
	$100,000+	368,125	28.40%	367,505	28.30%
	Total	**1,298,351**	**100.00%**	**1,298,352**	**100.00%**
Wisconsin	Less than $25,000	11,025	17.00%	11,062	17.10%
	$25,000-$50,000	14,692	22.70%	14,677	22.60%
	$50,000-$75,000	13,628	21.00%	13,620	21.00%
	$75,000-$99,999	10,436	16.10%	10,441	16.10%
	$100,000+	15,023	23.20%	15,005	23.20%
	Total	**64,804**	**100%**	**64,805**	**100.0%**

Table 4.3 compares the synthetic household distribution by household size categories to the TAZ level marginal totals provided by Metropolitan Council.

- For households with fewer than six members, the percentage difference in the synthetic households vs. the Metropolitan Council reported totals do not exceed 1.5 percent.
- For larger households that are less frequently observed in the population, the percentage difference is over five percent. However, the absolute differences in totals never exceeds 1,000 households in any category.

Table 4.3 Household Size Comparison – Synthetic Households vs. Metropolitan Council Control Totals

Region	Household Size	Synthetic Households		Metropolitan Council TAZ Marginal Totals	
		Count	Percentage	Count	Percentage
Study Area	1 member	374,771	27.50%	374,208	27.50%
	2 members	454,828	33.40%	453,796	33.30%
	3 members	210,297	15.40%	210,040	15.40%
	4 members	191,307	14.00%	191,056	14.00%
	5 members	83,065	6.10%	83,247	6.10%
	6 members	29,407	2.20%	29,852	2.20%
	7 members	10,832	0.80%	11,537	0.80%
	8 or more	8,648	0.60%	9,421	0.70%
	Total	**1,363,155**	**100.00%**	**1,363,157**	**100.00%**
Minnesota	1 member	359,846	27.70%	359,337	27.70%
	2 members	430,835	33.20%	429,874	33.10%
	3 members	199,907	15.40%	199,676	15.40%
	4 members	181,756	14.00%	181,520	14.00%
	5 members	78,935	6.10%	79,109	6.10%
	6 members	28,076	2.20%	28,499	2.20%
	7 members	10,491	0.80%	11,136	0.90%
	8 or more	8,505	0.70%	9,201	0.70%
	Total	**1,298,351**	**100.00%**	**1,298,352**	**100.00%**
Wisconsin	1 member	14,925	23.00%	14,871	22.90%
	2 members	23,993	37.00%	23,922	36.90%
	3 members	10,390	16.00%	10,364	16.00%
	4 members	9,551	14.70%	9,536	14.70%
	5 members	4,130	6.40%	4,138	6.40%
	6 members	1,331	2.10%	1,353	2.10%
	7 members	341	0.50%	401	0.60%
	8 or more	143	0.20%	220	0.30%
	Total	**64,804**	**100.00%**	**64,805**	**100.00%**

Table 4.4 compares the distribution of employed individuals in the synthetic population outputs with the TAZ level marginal totals.

- In total, the synthetic population is about 20,000 less than the observed totals. This is primarily because of the capping of household sizes at 8 members and because of the lower number of larger households in the synthetic population when compared to the marginal totals.
- PopGen results map well against the Metropolitan Council targets. There is slightly more variation between the control totals and the PopGen reported totals (for each segment) than what was observed at the household level.

- In total, PopGen predicts about 9,000 fewer employed individuals than the Metropolitan Council reported data. This is only about one-fourth of a percentage point of the regional population suggesting a very close match.

Table 4.4 Employment Status Comparison – Synthetic Households vs. Metropolitan Council Control Totals

Region	Household Income	Synthetic Population		Metropolitan Council TAZ Marginal Totals	
		Count	Percentage	Count	Percentage
Study Area	Full-time Worker	1,358,937	39.70%	1,360,472	39.50%
	Part-time Worker	442,598	12.90%	450,124	13.10%
	Unemployed	1,620,236	47.40%	1,630,220	47.40%
	Total	**3,421,771**	**100.00%**	**3,440,816**	**100.00%**
Minnesota	Full-time Worker	1,293,213	39.70%	1,294,903	39.50%
	Part-time Worker	422,158	13.00%	429,137	13.10%
	Unemployed	1,541,831	47.30%	1,551,259	47.40%
	Total	**3,257,202**	**100.00%**	**3,275,299**	**100.00%**
Wisconsin	Full-time Worker	65,724	39.90%	65,569	39.60%
	Part-time Worker	20,440	12.40%	20,987	12.70%
	Unemployed	78,405	47.60%	78,961	47.70%
	Total	**164,569**	**100.00%**	**165,517**	**100.00%**

Table 4.5 compares the distribution of students in the synthetic population outputs with the TAZ level marginal totals.

- Overall, the pattern of students vs. non-students is well captured in the synthetic population.
- PopGen predicts about 14,000 fewer employed individuals than the Metropolitan Council reported data and five thousand fewer non-students.

Table 4.5 Student Status Comparison – Synthetic Households vs. Metropolitan Council Control Totals

Region	Household Size	Synthetic Households		Metropolitan Council TAZ Marginal Totals	
		Count	Percentage	Count	Percentage
Study Area	Student	869,825	25.40%	883,802	25.70%
	Non-Student	2,551,946	74.60%	2,557,014	74.30%
	Total	**3,421,771**	**100.00%**	**3,440,816**	**100.00%**
Minnesota	Student	828,683	25.40%	842,031	25.70%
	Non-Student	2,428,519	74.60%	2,433,268	74.30%
	Total	**3,257,202**	**100.00%**	**3,275,299**	**100.00%**
Wisconsin	Student	41,142	25.00%	41,771	25.20%
	Non-Student	123,427	75.00%	123,746	74.80%
	Total	**164,569**	**100.00%**	**165,517**	**100.00%**

Table 4.6 compares the distribution of various age groups in the synthetic population outputs with the TAZ level marginal totals.

- Overall, the pattern of different age groups is well represented in the synthetic population.
- PopGen predicts a slightly smaller number of individuals in the 18-24 age category than the observed data.
- All other age groups are reasonably well-matched. It must be noted that individuals who are younger than six years old are not included in the model structure.

Table 4.6 Age Category Comparison – Synthetic Households vs. Metropolitan Council Control Totals

Region	Household Size	Synthetic Households		Metropolitan Council TAZ Marginal Totals	
		Count	Percentage	Count	Percentage
Study Area	Less than 6	288,104	8.40%	290,090	8.40%
	6 to 12	336,060	9.80%	338,644	9.80%
	13 to 15	144,172	4.20%	145,458	4.20%
	16 to 17	96,910	2.80%	99,806	2.90%
	18 to 24	281,745	8.20%	288,606	8.40%
	25 to 34	494,944	14.50%	497,180	14.40%
	35 to 44	477,331	13.90%	478,655	13.90%
	45 to 54	537,867	15.70%	538,371	15.60%
	55 to 64	396,280	11.60%	396,064	11.50%
	65 and Over	368,358	10.80%	367,942	10.70%
	Total	**3,421,771**	**100.00%**	**3,440,816**	**100.00%**
Minnesota	Less than 6	274,482	8.40%	276,310	8.40%
	6 to 12	319,470	9.80%	321,993	9.80%
	13 to 15	136,988	4.20%	138,224	4.20%
	16 to 17	92,243	2.80%	94,989	2.90%
	18 to 24	269,499	8.30%	275,834	8.40%
	25 to 34	474,275	14.60%	476,460	14.50%
	35 to 44	454,137	13.90%	455,461	13.90%
	45 to 54	510,781	15.70%	511,309	15.60%
	55 to 64	375,962	11.50%	375,666	11.50%
	65 and Over	349,365	10.70%	349,053	10.70%
	Total	**3,257,202**	**100.00%**	**3,275,299**	**100.00%**
Wisconsin	Less than 6	13,622	8.30%	13,780	8.30%
	6 to 12	16,590	10.10%	16,651	10.10%
	13 to 15	7,184	4.40%	7,234	4.40%
	16 to 17	4,667	2.80%	4,817	2.90%
	18 to 24	12,246	7.40%	12,772	7.70%
	25 to 34	20,669	12.60%	20,720	12.50%
	35 to 44	23,194	14.10%	23,194	14.00%
	45 to 54	27,086	16.50%	27,062	16.30%
	55 to 64	20,318	12.30%	20,398	12.30%
	65 and Over	18,993	11.50%	18,889	11.40%
	Total	**164,569**	**100.00%**	**165,517**	**100.00%**

4.4 CALIBRATION OF THE ACTIVITY-BASED MODEL FRAMEWORK

There are several different types of models within the Activity-Based Model Framework including:

- Daily Activity Pattern Models;
- Generation Models that include tour generation and stop generation;
- Destination Choice Models;
- Time-of-Day Choice Models; and
- Mode Choice Models.

This sub-section describes the approach undertaken to calibrate the models and highlights key procedures from some of the models.

Calibration Approach

The calibration procedure was similar for each of these models except the mode choice models which are discussed in a separate sub-section.

- Step 1. Since the activity-based model framework is a highly inter-related model structure, the model calibration was conducted sequentially. The order of calibration was exactly the same as the order in which the model are applied. This ensures that calibration to downstream models has the full advantage of the calibrated model results from the upstream models.
- Step 2. For each of the models the key calibration dimensions were first identified.
- Step 3. The appropriate data sources were summarized across the key dimensions and spreadsheets were developed to run the comparisons.
- Step 4. The coefficients which may be adjusted to help the model better represent the patterns in the data sources were then identified and highlighted.
- Step 5. Model outputs were compared against the data source summaries to identify the coefficients that had to be adjusted. To the extent possible, the adjustments were limited to the model constants. In a few cases, adjustments also needed to be made to some of the model coefficients to better reflect travel patterns.
- Step 6. The adjusted coefficients were incorporated and the model was run until the next downstream step to ensure that the downstream model calibration benefits from the changes made in all prior model steps.

In this report, we highlight examples from each of the major model structures and identify some of the key dimensions along which the models were calibrated. For each model, a customized spreadsheet that included the most relevant dimensions for the calibration of that spreadsheet was developed. Each of these calibration spreadsheets is available in the supporting documentation and is named as "*Model Name Calibration.xlsm*". These spreadsheets are provided as supporting documentation to describe the work conducted to validate the models.

Daily Activity Patterns

The daily activity pattern models (DAP) were one of the earliest models to be calibrated. Separate calibration sheets were developed for each of the seven person types being calibrated.

- Child between 6 – 15 years;
- Child 16+ years;
- Non-working adults;
- Seniors (all individuals 65 years and above);
- Part-time workers;
- Full-time workers; and
- Adult students.

Table 4.7 highlights the calibration efforts from the full-time worker DAP model. The DAP models were applied in sequence, right after the long-term choice models. Therefore, the only simulated travel behavior that is included in the DAP models are the work-location related variables. It was observed that the calibration of this model could be conducted very effectively by the adjustment of the alternative-specific constants alone. As a result, no other variables were modified during the calibration of the DAP models. The study team focused on matching both regionwide and sub-region specific DAPs for each person type[2].

- **Table 4.7** outlines the following:
  - Estimated constants and the original DAP shares when the estimated models were applied in the activity-based model;
  - Survey reported DAP shares which were used to calibrate the model;
  - Adjusted constants for the last two rounds of calibration; and
  - Revised DAP shares when the calibrated models were applied in the activity-based model.

At this aggregate level, the model does a good job in replicating survey results. **Table 4.8** outlines the results of the calibrated DAP model at a more detailed geographic area.

[2] There are two fully formatted excel spreadsheets for the DAP calibration; one each for full-time worker and child 6-15 years. The calibration sheets for the remaining five person types follow the same structure.

- The key activity patterns that include more than one work tours and the non-mandatory travel are all well captured in the model across geographic regions.
- There are a few differences in the RMN (rural Minnesota) and RWI (rural Wisconsin) regions for two work tours. However, the total number of two mandatory work tours in these markets are rather small (50,000 out of a total of 1.35 million workers) and as such the differences amount to no more than 2,000-3,000 work tours.

Table 4.7 DAP Full-Time Worker Calibration – Adjustments of Model Constants

	One Work Tour No Stops	One Work Tour With Stops	Two Work Tours No Stops	Two Work Tours Stops On One	Two Work Tours Stops On Both	One University - One Work Tour No Stops	One University One Work Tour Stops On Work Tour	One School One Work Tour No Stops	One School One Work Tour Stops On Work Tour	One University Tour	Two University Tours	One School Tour	Two School Tours	Non-Mandatory Travel	Stay At Home	Out Of Area	External Travel Only
Estimated Constant	4.530	4.990	1.900	1.800	1.370	-0.823	-0.823							2.810	3.720		2.680
Version 0 Model Shares	42.0%	37.2%	2.1%	1.0%	0.6%	0.05%	0.0%			0.2%				7.8%	5.5%		3.4%
Survey-Observed Shares	35.3%	38.2%	1.9%	1.1%	0.5%	0.11%	0.0%			0.3%		0.1%		12.3%	7.8%	0.1%	2.2%
Adjusted Constant	3.980	4.626	1.404	1.509	0.765	-0.444	-2.401							2.937	2.614		2.913
Revised Model Shares	35.4%	38.3%	1.9%	1.2%	0.6%	0.11%	0.0%			0.3%				12.2%	7.9%		2.2%
Model vs. Survey Diff	0.1%	0.0%	0.0%	0.0%	0.0%	-0.01%	0.0%	0.0%	0.0%	0.0%	0.0%	-0.1%	0.0%	0.0%	0.1%	-0.1%	0.0%

Round (N+1) Adjustment	-0.002	-0.001	0.000	-0.005	-0.006	0.053	-0.006			0.030				0.003	-0.014		-0.012
Constants in Model	3.949	4.595	1.374	1.475	0.729	-0.421	-2.436							2.910	2.571		2.871

Table 4.8 DAP Full-Time Worker Calibration – Sub-Regional Differences between Model Outputs and Survey Reported Results

Daily Activity Pattern	Geographic Regions[3]						
	MN	SMN	SP	SSP	RCR	RMN	RWI
None	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
One Work Tour - No Stops	1.8%	1.7%	-2.7%	-1.7%	-1.2%	1.9%	-0.6%
One Work Tour With Stops	-0.1%	-1.7%	-0.8%	0.3%	-2.4%	5.3%	5.3%
Two Work Tours - No Stops	0.4%	-0.1%	0.7%	-0.1%	0.7%	-0.2%	-2.8%
Two Work Tours - Stops On One	0.1%	-0.5%	-0.4%	0.3%	0.0%	0.3%	0.3%
Two Work Tours - Stops On Both	0.1%	0.0%	-0.2%	-0.1%	0.2%	-0.2%	0.3%
One University - One Work Tour - No Stops	0.0%	0.1%	0.0%	-0.2%	0.0%	0.1%	0.1%
One University - One Work Tour - Stops On Work Tour	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
One School - One Work Tour - No Stops	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
One School - One Work Tour - Stops On Work Tour	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
One University Tour	-0.6%	0.1%	0.2%	0.1%	-0.2%	0.0%	0.2%
Two University Tours	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
One School Tour	0.0%	-0.1%	0.0%	0.0%	-0.3%	0.0%	0.0%
Two School Tours	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Non-Mandatory Travel	2.2%	-1.2%	1.7%	0.3%	0.1%	-0.8%	0.2%
Stay At Home	-4.3%	1.2%	2.3%	0.6%	3.0%	-3.4%	-2.9%
Out Of Area	0.0%	-0.1%	-0.1%	0.0%	0.0%	-0.7%	0.0%
External Travel Only	0.3%	0.6%	-0.8%	0.5%	0.1%	-2.3%	-0.2%

Tour Generation Models

The tour generation models were calibrated according to the order in which they operate in the model so that the inputs from upstream models are observed to match observed patterns before evaluating the models. Mandatory tours are generated as part of the DAP models. The DAP calibration process is discussed in the previous section. The remaining tour generation models include:

- Non-mandatory tours both for fully joint and for individual travel; and
- Work-based sub-tours, which include tours of both mandatory and non-mandatory purposes.

