

## **Appendix 3.2-C**

# **Methodology and Assumptions of Central Transportation Planning Staff Regional Travel Demand Modeling**

**METHODOLOGY AND ASSUMPTIONS OF  
CENTRAL TRANSPORTATION PLANNING STAFF  
REGIONAL TRAVEL DEMAND MODELING**

**South Coast Rail Project**

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## INTRODUCTION

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The regional travel model set of the Central Transportation Planning Staff (CTPS) is based on procedures that have evolved over many years at CTPS. It follows the traditional four-step travel-modeling process of trip generation, trip distribution, mode choice, and trip assignment and is implemented in the EMME software package. This modeling process is employed to estimate present and future daily transit ridership and daily highway traffic volumes, primarily on the basis of demography and the characteristics of the transportation network. The model set simulates travel on the entire eastern Massachusetts transit and highway systems. When the model set is estimating future travel, the inputs include forecasts of demography and projections of transit and highway improvements.

The CTPS regional travel model set was expanded and customized for the purposes of the South Coast Rail (SCR) project. However, the resulting model set is very similar to the standard regional travel model set used by CTPS. The methodologies, procedures, and theories underlying the trip generation, trip distribution, mode-choice, and trip assignment sub-models of the standard CTPS model set are used by the SCR model set. The two model sets also use the same software, and there are other similarities as well.

The most notable modification of the standard CTPS model to produce the SCR model was the addition of 191 transportation analysis zones and the associated expansion of the highway and transit networks. The SCR model set thus also includes transit services not included in the standard model set. For future years, the operating plan for proposed SCR build transit services was provided by Vanasse Hangen Brustlin, Inc. (included as an appendix to the present document). Where possible, the expanded zone system and networks included in the SCR model set were developed from a statewide travel model maintained by the Executive Office of Transportation and Public Works (EOT) (the EOT model itself was not used for the SCR forecasting primarily because it did not include a mode choice sub-model). Other differences between the standard CTPS model and the SCR model are found in some of the inputs needed for the various sub-models; in most cases, these differences stem from the addition of zones and the associated enlargement of the highway and transit networks.

This memorandum describes in detail the model set developed for the SCR project. The model set will generally be referred to as “the model,” for simplicity’s sake. The organization of this memorandum is:

### Description of the Model

- Overview of the Four Steps
- Notable Features of the Model
- Model Structures and Inputs

### The Four Steps of the Travel Demand Modeling Process

- Trip Generation
- Trip Distribution
- Mode Choice
- Trip Assignment

### Air Quality Analysis

## DESCRIPTION OF THE MODEL

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### OVERVIEW OF THE FOUR STEPS

In the first step, trip generation, the total number of trips generated by residents of the 182 municipalities constituting the modeled area were calculated using demographic data. Similarly, the number of trips attracted to different types of land use, such as employment centers, schools, hospitals, shopping centers, etc., were estimated using land use data and trip generation rates obtained from travel surveys. This information on trips generated and attracted was produced at the level of disaggregated geographic areas known as transportation analysis zones (TAZs). All calculations were performed at the TAZ level.

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

Once the total number of trips between each pair of TAZs was determined, the mode choice step of the model (step three) allocated the total trips among the available modes of travel. The available modes of travel were walk, auto (single-occupant vehicle [SOV] and carpool), and transit (subdivided by access mode: walking to transit or driving to transit). To determine the proportion of trips to allocate to each mode, the model took into account the travel times, number of transfers required, parking availability, and costs associated with each option. Other variables, such as auto ownership and household size, were also included in the model.

After estimating the number of trips by mode for all possible TAZ combinations, in trip assignment (the fourth and final step) the model assigned trips to their respective specific routes. This was necessary because there is often more than one highway route or transit service between two TAZs.

