# Description of Modeling Assumptions and Analysis Methodology for the State Implementation Plan Transit Commitment Projects Current and Proposed Substitutions

**December 28, 2006**

Prepared by the Central Transportation Planning Staff
10 Park Plaza, Suite 2150
Boston, MA 02116
Phone 617 973-7100

For the Executive Office of Transportation
Office of Transportation Planning
Room 4150, 10 Park Plaza
Boston, MA 02116

## PURPOSE

This document presents the supporting material associated with the re-evaluation of the State Implementation Plan (SIP) transit commitments. This memo includes background of the process, history of the analysis, transportation network assumptions, modeling methodology, and the results of the analysis that were used in this re-evaluation. This memo is intended to comply with the amendments to Massachusetts Regulation 310 CMR 7.36 (8) as it relates to air quality emission reductions.

## BACKGROUND OF THE PROCESS

Although the 1990 Clean Air Act is a federal law covering the entire country, the states do much of the work to carry out the Act. The law requires each state to develop a SIP that explains how they will enforce the Clean Air Act. The SIP is a plan that contains procedures and programs to monitor, control, maintain, and enforce compliance with all national air quality standards.

As part of the SIP, the Massachusetts Department of Environmental Protection (DEP) mandates a number of measures to control the emission of pollutants from mobile sources. One of the specific programs in the SIP is the implementation of transportation control measures. A transportation control measure (TCM) is any measure directed toward reducing emissions of air pollutants from transportation sources by improving traffic flow, reducing congestion, or reducing vehicle use. TCMs were submitted as a SIP commitment as part of the Central Artery/Tunnel Project mitigation. The Commonwealth's SIP commitments associated with the Central Artery/Tunnel Project involved improvements related to air quality, traffic management, and transit infrastructure. A number of these TCMs have already been implemented. They include the Framingham Commuter Rail Extension to Worcester, the Ipswich Commuter Rail Extension to Newburyport, additional park and ride facilities, and a high occupancy vehicle lane on the Southeast Expressway. In addition, other projects were included that have not yet been completed. They include the Arborway Restoration Project, the Green Line Extension to Ball Square and the Red Line/Blue Line Connector. The specific SIP submission for these projects was included as the transit regulation in 310 Code of Massachusetts Regulations (CMR) 7.36.

In December 2004, the Office of Commonwealth Development (OCD), the Executive Office of Transportation (EOT) and DEP began a process of reevaluating the three outstanding projects – the Arborway Restoration, the Green Line Extension and the Red/Blue Connector – to ensure that any further investments fund the best regionally significant projects that meet air quality goals and requirements. These commitments were meant to reduce regional emissions and offset limited roadway capacity occurring while the Central Artery was under construction. With the Central Artery construction nearing completion, the original transportation projects included in the SIP to meet the air quality goals of the region needed to be reevaluated, largely because transportation planning and decision-making had changed significantly since adoption of these Central Artery SIP commitments.

In 2003, the Massachusetts Bay Transportation Authority (MBTA) completed the Program for Mass Transportation (PMT). The PMT, which is the foundation for transit capital planning in Eastern Massachusetts, prioritized projects within modes and by investment category type. The PMT rated the Arborway Restoration, Red/Blue Connector and Green Line Extension as medium priorities suggesting that these projects may not be the best investments for the region.

In the *2004 Regional Transportation Plan* of the Boston Region Metropolitan Planning Organization (MPO), the PMT ratings were used to select transit projects. Despite their medium rating within the PMT, the Boston Region MPO did prioritize funding for these projects because they are SIP commitments, and the Commonwealth is required to show timely implementation of the TCMs.

The Romney Administration placed a significant emphasis on objective criteria, and this focus has been implemented within the transportation decision-making process. In 2003, EOT developed objective criteria, and presented them to the Commonwealth's MPOs and the general public. In the case of the Boston Region MPO, it had already begun work on objective criteria, and its criteria were similar to those developed for statewide use. The use of objective selection criteria in programming funds is an important change within the Commonwealth. The state, along with its MPOs, has adopted a more rational, transparent approach to project prioritization.

For these reasons, OCD, EOT, and DEP, along with other partners, began the process of reexamining the Arborway Restoration, the Red/Blue Connector, and the Green Line Extension. The re-evaluation process included a number of steps. The first step was initial outreach and air quality goal setting. This process began with a number of public meetings to introduce the rationale for reevaluation and discuss the need for regulatory change to reconsider SIP TCMs and to solicit comments on the proposed reevaluation process from the public. DEP reviewed the public comments and provided an air quality budget to EOT that quantified the air quality benefits needed to complete the Commonwealth's obligations to the SIP. They established the air quality benefits associated with the three existing projects and required any proposed changes to equal or exceed 110 percent of those benefits.

The second step included the evaluation of the original and alternative SIP TCM projects. This involved the examination of the transit projects included in the *2003 PMT* using the state's objective criteria to determine the most important regional projects. The analysis was performed on all high priority projects in the PMT and all outstanding SIP transit commitments in the Boston Region MPO area.

The criteria used in the evaluation were as follows:

- Utilization
- Mobility
- Cost-effectiveness
- Air Quality
- Service Quality

- Economic and Land Use Impacts
- Environmental Justice

EOT reviewed the results of the analysis and presented its preferred alternative to DEP. The preferred alternative included:

- Enhanced Green Line extended beyond Lechmere to West Medford and Union Square*
- Fairmont Commuter Rail Line Improvements
- 1,000 Additional Commuter Rail Parking Spaces in the Boston Region

The agencies are currently in the third and final steps of the process – actually amending the SIP projects. This report provides documentation of the description of the modeling assumptions and analysis methodology used in the development of the SIP amendment. It will be available for a 45-day public comment period. Once the comment period is completed, EOT will submit the report along with a summary of and response to public comments to DEP.

The remaining steps in the process include review and approval by the United States Environmental Protection Agency. Once that is completed, the SIP revisions will have to be included in the Boston Region MPO's Regional Transportation Plan.

## HISTORY OF THE ANALYSIS

The Central Transportation Planning Staff (CTPS) maintains a regional travel demand model set that is used to measure a variety of impacts associated with changes to the transportation infrastructure, one of which is air quality emissions. This model set is continuously improved, as newer information is made available. This process of updating inputs and methods has led to several intermediate sets of results during the process of evaluating the proposed SIP transit commitments. The final recommendations were made using results of the best model and inputs available to CTPS as of the summer of 2006. A brief review of the key differences between the intermediate analyses and the final version are presented below.

In winter of 2004/2005 OCD, EOT, and DEP started to re-evaluate the SIP transit commitments. Some of the information they used to re-evaluate the projects at that time was based on modeling assumptions originating in the *2003 PMT*, which was a readily available source of air quality and transit information for all major transit projects. There were several key assumptions that were improved upon in the final analysis as the process unfolded, these are outlined below:

1. This analysis used forecast year 2025 demographic assumptions from the *2003 PMT*, that were based on the *2000 Regional Transportation Plan*.
2. Emission rates in this analysis used air quality emission factors from the *2003 PMT*, which utilized MOBILE 5a. MOBILE is an air quality emissions model that generates

*In the final regulation this commitment was modified to construct the Green Line Extension from Lechmere Station to Medford Hillside and a Green Line Union Square spur of the Green Line Extension to Medford Hillside.

emission factors by roadway type, speed, pollutant, and year that are used in the regional travel demand model.
3. Comparisons between transit projects were based on a no-build transportation network that assumed the *2000 Regional Transportation Plan* 2025 transportation network minus any of the transit projects that were included in the PMT.
4. The initial analysis used project descriptions from the *2003 PMT*. This information consisted of service plans, station location, parking assumptions, and alignments.

In the late spring of 2005, two analyses were conducted using updated demographics and refined modeling practices in response to questions from the Boston MPO and EOT:

1. The first analysis was for the Boston MPO and compared all of the transit projects in question against a common no-build. This no-build was based on the *2004 Regional Transportation Plan*.
2. The second analysis was for EOT and compared all of the transit projects in question against a customized baseline alternative unique to the project being studied. A baseline is a Federal Transit Administration (FTA) New Starts requirement that is basically a no-build transportation network that contains some additional cost-effective transit improvements in the corridor of concern, without undertaking a major capital improvement. The New Starts Baseline Alternative is essentially a Transportation Systems Management (TSM) alternative.

In the summer of 2006, OCD and EOT requested CTPS to conduct a final analysis that incorporated the latest planning assumptions and most current modeling methodology. The major assumptions that were updated included:

1. The latest MOBILE 6.2 emission factors were used to estimate air quality emissions for each alternative in the analysis.
2. The latest 2025 forecast year demographic assumptions from the *2004 Regional Transportation Plan* were used.
3. This analysis included refinements to the modeling process including a more detailed roadway network, methodological recommendations from FTA, and a calibration effort that focused on the project corridors.
4. Updated information on service plans, station location, parking assumptions, and alignments were used.
5. Comparisons of the old and proposed SIP transit commitments packaged together against a common no-build, as well as an examination of the projects individually were undertaken.