[3] MN = Minneapolis; SMN = Suburban Minneapolis; SP = St. Paul; SSP = Suburban St. Paul; RCR = Rest of Core Region; RMN = Rural Minnesota; RWI = Rural Wisconsin

The tour generation model results were compared to the household survey summaries. In general, model results were summarized by area type, person type, household income, auto ownership, household size, and parent tour characteristics for work-based sub-tours. The specific comparisons and some example results are provided below.

The **Fully Joint** generation model was calibrated according to the rate of tours per household by tour purpose. **Table 4.9** shows the percentage difference between the observed fully joint tours in the household survey and the model produced tours by purpose. Additionally, the likelihood that each person within the household would participate in a fully joint tour was calibrated so that the tour person compositions match the distributions observed in the household survey. The fully joint tour generation was also examined by:

- Rate per household by county and super district;
- Rate per household by household size, income, number of cars and workers;
- Number of fully joint tours by group size and purpose;
- Number of fully joint tours by county and purpose;
- Number of fully joint tours by household size, income and purpose;
- Number of fully joint tours by household size, workers, and purpose; and
- Persons by type on fully joint tours by purpose.

Table 4.9 Fully Joint Tour Generation Differences from the Household Survey

Activity	Percentage Difference (Model - Observed)/Observed
Meal	5.6%
Shopping	6.7%
Personal Business	8.8%
Social Recreational	1.5%
Total	4.4%

Individual Non-Mandatory tour generation was calibrated by person type and household income. **Table 4.10** shows the percentage differences between the model results and household survey by person type and income. There is very little deviation between the model and survey results both by individual tour purpose and for the total number of tours generated. Comparisons were also made by:

- County;

- Gender;
- Age group; and
- Household size.

The model fits these comparisons well.

Table 4.10 Individual Non-Mandatory Tour Generation Differences from the Household Survey

Person Type	Tour Purpose					
	Meal	Shop	Personal Business	Social Recreational	Escort	Total
Child2	4%	8%	9%	9%	11%	8%
Child3	-10%	-1%	1%	-3%	-2%	-3%
Adult Student	8%	7%	3%	5%	4%	5%
Full Time Worker	-7%	-5%	-6%	-6%	-2%	-5%
Part Time Worker	2%	-3%	-1%	-7%	-8%	-4%
Non-Working Adult	-7%	-3%	-7%	-8%	2%	-5%
Senior	8%	6%	8%	8%	4%	7%

Work-based subtours were calibrated so that the rates of work-based subtours match the observed subtours by purpose. Work subtours were also summarized by:

- Area type;
- Parent tour mode;
- Person type;
- Gender and age group; and
- Household size and income.

The validation sheets contain comparisons similar to **Table 4.9** for each of the cross-classifications described.

Destination Choice Models

Destination choice calibration took place at various points in the process – the usual workplace location before tour generation, the tour destination choice following the tour generation, and stop destination after all tour level models.

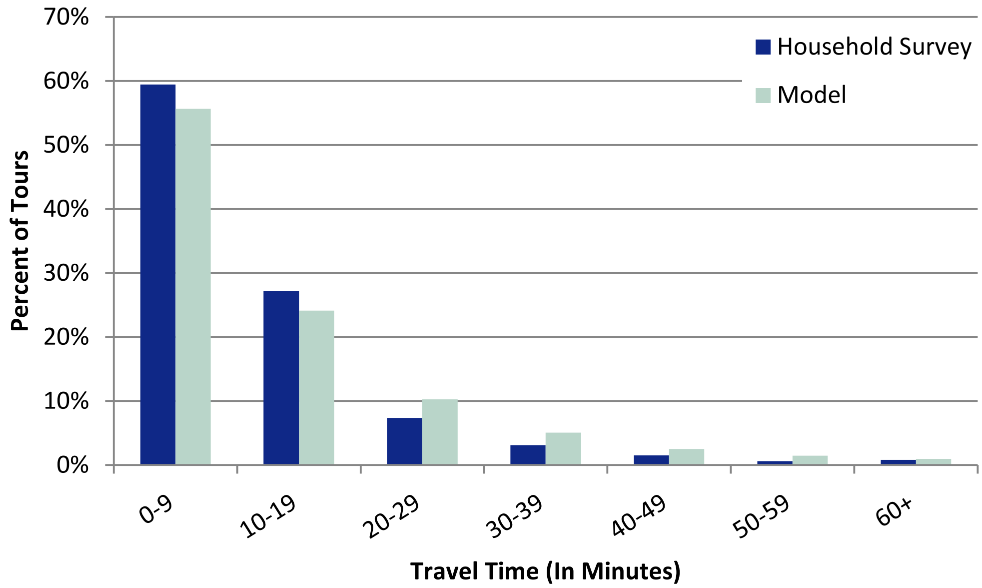
- Since the distribution of origin-to-destination distance drives the regional VMT, it is essential for overall model performance and its accuracy as reflected in the assignment results.

- To match the observed behavior, the calibration of destination choice focused on matching impedance distributions (travel distance and time) and intrazonal percentages.
- While conducting this validation checks, special care was taken to identify and clean any lingering issues with the skim matrices.
- **Table 4.12** shows the average travel time and distance in the destination choice for individual non-mandatory tours by household income.
- The model captures the effect that higher income households travel further on average than lower income households.
- Time is not included in this model as a stand-alone variable, and is instead included as a variable in the mode choice logsum.
- **Figure 4.1** shows the distribution of travel times in the survey and the model.
- The model includes log distance variables, segmented by purpose, which were used to calibrate average time and distance.
- Adjustments to distance and intrazonal coefficients were used to match model distributions to survey distributions.

Table 4.11 Average Impedance of Individual Non-Mandatory Tours

Household Income	Average Time			Average Distance		
	Survey	Model	Difference	Survey	Model	Difference
<$25,000	12.21	11.80	-3.3%	8.05	7.37	-8.5%
$25,000-$49,999	11.68	12.75	9.2%	7.43	8.15	9.7%
$50,000-$75,999	12.40	13.55	9.2%	8.30	8.76	5.6%
$75,000-$99,999	12.70	13.87	9.3%	8.32	8.99	8.1%
>$100,000	12.77	13.88	8.7%	8.34	8.85	6.1%
All	12.46	13.43	8%	8.16	8.60	5%

Figure 4.1 Travel Time Distribution of Individual Non-Mandatory Tours



All work-based subtours including different purposes were estimated and calibrated together.

- These sub-tours had much lower average travel distances than their home-based tours because they start and end at work. As a result, their patterns are determined by the time available within the constraints of a work activity.
- The model reflects variation between purposes, especially for work and meal tours which accounted for the majority of work-based sub-tours, as **Table 4.12** illustrates.
- In cases with limited survey data, such as personal business and social/recreation, the overall trend was considered more important than matching the exact impedance distributions.

Table 4.12 Average Impedance of Work-Based Sub-Tours

Tour Purpose	Average Time			Average Distance		
	Survey	Model	Difference	Survey	Model	Difference
Work	13.6	13.4	-1.5%	9.0	8.9	-2.0%
Meal	6.0	6.1	1.2%	3.3	3.2	-3.2%
Shop	5.9	6.5	8.7%	3.4	3.5	3.2%
Personal Business	7.5	6.6	-12.4%	4.4	3.7	-16.1%
Social/Recreation	7.2	6.8	-5.5%	4.5	3.8	-15.8%

- **Table 4.13** shows the percentage of tours which do not leave the work location zone with the survey suggesting that one out of three workers remains within the same zone when taking a work-based sub-tour.
- The intrazonal coefficient in the model was adjusted to match this percentage while monitoring the impact of this adjustment on the average impedance and its distribution.

Table 4.13 Work-Based Subtours with a Destination in the Base Zone

Area Type	Intrazonal Percentage		
	Survey	Model	Difference
Terminal Time 1	34%	33%	-1%
Terminal Time 2	18%	12%	-6%
Terminal Time 3	10%	15%	6%
Terminal Time 5	17%	15%	-2%
Total	17%	15%	-2%

Time-of-Day Choice Models

The time of day (TOD) models were calibrated individually for each of the following tour purposes:

- Work;
- School;
- University;
- Fully joint;
- Individual non-mandatory; and
- Work-based sub-tours.

There are two sets of time of day models, one for the tours and another one for the individual trips/stops that are part of the larger tours. The duration and travel pattern of the trip-based models are determined, in part, by the selections made at the tour level. From a modeling standpoint, it is, therefore, vital to validate the tour level models with great accuracy.

The time of day model consists of three attributes that are chosen simultaneously: arrival time, departure time, and duration of the tour/trip.

- In calibration, the arrival and departure time distributions were examined at the half-hour level.
- The overall average duration was compared and segmented by:

- Income;
- Person type;
- Gender; and
- Age.

The time of day models were calibrated by adjusting the arrival and departure constants, which are specified for each half-hour time period, until the modeled behavior matched well against the survey reported data. This process was carried out for each tour purpose separately.

Key patterns that were targeted during calibration include:

- Matching tour arrivals for mandatory tour purposes (including school escorting) during the AM peak period;
- Matching tour departures for mandatory tour purposes during the PM peak period;
- Capturing non-mandatory travel patterns during the PM Peak and Evening periods; and
- Matching work-based subtour patterns during the mid-day period.
- Overall, the calibration process was conducted to ensure that there was enough traffic moving during the peak periods to be consistent with the highway calibration that follows.

The duration shift variables were also adjusted to fit the activity duration by person type and tour sub-purpose.

Figure 4.2 and **Figure 4.3** show the arrival and departure time distributions for work tours. The close match that is observed suggests that there is little deviation between the model and survey results.

Figure 4.2 Work Tour Arrival Time Distribution

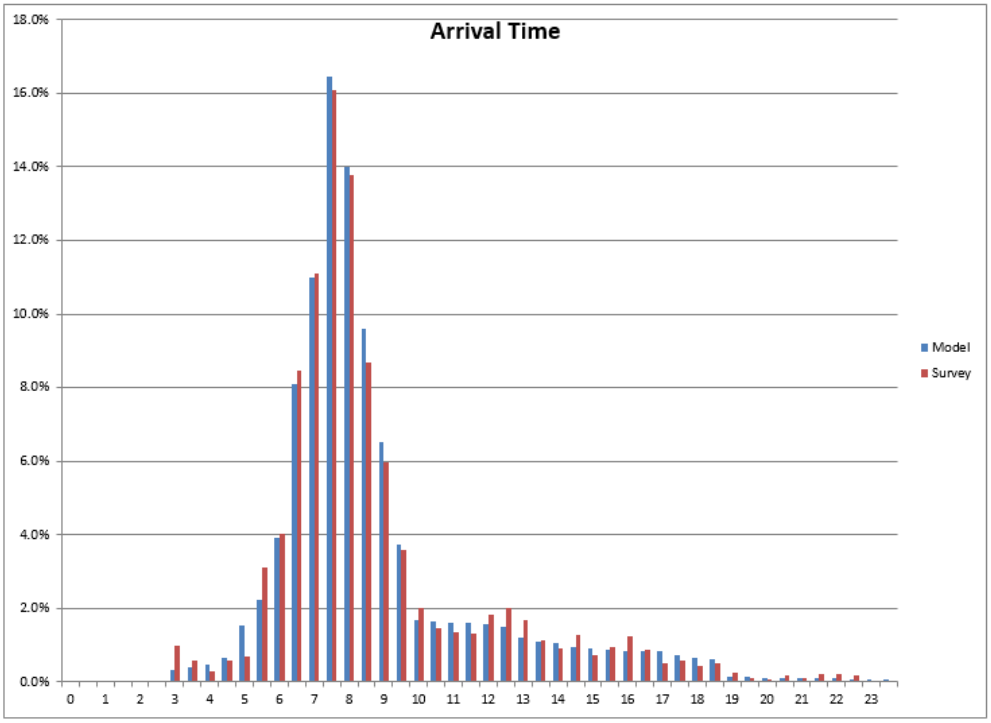
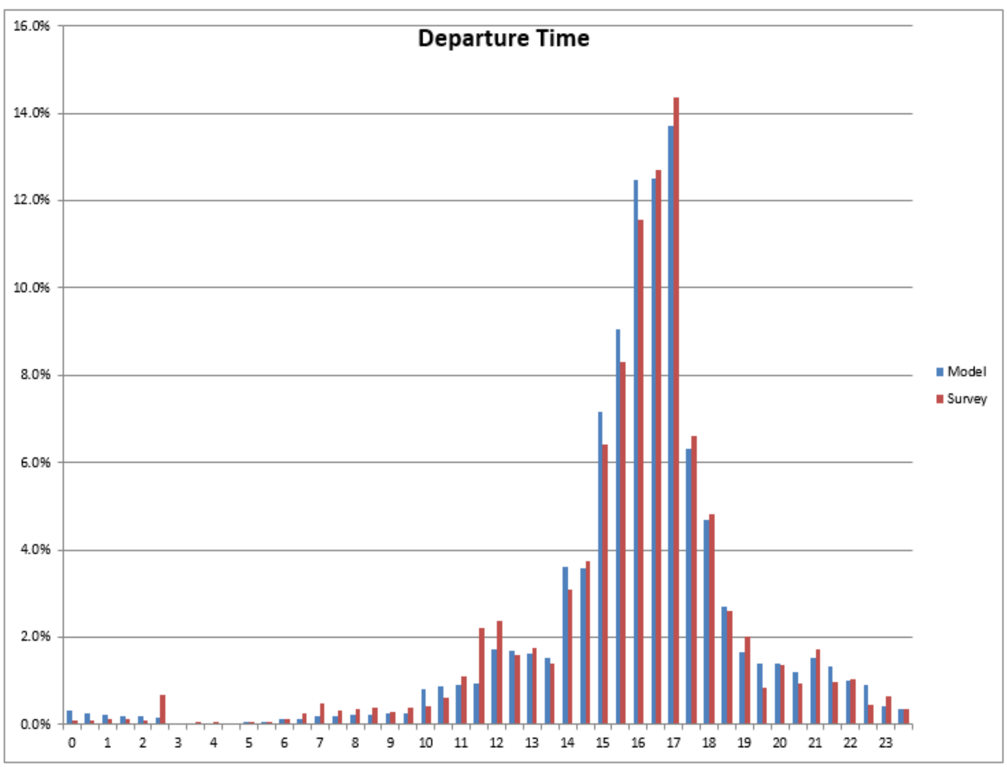


Figure 4.3 Work Tour Departure Time Distribution



Stop Generation Models

Calibration of stop generation followed the calibration of the tour time of day. After the stops model was run using calibrated synthetic tours, the combination of stops on each half-tour could be compared to the estimates of the weighted survey half-tours. Separate calibration sheets were developed for the following tour categories:

- Mandatory;
- Individual non-mandatory;
- Individual non-mandatory escort;
- Fully joint; and
- Work-based[4].