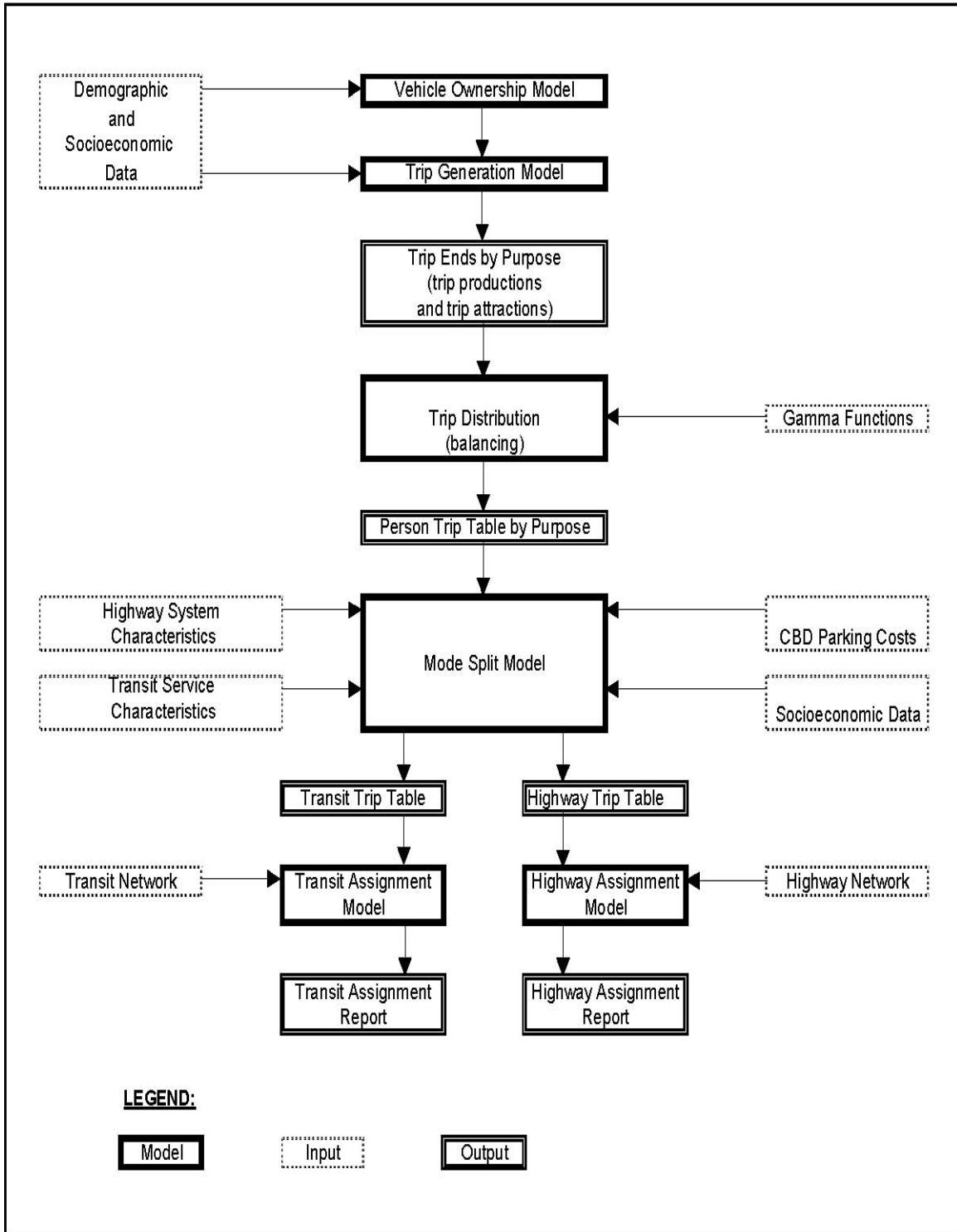
Various reports showing the transit ridership on different transit modes (including the specific ridership on each of the existing and proposed individual transit lines) and traffic volumes on the highway network were produced as needed. A schematic representation of the modeling process is shown in Figure 1.

### NOTABLE FEATURES OF THE MODEL

The model developed for the South Coast Rail Study uses the best component models, networks, and input data available to CTPS at this time. Some of the notable features of the model are as follows:

- It incorporates both motorized and non-motorized trips.
- It simulates transit and highway travel during four time periods of a typical weekday.
- The trip generation, trip distribution, and mode choice components are well calibrated
- EMME 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.

**FIGURE 1**  
**The Four-Step Demand Modeling Process**



- The procedure that estimates air quality benefits is sophisticated and well integrated within the main model.

## **MODEL STRUCTURES AND INPUTS**

### **Modeled Area**

The model developed for the South Coast Rail project encompasses the 182 cities and towns in eastern Massachusetts indicated in Figure 2, which include the 101 municipalities of the Boston Region Metropolitan Planning Organization area and 81 additional communities. The figure also shows the boundaries of a core area and four 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 for the South Coast Rail project is divided into 2,918 internal TAZs. There are also 117 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 network: transit and highway. Both are integrated in EMME. The highway network comprises express highways, principal and minor arterials, and local roadways. The transit network comprises commuter rail lines, rapid transit lines, and bus lines (MBTA and private carriers). The model contains service frequency (i.e., how often trains and buses run), routing, travel time, and fares for all lines.