## TRANSPORTATION NETWORK ASSUMPTIONS

A total of eight model runs were conducted. These are described in detail below:

1. The no-build scenario for the SIP analysis comprises highway and transit projects that are included in the *2007 Journey to 2030 Regional Transportation Plan No-Build* scenario. These projects include those that: 1) currently exist 2) are under construction 3) have been

advertised or 4) have been programmed by the MPO. The No-Build Scenario networks are made up of the transportation system, as it exists today plus the following projects:

Highway

- Completed Central Artery Tunnel
- Massachusetts Avenue/Lafayette Square, Cambridge
- Cambridgeport Roadways (Cambridge)
- I-95 (SB)/Dedham Street On-Ramp (Canton)
- Route 140 (Franklin)
- Route 139 (Marshfield)
- Route 20, Segments 2 &3 (Marlborough)
- Bridge Street Bypass (Salem)
- Route 128 Additional Lanes (Randolph to Wellesley)
- Route 38 (Wilmington)
- Route 1 and Associated Improvements (Foxborough)
- Route 3 North
- Route 53, Hanover
- Burgin Parkway, Quincy
- Route 53/228, Hingham & Norwell
- Crosby Drive, Bedford
- I-93/Ballardvale Street Interchange, Wilmington

Transit

- North Station Improvements
- Blue Line Modernization
- Additional Park and Ride spaces (20,000 spaces)
- Worcester Commuter Rail, full service with four new stations
- Silver Line – Transit-way, Phase 2
- Silver Line – Washington Street, Phase 1
- Mattapan Refurbishment
- Airport Intermodal Transit Connector
- Anderson Intermodal Transportation Center (Woburn)
- New Commuter Rail Station at JFK/U Mass Station
- Greenbush Commuter Rail Service

2. This build scenario includes the three existing SIP Commitments: Arborway, Red/Blue Connector, and Green Line to Ball Square. This scenario adds the following three transit projects to the no-build as described in number (1).

Arborway Restoration

- Alignment: The Green Line E branch was extended south along S. Huntington Ave., Centre St., and South St., where it ended at Arborway at a location adjacent to the Orange Line's Forest Hills Station. In this extension the Green Line shared the right of way with traffic.

- Service: The Green Line E branch currently travels between Lechmere and Heath Street with headways of 7 min. in the peak periods, 9 min. in the midday, and 10 min. at night. These service frequencies were maintained to Arborway.
- Stations: The Arborway Restoration added 8 new stops after Heath St.: VA Hospital, Bynner St., Perkins St., Moraine St., Beaufort St., JP Center, Monument St., Child St., Forest Hills
- Fares: The current Green Line surface fare structure was used.
- Transfers: The Green Line provides transfers in the Central Subway to the Red, Silver, and Blue Lines. Several of the new stations provided transfers to bus stops.
- Other Changes: The proposed project eliminated the Route 39 bus that currently travels from Forest Hills to the Back Bay with headways of 5 min. in the peaks, 10 min. in the midday, and 10 min. in the evening.
- Park-and-Ride: No new lots are added.

Green Line to Ball Square

- Alignment: The alignment for this extension starts at Lechmere Station and heads northwest, meeting with the Lowell Line just south of Washington St. in Somerville. From there the alignment runs parallel to the Lowell Line to Ball Square.
- Service: This service operates on headways of 7 min. in the peak periods, 9 min. in the midday, and 10 min. at night.
- Stations: The Green Line to Ball Square adds 4 news stops after Lechmere: Washington St., School St., Lowell St. and Ball Square.
- Fares: The boarding fares at the new stations are $1.25.
- Transfers: The Green line provides transfers in the Central Subway to the Red, Orange, Silver, and Blue lines. Several of the new stations allow for transfers to nearby bus stops.
- Other Changes: None.
- Park-and-Ride: No new lots are added.

Red/Blue Connector

- Alignment: The Blue Line was extended 0.4 miles from Bowdoin Station to Charles/MGH Station on the Red Line.
- Service: There were no changes to the Red Line or Blue Line services.
- Stations: A new station was added to the Blue Line at Charles/MGH.
- Fares: The fare assumed at Charles St. was the existing $1.25. A free transfer between the Red and Blue Lines was provided.
- Transfers: The new Blue Line station at Charles/MGH provided a transfer between the Blue Line and the Red Line.
- Other Changes: None.
- Park-and-Ride: No new lots are added.

3. This build scenario includes only the Arborway Restoration SIP Commitment. This project is described in detail in scenario 2.

4. This build scenario includes only the Green Line to Ball Square SIP Commitment. This project is described in detail in scenario 2.

5. This build scenario includes only the Red/Blue Connector SIP Commitment. This project is described in detail in scenario 2.

6. This build scenario adds the Green Line to Medford Hillside and Union Square and the Fairmount Commuter Rail Line improvements to the no-build scenario. This scenario doesn't include the 1,000 additional Park-and-Ride spaces, which were examined separately in a spreadsheet-based model. The Green Line and Fairmount improvements are defined as follows:

   Enhanced Green Line to Medford Hillside and Union Square

   - Alignment: The alignment for this extension consists of two branches, both extending from Lechmere, with one going to School St. and the other going to Union Square in Somerville. The Medford Hillside Branch starts at Lechmere Station and heads northwest, meeting with the Lowell Line just south of Washington St. in Somerville. From Washington St., the alignment runs parallel to the Lowell Line to School St. The Union Square Branch starts at Lechmere Station and heads northwest along the Fitchburg commuter rail line to the Union Square area.
   - Service: The Green Line service to Medford Hillside operates on headways of 5 min. in the peak periods, 10 min. in the midday, and 10 min. at night. The Green Line service to Union Square operates on headways of 7 min. in the peak periods, 9 min. in the midday and 10 min. at night.
   - Stations: The Green Line to Medford Hillside component of this project adds 5 new stops after Lechmere: Washington St., School St, Lowell St., Ball Sq., and Medford Hillside/College Ave. The Green Line-to-Union Square branch adds one new stop at Union Square.
   - Fares: The boarding fares at the stations added for this project are $1.25.
   - Transfers: The Green Line provides transfers in the Central Subway to the Red, Orange, Silver, and Blue lines. Several of the new stations allow for transfers to nearby bus stops.
   - Other Changes: No other changes were made.
   - Park and Ride: No new lots were added.

   Fairmount Commuter Rail Line Improvements

   - Alignment: The project improves the Fairmount Line but does not change its alignment. It is approximately 9.2 miles long, running from South Station to Readville. It passes through the communities of Dorchester, Roxbury and Mattapan.

- Service: The Fairmount commuter rail line service to Readville currently operates on headways of 25 min. in the peak periods, 60 min. in the midday, and 80 min. at night. The new service improves midday and nighttime headways on average of 40 min.
- Stations: The project upgrades the existing Uphams Corner and Morton Street Stations ad provides four new stations located at New Market, Four Corners, Talbot Ave., and Blue Hill Ave.
- Fares: The existing stations use the existing MBTA commuter rail zonal fare system; the new stations are assumed to be in fare zones 1, 1a, and 1b.
- Transfers: The Fairmount commuter rail line service provides transfers at South Station to he Red and Silver Lines. Several of the new stations allow for transfers to nearby bus sops.
- Other Changes: None.
- Park and Ride: No new lots were added but the Morton Street lot was expanded.

7. This build scenario includes only the enhanced Green Line to Medford Hillside and Union Square SIP Commitment. This project is described in detail in scenario 6.

8. This build scenario includes only the Fairmount Commuter Rail Line Improvements that are part of the SIP Commitment. This project is described in detail in scenario 6.

## METHODOLOGY

The travel model set is based on procedures that have evolved over many years at CTPS. The model set is based on the traditional four-step urban transportation planning process of trip generation, trip distribution, mode choice, and trip assignment. The model set is of the same type as those used in most large urban areas in North America and is used to simulate existing travel conditions and to forecast future year travel on the transit and highway system. As such, it contains all the major transit services; namely commuter rail, rapid transit, bus, ferry, and private express bus lines. All express highways, principle arterials and many minor arterial and local roadways are also included.

The geographic area represented in our model, Eastern Massachusetts, is divided into 2,727 smaller areas called traffic analysis zones. The model set simulates the modes and routes of trips from every zone to every other zone. Population, employment, number of households, auto ownership, highway and transit levels of service, downtown parking costs, auto operating costs and transit fares are some of the most important inputs that are used in applying the model to a real world situation. These inputs are constantly updated so that the model set simulates current travel patterns with reasonable accuracy. The travel demand modeling methodology is discussed in more detail in Appendix A.

The proposed package of projects includes the addition of 1,000 parking spaces at several public transportation stations. At the time of analysis these stations had not yet been identified. Therefore, the analysis of the air quality benefits of these spaces was not included in the regional travel demand model analysis, but was conducted using a spreadsheet model using the following parameters.

The following assumptions were made:

- Total parking spaces added at all stations equals 1,000.
- The utilization rate of the added parking spaces would be 80%, translating into 800 spaces.
- The majority of the added parking spaces would be located within the Route 128/ I-95 beltway.
- The average one-way trip length of commuters using the new spaces, wishing to divert from the auto mode to transit would be 8.0 miles.
- The average one-way driving distance from the users' homes to the park-and-ride lots they would use to access transit to get into Boston would be 1.5 miles.
- The result of the previous assumption provide an average savings in vehicle miles traveled (VMT) per one-way trip of 6.5.
- The average vehicle-occupancy rate would be 1 person per vehicle.
- The average driving speed of the diverted trips would be 23 mph (they would most likely have occurred in the AM and PM peak periods of congestion).
- Parking-space-turnover rates were not significant for this analysis.

## RESULTS

The results of each of the two packages of SIP transit commitments and the collective sum of each project for the original SIP transit commitments (scenario 2) and the proposed (scenario 6), relative to the no-build (scenario 1), are presented in Table 1 for the 164 communities in eastern Massachusetts. The differences in emissions of the three primary pollutants, CO, NOx, and VOC, between the original package of projects and the no-build were multiplied by 110% in order to establish the reduction benchmarks that must be met by the proposed package.

The resulting emission reduction benchmarks that include 110% of the difference by package of projects are 321.2 kg of CO, 8.8 kg of NOx, and 12 kg of VOC. The proposed package, compared with the no-build, produces reductions of 435kg of CO, 11 kg of NOx, and 17 kg of VOC. For all three pollutants, the 110% threshold is met.