The primary calibration targets were the **rate of stops per half-tour** and the **number of stops on half-tours**. Choices were zero, one, two, or three stops on a half-tour and adjustments could be made to adjust the probabilities for each of the alternatives. These adjustments were made to coefficients of one or more of the following:

- Alternative specific constants;
- Departure time;
- Income; and
- Person type.

Table 4.14 shows the results of calibration for home-based work and non-mandatory tours by income.

- In work tours, the trend of stops increasing with income was matched.
- Non-mandatory stops had a less pronounced effect with income. Hence, the decision was made to match stop patterns for non-mandatory tours for other key variables such as person type.

[4] Work-based stop generation followed work-based time of day which came later.

Table 4.14 Stop Generation Calibration: Stops per Half-tour by Income

Household Income	Home-Based Work			Home-Based Non-Mandatory		
	Survey	Model	Difference	Survey	Model	Difference
Less than $25,000	0.39	0.40	4.5%	0.43	0.50	17.6%
$25,000-$49,999	0.41	0.41	1.6%	0.46	0.47	1.7%
$50,000-$75,999	0.44	0.48	9.1%	0.46	0.43	-7.1%
$75,000-$99,999	0.47	0.47	0.1%	0.39	0.38	-2.8%
$100,000 and over	0.52	0.51	-2.1%	0.43	0.43	-0.1%
All	0.47	0.47	-0.1%	0.43	0.43	0.1%

In addition to the overall stop rates, the distribution of the stops over tours was also calibrated. **Table 4.15** presents the distribution of number of stops for half-tours with at least 1 stop[5]. The calibrated model replicates survey-reported patterns almost exactly for both work and non-mandatory tours.

Table 4.15 Stop Generation Calibration: Number of Stops in Half-tours

Number of Stops in Half-tour	Home-Based Work			Home-Based Non-Mandatory		
	Survey	Model	Difference	Survey	Model	Difference
1 Stop	63%	68%	4%	66%	62%	-4%
2 Stops	22%	18%	-4%	21%	21%	1%
3 Stops	15%	15%	0%	14%	17%	3%

The last major segmentation within stop generation was the analysis of the number of stops on the outbound half-tour (called HT1) and the return half-tour (called HT2).

- The stop making patterns on HT1 were distinctly different from those in HT2, as shown in Table **4.16**.
- Work tours had the largest imbalance of stop rates between the half-tours, and efforts were made to reflect this both in estimation and during calibration.
- Overall, the calibrated model represents stop making patterns on both the outbound and return half-tours by different times of day.

[5] Note, this does not include those who chose 0 stops, which constitutes more than 70% of all half tours

Table 4.16 Stop Generation Calibration: Rates by Half-tour

Number of Stops in Half-tour	Survey Results		Model Results		Percentage Difference	
	HT 1	HT 2	HT 1	HT 2	HT 1	HT 2
AM Peak	0.22	0.72	0.22	0.58	1%	-19%
Mid day	0.59	0.91	0.56	0.85	-6%	-6%
PM Peak	0.41	0.57	0.34	0.62	-19%	9%
Off Peak	0.11	0.24	0.11	0.25	0%	4%
Total	0.34	0.61	0.33	0.62	-3%	2%

4.5 Validation of the School Location Model

The school location model was generated by developing a probabilistic model that aims to better represent the travel distance distribution for school tours observed in the household survey.

During validation, the specified model was compared against two other models: (a) A random allocation procedure, and (b) Nearest school location process to assess the model performance.

Figure 4.4 shows the distribution of the survey respondents compared to each of the three methods for the different age groups.

- For all three school types, the model outperforms both other methods.
  - The random method produces higher average travel times when compared to the survey; and
  - The nearest school method produces much shorter average travel times when compared to the survey.
- The probabilistic model matches survey distributions almost identically in 80 percent of the cases.
  - For survey records where respondents reported traveling very long distances, the model underreports travel.
  - However, it should be noted that the probabilistic model does not have information about private schools and the decision that drives households to choose private schools that are further away from home.

Figure 4.4 Cumulative Distributions of Distance to School

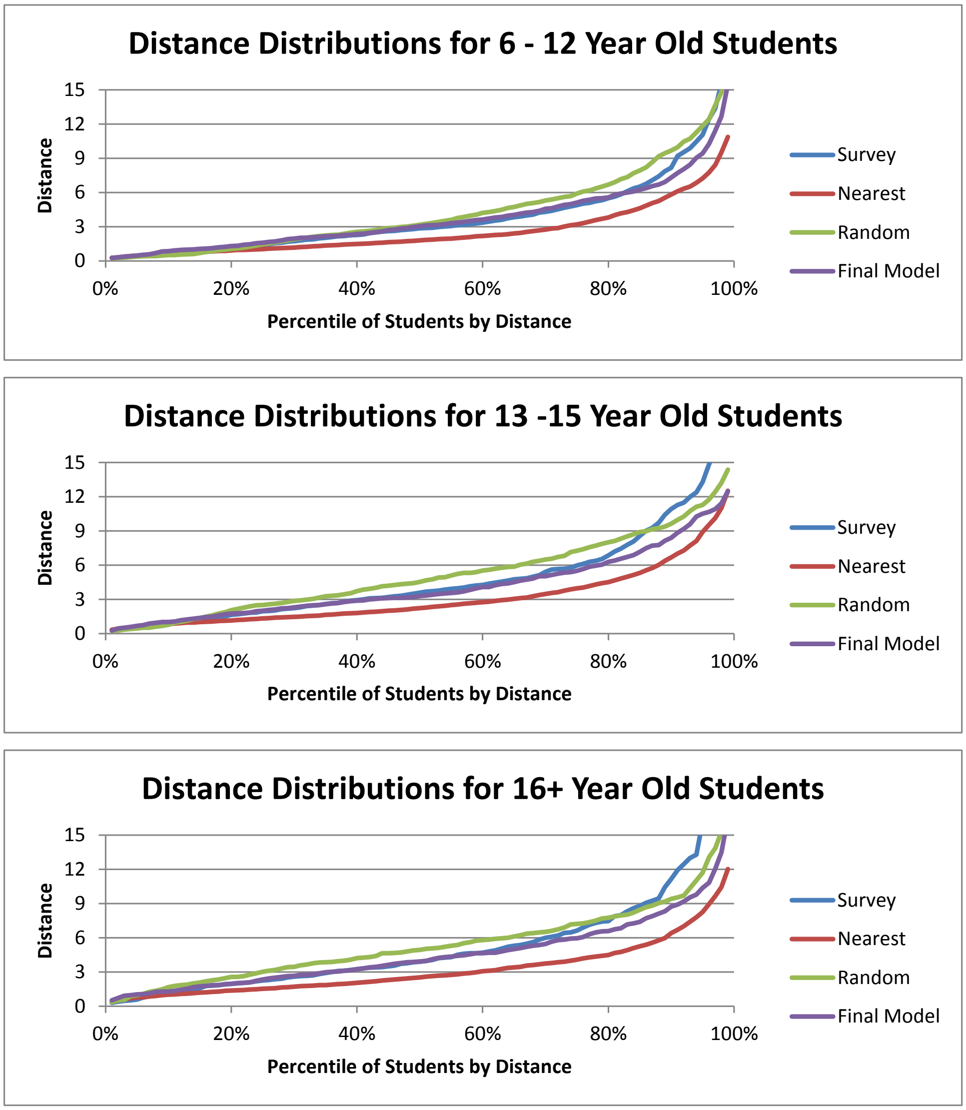


Table 4.17 shows the round trip distance to school in total and the average travel distance per student.

- Simulating the distribution of travel and the total amount of travel is a key objective of this model.
- The model results clearly indicate that the model does a good job representing regional school travel.
- The model does not identify the exact school location zone in many cases, but this is not a key objective of the model in any case.

Table 4.17 Results of School Location Validation

Travel Distances	Observed		Model		Comparison	
	Total	Average	Total	Average	Difference	Exact Zone
Distance, Ages 6-12	13,149	3.74	13,196	3.73	0%	16%
Distance, Ages 13-15	6,392	4.59	5,850	4.13	-8%	20%
Distance, Ages 16+	4,363	4.82	4,274	4.59	-2%	30%
Distance, Total	23,905	4.11	23,321	3.96	-2%	23%

Note: Observations with distances of 25+ miles were removed from the analysis.

4.6 Calibration of the Tour and Trip Mode Choice Models

The tour mode choice models are the last of the tour-level models and were calibrated after the calibration of all other tour-level models was completed. Tour-level mode choice models were calibrated for each tour purpose separately.

Adjustment of Transit Targets for the Tour and Trip Mode Choice Models

Original control totals were developed using the household travel survey. However, it was observed that the transit totals generated from the household survey were resulting in a very high number of transit trips and boardings when compared to regional transit ridership totals. Therefore, an adjustment procedure was developed to modify the tour-level transit totals to better reflect regional transit totals. This procedure is described below:

- **Step 1**. Compare trip-based transit totals from the household survey and the regional on-board survey by purpose.
- **Step 2**. Develop adjustment factors to the household survey trip totals so that they match the transit on-board survey totals.
- **Step 3**. Use the new weights developed for the transit trips in the household survey along with unadjusted weights for non-transit trips to calculate new tour weights. An example is listed below:
  - *Consider a tour with 4 trips, exactly one of which is on transit.*
  - *Original tour weight in household survey = 160.*
  - *Adjustment factor to the transit trip in the tour after comparison to the on-board survey = 0.5.*
  - *New weight for transit trip in tour = 80.*
  - *New tour weight = (80 +3*160)/4 = 140*

- **Step 4**. Use the new tour weights to recalculate tour targets for each of the modes. The most noticeable changes to targets were for transit. However, small changes were observed for the other modes as well.

It was observed that the original transit trip targets without adjustments was 285,000 while the original transit boarding targets were 458,000. After the adjustments were made, the transit trip targets were scaled to 198,000 and 275,000 respectively. Similarly, the tour targets for transit were adjusted from 141,000 to 88,000. Table 4.18 outlines the home-based work tour targets before and after the transit trip weight adjustment.

Table 4.18 Home-based Work Tour Targets Before and After Adjustment

Tour Mode	Old Target Count	Old Target Percentage	New Target Count	New Target Percentage
Drive Alone	1,098,930	65.7%	1,118,512	67.1%
Shared Ride 2	183,396	11.0%	187,030	11.2%
Shared Ride 3+	224,781	13.4%	228,704	13.7%
Walk to Transit	83,110	5.0%	57,950	3.5%
Drive to Transit	21,381	1.3%	13,377	0.8%
Walk	30,452	1.8%	30,716	1.8%
Bike	30,880	1.8%	31,394	1.9%

Transit Calibration

As a first step, the alternative specific constants were adjusted during calibration so that the modal targets were met. At the end of this round of adjustments, the regional totals for each mode were met. However, it was determined that the transit model calibration would need to be conducted at a more aggregate level to capture both the socio-demographic patterns as well as geographic (corridor) patterns.

- As a first step, the transit trip table produced from the model was aggregated to a district level and compared to the transit trip table developed from the on-board survey.
- Second, the model reported boardings were aggregated to route corridors and compared against the survey reported boardings by route corridor.
- Third, both the trip tables and model reported boardings were segmented by walk and drive to ensure that the model accurately represents the access shares.

During this detailed calibration, the following steps were implemented:

- Ensure that park-and-ride lots are adequately connected to the network.

- Increase the drive access distance for park-and-ride lots serving train stations to better reflect the ability of rail to attract commuters that live further away from the train station.
- Adjust the transfer penalties between bus and also between bus and rail to better reflect transferring patterns in the region. Final penalties are listed below:
  - Walk to Transit:
    - » Rail-rail transfer penalty = 3 minutes
    - » Rail-bus transfer penalty = 3 minutes
    - » Bus-bus transfer penalty = 8 minutes
  - Drive to Transit
    - » Rail-rail transfer penalty = 5 minutes
    - » Rail-bus transfer penalty = 5 minutes
    - » Bus-bus transfer penalty = 9 minutes
- Give rail a travel time discount to account for the fact that rail is more convenient, has greater reliability, and is served on specialized right of way that is unaffected by congestion. Since local bus, express bus, light rail, and commuter rail are bracketed within one transit mode, these discounts may be considered to serve as a transit sub-mode specific constant.
  - Modeled rail travel times = 80 percent of observed travel times
  - Modeled bus travel times = 130 percent of observed travel times
- Introduce 1-2 area specific constants to better capture transit market sheds within downtown and urban areas in the region.
- In total, over 20 model calibration runs were conducted to ensure that the model reported transit mode share better represents the patterns observed in the transit on-board survey.
- **Table 4.19** outlines the corridor-level comparisons between the transit on-board survey and the travel demand model. In all corridors, except the I-494 corridor, the difference between survey and model boardings is less than 25 percent. In key corridors such as the Bottineau and the Hiawatha rail corridor, the differences are significantly lower.

Table 4.19 Corridor-level Boardings Comparison – Model vs. Transit On-board Survey

Travel Distances	On-board Survey		Model		Comparison	
	Peak	Off-Peak	Peak	Off-Peak	% Peak Diff	% Off-Peak Diff
Bottineau	28,742	17,672	30,766	19,527	7%	10%
Central	22,933	18,315	18,022	11,722	-21%	-36%
Hiawatha	15,463	13,084	14,966	10,570	-3%	-19%
Southwest	15,041	11,464	18,355	12,406	22%	8%
Nicollet Ave	9,667	5,419	7,486	5,271	-23%	-3%
Gateway	7,027	4,759	6,391	4,725	-9%	-1%
Central Ave	4,855	3,725	4,654	4,225	-4%	13%
Robert St	4,641	3,103	5,296	4,498	14%	45%
East 7th	3,933	3,600	6,489	4,757	65%	32%
I-494 American Blvd	2,979	3,956	6,097	3,373	105%	-15%
West 7th	2,679	1,319	2,255	1,963	-16%	49%
I-35 W North	2,175	826	1,485	119	-32%	-86%
Snelling	1,592	2,191	1,832	1,823	15%	-17%
Total	**121,727**	**89,432**	**124,094**	**84,980**	**2%**	**-5%**

4.7 Network Updates

This section documents key updates that were made to the highway network and then describes the QA/QC checks that were conducted to assess the performance of the updated network.