- *Highway Network:* The regional highway network contains in excess of 100,000 links and 24,000 nodes. Like any highway 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 (HOVs) or closed to trucks.
- *Transit Network:* The transit network represents all MBTA bus and rail services in eastern Massachusetts, as well as private express buses, local transit agency bus routes, and Boston Harbor ferries. Included among the local transit agency bus routes are all of the Southeastern Regional Transit Authority (SRTA) bus routes. The private express bus services include existing DATTCO and Bloom buses between the South Coast study area and Boston. Most-likely travel paths are built through the network and afterwards 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.

## Major Data Inputs

CTPS's travel model underwent a major revision in 1993, and several important data sources were used in that revision. Those and other major data items underlying the model are as follows:

- *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 models for trip generation, auto ownership, trip distribution, and mode choice.
- *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 were combined into a single, unified regional employment database that was updated to the base year 2000 based on employment data from the Department of Employment and Training and on extensive research by CTPS.
- *2000 U.S. Census:* Various census files were used in model estimation and calibration processes. In particular, Census Journey to Work information was incorporated into the model at several stages of model development for the South Coast Rail project.
- *Ground Counts:* Transit ridership and highway traffic volume data representing early 1990s conditions were amassed into a database and used to calibrate the travel sub-models. Updated counts and volumes have been used for model validation.

## Analysis Year

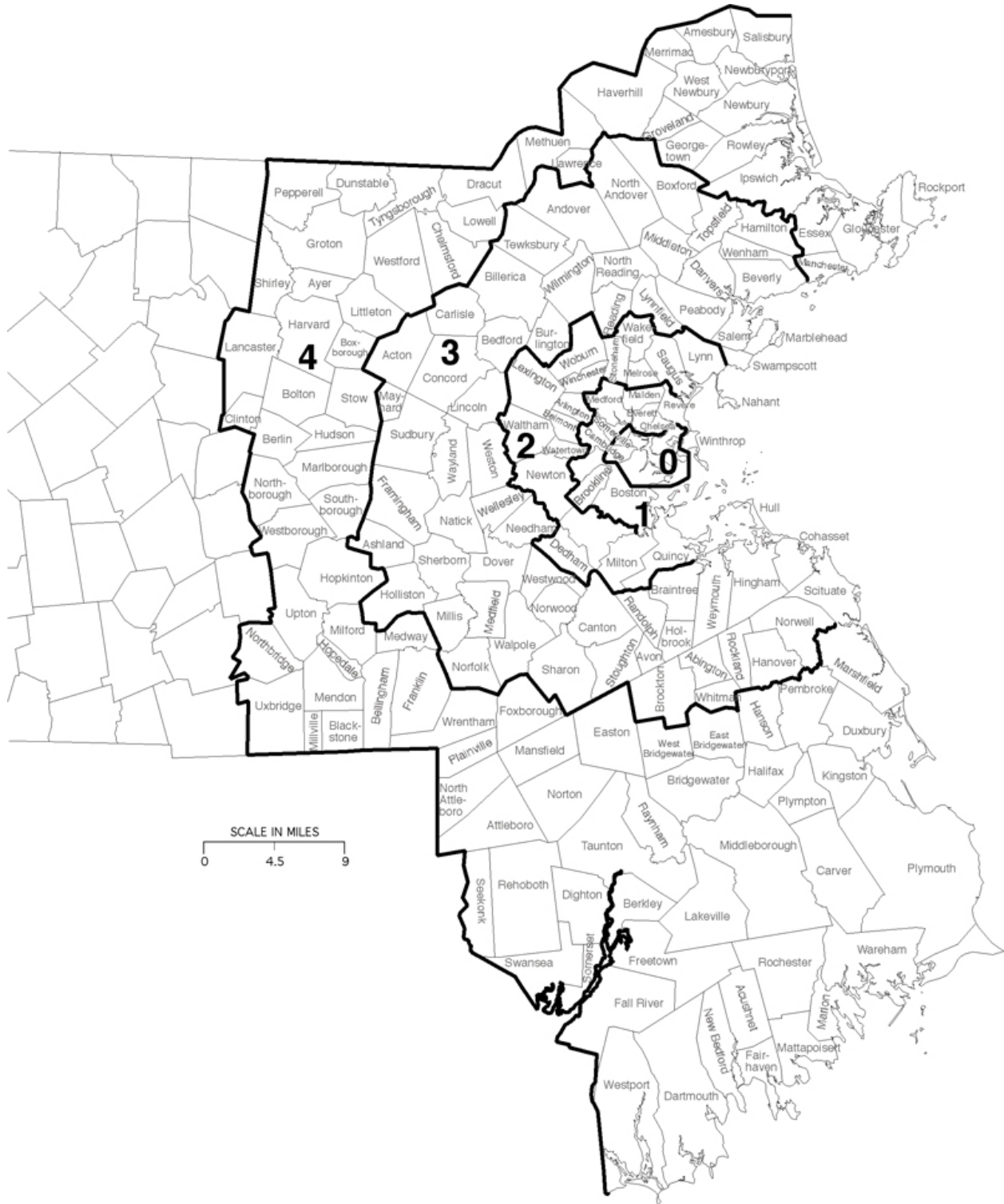
The base year is 2000 and the horizon year is 2030.