The resulting benchmarks derived by summing the individual old SIP transit projects are 447.7 kg of CO, 6.6 kg of NOx, and 23.1kg of VOC. The proposed SIP transit projects individually compared with the no-build then summed, produce reductions of 502 kg of CO, 11 kg of NOx, and 24 kg of VOC. For all three pollutants, the 110% threshold is met.

The results of the emission reduction associated with the additional park-and-ride spaces are shown in Table 2. They are based on the spreadsheet-based approach and the reductions shown are included in Table 1. The average of thirteen round-trip vehicle miles of travel (VMT) is multiplied by the number of vehicles, 800, which results in a savings 10,400 VMT daily. With an average speed of 23 mph, emission factors for the three key pollutants, CO, NOx, and VOC, were extracted from MOBILE 6.2 for arterial roadways in the year 2025. Multiplying the emission factors by the VMT saved produces daily reductions of 77.0 kg of CO, 2.0 kg of NOx, and 2.3 kg of VOC.

# TABLE 1
# EOT SIP Air Quality Analysis (2025) for Eastern Massachusetts
# By Package and by Project

| Scenario | Description | Daily Emissions (in kilograms) 164 Communities in Eastern Massachusetts (EMRPP Study Area) Carbon Monoxide | Nitrogen Oxides | Volatile Organic Compounds |
|---|---|---|---|---|
| 1 | **2025 RTP No-build scenario** | 1,106,943 | 28,347 | 28,984 |
| | **Comparison by Package** | | | |
| 2 | **Original SIP package of projects**<br>**Green Line Extension to Ball Sq.**<br>**Red-Blue Connector**<br>**Arborway Restoration** | 1,106,651 | 28,340 | 28,973 |
| | a. Diff (2-1) | -292 | -8 | -11 |
| | b. 110% of Diff (2-1) | -321.2 | -8.8 | 12.1 |
| 6 | **Proposed SIP package of projects**<br>**Green Line to Union Sq. & Medford Hillside**<br>**Fairmount Improvements** | 1,106,585 | 28,338 | 28,969 |
| | a. Diff (6-1) | -358 | -9 | -15 |
| | b. Additional Parking Spaces | -77 | -2 | -2 |
| | c. Sum (a+b) | -435 | -11 | -17 |
| | d. Does it exceed 2 b? | Yes | Yes | Yes |
| | **Comparison by Project** | | | |
| 3 | **Arborway Restoration** | 1,106,858 | 28,346 | 28,977 |
| 4 | **Green Line Extension to Ball Sq.** | 1,106,777 | 28,346 | 28,979 |
| 5 | **Red-Blue Connector** | 1,106,787 | 28,343 | 28,975 |
| | a. Diff (3-1) | -85 | -1 | -7 |
| | b. Diff (4-1) | -166 | -1 | -5 |
| | c. Diff (5-1) | -156 | -4 | -9 |
| | d. Sum of Diff (a+b+c) | -407 | -6 | -21 |
| | e. 110% of Diff (d) | -447.7 | -6.6 | -23.1 |
| 7 | **Green Line to Union Sq. & Medford Hillside** | 1,106,565 | 28,339 | 28,967 |
| 8 | **Fairmount Improvements** | 1,106,896 | 28,346 | 28,979 |
| | a. Diff (7-1) | -378 | -8 | -17 |
| | b. Diff (8-1) | -47 | -1 | -5 |
| | c. Additional Parking Spaces | -77 | -2 | -2 |
| | d. Sum of Diff (a+b+c) | -502 | -11 | -24 |
| | e. Does it exceed 5 e? | Yes | Yes | Yes |

# TABLE 2
# EOT SIP Off-Model Analysis of Air Quality Reductions Due to 1,000 Additional Park-and-Ride Spaces

| Daily Off-Model Impact of 1,000 Additional Park-and-Ride Spaces on Emissions | | | |
|---|---|---|---|
| **Assumptions** | **Assumed** | **Derived** | |
| **Parking spaces assumed** | 1,000 | | |
| **Utilization** | 80% | | |
| **Parking spaces utilized** | | 800 | |
| **Avg. trip length (miles), one-way to Boston** | 8 | | |
| **Avg. trip to park-and-ride lot (miles), one-way** | 1.5 | | |
| **Avg. trip VMT reduction (miles), one-way** | | 6.5 | |
| **Avg. trip VMT reduction (miles), two-way** | | 13 | |
| **Daily VMT reduction for all vehicles, two-way** | | 10,400 | |
| **Occupancy per vehicle** | 1 | | |
| **Avg. speed (mph)** | 23 | | |
| **MOBILE 6.2 Air Quality (kg)** | **Factor (g / mile)** | **Grams * Daily VMT Reduct.** | **Kilograms** |
| **Carbon monoxide** | 7.394 | -76,898 | -76.9 |
| **Nitrogen oxides** | 0.194 | -2,018 | -2.02 |
| **Volatile organic compounds** | 0.22 | -2,288 | -2.29 |

# APPENDIX A

## Travel Demand Modeling Methodology

## General Description of the Model

The travel model set is based on procedures that have evolved over many years at the Central Transportation Planning Staff (CTPS). The model set is based on the traditional four-step urban transportation planning process of trip generation, trip distribution, mode choice, and trip assignment and is implemented in the EMME/2 software package. This process is employed to estimate daily transit ridership and highway traffic volumes, primarily on the basis of forecasts of study area demography and projected highway and transit improvements. The model set simulates travel on the entire Eastern Massachusetts transit and highway system.

## The Four Steps

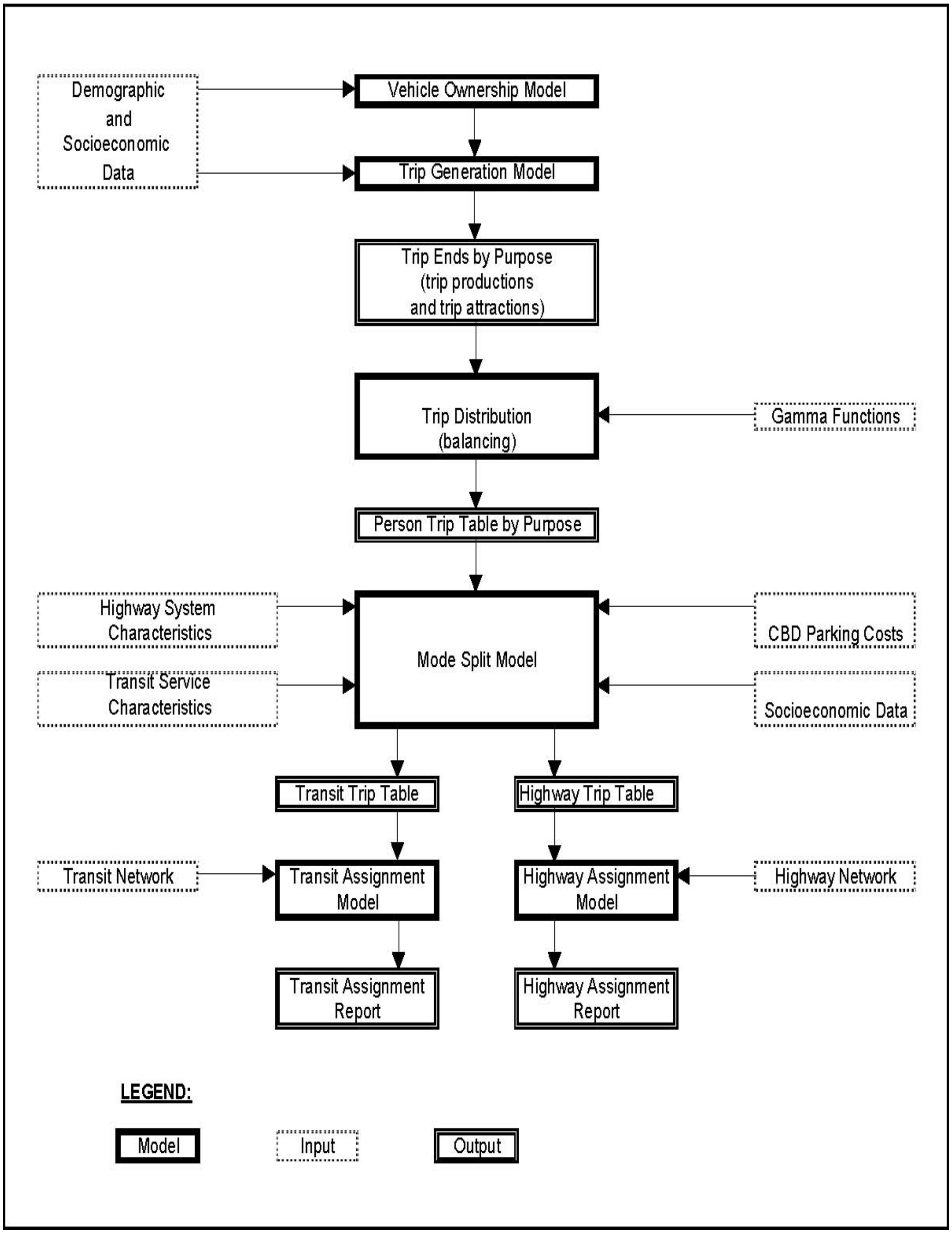
In the first step, the total number of trips generated by residents of the CTPS Modeling Area (the 101 MAPC cities and towns that make up the Boston MPO together with 63 communities outside of the Boston MPO) is calculated using demographic and socioeconomic data. Similarly, the number of trips attracted to different types of land use such as employment centers, schools, hospitals, shopping centers etc., is estimated using land use data and trip generation rates obtained from travel surveys. This information is produced at disaggregated geographic areas known as traffic analysis zones (TAZ). All calculations are performed at the TAZ level.