Creating New Roadways

The previous travel demand model network contained 1,632 traffic analysis zones. During the update of the model, additional zones were added by splitting existing zones resulting in a new model with 3,030 zones. The increase and subdivision of the zones necessitated an increase in roadways within the highway network to ensure that trips are loaded from the zones to the network in a reasonable manner.

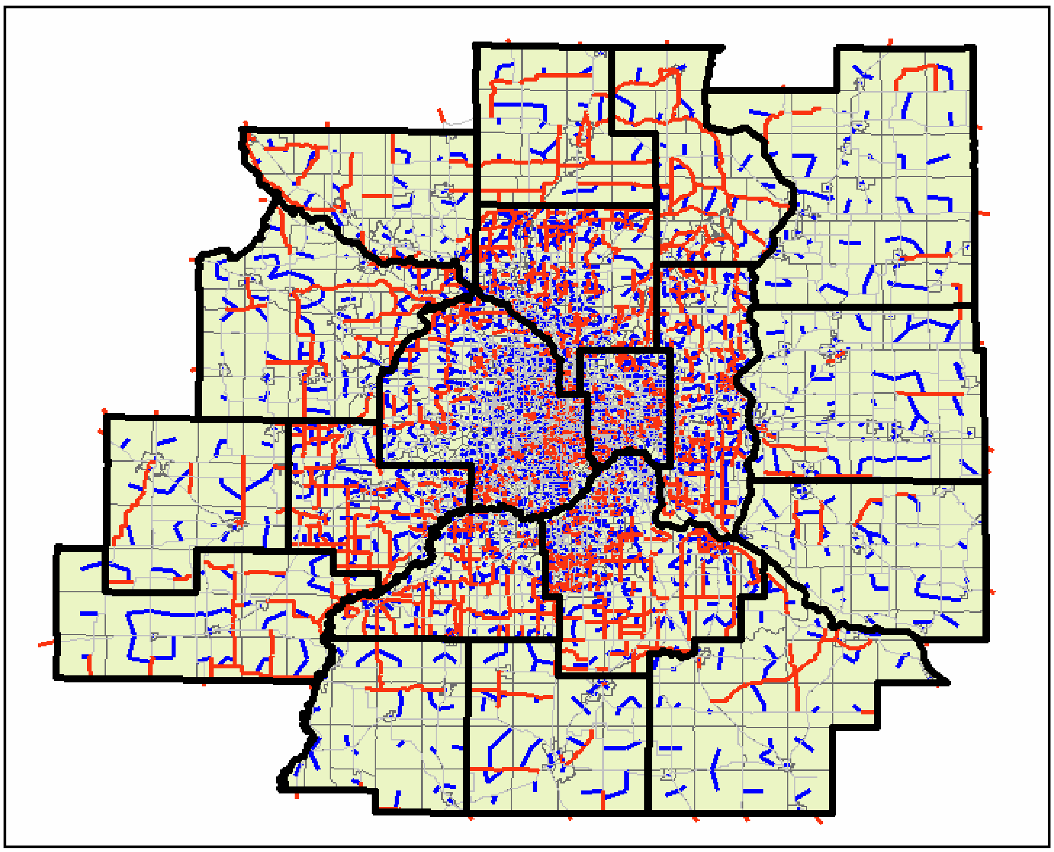
New roads were added to the network using the NCompass dataset which contains all roadways within the Metropolitan Council planning region. The update process was performed using a combination of Cube and GIS. Roads that were added to the model network were first identified in GIS and then transferred to the Cube geodatabase. Once in the geodatabase, the roads were physically joined to the network.

Connecting New Zones with the Transportation Network

The increased zonal detail resulted in a large number of new zones that had to be connected to the network. Since the number of zones effectively doubled, it was determined that maintaining the existing zone connectors would not be practical and that new connectors for all zones would be preferable. Cube's automated connection process was used and the connections that were generated were reviewed. Every zone connection was manually inspected and some of the connections were edited. The types of changes that were made included the reattachment of zones to appropriate roadway links (e.g. not assigning to freeways) and the addition of more connections where appropriate.

Figure 4.5 shows the new model roads in red and the new zone connectors in blue.

Figure 4.5 New Network Roads and Zone Connectors



Coding Area Type

Demand model networks typically use area type and roadway type to apply speed and capacity look up tables to determine the free flow speeds and the lane capacity of the network.

The previous model used seven area types. The new area types in the model are based on this classification, but with the "Collar County" area type removed. This area type was previously used in the collar counties and contained the same value as the rural area type. In the re-coding of the area types, the definitions that apply within the core counties were applied to the collar counties as well. This allows for some of the more developed areas within the collar counties to be coded differently than rural areas based on their socioeconomic characteristics.

Population and employment density are used to determine a zone's area type. To smooth out the effect of neighboring zones with different characteristics, a zone's area type is determined by its own population and employment density but also takes into account the density of neighboring zones.

For example, if a zone borders three other zones, its own density and the density of the three zones are combined to establish the density that determines the area type. **Table 4.20** shows the population and employment density thresholds that were used to determine each area type. This approach is consistent with previous efforts with minor changes implemented to create a smoother transition between zone types.

Table 4.20 Area Type Population and Employment Densities

Description	Area Type	Population Density Low	Population Density High	Employment Density Low	Employment Density High
Rural	1	0	500	0	3,000
Developing	2	500	3,000	0	2,500
Developed	3	3,000	5,000	0	4,000
Residential Core	4	5,000	1,000,000	0	20,000
Business Core	5	0	1,000,000	20,000	1,000,000
Other Business Core	6	0	5,000	2,500	20,000

We should note that the "Other Business Core" definition supersedes the "Developed" definition in cases where both definitions apply. If a TAZ satisfies both definitions, it is coded as "Other Business Core". An example would be a case where a TAZ has a population density of 4,000 persons per mile and an employment density of 3,000 employees per square mile. In this case, the TAZ meets both area type criteria and it is assigned as "Other Business Core".

Functional Classification

The second component of the speed and capacity lookup process is the functional classification of the road (roadway type). The actual functional classification is typically not the preferred manner to determine roadway type since these classifications tend to be administrative and/or jurisdictional in nature and do not offer a true indicator of the roadway type.

The new set of roadway types used in the model network were developed by using a combination of the previous model roadway types and the NCompass classification which lists the roads as:

- Interstate,
- Trunk Highways,
- Primary Roads,
- Major Roads,
- Residential Roads, and
- Ramp and Gravel Roads.

The NCompass classification was used as the basis of the model roadway types. Previous definitions used in the model were applied to subdivide the classifications and provide additional detail. **Table 4.21** lists the roadway characteristics index (RC), the old classification, and the new roadway type.

Table 4.21 Roadway Characteristics Index

RC Index	RC Number	ASGNRP09 Old classification	New Roadway
1	10	1	1 - Interstate - Metered
2	10	2	1 - Interstate –UnMetered
3	20	15	2 - Trunk Highway - Expressway
4	20	5	2 - Trunk Highway - Divided Arterial
5	20	6	2 - Trunk Highway - Arterial
6	30	5	3 - Primary Road - Divided Arterial
7	30	6	3 - Primary Road - Arterial
8	40	5	4 - Major Road - Divided Arterial
9	40	6	4 - Major Road – Arterial
10	40	7	4 - Major Road – Collector
11	50	6	5 - Residential – Arterial
12	50	7	5 - Residential - Collector
13	60	4	6 - Ramp – UnMetered
14	60	3	6 - Ramp – Metered
15	70	7	7 - Gravel – Collector

Observed Roadway Speeds - TomTom Data

The grouping of the roadway types was guided in part by the information provided in the TomTom dataset. The updated travel demand model network includes the following information that is attached to it:

- TomTom data,
- existing assignment group code (ASNGRP09), and
- the NCompass roadway characteristic (RC) codes.

TomTom speed observations were grouped by combinations of assignment group, RC code, and area type. The goal was to have a diverse set of roadway types to properly capture the model speeds across all roadway types in each area type. Assessing the TomTom data observations ensured that there were enough speed observations to support each roadway and area type combination.

Table 4.22 lists the free flow speeds as determined by the TomTom data. Cells that are labelled N/A did not have speed observations.

- The speeds in this table are reasonable as they generally decrease with roadway type starting with highest speeds on the Interstate (RC values of 1 and 2) and lowest speeds in Residential Arterials and Collectors (RC values of 11 and 12).
- The pattern of speeds is also consistent across area types. For any given roadway classification, speeds are highest in Rural and Developing areas and lowest in the Business Core areas.

Table 4.22 Unadjusted TomTom Speeds

RC Index	Rural	Developing	Developed	Residential Core	Business Core	Other Business Core
1	62.66	61.53	59.95	55.77	53.17	58.63
2	65.29	63.06	61.2	57.52	45.13	59.00
3	61.59	49.05	44.32	38.23	39.55	41.27
4	54.56	44.00	39.35	34.26	N/A	37.91
5	47.41	43.04	40.27	N/A	N/A	30.80
6	47.34	37.69	34.77	29.05	24.17	30.57
7	48.19	38.45	32.51	26.53	21.84	31.42
8	39.33	31.28	29.54	24.98	30.00	27.89
9	44.88	32.58	28.97	25.82	27.74	28.12
10	35.13	29.54	27.50	23.71	17.98	26.50
11	33.04	29.51	26.35	18.77	N/A	27.90
12	26.04	25.58	24.92	20.35	18.56	22.88
13	45.24	41.82	39.94	38.98	37.40	36.59
14	36.17	40.24	39.04	39.79	35.95	38.82
15	N/A	N/A	N/A	N/A	N/A	N/A

These speeds were then manually smoothed out to provide a continuous transition among different functional classes and area types. These values are listed in **Table 4.23**. The speeds for cells that were previously empty and labelled N/A are imputed based on speeds from neighboring cells in the same row or column.

Table 4.23 Adjusted TomTom Speeds

RC Index	Rural	Developing	Developed	Residential Core	Business Core	Other Business Core
1	63	62	60	56	53	59
2	65	63	61	58	45	59
3	62	49	44	38	40	41
4	55	44	39	34	34	38
5	47	43	40	34	34	31
6	47	38	35	29	24	31
7	48	38	33	27	22	31
8	39	31	30	25	30	28
9	45	33	29	26	28	28
10	35	30	28	24	18	27
11	33	30	26	19	19	28
12	26	26	25	20	19	23
13	45	42	40	39	37	37
14	36	40	39	40	36	39
15	26	26	25	20	19	23

4.8 Network Validation Checks

A series of network-related validation checks were implemented to test the quality of the updates made to the network. Some of the key tests that are highlighted in this section include the following:

- **Ensure Consistent Coordinate System.** The coordinate system for the geodatabase is:

  Projection: Transverse_Mercator

  False Easting: 500000

  False Northing: 0

Central Meridian: -93

Latitude of Origin: 0

Linear Unit: Meter(1)

Geographic Coordinate System: GCS_GRS_1980

Angular Unit: Degree(0.0174532925199433)

Prime Meridian: Greenwich(0)

Datum: D_GRS_1980

Spheriod: GRS_1980

Semimajor Axis: 6378137

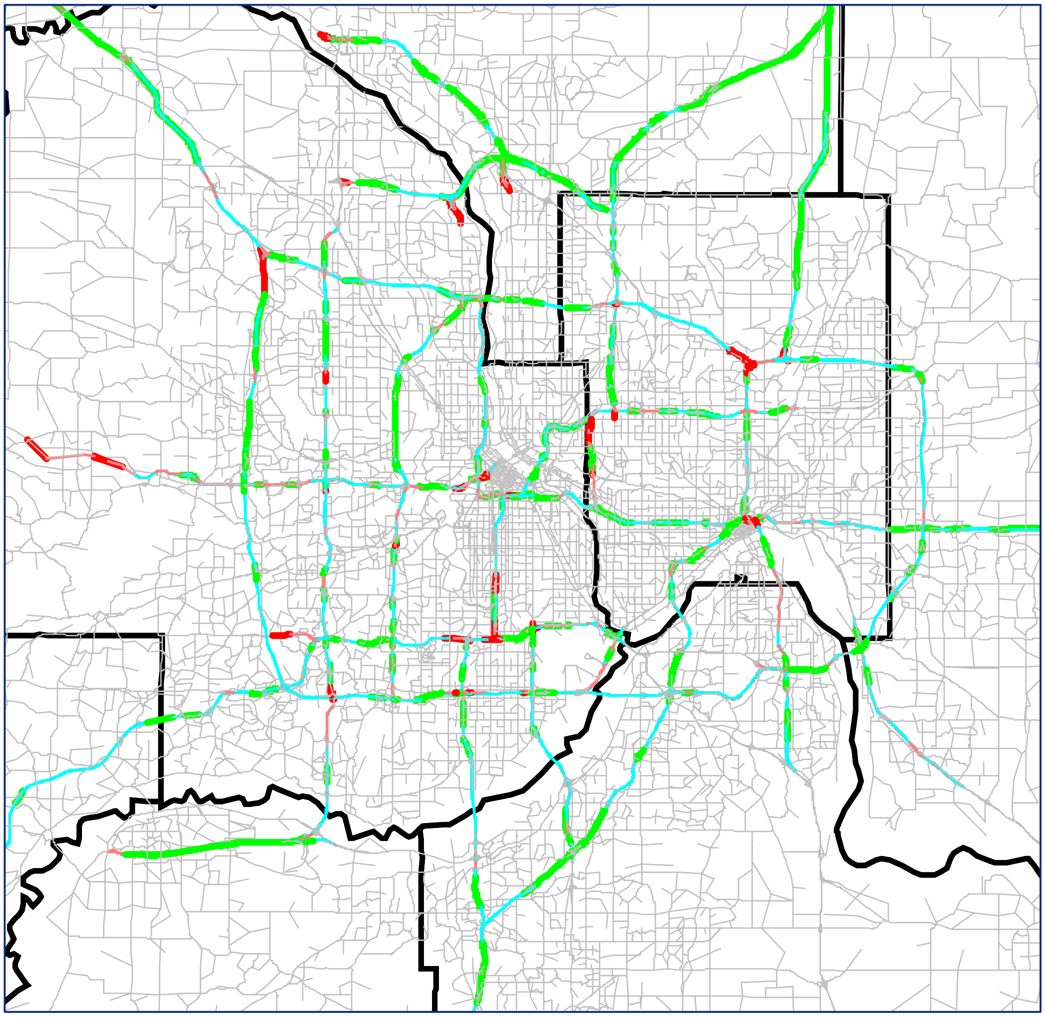
Semiminor Axis: 6356752.31414028

Each node created from the geodatabase and used in the creation of network files was checked to ensure that it had the correct coordinates.