## Time-of-Day Considerations

The mode choice and transit assignment steps of the modeling process are conducted on the basis of time periods. The four time periods modeled are an AM peak period, a midday period, a PM peak period, and a nighttime period. The trip generation model, however, is based on daily trips. The trip distribution model considers two time periods: peak and off-peak.

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 and transit person trips created by the mode choice model are converted from production/attraction format to an origin/destination format, based upon the 1991 Household Travel Survey, prior to network assignment.

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





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 reflect 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**

<b>Time Period</b>	<b>Highway Vehicle Trips</b>	<b>Transit Person Trips</b>
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

### **Population, 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 estimates are based. The forecasts for the region were developed by combining household and employment predictions independently produced by the seven regional planning agencies/metropolitan planning organizations (RPAs/MPOs) in eastern Massachusetts: the Central Massachusetts Regional Planning Commission (CMRPC), Merrimack Valley Planning Commission (MVPC), Metropolitan Area Planning Council (MAPC), Montachusett Regional Planning Commission (MRPC), Northern Middlesex Council of Governments (NMCOG), Old Colony Planning Council (OCPC), and Southeastern Regional Planning and Economic Development District (SRPEDD).

Forecasts for the 101 cities and towns that make up the Boston Region MPO area were developed by MAPC based on its MetroFuture land use scenario. Forecasts for the 63 communities in the model belonging to RPAs/MPOs other than the Boston Region MPO were developed in a slightly different fashion. Each RPA/MPO independently maintains its own travel demand model, TAZ system, base-year estimates, and future-year forecasts. However, the Boston Region MPO’s year 2000 base-year data have long been widely accepted as the most refined and detailed data set for the year 2000 for eastern Massachusetts, and significant faith has been invested in this data set in other studies, past and ongoing. Therefore, in the present modeling effort, future-year forecasts for these 63 communities pivoted off this vetted and reliable data but allowed for the growth projections envisioned by the individual RPA/MPO. This was done by adding the absolute changes in population and households predicted by the RPA/MPOs for the 63 communities to the Boston Region MPO’s base-year estimates.

Employment forecasts were developed differently but also used the absolute change projected by the RPA/MPO and also pivoted off the Boston Region MPO’s year 2000 data. The future-year Boston Region MPO distribution of employment by TAZ and by employment sector was applied to the RPA/MPO’s absolute change at the community level. The resulting change was then added to the base-year Boston Region MPO employment data to produce the future-year

forecasts. This hybrid approach took advantage of the accuracy of the Boston Region MPO's widely accepted demographic data sets while still capturing and respecting the growth expressed and projected by the individual RPAs/MPOs.

For the 18 SRPEDD communities not within the boundaries of the standard CTPS regional travel demand model set, SRPEDD land use forecasts and base year estimates of population, households, and employment were used. These SRPEDD forecasts were constrained by town-level control totals developed by the Executive Office of Transportation and Public Works (EOT). In some instances SRPEDD re-allocated demographics within one of the given 18 communities, but in all instances the EOT town-level control totals were maintained.

## **CALIBRATION OF THE MODEL**

Calibration is the process in which model results or outputs are compared with observed data in order to assess the accuracy of a model. The model set used in the SCR study underwent an extensive calibration process. For the base year, the trip distribution, mode choice, and trip assignment sub-models of the SCR model set were run through an iterative feedback loop dozens of times to estimate the most accurate model parameters possible. This process constitutes a feedback loop in that certain outputs from each sub-model are in turn used as an input into another sub-model. For instance, highway and transit skims are an output of the assignment sub-model but are also an input into the trip distribution and mode choice sub-models. An accurate model can thus be obtained by iteratively running this chain of sub-models.

Within this iterative calibration process, particular attention was paid to the trip distribution sub-model calibration. The trip tables used and produced in trip distribution were scrutinized to ensure they were consistent with observed data. The observed data to which the trip distribution sub-model was calibrated were origin-destination and trip-length frequency data from the regional Household Travel Survey and census Journey to Work data sets. The parameters of the trip distribution sub-model were estimated so that the sub-model would distribute trips in a way that closely mimics the actual pattern of how trips are distributed in reality.

Mode choice sub-model parameters were also calibrated within the iterative feedback loop. Certain mode choice coefficients were estimated so that mode shares produced by the sub-model matched observed mode shares found in the area being represented. The observed data to which the mode choice sub-model was calibrated were from the Household Travel Survey.