In the second step, the model determines how the trips generated in each TAZ are distributed throughout the region. Trips are distributed based on transit and highway travel times between TAZs and the relative attractiveness of each TAZ which is influenced by the number of jobs available, size of schools, hospitals, shopping centers etc.

Once the total number of trips between TAZs is determined, the mode choice step of the model (step three) allocates the total trips among the available modes of travel. In our case, the available modes of travel are walk, auto (SOV and carpools) and transit (walking to transit and driving to transit). To determine the proportions of each mode, the model takes into account the travel times, number of transfers required, parking availability and costs associated with these options. Other variables such as the auto ownership and household size are also included in the model.

After estimating the number of transit and auto trips for all possible TAZ combinations, the model assigns them to their respective mode of transportation (this is the fourth and final step). Various reports showing the transit ridership on different transit modes (including estimates of passenger boardings on all the existing and proposed transit lines) and traffic volumes on the highway network are produced according to our needs. A schematic representation of the modeling process is shown in Figure 1.

## Figure 1: The Four Step Demand Modeling Processes



**Model Features**

The model set uses the best component models, networks and input data available to CTPS at this time. Some of the features of the model set include:

- The model set incorporates motorized and non-motorized trips.
- The model is set up to simulate passenger and highway travel during four time periods of a typical weekday.
- The trip generation, trip distribution and mode choice portions of the model set are well calibrated.
- The model set recognizes the parking lot capacity constraints when assigning park and ride trips.
- The transit assignment procedure can be constrained to a given line capacity.
- The park and ride trips can be reassigned to the highway network for a more realistic highway assignment.
- EMME/2 software used in implementing the model is capable of performing multi-class, multi-path assignment that is superior to the traditional all-or-nothing assignment.
- The procedure that estimates air quality benefits is sophisticated and well integrated within the main model.

**Description of Model Parameters**

Modeled Area: The modeled area encompasses 164 cities and towns in Eastern Massachusetts, which includes 101 MAPC region cities and towns, and 63 Communities outside of Boston MPO, as shown in Figure 2. The figure also shows the boundaries of five concentric rings into which the modeled area is divided for model estimation and calibration purposes. These rings will be referred to in subsequent discussions.

Zone System: The modeled area is divided into 986 internal Traffic Analysis Zones (TAZs). There are 101 external stations around the periphery of the modeled area that allow for travel between the modeled area and adjacent areas of Massachusetts, New Hampshire and Rhode Island.

Transportation Networks: There are two types of networks; transit and highway. Both are integrated in EMME/2. The highway network is comprised of express highways, principal & minor arterials and local roadways. The transit network is comprised of commuter rail lines, rapid transit lines and bus lines (MBTA + Private carriers). The model contains service frequency (i.e. how often trains and buses run), routing, travel time and fares for all lines.

Major Data Inputs: CTPS's travel model set underwent a major revision in 1993, and several important data sources were used in that revision. This section lists the major data items underlying the model set.

**FIGURE 2 CTPS Modeled Area and Ring Boundaries**

Household Travel Survey: In 1991, CTPS conducted a household travel survey. The survey took the form of an activity-based travel diary that was filled out for one weekday. Approximately 4,000 households, generating some 39,000 weekday trips were represented in the final database. The data were used to estimate new trip generation, auto ownership, trip distribution and mode choice models.

External Cordon Survey: Also in 1991, a survey of automobile travelers bound for the modeled area from adjacent areas was performed. Survey results were used in trip generation and distribution to update estimates of external trips.

Site-level Employment Database: Employment estimates for 1991 were taken from state-provided sources and a commercial vendor's database purchased by CTPS, and combined into a single, unified regional employment database.

2000 U.S. Census: Various files were used in model estimation and calibration processes.

Ground Counts: Transit ridership and highway traffic volume data representing early 1990's conditions were amassed into a database and used to calibrate the travel sub models.

Analysis Year: Base year is 2000 and the horizon year is 2025 for which the Land Use Scenario is based on Trends Extended.

Model Inputs: The model inputs include: Population/households, employment, transit level of service, transit fares, highway level of service, highway tolls, and automobile operating costs including parking.

Highway Network

The regional highway network contains in excess of 40,000 links and 15,000 nodes. It is fairly dense in the study area, although like any modeled network, it does not include some local and collector streets. Each link is coded with the appropriate free-flow speed, number of lanes and lane capacity. Functional class is coded, as are various geographic flags useful for summarizing emissions. Another code is used to distinguish links open only to High-Occupancy Vehicles (HOV) from all other links.

Transit Network

The transit network represents all MBTA bus and rail services in Eastern Massachusetts, as well as private express buses and Boston Harbor ferries. Most-likely travel paths are built through the network, then skimmed and the resulting impedances are input to the trip distribution and mode choice models. After mode choice, transit trip tables by time of day are assigned to the network travel paths.

Time of Day Considerations

In the current version of the travel model set, the mode choice and transit assignment are conducted for four time periods: AM peak period, Midday, PM peak period, and Nighttime. The trip generation model however, is based on daily trips. The trip distribution model considers two time periods, peak and off-peak periods.

The highway and transit networks are built separately for each time period. Table 1 shows the time intervals associated with each time period. The highway vehicle trips created by the mode choice model are converted from production/attraction format to an origin/destination format prior to network assignment. Transit person trips are also transformed from production/attraction format to origin/destination format, for each time period and assigned to the transit network.

The factors used in dividing the highway person trips into different time periods were obtained from the 1991 Household Travel Survey. The final trip tables created for each time period correspond to observed levels of congestion on the highway system. The results of the four assignments are summed to obtain daily (AWDT) results.

**Table 1 – Time Periods for Trip Assignment**

| Time Period | Highway Vehicle Trips | Transit Person Trips |
|---|---|---|
| AM Peak Period | 6:00 am - 9:00 am | 6:00 am - 9:00 am |
| Midday | 9:00 am - 3:00 pm | 9:00 am - 3:00 pm |
| PM Peak Period | 3:00 pm - 6:00 pm | 3:00 pm - 6:00 pm |
| Early/Evening/Night | 6:00 pm – 6:00 am | 6:00 pm – 6:00 am |

Household and Employment Forecasts

Households and employment by type are major inputs to the travel model process: they are the variables upon which trip generation is done. The Metropolitan Area Planning Council (MAPC) using what is called a "Targeted Growth" method developed the forecasts of households and employment for this region independently. In this method, growth is targeted to denser areas with available water and sewer infrastructure with a focus on development around transit stations.

**Trip Generation Model**

The first step in the CTPS Regional Travel Forecasting Model Set for Eastern Massachusetts is the trip generation model. This model uses socioeconomic characteristics of the region and basic information about regional transportation infrastructure, transportation services, and geography to predict the amounts of travel which will be produced and attracted to the transportation analysis zones (TAZs) within the Eastern Massachusetts region.

The CTPS trip generation model is composed of the following nine parts and a description of each of these parts is presented thereafter:

- Base year inputs
- Future year inputs

- Estimation of base year input requirements for future years
- Estimation of detailed socioeconomic characteristics
- Estimation of vehicle ownership
- Estimation of trip productions and attractions
- Balancing of trip productions and attractions
- Elimination of Logan trip productions and attractions
- Preparation of files for other components of the regional model set

Base Year Inputs:

The base year inputs required for the trip generation model include the following: total households, total population, group quarters population, households by household size, households by income quartile, households by workers per household, households by size, income, and workers per household, population by age, basic employment, retail trade employment, services employment, school employment (K-12 and college), resident workers, dorm population, labor participation rates, land area, Logan person trips, external person trips, attraction and production terminal times, and transit walk access factors

For the base year trip generation applications, data from the 2000 US Census of Population is used where available. Estimates for the year 2000 are generated for those variables that are still based upon 1990 US Census data through application of the forecast year procedures described below.

Future Year Inputs:

The future year inputs required for the trip generation model include the following: total households, total population, group quarters population, population by age, basic employment, retail trade employment, services employment, labor participation rates, Logan growth factors, external growth factors, and transit walk access factors. These data are used to estimate the future year levels for the variables listed as base year input requirements following the procedures described below.

Estimation of Base Year Input Requirements for Future Years

Various procedures are used to prepare the trip generation model input data for future years. The variables that are estimated in these procedures include the following: households by household size, households by income quartile, resident workers, households by workers per household, school employment (K-12 and college), dorm population, Logan person trips, external person trips, and attraction and production terminal times.

Household Size: The change in TAZ average household size is implied in the base year inputs and future year forecasts (total population minus group quarters population divided by total households). The new distribution of households by household size is estimated by first distributing the future year households by size in the same proportions as in the base year. It is then assumed that all households capable of making the implied change (households of two or more for household size reductions; all households for household size increases) will have the same probability of changing in size by one. This probability of changing is set equal to the extent needed to match the forecast change in household size, and the resulting distribution of households by household size is used for the future scenario.

Household Income: The future year distribution of households by income quartile is estimated by assuming the proportional distribution of households by income quartile remains constant within each TAZ.

Resident Workers per Household: The change in the number of resident workers at the town level is obtained from combining base year and future year estimates of over-age-15 population and labor force participation by gender and age cohort. Dividing the base year and future year estimates of town-level resident workers by the base year and future year number of households in the town, respectively, produces estimates of the base year and future year average workers per household. All of the TAZs within each town are assumed to have the proportional change in workers per household implied by these base year and future year town-level estimates.

Household Workers: The future year TAZ number of households within each category of worker per household is estimated by using worker-per-household distribution curves developed by CTPS from the 1990 U.S. Census. These curves, summarized in Exhibit 4, indicate a default percentage distribution of households for the base year and future year TAZ estimates of average worker per household. The proportional changes in the default number of households within each category of worker per household implied by this comparison are applied to the actual base year TAZ distribution of households to obtain the distribution of households by workers per household to be used for the future scenario.