- **Distance Coded to Each Link**. The network creation process performed a check to ensure that each link contains a correct distance value in miles. Since the coordinate system is in meters, we ensured that the export process adjusted for this change in measurement systems.
- **Area Type**. Every link in the geodatabase had a non-zero value for area type coded into the AREA data field based on **Table 4.20** values. Some exceptions have been made, primarily for divided highways, to ensure that the same values were used for both directions of the highway. The zone connectors were all coded with a rural area type regardless of location. The network was visually inspect to ensure that each link had a non-zero value.
- **Facility Type**. Each link was coded with a Roadway Characteristics Index (RCI) value as defined in **Table 4.21.** The network was visually inspected to ensure that each link had a non-zero value.
- **Free Flow Speed**. The network links were visually inspected to confirm that every link had a non-zero value. Free flow speed values were assigned based on the adjusted TomTom speed data presented in **Table 4.23**.
- **Divided Highway Connections**. The connections of the divided highways in the network were reviewed to confirm proper connectivity.
- **One-way / Two-way**. One-way roads in the network were reviewed to ensure that assigned traffic moves only in the appropriate direction. This process included a review of one-way pairs that make up the divided highway system.
- **Zone Connectors**. All zone connectors were coded with the same speed and were assigned very large capacities. Each zone had at least one zone connector with a maximum of four connectors. The average number of connectors for the internal zones was 1.4. Internal zones were numbered 1-3030 and the extrernals ran from 3,031 to 3,061.

- **Network Skim Checks**. Highway skims were produced and reviewed for the network. All zones had reasonable free flow travel times and distances. Each zone was able to connect to every other zone using the highway network.
- **Congested Model Speeds**. Congested model speeds were developed by assigning a trip table to the network. The trip table used in the congested travel time estimates was the expanded version of the previous model's trip table. The expansion was needed to account for the additional zones in the new model and used the population and employment of the updated TAZ system to disaggregate the trip tables from the TAZ structure in the previous model.
- The comparisons show the differences in congested speeds between the model assignment results and the TomTom speed data for the AM peak period and the Mid-Day period for the freeway and trunk highway systems respectively. These comparisons suggest that the model does a very good job replicating observed traffic movements resulting in comparable speeds:
  - **Figure 4.6** shows the comparisons of congested freeway speeds between the model and the TomTom data during the AM peak;
  - **Figure 4.7** presents the trunk highway congested speeds for the AM peak;
  - **Figure 4.8** compares midday congested conditions on the freeways as they appear in the model versus the TomTom data; and
  - **Figure 4.9** presents the trunk highway data for midday conditions.

Figure 4.6 AM Peak Model versus Congested TomTom Freeway Speeds



Note:

GREEN: Model speeds and TomTom speeds are within 2 MPH of each other

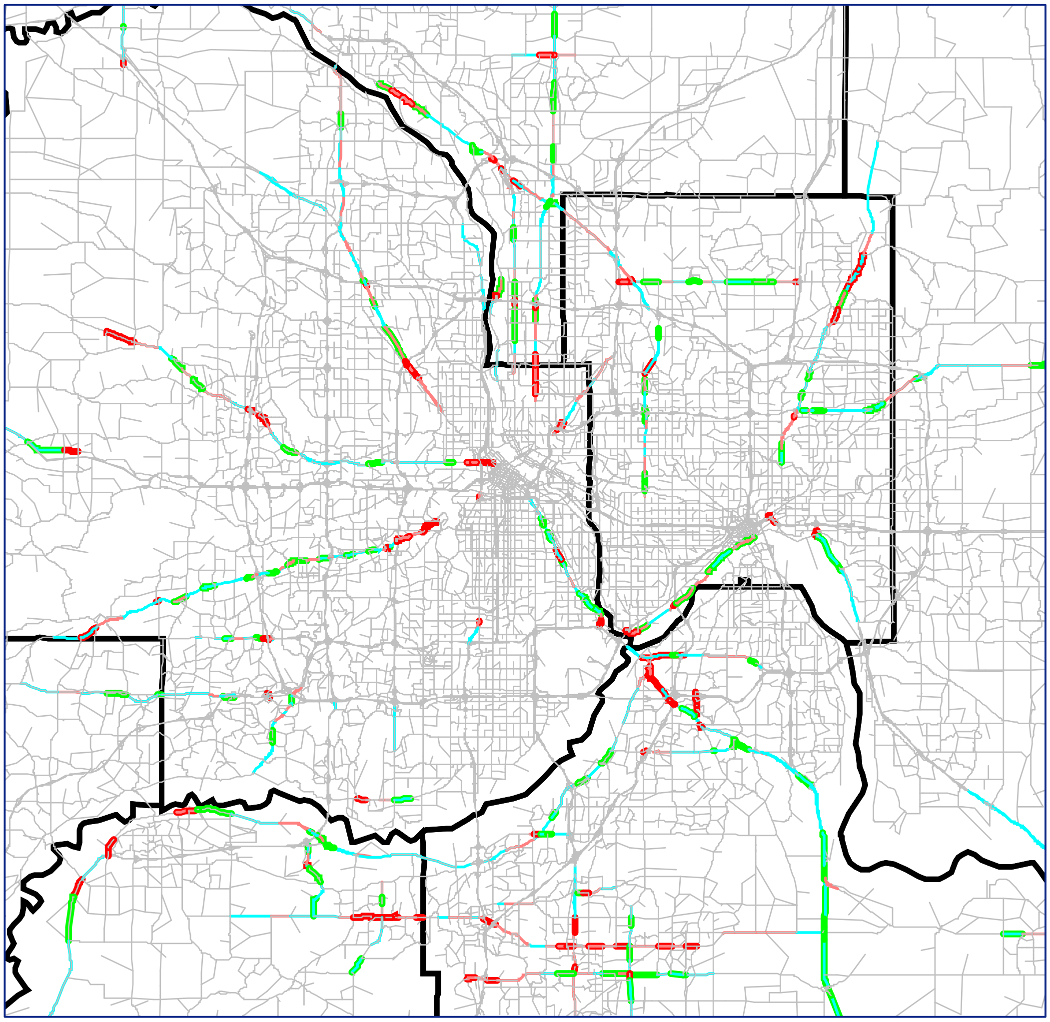
LIGHT BLUE: Model speeds are between 2 and 5 MPH slower than TomTom speeds

DARK BLUE: Model speeds are more than 15 MPH slower than TomTom speeds

LIGHT RED: Model speeds are between 2 and 5 MPH faster than TomTom speeds

DARK RED: Model speeds are more than 15 MPH faster than TomTom speeds

Figure 4.7 AM Peak Model vs. Congested TomTom Trunk Highway Speeds



Note:

GREEN: Model speeds and TomTom speeds are within 2 MPH of each other

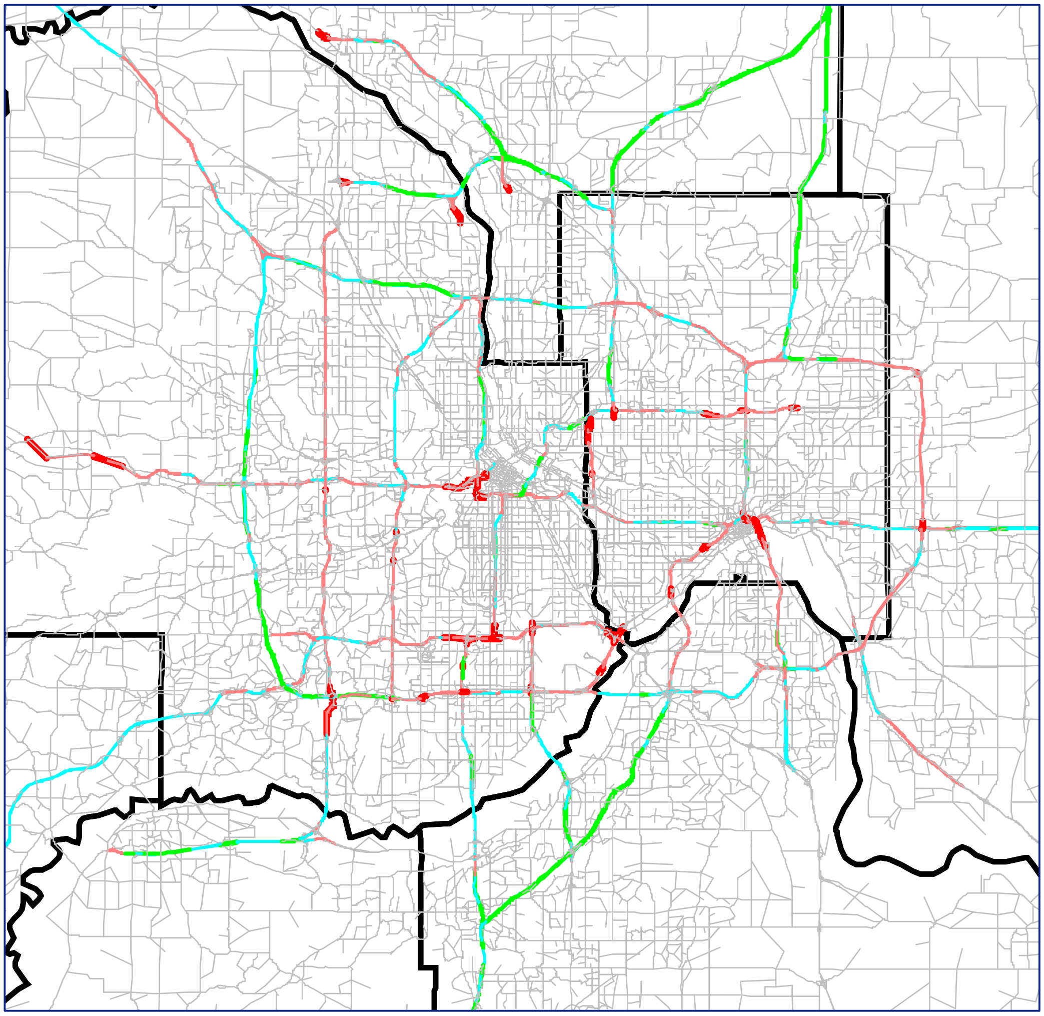
LIGHT BLUE: Model speeds are between 2 and 5 MPH slower than TomTom speeds

DARK BLUE: Model speeds are more than 15 MPH slower than TomTom speeds

LIGHT RED: Model speeds are between 2 and 5 MPH faster than TomTom speeds

DARK RED: Model speeds are more than 15 MPH faster than TomTom speeds

Figure 4.8 Midday Model versus Congested TomTom Freeway Speeds



Note:

GREEN: Model speeds and TomTom speeds are within 2 MPH of each other

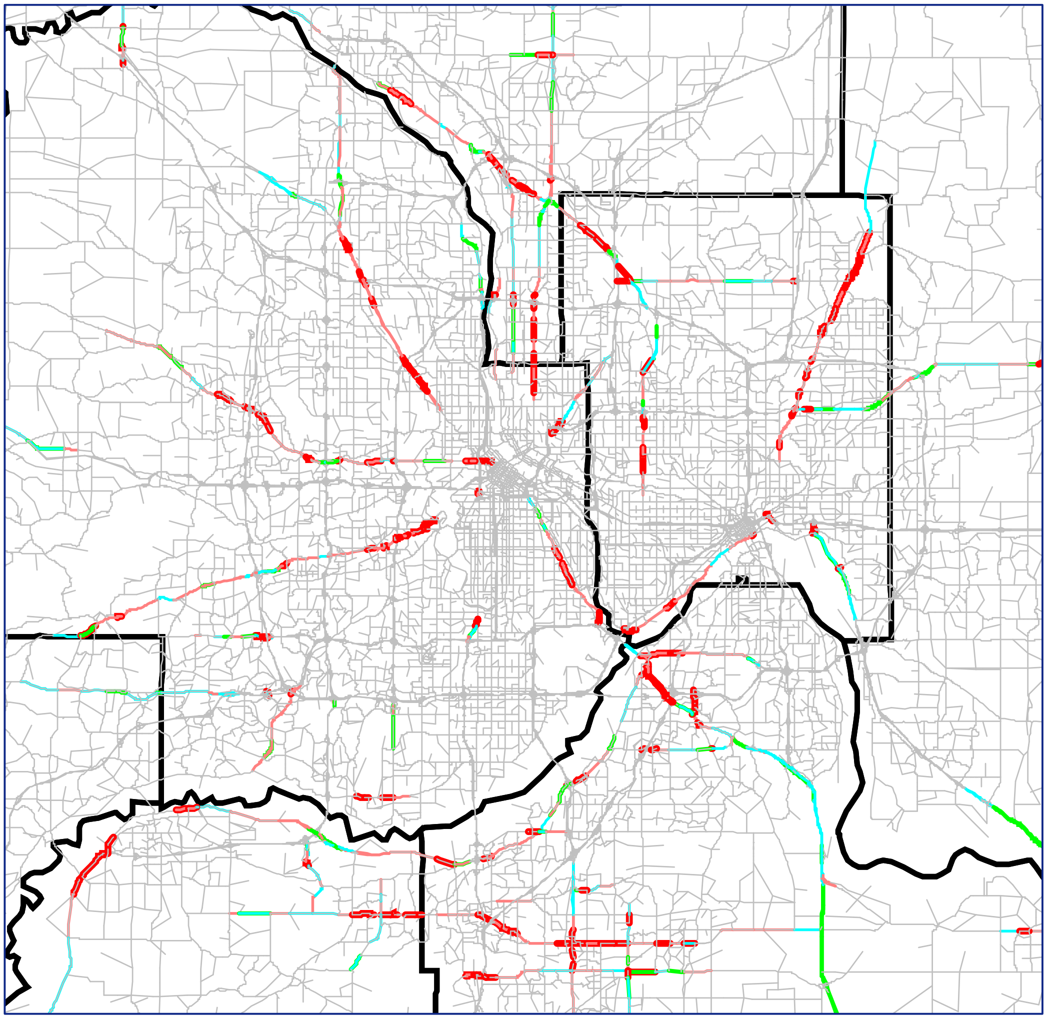
LIGHT BLUE: Model speeds are between 2 and 5 MPH slower than TomTom speeds

DARK BLUE: Model speeds are more than 15 MPH slower than TomTom speeds

LIGHT RED: Model speeds are between 2 and 5 MPH faster than TomTom speeds

DARK RED: Model speeds are more than 15 MPH faster than TomTom speeds

Figure 4.9 Midday Model vs. Congested TomTom Trunk Highway Speeds



Note:

GREEN: Model speeds and TomTom speeds are within 2 MPH of each other

LIGHT BLUE: Model speeds are between 2 and 5 MPH slower than TomTom speeds

DARK BLUE: Model speeds are more than 15 MPH slower than TomTom speeds

LIGHT RED: Model speeds are between 2 and 5 MPH faster than TomTom speeds

DARK RED: Model speeds are more than 15 MPH faster than TomTom speeds

4.9 Additional Attributes

Some new attributes were developed during post-processing steps to support model estimation. These attributes include ***terminal times*** to reflect the additional times that drivers spend while parking and reaching their destination and ***parking costs*** that were assigned to different parts of the Twin Cities metropolitan region.

Terminal Times

Terminal times were added to the auto modes to account for the time spent:

- Accessing their car as they were preparing to leave their origin and
- The time spent walking from the parking location to their destination.