Within the iterative calibration process, the final product—highway and transit volumes loaded onto the network—was also given close attention. The observed data to which the highway and transit assignment results were calibrated included observed highway counts, transit counts, and transit information from specific transit project studies.

Highway assignment results were compared to observed road counts along several screenlines and at several different locations on major area highways. The locations of these counts are given in Table 2.

**TABLE 2  
Screenline and Roadway Calibration Locations**

**North-South Screenline**

Route 152	Attleboro
Oak Hill Avenue	
Route 118	
Tremont Street	Taunton
Route 44	
Route 138	
Berkley Street	
Route 24	
Route 79	
Pierce Avenue	Lakeville
Howland Road	
Route 140	
County Street	
Route 18	
Route 105	Middleborough
South Street	
Route 28	
Route 58	
I-495	Plymouth
Wareham Street	
Wareham Road	
Bourne Road	
Herring Run	
Route 3	
Route 3A	

**External Western Screenline**

Route 15	Seekonk
Route 152	
Route 114	
Route 44	
I-195	
Route 6	
Route 114	Swansea
Route 136	
Route 103	

**External Southern Screenline**

Route 138	Fall River
Route 24	
Route 81	
Route 177	Westport

**External Cape Screenline**

Route 28	Plymouth
Route 6	

**Roadway Calibration Locations**

Route 3 South	South Plymouth
	North Plymouth
	Marshfield
	Norwell
	North Weymouth

I-195	Swansea
	Dartmouth
	Marion
Route 24	Freetown
Route 140	New Bedford

Route 44	Seekonk
	Rehoboth
	West Taunton
	East Taunton
	West Middleborough

I-95	North of I-295
	North of Route 140
	South of Route 1
	South of Neponset Street

I-495	West of I-95
	East of Route 140
	West of Route 24
	East of Route 24
	Lakeville
	East of I-195

Transit assignment results were scrutinized at more than one level. Transit ridership was calibrated to systemwide ridership statistics. Particular attention was also paid to existing commuter rail stations in the study area on the Providence and Middleborough/Lakeville lines as well as to the existing private bus lines from Boston to New Bedford, Taunton, and Fall River. Modeling of ridership on the local bus service provided by the SRTA was calibrated to passenger counts conducted by CTPS.

## **THE FOUR STEPS OF THE TRAVEL DEMAND MODELING PROCESS**

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### **TRIP GENERATION**

The first step in the travel forecasting process is performed by the model set's trip generation model. This model uses socioeconomic characteristics of the region's population and information about the region's transportation infrastructure, transportation services, and geography to predict the amounts of travel that will be produced by and attracted to each of the TAZs within the region.

The trip generation model is composed of seven parts:

- Base-year detailed inputs
- Future-year inputs
- Estimation of base-year detailed input requirements for future years
- Estimation of disaggregate socioeconomic characteristics
- Estimation of vehicle ownership
- Estimation of trip productions and attractions
- Balancing of trip productions and attractions

A description of each of these parts is presented below.

#### **Base-Year Inputs**

The base-year inputs required for the trip generation model are presented in Table 3.

#### **Future-Year Inputs**

The future-year inputs required for the trip generation model, some of which are the same as for the base year, are:

- Total TAZ households
- Total TAZ population
- Total TAZ group quarters population
- Total community population by age
- TAZ employment in basic industries
- TAZ retail trade employment

**TABLE 3**  
**Trip Generation Model: Base-Year Input Requirements**

<b>Data</b>	<b>Source</b>	<b>Geographic Level</b>
Population	2000 U.S. census	TAZ (census block)
Group Quarters Population	2000 U.S. census	TAZ (census block)
Household Size, Income, Workers, Vehicles	2000 U.S. census	TAZ (census block)
Population Age	2000 U.S. census	City or town
Basic, Retail, Service Employment	2000 CTPS estimates	TAZ
Public K-12 Employment	2000 CTPS estimates	TAZ
Private K-12 Employment	2000 CTPS estimates	TAZ
College Employment	2000 CTPS estimates	TAZ
Resident Workers	2000 U.S. census	TAZ (census block group)
Dorm Population	2000 U.S. census	TAZ (census block)
Labor Participation Rate by Age Group	Bureau of the Census	Region
Land Area	CTPS regional database	TAZ
Geographical Ring	CTPS regional database	TAZ
Public Use Microdata Areas	CTPS regional database	Public Use Microdata Areas
External Trip Productions and Attractions	1991 External Survey, 2000 U.S. Census	External station
External Growth Factors	RPA and CTPS estimates	External station
External Growth Factors	RPA forecasts	External station
Transit Walk Access Factor	Transit network	TAZ
External Attraction and Production Terminal Times	Trip distribution model	External station

- TAZ employment in service industries
- Regional labor participation rates
- External trip production and attraction growth factors
- Transit walk-access factors

### **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 are listed below. A description of how future-year estimations for these variables are made follows the list.