K-12 Employment: The level of employment in schools providing Kindergarten – 12th grade education is assumed to be proportional to the number of town residents of ages 5 19.

College Employment: The level of employment at all colleges within the region is assumed to be proportional to the number of regional residents of ages 20-24.
Dorm Population: The dorm population within a TAZ is assumed to be proportional to the total group quarters population within a TAZ.

Logan Person Trips: Base year Logan passenger trips are factored up by projected passenger growth rates to the future year. Base year Logan employee trips are factored up by projected Logan work force growth rates to the future year.

External Person Trips: Base year external person trips are factored up by population and employment growth rates implied in the forecasts of the neighboring regional planning agencies to the future year. These growth rates are presented in Exhibit 6.

Attraction and Production Terminal Times: The attraction and production terminal times are estimated through the application of a model developed at CTPS. This model estimates terminal times as a function of household and employment density. Alternative estimates of the production and attraction terminal times for each TAZ are based on the household density ranges and employment density ranges. The larger of each pair of estimates are assigned to the TAZ. A few TAZs (locations of major generators such as airport or large colleges) were assigned terminal times in the base year different from the terminal time model estimates. In these cases, the model is used to estimate changes in the terminal times.

### Estimation of Detailed Socioeconomic Characteristics

A three-way distribution of the households within each TAZ by household size, income, and workers is required in order to estimate the distribution of households by vehicle ownership levels. While this is available from the US Census at the regional level, such distributions at the TAZ level must be estimated through iterative proportional fitting techniques. Using the regional matrix as a seed, the cell values are adjusted through ten iterations to match row and column totals to the estimated ring-level totals to produce the three-way distribution of households for each geographical ring. Using these ring-level matrices as seeds, this process is then repeated for each TAZ within each ring.

### Estimation of Vehicle Ownership

Household auto ownership is an input to trip generation and mode choice. It is forecast using a logit model developed with the 1991 Household Travel Survey and 1990 U.S. Census data. The model is integrated with the trip production procedures. The distribution of households by vehicle ownership estimated through the application of a set of models developed at CTPS. These models estimate the probability of a household owning a certain number of vehicles as a function of income, household size, workers per household, household density, employment density, household location, and transit walk access factors.

### Estimation of Trip Productions and Attractions

The number of trip productions and trip attractions within a TAZ is estimated through the application of a set of models developed at CTPS. These models estimate the number of trip productions and attractions as a function of household size, workers per household, vehicles per household, income, household location, households, basic employment, retail employment, college employment, school employment, and service employment.

### Balancing of Trip Productions and Attractions

Connecting a trip production with a trip attraction of the same trip purpose forms a trip. As a result, the number of productions and attractions for each trip purpose must be equal. In order to achieve this, the trip productions and attractions are balanced. The normal balancing procedure is to set the total number of regional attractions equal to the difference between the grand total of productions and the total number of external attractions. While that procedure was used to balance trip productions and attractions in 1995, the procedure required modifications for future year scenarios.

The large difference between regional employment and the number of resident workers and the large increase in external employment forecasted by the neighboring regional planning agencies and states produced home-based work trip volumes which seemed to be too high. In order to restrict trip volumes to plausible levels, the following changes were made in the balancing procedure:

- Regional home-based work trip productions are adjusted so that the increase from the base year total to the future year total is proportional to the forecast change in regional resident workers.
- Regional home-based work attractions were reduced by 3%, as was required to balance home-based work productions and attractions in 1990.
- External home-based work productions were set equal to the difference between the grand total of home-based work attractions and the regional home-based work productions.

Elimination of Logan Trip Productions and Attractions

While the total number of trip productions and attractions are equal, they include trips produced and attracted to Logan Airport. Since a separate model is used to estimate travel patterns to and from Logan Airport, Logan trips have to be purged from the trip matrices. The trips produced by or attracted to the Logan TAZs are thus eliminated, and Logan Airport passenger and employee survey data are used to identify the productions and attractions of other TAZs which correspond to the Logan TAZ productions and attractions.

All of these Logan-related trips are eliminated from the original balanced estimates of trip productions and attractions, and files are produced which present estimates of the productions and attractions within each TAZ for home-based work, home-based personal business, home-based social and recreational, home-based school, home-based pick-up and drop-off, non-home-based work, and non-home-based other travel.

Preparation of Files for Other Components of Regional Model Set

In addition to trip productions and attractions, the results of the trip generation model also include several files used as inputs to other components of the regional model set.

## Trip Distribution Model

The trip distribution model is the second step in the CTPS Regional Travel Forecasting Model Set. The trip distribution model links trip productions with trip attractions in the region to create matrixes of intraregional and a portion of interregional travel.

Distribution of Internal-Internal Trips

The procedure developed relies on the implementation of a three-dimensional trip balancing strategy, as provided by the EMME/2 transportation planning software. Three-dimensional trip balancing distributes production and attraction, which constitute the first and second dimensions respectively, subject to a third constraint on the distributed trips which is a combination of the scaled composite impedances and the total number of trips between districts. The 1991 transportation demand survey was used to define this third dimension constraint.

When applying the transportation demand model to generate trip demand forecasts, the object of a trip distribution model is the estimation of trip matrices based on future productions and attractions (P's & A's) given new transportation supply conditions, which translate into new composite impedance. A transportation demand survey exists only for the "base case", and therefore cannot be integrated in the procedure for evaluation of future scenarios. Thus, the object of the three-dimensional balancing procedure is broader than the generation of a trip matrix, which is the direct result of the balancing of productions and attractions. This step generates intermediate results useful for the calibration of a two-dimensional balancing for future year studies. The multipliers associated with the third dimension of this procedure were used to estimate "gamma" functions. Such functions of scaled composite impedances then allow for the creation of seed matrices of the trip distribution procedure (two-dimensional) to apply in scenario studies. These gamma functions translate the "reaction" of the three-dimensional procedure to the third dimension constraint and therefore, account for this constraint when applied to define a seed matrix.

Inputs

The inputs of the procedure are:

- matrices of trip utilities, which are an output of the mode choice procedure;
- split factor matrices, which provide the total number of trips between district pairs for the peak and off-peak periods;
- trip-ends (production and attraction);
- household survey trip data.

Methodology

The procedure developed to distribute internal-internal trips relies on gamma functions derived from a three-dimensional balancing procedure and does not involve "friction factors" or "K factors." The gamma functions transform scaled composite impedances into seed values for the two-dimensional balancing. This procedure involved three steps:

- three-dimensional balancing, in which geographical information is combined with scaled composite impedance values to define the third constraint;

- estimation of gamma functions;
- two-dimensional balancing for future years productions and attractions, using the gamma functions to compute seed values.

A three-dimensional balancing model was calibrated first with the 1991 data (productions, attractions and household survey results) on 12 combinations of six trip purposes and of two time periods. The six purposes considered are: home-based work, “wk”; non home-based work, “nw”; non home-based other, “nbo”; school, “sc”; socio-recreational, “sr”; and shopping, “sh”. The two periods considered are: peak, “pk”; and off-peak, “op.” The “peak” context includes the AM and PM peak periods while the “off-peak” context regroups the mid-day and evening periods.

The mode choice model generates sets of 4 utility matrices, one for each of four periods considered in the mode choice model (AM, PM, MD and NT). The AM and PM utilities are combined to compute PK composite impedances and the MD and NT utilities are combined to compute OP composite impedances. Although 6 purposes are considered in this procedure, only 5 sets of utility matrices are used as input to the procedure, since the same utilities are applied to the shopping and socio-recreational purposes. There are 12 split factor matrices, corresponding to each purpose and period combination of the trip distribution procedure. These matrices provide the respective shares of AM and PM trips for the PK periods, and the shares of MD and NT trips for the OP periods. As a result, we get 12 pairs of productions and attractions (P’s and A’s) corresponding to each purpose and period combination of the trip distribution procedure are developed.

The result of this effort leads to the estimation of some 60 gamma functions for the different combinations of period, purpose and interchange category. Gamma functions were then applied to compute the seed matrices of a two-dimensional balancing model for year 1991. Results of the two-dimensional balancing were compared to those obtained with the three-dimensional balancing. This comparison confirmed that the gamma functions used to generate seed values of the two-dimensional balancing were efficient in implicitly applying the third dimension constraint of the three-dimensional balancing procedure. Then, the two-dimensional balancing strategy was applied to distribute the productions and attractions for the future year.

Internal-External Trip Distribution

Internal-external trip distribution refers to a process in which all internal and external, that is, all 1083 traffic analysis zone AWDT trips ends, are distributed using AWDT highway impedances, but only the trips with one end in an internal zone and other end in an external zone are retained. The term “internal-internal” distribution refers to a redistribution of the internal zone trip ends that the internal-external distribution matched with other internal zone trip ends. The trip ends are split into peak period trip ends and off-peak period trip ends. These trip ends are then distributed separately using mode choice derived log sums of disutilities, appropriately calculated to reflect either the peak period (combining AM and PM peak log-sums) or the off-peak period (combining midday and night log-sums).

At the core of the internal-external trip distribution is the EMME/2-based three-dimensional balancing strategy, the third dimension incorporating the functions of constraining “k factors” and “f factors” which were carried over from our model set developed in UTPS software. This three dimensional balancing strategy performs a balancing of a seed matrix to zonal productions, zonal attractions, and subclass totals representing characteristics of the O-D trips of a transportation system, in this case, trip lengths as captured by highway impedances.