The terminal times vary between one and five minutes and are segmented by area type, which serves as an indirect indicator of parking availability and accessibility.

Parking times were added to all three drive modes (drive alone, shared ride 2 and shared ride 2+) and for the drive access portion of the "drive to transit" mode.

Table 4.24 Terminal Times by Area Type

Description	Area Type	Terminal Time (minutes)
Rural	1	1
Developing	2	2
Developed	3	2
Residential Core	4	2
Business Core	5	5
Other Business Core	6	3

Parking Costs

Zonal level parking costs were calculated using the following steps:

- Metropolitan Council provided information on parking lot costs, ramp costs and the number of parking spaces available in downtown Minneapolis and St. Paul. Costs were provided at an hourly, daily and monthly level and were used to calculate initial estimates of parking costs.
- The data provided by Metropolitan Council did not include parking costs data for all of the downtown zones especially in Minneapolis. To fill that gap, publicly available information[6] were used to identify parking costs in additional zones and enhance the robustness of the parking data.

[6] http://www.mplsparking.com/includes/multi_space_map.pdf

- The parking cost data were geocoded using the address information of the parking lot/ramp and the corresponding TAZ used in the model. Based on the number of differentially priced parking spaces available for each parking lot in a TAZ, the weighted average parking costs were calculated at the hourly, daily and monthly level. In cases where data on the number of parking spaces were not available, a simple zonal average value was calculated.
- In cases where parking costs varied by season, the maximum value of the range was assigned as the parking cost. In cases where hourly and daily parking costs were missing, monthly costs were divided by a factor of 20 to obtain daily costs. These estimates were then divided by a factor of 3 to obtain hourly costs based on the observed relationships between monthly, daily and hourly rates for lots where full information was available.
- A cost of at least $1 per hour was used in all zones which had priced parking.
  - Average daily parking costs by zone were labeled as work related parking costs for each zone.
  - For non-work related parking costs, the lower of the following two values was used:
    - Daily parking cost divided by 3; or
    - The hourly parking cost multiplied by 3.

Figure 4.10 and **Figure 4.11** highlight the zones with non-zero parking costs.

Figure 4.10 Zones with Parking Costs

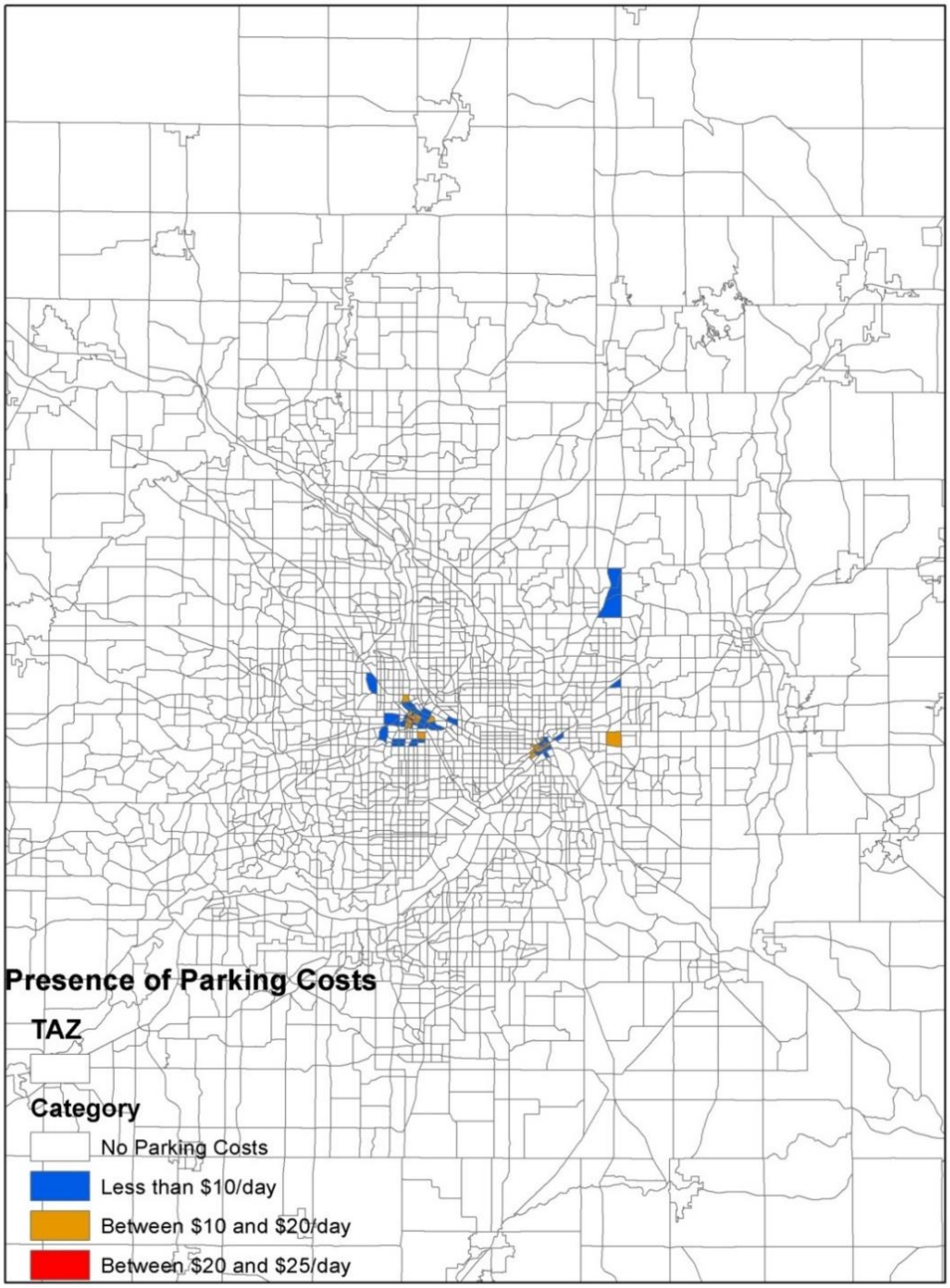
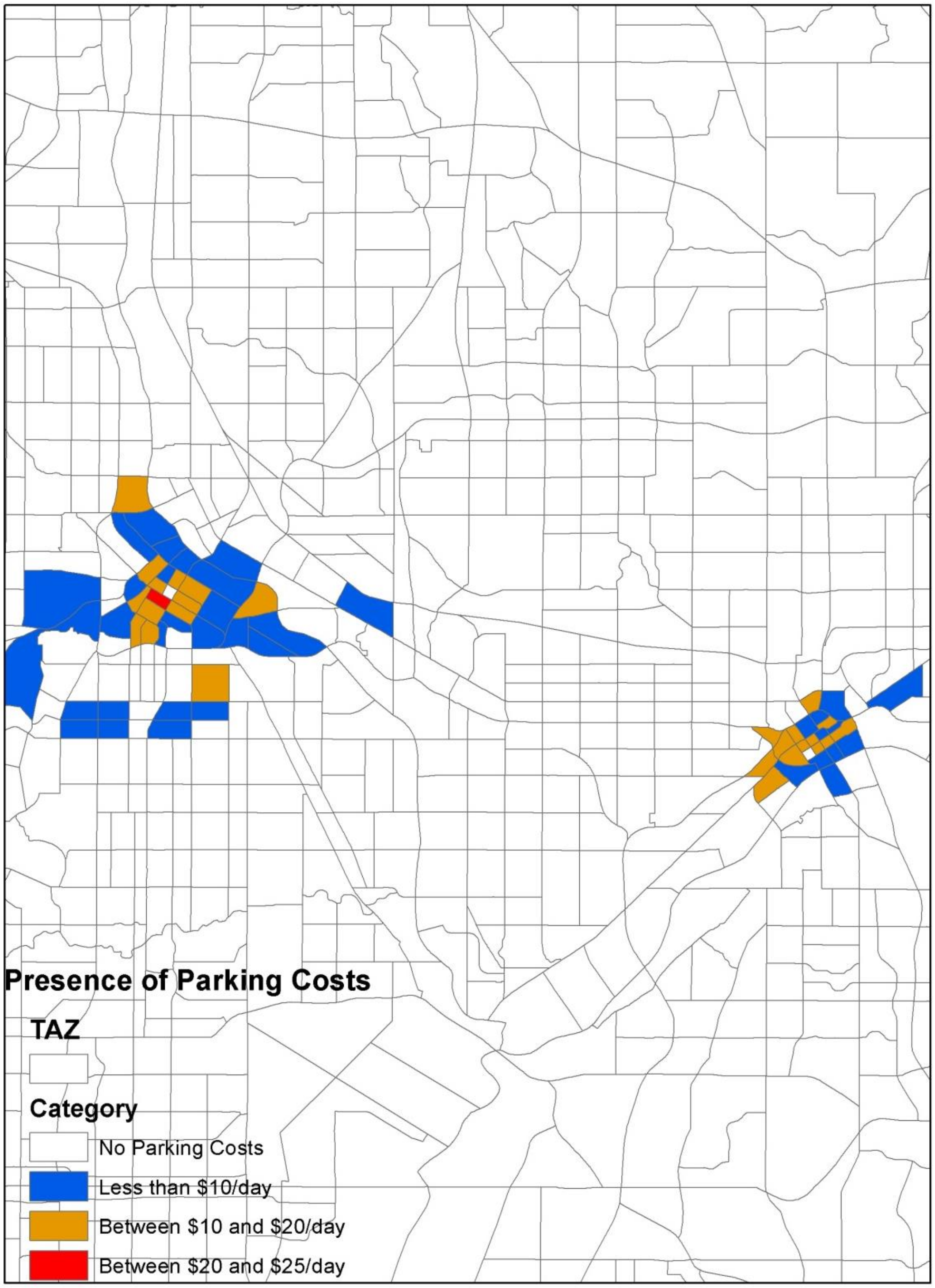


Figure 4.11 Minneapolis and St. Paul Zones with Parking Costs



4.10 Highway Traffic Assignment Validation

Highway traffic assignment validation was a critical element of the whole validation process. Since a majority of travel in the region relies on the use of an automobile, it is essential the model matches observed traffic patterns and counts within the parameters established for highway validation. The highway validation consisted of three key steps:

- Incorporate traffic counts from Minnesota DOT (MnDOT) into the model network. Compare the model reported volumes against those reported in the traffic counts database.
- Code screenlines and bridge crossings in the model network and compare metrics such as vehicle-miles traveled (VMT) on these major crossings.
- Compare overall model VMT against historical data and against VMT from the previous iteration of the model.

Traffic Count Locations

Count data were obtained using MnDOT's web-based portal. The count data were snapped to the model network and exhaustive manual checks were conducted to ensure that the counts were snapped to the appropriate link in the model network.

- After the manual checks, traffic counts from nearly 6,000 locations were found to have been snapped to the correct location (**Table 4.25**).
- Of these, 1,175 locations had traffic counts broken down by time-of-day which was to conduct calibration by time-of-day.
- The traffic count locations were well distributed by roadway facility and area type.
- In addition, the traffic counts coded into the network were also well distributed across the screenlines identified for calibration.

Model vs. Count Location Comparisons

The model results were compared against the counts across two dimensions – traffic volume and traffic VMT. Both passenger and traffic volumes were included in the model results since the traffic counts also include all types of vehicular traffic. Key findings include:

- Total observed volume on the count locations is 71 million while the model volumes on the same locations equal 66 million (7 percent difference).
- For the 1,175 locations that have time-of-day components, the AM and PM peak period differences do not exceed 8 percent suggesting that the model does a good job in capturing traffic volumes during the congested periods.

Table 4.25 Distribution of Traffic Counts by Facility Type

Facility Type	Number of Count Locations
Interstate & Trunk Highway Expressway	1575
Trunk Highway - Divided Arterial	311
Trunk Highway - Arterial	44
Primary Road - Divided Arterial	670
Primary Road - Arterial	730
Major Road - Divided Arterial	397
Major Road - Arterial	460
Major Road - Collector	960
Residential - Arterial	22
Residential - Collector	344
Ramp - UnMetered	242
Ramp - Metered	228
Total	**5,983**

Table 4.26 outlines the volume and VMT comparisons between observed and model data by facility type.

- On the major interstate and trunk highway expressway facilities the model volumes are within 3.5 percent of observed count volumes and the VMT difference is only 1.8 percent. The FHWA Target for VMT difference for such facilities is 7 percent.
- On the other major facilities such as divided trunk highway arterials, the VMT difference is only 3.1 percent compared to an FHWA target of 10 percent.
- Similar patterns are also observed on screenlines and breakdowns by county/area type.
- No adjustments were made to the volume delay functions since the model replicates regional behavior reasonably well.
- Total VMT in the region is about 84 million vehicle-miles. Based on information provided by MetCouncil, this number is slightly lower than the VMT observed in the previous model and is consistent with findings of VMT reductions.

Table 4.26 Model vs. Observed Count Data

Facility Type	Observed Data		Model Data		Comparison	
	Volume	VMT	Volume	VMT	% Diff Volume	% Diff VMT
Interstate & Trunk Highway Expressway	48,378,760	26,529,514	46,675,216	26,063,394	-3.5%	-1.8%
Trunk Highway - Divided Arterial	3,377,825	1,870,290	3,304,472	1,927,617	-2.2%	3.1%
Trunk Highway - Arterial	254,150	228,191	246,152	202,750	-3.1%	-11.1%
Primary Road - Divided Arterial	5,771,450	1,520,522	5,279,860	1,406,130	-8.5%	-7.5%
Primary Road - Arterial	3,120,225	2,432,045	3,123,443	2,460,336	0.1%	1.2%
Major Road - Divided Arterial	2,467,600	584,456	1,745,195	383,704	-29.3%	-34.3%
Major Road - Arterial	1,404,550	670,245	1,083,027	531,315	-22.9%	-20.7%
Major Road - Collector	2,587,900	754,716	1,782,001	462,951	-31.1%	-38.7%
Residential - Arterial	69,525	40,411	60,152	34,052	-13.5%	-15.7%
Residential - Collector	750,450	239,856	393,676	85,891	-47.5%	-64.2%
Ramp - UnMetered	1,447,829	379,515	1,235,572	318,004	-14.7%	-16.2%
Ramp - Metered	1,362,987	337,742	1,050,491	254,841	-22.9%	-24.5%
Interstate & Trunk Highway Expressway	48,378,760	26,529,514	46,675,216	26,063,394	-3.5%	-1.8%
Total	**70,993,251**	**35,587,503**	**65,979,257**	**34,130,984**	**-7.1%**	**-4.1%**

5.0 Model Sensitivity Runs

As the last step in model development, the newly calibrated model was tested under four different operational scenarios to test model performance. Model results from each run were synthesized and compared either against observed data or against expected performance given the changes in inputs. The four model scenarios included the following:

- Base year model run to test toll road usage;
- Base year model run that included the Green Line;
- Future year (2040) model run with new socio-demographics and two changes to the network to include Green Line and I-610; and
- Base year model run with revised BPR curve parameters that were updated based on comparisons with TomTom speed data.