- Households by household size
- Households by income quartile
- Resident workers
- Households by workers per household
- School employment (K-12 and college)
- Dorm population
- External person trips
- 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 distribution of future-year households by household size is estimated by the following procedure.

First, the future-year households are distributed among the household size categories 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 person. This probability of changing is set equal to the extent needed to match the forecasted change in household size, and the resulting distribution of households by household size is used for the future-year scenario.

As an example, suppose that in the base year the numbers of 1-person, 2-person, 3-person, 4-person, 5-person, and 6+-person households are, respectively, 100, 200, 50, 25, 10, and 5, with a total household population of 835. This represents an average household size of 2.141. If there were 780 future-year households, they would initially be distributed as 200, 400, 100, 50, 20, and 10 1-person, 2-person, 3-person, 4-person, 5-person, and 6+-person households, respectively.

However, if the future-year average household size were 2.000, then the households with 2 or more persons would have a 19 percent  $[(2.141 - 2) * 780/580]$  probability of dropping in size by one. The resulting distribution would thus be estimated as follows:

276 1-person households  $[200 + (.19 * 400)]$ ,  
 343 2-person households  $[400 - (.19 * 400) + (.19 * 100)]$ ,

90.5 3-person households [ $100 - (.19 * 100) + (.19 * 50)$ ],  
44.3 4-person households [ $50 - (.19 * 50) + (.19 * 20)$ ],  
and 26.2 5+-person households [ $20 - (.19*20) + 10$ ].

In the case of TAZs with no households in the base year, the proportional distribution of households by household size at the community level is used for the base year in these calculations.

### *Household Income*

The future-year distribution of households by household income quartile is estimated by assuming that the proportional distribution of households by income quartile remains constant within each TAZ. In the case of TAZs with no households in the base year, the proportional distribution of households by household income at the community level is used for the base year.

### *Resident Workers per Household*

The change in the number of resident workers at the community level is obtained by combining base-year and future-year estimates of over-age-15 population and labor force participation by age cohort. Dividing the base-year and future-year estimates of community-level resident workers by the base-year and future-year numbers of households in the community, respectively, produces estimates of the base-year and future-year average workers per household. All of the TAZs within each community are assumed to have the proportional change in workers per household implied by these base-year and future-year community-level estimates. Multiplying the resultant estimate of resident workers per household by the forecasted number of households yields the forecasted number of resident workers by TAZ.

This estimation method (see Table 4) may be described via the following example. Assume that a community's 2000 and 2010 populations are distributed by age as follows: 1,000 and 1,200, 10,000 and 11,000, 2,000 and 2,500, and 500 and 600, respectively, in the 16-24, 25-54, 55-64, and 65+ age ranges. If the applicable labor force participation rates are applied, the estimated numbers of community resident workers become 10,317 and 11,785 for 2000 and 2010, respectively. If the estimated numbers of community households were 5,500 and 6,000 for 2000 and 2010, respectively, the community average workers per household for 2000 and 2010 would be 1.88 and 1.96, respectively. As 1.96 is 4.3% greater than 1.88, all of the TAZs in that community would be assumed to have a 4.3% increase in workers per household between 2000 and 2010.

**TABLE 4**  
**Labor Force Participation Rates**

<b>Age</b>	<b>2000</b>	<b>2010</b>	<b>2025</b>	<b>2030</b>
16-24	65.9%	63.9%	63.4%	63.4%
25-54	84.1%	84.7%	85.1%	85.0%
55-64	59.2%	64.4%	63.6%	63.7%
65+	12.8%	15.2%	15.6%	14.5%

*Household Workers*

The future-year number of households per TAZ within each category of number of workers per household is estimated by using workers-per-household distribution curves developed by CTPS from the 1990 U.S. census. These curves, summarized in Table 5 below, indicate a default percentage distribution of households for the base-year and future-year TAZ estimates of average workers per household. The proportional changes in the default number of households within each category of workers 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. The average number of workers per household at the community level is used for the base year in TAZs with no households in the base year.

For example, if the average number of workers per household changes from 1.7 to 1.8, the default distribution of households among the categories 0-worker, 1-worker, 2-worker, and 3+-worker would change from 7%, 32%, 45%, and 16% to 5%, 29%, 47%, and 19% households, respectively. If the actual base-year distribution of households among those categories is 8%, 31%, 44%, and 17%, the changes in the default distributions indicates a future-year distribution of households of 6%, 28%, 46%, and 20% 0-worker, 1-worker, 2-worker, and 3+-worker households, respectively.