The basic output of the internal-external trip distribution model for the base year is an OD trip matrix, resulting from the third dimensional trip distribution as well as third dimension constraint and gamma functions. The base year inputs required for internal-external trip distribution include:

- Production and attractions matrixes by seven trip purposes output from the trip generation model: home-based work (wk); non home-based work (nw); non home-based other (nbo); school (sc); social-recreational (sr); shopping (sh); and pick-up and drop-off (pudo).
- The internal-external survey trip tables by purpose, which could only be coded at the 300 zone “land use’ level: one zone for each of twenty-three Boston and five Cambridge neighborhoods; one zone for each of the remaining towns; and one zone for each of the ninety-seven externals.
- The AWDT 1083-zone highway skims files, one for time in minutes and another for tolls in cents (from UTPS files). [Note: It was determined that a peak, off-peak factor split was unnecessary given their similarity within each trip purpose.]
- Production and attraction terminal times. The terminal times were modeled (in EMME/2) but then were modified at major external zones during the development of the internal-external distribution model. These elements were used to create AWDT highway impedances.

The core of future year forecasting is the two-dimensional balancing strategy. It consists of preparing a seed matrix, through application of the relevant gamma functions on scaled highway impedance values, and using the resulting seed matrix within a two-dimensional balancing procedure. For the future year, inputs required for internal-external trip distribution and pudo trip distribution include:

- Production and attractions matrixes by seven trip purposes output from the trip generation model: hone-based work (wk); non home-based work (nw); non home-based other (nbo); school (sc); social-recreational (sr); shopping (sh); and pick-up and drop-off (pudo).
- Production and attraction terminal times
- Nine gamma functions for each of six internal-external trip purposes

computed from base year three-dimensional balancing.

- Nine gamma functions for internal-external pudo trips computed from k and f factors derived from UTPS AGM module.
- Split factor matrices for allocating internal-external trips to four time periods based upon the 1991 external travel survey and the household survey
- SOV/HOV occupancy rates by time periods to allocate internal-external trips and internal-internal pudo trips.

**Mode Choice Model**

Mode choice models by trip purpose were developed using 1991 Household Travel Survey data, travel impedances obtained from highway and transit networks, 1990 U.S. Census data and other data sources. There were not enough survey records for each chosen mode to estimate separate model parameters for home-based shopping/personal business and home-based social/recreational trips. Therefore, these two purposes were combined into one, and four mode choice models were developed. These were 1) home-based work and work related (HBW); 2) home-based other (HBO), which include home-based shopping, personal business, social, recreation and other miscellaneous purposes; 3) home-based school (HBSC) and 4) non home-based (NHB) trips. The available travel modes were: 1) walk-access transit, 2) drive-access transit 3) single-occupancy vehicles 4) high-occupancy vehicles (2 persons only for HBW trips) 5) high-occupancy vehicles with 3 or more persons (HBW trips only) and 6) walk. Specific transit mode selection,
i.e. local bus, express bus, light rail, commuter rail, occurs during the transit assignment process.

Mode choice deals with intra-regional trips only. Trips to and from external areas are dealt with separately and assumed to be only auto trips. Mode choice results in a split of both interzonal and intrazonal trips; however, intrazonal are only split between the walk and auto modes (SOV, HOV/HOV2, and HOV3). The transit modes do not capture intrazonal trips. The mode choice model variables are defined as follows:

Tree coefficient: This represents the combined utilities of the drive-access and walk-access components of the transit nest.

In-vehicle time: Time spent in a transit vehicle during the trip. For the shared-ride modes, in-vehicle and out-of-vehicle time are functions of drive alone time.
Out-of-vehicle time: Includes all walk and wait time and drive-access time, unless the last is specified separately.

Drive-access time: Time, by automobile, to drive from a trip origin to a transit station.

Terminal time: The time spent getting in a vehicle at the production end and entering the modeled highway network and the time spent leaving the modeled network and parking the vehicle and walking at the attraction end of the trip. These times are as high as five minutes in the Boston CBD and as low as one minute in suburban areas.

They are assumed to remain constant in the future.

Fare: Transit fare, in dollars, including one-half of any park-and-ride charges (because fare per one-way trip is used). The adult cash fare is used because that is what is coded within the transit network. Fares are assumed to remain constant over time.

Auto cost: Auto operating cost in dollars, which is computed using 9.8 cents per mile (1991 dollars) and toll costs, if any. Also, one-half any applicable parking costs (because costs per one-way trip are used). Parking costs are computed at the district level based on the average parking costs reported by auto mode users in the 1991 House Hold travel survey. For shared ride modes, total costs are divided by the appropriate auto occupancy. They are assumed to remain constant over time.

Household size: Persons per household. For 2025, population and household forecasts are provided by MAPC.

Vehicles/person: Total vehicles per person in the household. Vehicles are forecast for 2025 using the vehicle availability model described earlier.

Population density: Total population per acre.

Percent transit origins/destinations: The transit share of work trip ends in the TAZ, as computed by the home-based work mode choice model.

Work dummy: Equal to one, if the trip is work-related. Zero otherwise.

Input Data: The input files include: impedance matrices for each mode, the person trip tables to be split, pre-determined coefficients for utility equations and socioeconomic characteristics by TAZ.

Home Based Work Model

Home-based work (HBW) mode choice is the only trip purpose that distinguishes between two person carpools (HOV2) and three or more person carpools (HOV3). The model specifications are shown in Table 3. Formerly, travel on HOV lanes was restricted to HOV3 vehicles during peak hours. For the past several years, any 2-person vehicle may also use these facilities.

A transit nest is incorporated into the model on the basis that the decision to take transit over the other modes is done before selection of a particular transit mode. The transit coefficients are generic for both walk access (WAT) and drive access (DAT) and include a coefficient for in-vehicle, initial wait, transfer wait and total walk time. Drive access time and production terminal times are included in drive access transit as one parameter. The HBW model utilizes two transit impedances that are exclusive to this trip purpose model, the WAT transfers and DAT transfers. Survey data indicate that the number of transfers is critical to mode selection for work trips. The WAT fare includes the transit fare in dollars. For DAT, fare includes the transit fare, any parking cost and the drive access cost, with the latter being computed as 9.8 cents per mile. Population density by traffic zone, in people per acre, is included in walk access transit, and is positively correlated so that the greater the density, the more likely a traveler is to choose this mode. The zones with high population densities also have more transit stops. Vehicles per worker is a socioeconomic input unique to this trip purpose for DAT. It is also positively correlated, since a higher vehicle per worker ratio increases the likelihood of taking a vehicle to a park-and-ride lot.

The auto times and costs are generic for the three auto modes. For HOV2, the auto cost is divided by 2 and for HOV3 it is divided by 3.66 to reflect splitting the cost between the vehicle occupants. Household size is included as a positively correlated variable for the shared-ride modes and has a somewhat greater impact for HOV3 than HOV2.

Home Based Other Model

The home-based other (HBO) mode choice model combines the home-based shopping and home-based recreational trip tables output from the trip distribution process into a single HBO trip table that is split. The model specifications are shown in Table 4. The model is similar to the HBW mode choice model, except for the following four differences. First, since there is only one shared ride mode, household size is only a parameter for shared ride two plus. Second, the vehicles per person in a household is used, as opposed to vehicles per worker. Third, the number of transfers in the transit modes was not found to be a significant variable and therefore was not included. Finally, a distance dummy equal to one if the trip distance was less than a mile, zero otherwise, was added to the walk mode. This reflects the fact that people taking short trips for this purpose are more likely to walk than choose another mode.

Home Based School

The home-based school (HBSC) model does not have separate utility equations for WAT and DAT, as there were not enough DAT trips for this purpose to develop a valid model. Therefore, one transit utility equation was developed and applied for splitting both WAT and DAT trips. The HBSC model has a non-motorized nest, meaning that people first choose whether they are going to walk or take a motorized mode. Following that decision, the secondary decision is whether to drive alone, carpool or take transit.

The equation for transit contains in-vehicle travel time and one out-of-vehicle travel time made up of initial wait, transfer wait and walk time. If the transit path is a drive access path, auto access time and production terminal time are included in total out-of-vehicle time. The fare variable includes the transit fare, parking cost (if any), and auto access cost (if applicable).

Non Home Based Model

The non home-based (NHB) model splits work trips and non-work trips. The model specifications are shown in Table 5. There is a work dummy variable in the two auto modes which is equal to one if the trip is a non home-based work trip and zero otherwise. The coefficient is positive for SOV and negative for HOV. The percent of trips attracted to the origin and destination zones, which are SOV, is a variable in the drive alone mode. The percentage is taken from Journey-to-Work data and is positively correlated. Finally, the distance dummy in the walk mode is equal to one if the distance is less than a mile. It has a positive coefficient. Pre Assignment Procedure (after Mode Choice)

The completion of the runs for the 16 mode choice applications (4 trip purposes by 4 time periods) results in the creation of 68 person trip tables. To prepare for subsequent highway and transit assignments, the trip tables must be converted from production-attraction to origin-destination formats (except for NHB trips where they are the same). For the highway assignment it is necessary to convert person trips to vehicle trips by applying vehicle occupancy factors for HOV modes. These occupancy factors vary by trip purpose and, in the case of HBW trips a higher occupancy factor is applied to HOV3 trips. Their values are the following:

home-based work trips HOV3 = 3.373
home-based other trips HOV = 2.404
home-based school trips HOV = 2.788
non-home-based trips HOV = 2.385

In addition to the manipulation of the output matrices from mode choice, it is necessary to bring in vehicle tables produced outside of the mode choice process. These include:

- Trucks – The truck trip tables that have been used up to the present are based on 1963 survey data factored to the present.
- External Through – This matrix includes trips that pass through the study area without stopping and hence are exogenous to the travel model. The trips were estimated from the 1991 external travel survey and have been factored since that time based upon production and attraction growth.
- Taxi – The taxi vehicle trip table was originally developed from a 1993 survey and has been since revised several times based upon a factoring process. However, there has been no update of travel pattern data to create a true update trip table.
- Logan Airport SOV & HOV – This trip table is developed from a separate modeling procedure, described in another section of the traffic model documentation.
- Drive Access Transit Auto Access – DAT trips are determined through the mode choice process. Each DAT trip requires a vehicle access trip, with the total vehicle trips being slightly lower than the DAT total, as a small percentage of transit users carpool to park-and-ride-lots.