Detailed summaries are available as supporting documentation to this report in the folder titled "Sensitivity Runs".

5.1 MnPass Usage

During the model calibration stage, MnPass usage data were not used to test the model performance against observed data. Therefore, as part of the model testing, we compared model outputs for toll use against observed MnPass usage data.

Model Changes

The MnPass lanes were already coded in the base year network and the activity-based model and assignment routines already accounted for these lanes. Therefore, no new changes were necessary in either model scripting or in the model network to test the performance of the model.

MnPass Usage Data

There are two express lane corridors in the Metro region:

- Express lane system on I-394 between Gleason Avenue and I-94.
- Express lane system on I-35W between Crystal Lake Road and 38th Street.

The MnPass express lane system provides free access to higher occupancy vehicles throughout the day, but charges a pay-per-use fee for single occupancy vehicles during peak traffic periods (6 AM to 10 AM for both facilities, 2 PM to 7 PM for I-394 and 3 PM to 7 PM for I-35W). The toll rates are a function of roadway congestion on both the general purpose lanes as well as the express lanes.

Detailed historical MnPass usage data were obtained from MnDOT. These data provide information about system usage at hourly intervals. These data were assigned to the appropriate locations on the network and compared against model results for consistency.

Model Results

Separate comparisons were conducted for both the I-394 and the I-35W corridors. Detailed results are presented below:

I-394 Comparisons

The comparisons were conducted for two locations - Louisiana Avenue and Penn Avenue. Hourly MnPass data were provided for both the Penn Avenue and Louisiana Avenue locations. Of the two locations, Penn Avenue carries more overall traffic than Louisiana Avenue in the AM Peak.

Table 5.1 describes the Penn Avenue location observed and modeled traffic flows for the AM peak movements:

- The model does a very good job capturing total movements in this corridor location during the AM peak period (18,300 versus 19,300).
- There is a close match during each of the three hours in the AM peak period and particularly during the 7 to 8 AM hour.
- The model underrepresents HOV lane usage in all AM peak periods and especially between 8 and 9 AM while it is closer to the observed express lane traffic during the 6–7 AM period.

Table 5.1 MnPass Comparisons on I-394 – Penn Avenue in AM Peak (Eastbound Direction)

Observed Data

Lane Description	6 AM – 7 AM	7 AM – 8 AM	8 AM – 9 AM	AM Peak Total
HOV Lane	635	2,055	1,829	4,519
General Purpose Lane	4,105	5,279	5,376	14,760
Total	**4,740**	**7,334**	**7,205**	**19,279**

Model Results

Lane Description	6 AM – 7 AM	7 AM – 8 AM	8 AM – 9 AM	AM Peak Total
HOV Lane	584	1,522	1,095	3,201
General Purpose Lane	3,765	5,875	5,485	15,125
Total	**4,349**	**7,397**	**6,580**	**18,326**

Table 5.2 focuses on the PM peak movements for the Penn Avenue location:

- The model again does a very good job of capturing total movements in the corridor during the peak period (20,610 vs. 21,250).
- A very close match is observed during each one of the three hours in the peak period especially between 4 and 6 PM.
- The model over represents HOV lane usage during the PM peak period. The biggest percentage difference is observed between 3 and 4 PM with a smaller percentage difference between 4 and 5 PM and a close match during the 5 to 6 PM period.

Finally, when we examine the traffic at this location on a daily level, the traffic predicted by the model differs by only 500 vehicles (6 percent) below the observed traffic count data.

Table 5.2 MnPass Comparisons on I-394 – Penn Ave in PM Peak (Westbound Direction)

Observed Data

Lane Description	3 PM – 4 PM	4 PM – 5 PM	5 PM – 6 PM	PM Peak Total
HOV Lane	729	1,315	1,579	3,623
General Purpose Lane	5,687	6,087	5,851	17,625
Total	**6,416**	**7,402**	**7,430**	**21,248**

Model Results

Lane Description	3 PM – 4 PM	4 PM – 5 PM	5 PM – 6 PM	PM Peak Total
HOV Lane	1,069	1,663	1,709	4,441
General Purpose Lane	4,671	5,674	5,821	16,166
Total	**5,740**	**7,337**	**7,530**	**20,607**

Tables 5.3 and **5.4** describe the Louisiana Avenue location summaries. **Table 5.3** focuses on the AM peak movements:

- Overall, the model predicts 16,700 vehicles on all lanes in the eastbound direction at this location compared to traffic counts which suggest a total of 13,500 vehicles.
- The model over-predicts total eastbound traffic in the 7 to 9 AM period while it matches the 6 to 7 AM period.

- The model over-represents HOV lane usage in the 7-8 AM period by 15 percent. During the 8–9 AM period the model performs very well with a difference of only 3 percent compared to the counts.

Table 5.3 MnPass Comparisons on I-394 – Louisiana Avenue in AM Peak (Eastbound Direction)

Observed Data

Lane Description	6 AM – 7 AM	7 AM – 8 AM	8 AM – 9 AM	AM Peak Total
HOV Lane	402	1,291	1,023	2,716
General Purpose Lane	3,399	3,776	3,646	10,821
Total	3,801	5,067	4,669	**13,537**

Model Results

Lane Description	6 AM – 7 AM	7 AM – 8 AM	8 AM – 9 AM	AM Peak Total
HOV Lane	445	1,488	1,052	2,985
General Purpose Lane	3,239	5,473	4,998	13,710
Total	3,684	6,961	6,050	**16,695**

Table 5.4 shows the observed and modeled traffic at the Louisiana Avenue location during the PM peak and in the westbound direction:

- The model does a good job capturing total movements in the corridor during the peak period (17,900 versus 16,900).
- The model over-represents HOV lane usage in the 3-4 PM period and in the 5-6 PM period by about 100 vehicles only. However, during the 4–5 PM period, the model is off by 400 vehicles which represents a larger percentage difference.

Finally, the examination of traffic at this location on a daily level suggests a reasonable comparison with the model predicting about 18 percent above the observed traffic count data.

Table 5.4 MnPass Comparisons on I-394 – Louisiana Avenue in PM Peak (Westbound Direction)

Observed Data

Lane Description	3 PM – 4 PM	4 PM – 5 PM	5 PM – 6 PM	PM Peak Total
HOV Lane	417	695	898	2,010
General Purpose Lane	5,174	5,509	5,202	15,885
Total	5,591	6,204	6,100	**17,895**

Model Results

Lane Description	3 PM – 4 PM	4 PM – 5 PM	5 PM – 6 PM	PM Peak Total
HOV Lane	560	991	1,037	2,588
General Purpose Lane	4,040	5,070	5,202	14,312
Total	4,600	6,061	6,239	**16,900**

I-35W Comparisons

The comparisons between model estimates and detailed traffic counts were conducted at the Black Dog Road location. Hourly MnPass usage data were obtained from MnDOT to support these analyses.

Table 5.5 describes the observed and modeled traffic patterns at the Black Dog Road location for the AM peak traffic movements:

- The model does a very good job of capturing total movements in the corridor during the peak period (15,740 versus 14,670).
- There are larger percentage differences in the hourly totals with the 7-8 AM hour showing the highest volume in both the model and the observed data.
- The model provides a very close match in HOV lane usage during the busiest 7-8 AM period (a difference of only 2 percent) and a close match during the 8-9 AM period. The model underrepresents usage of HOV lanes in the 6 to 7 AM period.

Table 5.5 MnPass Comparisons on I-35W – Black Dog Road in AM Peak (Northbound Direction)

Observed Data

Lane Description	6 AM – 7 AM	7 AM – 8 AM	8 AM – 9 AM	AM Peak Total
HOV Lane	953	1,604	1,018	3,575
General Purpose Lane	3,783	3,749	3,564	11,096
Total	**4,736**	**5,353**	**4,582**	**14,671**

Model Results

Lane Description	6 AM – 7 AM	7 AM – 8 AM	8 AM – 9 AM	AM Peak Total
HOV Lane	537	1,631	1,197	3,365
General Purpose Lane	3,167	4,733	4,476	12,376
Total	**3,704**	**6,364**	**5,673**	**15,741**

Table 5.6 focuses on the observed and modeled traffic patterns at the Black Dog Road location for the PM peak traffic movements:

- The model does a very good job in capturing total movements in the corridor during the PM peak period (18,110 versus 17,870).
- The model also predicts total traffic during the 4 to 5 PM and the 5 to 6 PM hours very closely to the traffic counts.
- The model provides an excellent match for HOV lane usage in the 3-4 PM period with a difference of only 2 percent). During the 5–6 PM period, the model again performs well with a difference against the traffic counts of just 7 percent.

Finally, when we examine the total traffic observed at this location on a daily level, the model predict travel flows that were only 70 vehicles (1 percent) above the counts.

Summary

In summary, the patterns obtained for MnPass utilization at these two locations for each of the two time periods are very reasonable. Differences by time of day and by direction are expected since the model is calibrated at a region-wide level instead of at a corridor level. As a result, the model is not customized to capture the unique characteristics of congestion build-up in each of the corridors.

The reasonable replication of MnPass usage in the region and in these locations suggests that minor adjustments when studying corridor traffic are required to obtain good insights into the impacts of different policies on tolls.

Table 5.6 MnPass Comparisons on I-35W– Black Dog Road in PM Peak (Southbound Direction)

Observed Data

Lane Description	3 PM – 4 PM	4 PM – 5 PM	5 PM – 6 PM	PM Peak Total
HOV Lane	832	1,115	1,061	3,008
General Purpose Lane	4,749	5,092	5,017	14,858
Total	**5,581**	**6,207**	**6,078**	**17,866**

Model Results

Lane Description	3 PM – 4 PM	4 PM – 5 PM	5 PM – 6 PM	PM Peak Total
HOV Lane	818	1,198	1,270	3,286
General Purpose Lane	3,988	5,360	5,480	14,828
Total	**4,806**	**6,558**	**6,750**	**18,114**

5.2 Base Year with Green Line

The Green Line is an 11-mile light rail line that connects the central business districts of Minneapolis and Saint Paul as well as the University of Minnesota. The rail line began service in 2014. As such, this rail line was not included in the estimation and calibration of the regional ABM which had a base year of 2010.

Since the rail line has gained significant ridership since it began service in 2010, it was deemed important to conduct a sensitivity run that includes this rail line in the base year model network.

Model Changes

A few changes were made to the model networks and to supporting files. A summary of the changes we implemented and other changes that were considered includes the following:

- Train stations were coded on the model network and walk access links to the train stations were built.
- Since there are no park-and-ride locations along the Green Line, no changes were made to the drive access files.
- A new route line file was introduced to capture both directions of the Green Line. Run time estimates and frequency of rail service were obtained from Metro Transit schedules.

- Revised accessibility measures were developed in the ABM using the transit network that includes the Green Line to reflect greater transit accessibility.
- A few bus routes, primarily Routes 16, 50 and 94, underwent service modifications in response to the introduction of the Green line. Other bus routes were modified to provide better connectivity with the Green line. For purposes of this sensitivity run, no changes were made to bus route coding.
- Furthermore, no changes were made to the sociodemographic file since the model run was conducted for the base year (2010).

Green Line Ridership

The Green Line has been a very successful route in the first year of operation:

- Daily ridership, which stands at about 37,000 boardings, is 35 percent higher than the 24,000 boardings originally predicted using the existing Metropolitan Council model and the implemented changes in the bus route network and the level of service and operations of bus routes.
- Data from the 2010 on-board survey suggest that the total Central Corridor ridership was about 41,250 boardings (Routes 16, 21, 50, 53, and 94).

Model Results

Key results from the sensitivity run that includes the Green line compared to the base year 2010 model run include the following:

- Total transit trips in the region increased from 190,000 to 233,000 or about 22 percent. Total boardings also had a 22 percent increase to a total of 336,000. Transfer rates remained about the same.
- The base model run predicts a ridership of 30,000 boardings on the bus routes operating along the Central Corridor. This is 27 percent lower than the observed corridor transit ridership and suggests that the model under predicts the corridor ridership. In fact, this is the only major corridor with over 8,000 daily boardings in which the model results differ from observed ridership by more than 15 percent (**Table 5.7**).
- In the Green Line model sensitivity run, ridership for the Green Line is projected at 23,300 daily boardings. While this estimate is lower than the observed ridership, it is consistent with the results from the existing model.
  - However, it must be noted that all competing bus services (Route 16, 50 and 94) are coded as fully operational in the sensitivity run and do not reflect the changes implemented to support the Green line operations.
  - If these routes were scaled to their actual operational characteristics including their frequency of service, it is expected that the model results for Green Line ridership will increase further (**Table 5.7**).

- Overall, the Central Corridor (Central + Green Line) ridership in the sensitivity run is 47,000 riders compared to 30,000 riders in the base model run. This indicates a net ridership gain of over 60 percent that is attributed to the introduction of the Green line.

Table 5.7 Corridor Specific Ridership from On-board Survey and the Model

Travel Distances	On-board Survey		Base Model Run		Green Line Sensitivity Model Run	
	Peak	Off-Peak	Peak	Off-Peak	Peak	Off-Peak
Bottineau	28,742	17,672	30,766	19,527	37,042	23,127
Central	22,933	18,315	18,022	11,722	15,014	8,569
Hiawatha	15,463	13,084	14,966	10,570	16,616	11,998
Green Line	-	-	-	-	12,643	10,669
Southwest	15,041	11,464	18,355	12,406	19,398	12,613
Nicollet Ave	9,667	5,419	7,486	5,271	8,623	6,027
Gateway	7,027	4,759	6,391	4,725	7,586	5,379
Central Ave	4,855	3,725	4,654	4,225	5,440	5,001
Robert St	4,641	3,103	5,296	4,498	6,466	5,328
East 7th	3,933	3,600	6,489	4,757	7,686	5,281
I-494 Amr. Blvd	2,979	3,956	6,097	3,373	7,260	4,209
West 7th	2,679	1,319	2,255	1,963	2,824	2,463
I-35 W North	2,175	826	1,485	119	1,924	76
Snelling	1,592	2,191	1,832	1,823	2,431	2,521
Total	**121,727**	**89,432**	**124,094**	**84,980**	**150,953**	**103,260**

Summary

The model does a reasonable job in predicting Green Line ridership and performs similarly to the forecasts provided by the previous Metropolitan Council model.

Although the 2010 sensitivity run forecasts were considerably lower compared to the observed ridership, this is due in part to not coding the changes in the complementary and competing bus services. The following changes need to be made to properly reflect transit service and to improve model performance:

- Code the changes to the complementary and competing bus routes so that they more accurately represent current operational conditions.
- Use data from the on-board survey to capture rider patterns in the Central Corridor and compare those summaries to the model outputs.
- Calibrate the model to a new base year (2015) using observed data such as 2015 transit ridership and 2015 traffic count information.

5.3 Future Year Sensitivity Run

The model was tested against future year conditions to quantify regional metrics such as total trips, regional VMT, and total transit ridership. 2040 was selected by the Metropolitan Council as the horizon year for this model run.