*School Employment*

- K-12

The level of employment in schools providing education up to the 12<sup>th</sup> grade is assumed to be proportional to the number of community residents of ages 5-19.

- College

The level of employment at all colleges and technical schools within the region is assumed to be proportional to the number of regional residents of ages 20-24.



**TABLE 5**  
**Workers per Household Diversion Curves**

Avg. Workers per HH	Households by Number of Workers				Total
	0	1	2	3+	
<=.45	58%	40%	2%	0%	100%
.45 - .55	52%	46%	2%	0%	100%
.55 - .65	47%	46%	6%	1%	100%
.65 - .75	43%	46%	10%	1%	100%
.75 - .85	38%	46%	13%	3%	100%
.85 - .95	34%	46%	16%	4%	100%
.95 - 1.05	30%	45%	20%	5%	100%
1.05 - 1.65	65% - (35% * Avg)	60% - (16% * Avg)	(36% * Avg) - 15%	(15% * Avg) - 10%	100%
1.65 - 1.75	7%	32%	45%	16%	100%
1.75 - 1.85	5%	29%	47%	19%	100%
1.85 - 1.95	4%	26%	48%	22%	100%
1.95 - 2.05	3%	22%	48%	27%	100%
2.05 - 2.15	2%	18%	49%	31%	100%
2.15 - 2.25	1%	14%	49%	36%	100%
2.25 - 2.35	1%	10%	49%	40%	100%
2.35 - 2.45	1%	4%	50%	45%	100%
2.45 - 2.55	1%	4%	50%	45%	100%
> 2.55	0%	5%	50%	45%	100%

*Dorm Population*

The dorm population within a TAZ is assumed to be proportional to the total group quarters population within a TAZ.

*External Person Trips*

Base-year external person trips are factored up by forecasts of vehicle volumes at the external stations based upon the MassHighway statewide travel forecasting model.

*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. An alternative estimate of the production and attraction terminal times for each TAZ is based on household and employment density ranges. For regional modeling, the

larger of the two estimates is assigned to a TAZ. Several TAZs with regionally unique characteristics (locations of major generators such as airports 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 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 U.S. census at the subregional level, such distributions at the TAZ level are estimated through iterative proportional fitting techniques. Using the appropriate subregional matrix as a seed, the cell values are adjusted through 10 iterations to match row and column totals to the estimated TAZ-level totals in order to produce an estimated three-way distribution of households for each TAZ.

### **Estimation of Vehicle Ownership**

Base-year households are distributed by vehicle ownership based on data from the 2000 U.S. census. The distribution of future-scenario households by vehicle ownership is estimated through the application of a set of models developed by CTPS.

The CTPS vehicle ownership model was estimated as a set of four multinomial logit disaggregate choice models, one for each of four income categories, in which the decision maker was the household unit and the set of alternatives was the ownership, by the household, of 0, 1, 2, or 3-or-more vehicles. In this model, households were segmented into four income categories because of the belief that income is the most significant variable in vehicle-ownership choice. Other variables included in the model included household size, workers per household, household density, employment density, household location, and transit walk-access factors. The data set used to estimate this model contained 3,504 observations. Once estimated, the model was validated to observed vehicle ownership data. The models, one for each household income quartile, are presented in Table 6.

### **Estimation of Trip Productions and Attractions**

The number of trip productions and trip attractions within a TAZ are 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. The home-based trip production models are presented in Table 7, while the non-home-based trip production and trip attraction models are presented in Table 8.

**TABLE 6**  
**Summary of Auto Ownership Model**

	Constant	HH Size	Workers per HH	HHs per Acre	Employ per Acre	High-Density	Low-Density	Ring01	Transit Walk-Accessibility
<b>Low-Income Household Model</b>									
<b>0 Vehicles</b>	-0.0474	-0.1692	-0.1312	0.0239		0.7136			
<b>1 Vehicle</b>									
<b>2 Vehicles</b>	-3.139	0.6182	0.4414	-0.0424					
<b>3+ Vehicles</b>	-5.074	0.7968	0.6927	-0.2232					
<b>Medium-Low-Income Household Model</b>									
<b>0 Vehicles</b>	-1.573	-0.1874	-0.3417	0.05		0.5716		0.5392	
<b>1 Vehicle</b>									
<b>2 Vehicles</b>	-1.745	0.5202	0.4279	-0.0627	-0.0334				-0.0056
<b>3+ Vehicles</b>	-5.101	0.7371	1.112	-0.0627	-0.0693				
<b>Medium-High-Income Household Model</b>									
<b>0 Vehicles</b>	-2.63			0.0459		0.7704			
<b>1 Vehicle</b>									
<b>2 Vehicles</b>	-1.223	0.6609	0.2377	-0.0391			0.4026	-0.5962	-0.0054
<b>3+ Vehicles</b>	-4.572	0.7899	1.289	-0.0779				-1.223	-0.0073
<b>High-Income Household Model</b>									
<b>0 Vehicles</b>	-2.793			0.0349					
<b>1 Vehicle</b>									
<b>2 Vehicles</b>	0.5049	0.3475	0.2688	-0.06	-0.0154				-0.0074
<b>3+ Vehicles</b>	-3.807	0.5717	1.628	-0.136	-0.0468				-0.0077