- Internal-External SOV & HOV – The internal-external trip tables are generated through the trip distribution process.
- Pickup/Drop-off SOV & HOV – The pickup/drop-off (PUDO) tables are those trips in which a person is dropped off at their destination (not an intermediate park-and-ride lot) by the driver. They are produced in the trip generation process along with other productions and attractions, then put through trip distribution.

**Highway Assignment Model**

The coding of the EMME/2 highway network basically follows the hierarchy of the functional classification system. Expressways, other than through denser urban areas, are generally coded for 60 mph speeds and hourly capacity per lane of 1950. Higher level arterials are coded for speeds ranging from 45 to 50 mph and corresponding capacities of 1050 to 1100. Lower level arterials and major collectors range from 35 mph to 40 mph, with capacities of 950 and 1000. Minor collectors and local streets that are not in urban centers range from 23 mph to 30 mph, with capacity generally at 800. Streets in urban centers can have substantially lower speeds and capacities.

The highway assignment utilizes the BPR function, which is a traditional procedure for planning models. This curve was based on the 1965 Highway Capacity Manual, which was parabolic in shape, and speed was fairly sensitive to increasing flows. The BPR curve is as follows:

$$\text{Congested Speed} = (\text{Free-Flow Speed})/(1+0.15[\text{volume}/\text{capacity}]^{4})$$

For each time period the function is adjusted for apportioning the amount of demand to the number of hours. In the AM and PM peak periods, travel volume is apportioned to 3hour periods, for the midday it is 6 hours and for the night it is 12 hours.

The highway assignment follows a straightforward procedure consisting of an equilibrium auto assignment. A multiclass assignment with generalized cost is applied. Generalized cost is computed as the combination of the travel time plus a fixed link cost. The multiclass assignment runs an assignment for the demand matrices of two modes, single occupancy vehicles and high occupancy vehicles from the vehicle trip tables for each class that are assigned by time period. Link tolls are contained in an extra attribute (@toll), which has average tolls along links where they are collected. A weight factor of five is applied to @toll to convert the cost in dollars to a time cost. This factor is based on an assumed value of time of $12.

The additional options assignment is then applied in order to compute output impedance matrices, including travel time, travel distance and tolls matrices. The travel time matrix output matrix is an optional output each time the assignment is run, but only one other impedance matrix per assignment can be produced. To output both the distance and toll matrices, the highway assignment must be run a second time. There is no vehicle occupancy factor to adjust the trip table, since this was already done when converting auto person trips to vehicle trips in the post-mode choice procedure. The additional demand to be assigned for additional volumes then is the same demand matrix applied to Class 1 – the SOV trip table. There are four attribute options available for the attribute matrix that is calculated. Additional path attribute is selected, which gives the average value of the path attribute for all the paths used in the assignment. The module then prompts the next class to be assigned, which is the HOV vehicle trip table. The HOV matrix for the particular time period is then specified. Since output impedance matrices are not calculated based on this demand, the prompt for the matrix to hold travel costs is bypassed. For the present model, the HOV is the final class for assignment, so the prompt for class 3 is bypassed.

The default number of iterations is 15; however the standard number used for assigning the CTPS regional model is 20. The model then asks for the stopping criteria for the relative gap. The relative gap is an estimate of the difference between the current assignment and a perfect equilibrium assignment, in which all paths used for a given O-D pair would have exactly the same time. The default is .5%, but .01% is selected, which should enable the full number of iterations to be carried out.

The other stopping criteria are the normalized gap (or trip time differential), which is the difference between the mean trip time of the current assignment and the mean minimal trip time. The mean trip time is the average trip time on the paths used in the previous iteration; the mean minimal trip time is the average trip time computed using the shortest paths of the current iteration. Again, a minimum level is selected, .01 minutes, in order for the designated number of iterations to be carried out. Note that the relative gap always decreases from one iteration to the next, whereas the trip time difference does not necessarily have this property. In a perfect equilibrium assignment, both the relative gap and the normalized gap are zero.

**Transit Supply Model (Pre Trip Distribution)**

The transit supply model is integral to the forecast of transit demand and the performance of different scenarios of infrastructure investment. Interzonal travel impedances faced by those trip makers who walk to their transit access points are the product of the transit system skimming process. This process contributes the transit portion of impedance to drive access transit skims as well. For this purpose the park and ride lots are regarded as special intermediate origin and destination zones.

The real network of commuter trains, ferries, rapid transit trains, local and express busses are represented digitally by an interconnected topology of infrastructure links. These links represent roadway and railway segments. Each link has a start node and an end node defined geographically with x-y coordinates. Each link also has a defined length and description as to which transit modes may traverse the link. In the case of commuter rail and rapid transit modes a link travel time in minutes is also defined. In our representation of the network, busses may traverse all highway links, but commuter rail and rapid rail transit use exclusive links only. They also use exclusive nodes. There is always a walk link between busses and trains. The transit network building conventions are explained below:

Transit Links and Lines: Bus lines are overlaid on highway links and rail links are coded separately. Sequences of transit links are defined together as lines. Each line is represented for each time period of the day with its own headway (frequency of service) and points of boarding and alighting. Each instance of a transit line traversing a transit link is a transit segment. Segments of the two rail modes take their travel time from the time of the link. Segments of the bus modes have transit times based on the scheduled line times apportioned by distance. Thus highway congestion doesn't directly affect bus travel times in the model. But if needed, bus speeds can be made a function of highway travel speeds. Future-year bus speeds are estimated on the basis of future-year congested highway speeds. The speeds of the various modes are determined on the basis of level-of-service data provided by the client and their consultants.

Walk-access Links: Walk-access times coded onto walk links represent the average walk time from all points in a zone to the transit node. These times were initially measured using the Arc/Info Geographic Information System (GIS) and then input to the EMME/2 transit network. Walking speed was assumed to be three miles per hour. The maximum walking distance for a bus is coded as one-half of a mile. The distance increases to three-quarters and one mile for rapid transit and commuter rail respectively.

Drive-access Links: Each TAZ beyond the Boston core area is connected to the four closest park-and-ride nodes with drive-access links. Appropriate drive time and distance values were obtained from the highway network and coded onto these links. Each park-and-ride node is connected to its associated transit node by a walk link. In the Boston core, no drive-access links are provided. The parking lot fare is coded directly on the link connecting the park-and-ride node to the station node. In cases where more than one parking lot serves a station, an average of their parking fee is coded.
Transfer Links: Transfer links are provided in the network where appropriate. For all downtown and some other rail stations, actual walking times from line to line were recently measured and these values are coded onto the transfer links.

Walk Network: A walk network covers downtown Boston and serves as a circulator system between TAZs and transit stations/stops. In the CBD, travelers often alight their line-haul line and then walk several blocks to their final destinations instead of transferring downtown from one line to another and riding one or more stations before alighting. Prior to the introduction of the walk network, when each TAZ was directly connected to one or more stations, the pathbuilder usually found a path involving a transfer; hence, downtown transferring was overestimated. With the walk network, the pathbuilder finds more accurate paths. Each station and each TAZ is connected to the walk network, which then acts as a distribution system for the walk portion of downtown transit trips. The speed on the walk network is coded as three miles per hour. Each downtown TAZ is connected to a node on the network with a distance of 0.1 mile. TAZs on the periphery of the walk network are connected using the actual distance involved.

Fare Coding Conventions: Fares were coded in the EMME/2 network at the appropriate transit nodes. Adult cash fares are used. Each mode is assigned a boarding fare and up to seven fare link codes. Because of the complexity of the area's fare system, not all private express bus, Green Line and Red Line (Braintree branch) fares are represented exactly as they occur. Park-and-ride parking charges are coded onto the walk link that connects the park-and-ride node to the transit station node.

Fares are given the value of $12 per hour or 1 minute for every 20 cents of fare. Boarding fares are imposed at transit nodes to represent local bus fares and rapid rail transit fares. Special coding procedures are followed at free transfer points. There, a penalty is imposed on walk access links instead. On commuter rail and express bus lines there are also fare penalties imposed on each segment traversed. Although fares are expressed in minutes to allow them to be impedances that influences path selection, they are not just lumped in with travel time.

Finally, each component of travel impedance is skimmed from the interzonal travel path separately and stored in its own interzonal matrix. Walk time is computed as link distance at three miles per hour. In the path selection process, the walk time is considered as twice the weight of in-vehicle travel time. Wait time is stored separately for the initial boarding and subsequent (transfer) boardings. The wait time is also factored in accordance with the characteristics of the transit mode being boarded.

Each of these components of walk access transit impedance by time of day is input to the computation of drive access transit impedance and to the mode split process. They also become an element of the composite impedance upon which trip distribution is based.

Transit Assignment Model (post demand model)

After demand matrices of walk access and drive access transit trips have been forecast, these trips are assigned using our transit assignment model.

Drive access and walk access trips are combined by time period. The transit network and other parameters are the same for assignment as for the impedance skimming process. Currently, congestion of passengers at stops and terminals does not influence travel times or behavior in the model.