Model Changes

A few changes were made to the model networks and supporting files and included the following:

- Socio-demographic forecasts generated by Metropolitan Council were used to generate a new synthetic population for the horizon year. The data provided growth estimates for the core seven-county region and did not include growth estimates for the remaining 12 counties compared to the base year (**Table 5.8**).
- A PopGen run was completed using the control totals provided by the Metropolitan Council. The same set of households used in 2010 was used as the seed to the synthetic population generator run.
- The employment forecasts generated by Metropolitan Council were used to generate inputs to the truck model.
- New density measures were calculated using the revised population and employment forecasts.
- Two major investment projects were coded in to the model network:
  - Green Line and
  - US 610.
- New accessibility measures were calculated using the new network which had coded these two major projects.
- External traffic counts were assumed to grow by 38 percent at all locations.
- Airport traffic was expected to grow as a function of the regional socio-demographics with no additional changes made to the model.
- No changes were made to other input data such as parking costs, transit fares, and auto operating costs.

Model Data

The forecasts received from the Metropolitan Council reflected expected growth only in the core seven counties of Hennepin, Ramsey, Dakota, Scott, Carver, Washington, and Anoka. There is no change in socio-demographic data in any of the other 12 counties in the study region (**Table 5.8**).

- Regional employment is expected to rise 42 percent with Hennepin County (340,000) and Ramsey County (111,000) accounting for the majority of growth in the region. Dakota County is expected to have an increase of 85,000 jobs.

- Regional households are forecast to increase by 29 percent. Hennepin County is expected to have the largest growth (128,000) followed by Dakota County (58,000), Anoka County (50,000), Washington County (47,000) and Ramsey County (46,000). Carver County is also forecast to have the highest growth in households (90 percent).
- Regional population is expected to grow 23 percent with Carver County forecast to experience the highest growth (67 percent). Anoka County, which is third in households increase is expected to be second in population increase. between 2010 and 2040. Hennepin County again has the largest increase in population (275,000) while Carver County is expected to have the smallest increase in population (61,000).

Table 5.8 Base Year and Future Year Socio-Demographic Control Totals

County	2010 Households	2010 Population	2010 Employment	2040 Households	2040 Population	2040 Employment
Anoka	121,227	330,844	103,975	171,135	426,079	152,708
Carver	32,891	91,042	29,238	62,455	151,717	53,461
Chisago	*19,470*	*53,887*	*11,715*	*19,470*	*53,887*	*11,715*
Dakota	152,060	398,552	160,904	210,515	527,840	245,887
Goodhue	*18,730*	*46,183*	*17,851*	*18,730*	*46,183*	*17,851*
Hennepin	475,913	1,152,425	725,692	603,807	1,427,821	1,065,965
Isanti	*13,972*	*37,816*	*8,340*	*13,972*	*37,816*	*8,340*
Le Sueur	*10,758*	*27,703*	*6,379*	*10,758*	*27,703*	*6,379*
McLeod	*14,639*	*36,651*	*13,042*	*14,639*	*36,651*	*13,042*
Pierce	*15,002*	*41,019*	*8,609*	*15,002*	*41,019*	*8,609*
Polk	*18,004*	*44,205*	*15,257*	*18,004*	*44,205*	*15,257*
Ramsey	202,691	508,640	297,861	248,785	600,809	408,689
Rice	*22,315*	*64,142*	*18,688*	*22,315*	*64,142*	*18,688*
Scott	45,108	129,928	38,109	77,728	201,902	67,931
Sherburne	*30,212*	*88,499*	*20,169*	*30,212*	*88,499*	*20,169*
Sibley	*6,034*	*15,226*	*2,365*	*6,034*	*15,226*	*2,365*
St. Croix	*31,799*	*84,345*	*29,618*	*31,799*	*84,345*	*29,618*
Washington	87,859	238,136	65,497	135,040	337,513	107,211
Wright	*44,473*	*124,700*	*29,595*	*44,473*	*124,700*	*29,595*
Total	**1,363,157**	**3,513,943**	**1,602,904**	**1,754,873**	**4,338,057**	**2,283,480**

Model Results

Both highway and transit network statistics were calculated to find the net impact of traffic on the regional system in the 2040 horizon year.

- Transit trips went up from 190,000 in the base year to about 330,000 in the horizon year reflecting an increase of 74 percent. Similarly, total boardings went up to 462,000 from 274,000 (a 68 percent increase). This suggests that overall transfer rates went down slightly.
- The Hiawatha (Blue Line) ridership was estimated to be about 37,000 boardings in 2040 while Green Line ridership was expected to almost double

to about 39,000 boardings (from 23,000) during the same timeframe. As discussed in the Green Line sensitivity run, these estimates may understate Green line ridership since no changes were made to the coding of competing bus routes that have experienced operational changes already.

- On the highway side, total VMT increased by about 18 percent, while total VHT increased by 24 percent indicating that users will experience more congestion than the base year. Average speed for the region was projected to drop by about 5 percent.
- The congestion impact was projected to be far more pronounced for truck movements where the VMT increases by 38 percent, VHT increases by 47 percent and speed decreases by 6 percent.

Summary

The model does a reasonable job in developing future year forecasts for the region. The following changes may be considered to develop more detailed forecasts for the horizon year:

- Include sociodemographic forecasts for the entire 19-county region, including the 12 outlying counties when developing the synthetic population. This will capture expected growth in the entire region and will help capture changes in travel in the periphery of the regional model network.
- Incorporate all committed highway and transit projects such as the Red Line and Orange Line in the network so that the model captures system usage under the most realistic future-year scenario.
- Recommend changes, where needed, to other input data such as parking, transit fares, and auto operating costs, to provide a more realistic future year scenario.

5.4 The Impact of New Volume Delay Functions

During model estimation, network skims were generated using the volume delay function used in the old Metropolitan Council model network. To maintain consistency, the same approach was used during both model calibration and validation.

During the data evaluation phase for this project, TomTom speed data were purchased and analyzed. These data were conflated with the regional model network to provide a detailed speed profile for different roadway functional classes. Using these observed speed data, different alpha and beta coefficients for the volume delay function were estimated and differed by functional class.

This fourth sensitivity run provides an ideal venue to test the performance of these revised volume delay functions in representing regional roadway congestion.

Model Changes

No changes were made to the model network or the ABM model parameters. The only changes made were to the highway skimming and assignment routines where the new volume delay functions were introduced.

However, since several aspects of the ABM model are driven by congested skims including time-of-day and destination choice models, it is reasonable to assume that the results from applying the ABM model will also change somewhat when we use the new volume delay functions throughout the model stream.

Model Data

The original model for the Twin Cities region had a single volume delay function that was uniform across different functional classes. As part of the 2010 model update, alternative volume delay functions were explored. The empirical process of revising the "alpha" and "beta" coefficients of the typical BPR yielded the volume delay function coefficients that are listed in **Table 5.9**.

Table 5.9 Revised Volume Delay Functions by Functional Class

RC Index	Description	Alpha	Beta
1	Interstate - Metered	0.15	4
2	Interstate - UnMetered	0.15	4
3	Trunk Highway - Expressway	0.15	4
4	Trunk Highway - Divided Arterial	0.15	4
5	Trunk Highway - Arterial	0.9	2
6	Primary Road - Divided Arterial	0.8	2
7	Primary Road - Arterial	0.7	3.4
8	Major Road - Divided Arterial	0.9	2
9	Major Road - Arterial	0.6	2
10	Major Road - Collector	0.9	3.6
11	Residential - Arterial	0.9	3.6
12	Residential - Collector	0.5	2
13	Ramp - UnMetered	0.9	3.6
14	Ramp - Metered	0.9	3.6
15	Gravel - Collector	0.9	3.6
99	Zone Connector	0.9	3.6

A comparison of the AM peak speeds resulting from the new volume delay functions and the observed TomTom speeds is shown in **Table 5.10**. With the exception of arterial trunk highways and collectors, the revised volume delay functions match the observed TomTom speeds very well.

Table 5.10 AM Peak Model Speeds versus TomTom Observed Speeds

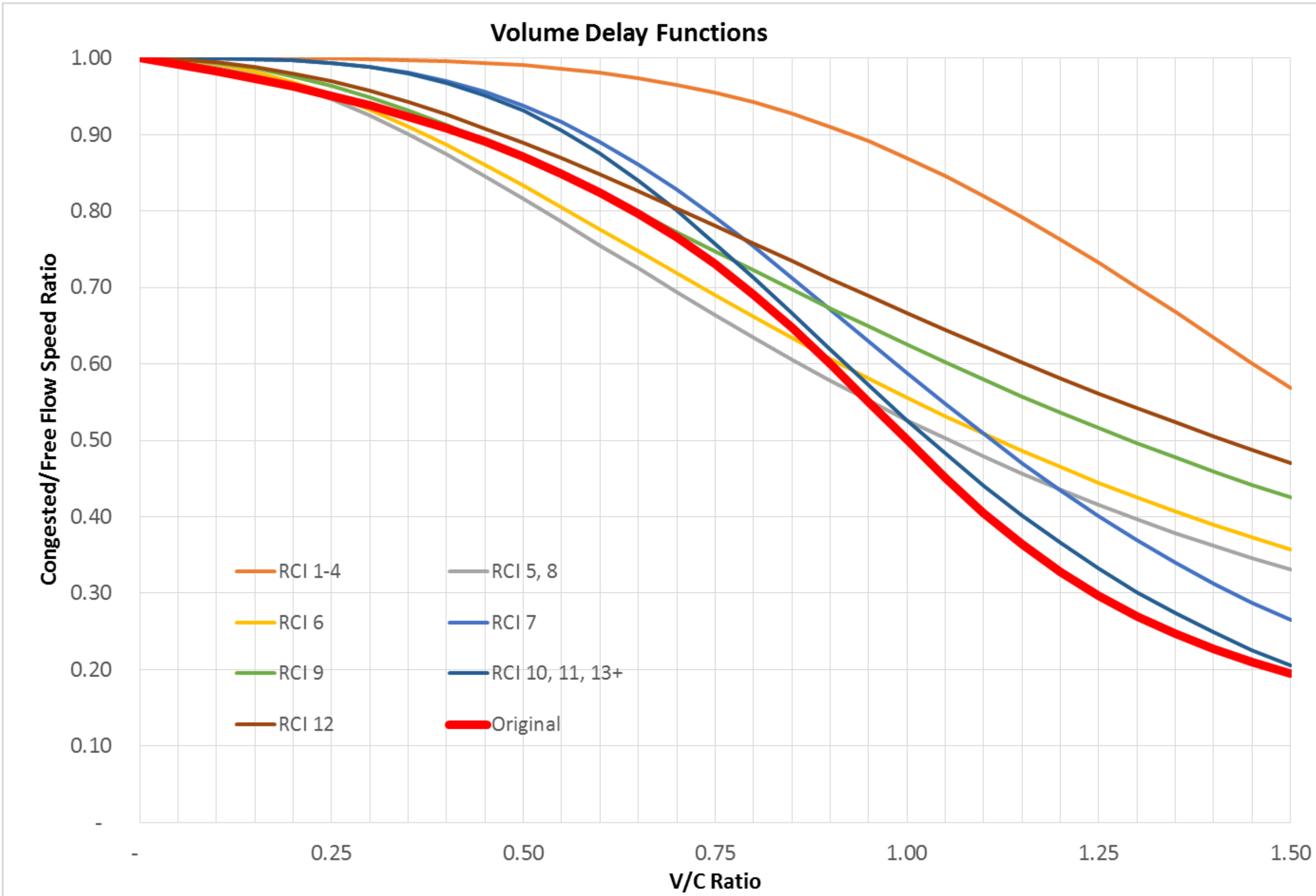
	RC Index	Model Speed	TomTom Speed	Percent Difference
1	1 - Interstate - Metered	53.7	55.5	-3.2%
2	1 - Interstate - UnMetered	58.6	62.3	-5.9%
3	2 - Trunk Highway - Expressway	47.3	48.2	-1.7%
4	2 - Trunk Highway - Divided Arterial	45.4	44.4	2.3%
5	2 - Trunk Highway - Arterial	38.9	45.9	-15.3%
6	3 - Primary Road - Divided Arterial	32.0	34.9	-8.4%
7	3 - Primary Road - Arterial	39.8	40.3	-1.3%
8	4 - Major Road - Divided Arterial	28.1	28.6	-1.8%
9	4 - Major Road - Arterial	35.8	33.3	7.7%
10	4 - Major Road - Collector	25.6	33.5	-23.7%
11	5 - Residential - Arterial	30.7	30.3	1.4%
12	5 - Residential - Collector	22.4	25.8	-12.9%

Figure 5.1 shows the estimates of congested speeds as a function of free flow speeds. The thick red line shows the original Metropolitan Council volume delay function. The other lines show the proposed volume delay function and how congestion is estimated to build differently for each functional class.

A general observation is that despite differences across different functional classes, the revised volume delay functions assume that congestion builds slower in the network that the original model. In particular:

- As the volume to capacity ratio increases and approaches the value of one, the revised parameters have less of an impact on congested speeds compared to the original volume delay function.
- This pattern is particularly true for expressways where the model now assumes that congested speeds are affected less by increased levels of traffic compared to the original volume delay function.

Figure 5.1 Congested Speeds as a Function of Roadway Volume



Model Results

The model was applied using the revised volume delay functions. As expected, most of the major impacts resulting from this change were found in the highway assignment. Transit ridership from this model scenario remained almost unchanged from the calibrated base year model results. Key changes included the following:

- Model results from the sensitivity run match the traffic count data almost perfectly for the 5,995 locations for which traffic counts are available.
  - The regional VMT is within 2.4 percent of the observed VMT; and
  - Total traffic volume is within 1.4 percent of the observed traffic.
- These results are actually better than the base model run for calibration where VMT differed by 4 percent and traffic volumes were off by 7 percent when compared to observed VMT and traffic count.
- When compared to the base year validation model run, the use of the revised volume delay functions resulted in the following patterns:
  - Overall model VMT increased by 2.8 percent from 84 million in the calibrated model to 86.3 million in the sensitivity run.
  - In contrast, VHT dropped by 6.7 percent from 1.98 million in the calibrated model to 1.84 million in the sensitivity run.
  - Correspondingly, the average speed in the region went up from 42.5 mph in the calibrated model to 46.8 mph in the sensitivity run.
- Comparisons by functional class revealed the following patterns:
  - VMT carried by high capacity roadways (interstates and trunk highways) is higher in the sensitivity run. The comparison with count data suggests a greater difference of 8.4 percent versus -1.8 percent.
  - The VMT comparisons for all other roadways suggest that the sensitivity run model results are lower than the calibrated model and do not fit the count data as well as the calibrated model.

Summary

The results from the sensitivity run suggest that on aggregate the model with the revised volume delay functions compares better than the calibrated model against the traffic counts and VMT data. Model results are less clear when the comparisons are conducted at a more disaggregate level by functional class.

It should be noted that the revised coefficients of the volume delay functions in were fitted to the observed TomTom speed data and may offer a more reliable basis for current and future year forecasts. They also provide the flexibility to change the coefficients as new speed data become available.