Path Building Conventions

The transit assignment implemented in EMME/2 is a multipath assignment, based on the computation of optimal strategies. The optimal strategy is one that minimizes the total expected perceived travel time. The values shown in Table 2 are currently being used in estimating the perceived travel times between a given origin and destination. These values apply both to walk-access transit and drive-access transit and to all submodes. They relate to in-vehicle time. For example, a transfer wait time factor of 2.45 implies that travelers perceive a minute of such time as 2.45 times more onerous than a minute spent riding in a transit vehicle. Although these values are theoretically supposed to correspond to marginal rates of substitution implicit in mode choice model coefficients, their final values are also based on what is needed to find reasonable paths through the network within the pathbuilder.

**Table 2 - Current Pathbuilding Parameter Values**

| Parameter | Value |
|---|---|
| Initial wait time factor | 1.1 |
| Transfer wait time factor | 2.45 |
| Drive-access time factor | 2.65 |
| Walk-access time factor | 1.6 |
| Walk speed | 3.0 mph |
| Fare factor | 1.0 |

Finally, summaries of transit boardings by mode and time of day are produced along with boardings and alightings at stations for rapid rail transit and commuter rail, with subtotals by line. For busses, summaries of boardings by MBTA bus route number and time of day are produced.

# TABLE 3
## Home-Based Work Mode Choice Model Specification

| | | Impedance Variables | | | | | | | | | Socio-Economic Variables | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Home-Based Work** | Nest Coeff | IVTT | Terminal Time | Walk Time | Initial Wait | Transfer Wait | Auto Access | Boarding Time | Fare ($) | Auto Cost ($) | Population. Density | Vehicles/ Worker | HHld Size |
| Drive Alone | | | | | | | | | | | | | |
| Top Level | 1 | -0.05466 | -0.292 | | | | | | | -0.32 | | | |
| Application Level | | -0.05466 | -0.292 | | | | | | | -0.32 | | | |
| Ratio to IVTT/VOT ($/hr) | | 1 | 5.34211 | | | | | | | $ 10.25 | | | |
| SR2 | | | | | | | | | | | | | |
| Top Level | 1 | -0.05466 | -0.292 | | | | | | | -0.32 | | | 0.07322 |
| Application Level | | -0.05466 | -0.292 | | | | | | | -0.32 | | | 0.07322 |
| Ratio to IVTT/VOT ($/hr) | | 1 | 5.34211 | | | | | | | $ 10.25 | | | -1.33955 |
| SR3+ | | | | | | | | | | | | | |
| Top Level | 1 | -0.05466 | -0.292 | | | | | | | -0.32 | | | 0.2168 |
| Application Level | | -0.05466 | -0.292 | | | | | | | -0.32 | | | 0.2168 |
| Ratio to IVTT/VOT ($/hr) | | 1 | 5.34211 | | | | | | | $ 10.25 | | | -3.96634 |
| Walk | | | | | | | | | | | | | |
| Top Level | 1 | | | -0.1007 | | | | | | | | | |
| Application Level | | | | -0.1007 | | | | | | | | | |
| Ratio to IVTT/VOT ($/hr) | | | | | | | | | | | | | |
| Walk-Transit | | | | | | | | | | | | | |
| Top Level | 0.6791 | -0.05466 | | -0.1007 | -0.11292 | -0.11292 | | -0.05466 | -0.32 | | 0.01889 | | |
| Application Level | | -0.08049 | | -0.14828 | -0.16628 | -0.16628 | | -0.08049 | -0.47121 | | 0.02781 | | |
| Ratio to IVTT/VOT ($/hr) | | 1 | | 1.8423 | 2.06593 | 2.06593 | | 1 | $ 10.25 | | -0.34551 | | |
| Drive-Transit | | | | | | | | | | | | | |
| Top Level | 0.6791 | -0.05466 | -0.292 | -0.1007 | -0.11292 | -0.11292 | -0.13665 | -0.05466 | -0.32 | -0.32 | | 0.2897 | |
| Application Level | | -0.08049 | -0.42998 | -0.14828 | -0.16628 | -0.16628 | -0.20122 | -0.08049 | -0.47121 | -0.47121 | | 0.4266 | |
| Ratio to IVTT/VOT ($/hr) | | 1 | 5.34211 | 1.8423 | 2.06593 | 2.06593 | 2.5 | 1 | $ 10.25 | $ 10.25 | | -5.30011 | |

# TABLE 4
## Home-Based Other Mode Choice Model Specification

| | | Impedance Variables | | | | | | | | | Socio-Economic Variables | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Home-Based Other** | Nest Coefficient | IVTT | Terminal Time | Walk Time | Initial Wait | Transfer Wait | Auto Access | Boarding Time | Fare ($) | Auto Cost ($) | Population. Density | Vehicles/ Worker | HHld Size | Distance Dummy |
| Drive Alone | | | | | | | | | | | | | | |
| Top Level | 1 | -0.01965 | -0.2308 | | | | | | | -0.22378 | | | | |
| Application Level | | -0.01965 | -0.2308 | | | | | | | -0.22378 | | | | |
| Ratio to IVTT/VOT ($/hr) | | 1 | 11.7463 | | | | | | | $ 5.27 | | | | |
| SR2+ | | | | | | | | | | | | | | |
| Top Level | 1 | -0.01965 | -0.2308 | | | | | | | -0.22378 | | | 0.1976 | |
| Application Level | | -0.01965 | -0.2308 | | | | | | | -0.22378 | | | 0.1976 | |
| Ratio to IVTT/VOT ($/hr) | | 1 | 11.7463 | | | | | | | $ 5.27 | | | -10.0566 | |
| Walk | | | | | | | | | | | | | | |
| Top Level | 1 | | | -0.05895 | | | | | | | | | | 0.9005 |
| Application Level | | | | -0.05895 | | | | | | | | | | 0.9005 |
| Ratio to IVTT/VOT ($/hr) | | | | | | | | | | | | | | -15.2757 |
| Walk-Transit | | | | | | | | | | | | | | |
| Top Level | 0.3722 | -0.01965 | | -0.05895 | -0.05895 | -0.05895 | | -0.01965 | -0.22378 | | 0.00883 | | | |
| Application Level | | -0.05279 | | -0.15838 | -0.15838 | -0.15838 | | -0.05279 | -0.60123 | | 0.02373 | | | |
| Ratio to IVTT/VOT ($/hr) | | 1 | | 3.0002 | 3.0002 | 3.0002 | | 1 | $ 5.27 | | -0.44951 | | | |
| Drive-Transit | | | | | | | | | | | | | | |
| Top Level | 0.3722 | -0.01965 | -0.2308 | -0.05895 | -0.05895 | -0.05895 | -0.04912 | -0.01965 | -0.22378 | -0.22378 | | 0.71239 | | |
| Application Level | | -0.05279 | -0.6201 | -0.15838 | -0.15838 | -0.15838 | -0.13198 | -0.05279 | -0.60123 | -0.60123 | | 1.914 | | |
| Ratio to IVTT/VOT ($/hr) | | 1 | 11.7463 | 3.0002 | 3.0002 | 3.0002 | 2.5 | 1 | $ 5.27 | $ 5.27 | | -36.2564 | | |

## TABLE 5
## Non-home Based Work Mode Choice Model Specification

| | | Impedance Variables | | | | | | | | | Socio-Economic Variables | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Non-Home-Based** | Nest Coefficient | IVTT | Terminal Time | Walk Time | Initial Wait | Transfer Wait | Auto Access | Boarding Time | Fare ($) | Auto Cost ($) | Work Dummy | Distance Dummy | Percent SOV |
| Drive Alone | | | | | | | | | | | | | |
| Top Level | 1 | -0.03022 | -0.3197 | | | | | | | -0.1817 | 0.1926 | | 0.00885 |
| Application Level | | -0.03022 | -0.3197 | | | | | | | -0.1817 | 0.1926 | | 0.00885 |
| Ratio to IVTT/VOT ($/hr) | | 1 | 10.5791 | | | | | | | $ 9.98 | -6.37326 | | -0.29295 |
| SR2+ | | | | | | | | | | | | | |
| Top Level | 1 | -0.03022 | -0.3197 | | | | | | | -0.1817 | -0.7627 | | |
| Application Level | | -0.03022 | -0.3197 | | | | | | | -0.1817 | -0.7627 | | |
| Ratio to IVTT/VOT ($/hr) | | 1 | 10.5791 | | | | | | | $ 9.98 | 25.2383 | | |
| Walk | | | | | | | | | | | | | |
| Top Level | 1 | | | -0.07525 | | | | | | | | 0.493 | |
| Application Level | | | | -0.07525 | | | | | | | | 0.493 | |
| Ratio to IVTT/VOT ($/hr) | | | | | | | | | | | | -6.5515 | |
| Walk-Transit | | | | | | | | | | | | | |
| Top Level | 1 | -0.03022 | | -0.07525 | -0.08333 | -0.08333 | | -0.03022 | -0.1817 | | | | |
| Application Level | | -0.03022 | | -0.07525 | -0.08333 | -0.08333 | | -0.03022 | -0.1817 | | | | |
| Ratio to IVTT/VOT ($/hr) | | 1 | | 2.49007 | 2.75745 | 2.75745 | | 1 | $ 9.98 | | | | |
| Drive-Transit | | | | | | | | | | | | | |
| Top Level | 1 | -0.03022 | -0.3197 | -0.07525 | -0.08333 | -0.08333 | -0.07555 | -0.03022 | -0.1817 | -0.1817 | | | |
| Application Level | | -0.03022 | -0.3197 | -0.07525 | -0.08333 | -0.08333 | -0.07555 | -0.03022 | -0.1817 | -0.1817 | | | |
| Ratio to IVTT/VOT ($/hr) | | 1 | 10.5791 | 2.49007 | 2.75745 | 2.75745 | 2.5 | 1 | $ 9.98 | $ 9.98 | | | |