*High-Density = 1 if HH/acre > 6 or Employ/acre > 7*

*Low-Density = 1 if HH/acre < 0.5 and Employ/acre < 0.7*

*Ring01 = 1 if TAZ is in Ring 0 or Ring 1*

*Transit Walk-Accessibility = Portion of TAZ within walk-access distance of transit service*

**TABLE 7**  
**Home-Based Trip Production Rate Models**

<b>Home-Based Work Trip Production Rates</b>				
<b>Workers per HH</b>	<b>HH Size</b>	<b>Vehicles per HH</b>		
		<b>0</b>	<b>1</b>	<b>2+</b>
1	1	0.94	1.17	1.11
1	2	1.01	1.23	1.18
1	3	1.15	1.38	1.32
1	4	1.48	1.7	1.65
1	5+	1.56	1.78	1.71
2	2	2.47	2.66	2.47
2	3	2.64	2.81	2.61
2	4	2.68	2.84	2.64
2	5+	2.83	2.99	2.79
3+	3	2.72	3.14	3.68
3+	4	2.75	4.02	4.55
3+	5+	2.88	4.15	4.68

<b>Home-Based Personal Business Trip Production Rates</b>					
<b>Workers per HH</b>	<b>HH Size</b>	<b>Vehicles per HH</b>			
		<b>0</b>	<b>1</b>	<b>2</b>	<b>3+</b>
0	1	1.19	1.95	2.11	2.87
0	2	2.91	3.32	3.5	4.24
0	3	3.29	3.7	3.88	4.62
0	4	4.16	4.58	4.73	5.49
0	5+	1.56	4.71	4.87	5.63
1	1	0.5	1.01	1.2	1.27
1	2	1.85	2.35	2.55	2.62
1	3	2.25	2.82	3.04	3.11
1	4	2.52	2.91	3.08	3.13
1	5+	2.55	2.93	3.15	3.23
2	2	1.04	1.5	1.63	2.12
2	3	1.4	1.87	1.99	2.48
2	4	2.37	2.83	2.95	3.45
2	5+	2.44	2.91	3.03	3.52
3+	3	1.43	1.96	2.24	2.49
3+	4	2	2.75	3.14	3.49
3+	5+	2.34	3.2	3.67	4.08

<b>HB Work-Related Trip Production Rates</b>			
<b>HH Size</b>	<b>Workers per HH</b>		
	<b>1</b>	<b>2</b>	<b>3+</b>
1	0.12		
2	0.1	0.18	
3	0.1	0.2	0.28
4	0.18	0.23	0.35
5+	0.21	0.29	0.41

**TABLE 8**  
**Trip Attraction Rates and Non-Home-Based Trip Production Rates**

	Households	Basic Employment	Retail Employment	Service Employment		
				College	K-12	Other
<i>Production Rate Models</i>						
Non-Home-Based Work	0.07	0.47	1.78	1.86	0.93	0.93
Non-Home-Based Other	0.57		1.74	2.49	0.28	0.28
<i>Attraction Rate Models</i>						
Home-Based Work		1.42	1.64	1.23	1.23	1.23
Home-Based Work-Related		0.06	0.35	0.27	0.08	0.08
Home-Based Personal Business	1.25		4.17			
Home-Based Social/Recreational	1.28		1.34	1.13		
Home-Based School				3.3	9.25	
Home-Based Pick-Up/Drop-Off	0.13	0.04	0.04	0.04	4.25	0.04
Non-Home-Based Work	0.11	0.32	2.36	1.85	0.79	0.79
Non-Home-Based Other	0.59		1.91	2.01	0.22	0.22

### **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.

For most trip purposes, the number of regional attractions is the least reliable estimate. As a result, 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.

However, future regional employment (the determinant of home-based work [HBW] trip regional attractions) is forecasted, so the numbers of future external HBW productions and attractions are less reliable. The model assumes that the number of external HBW productions will satisfy the forecasted employment within the region, so the HBW external productions are set equal to the difference between the total HBW attractions and the regional HBW productions.

The following changes were thus made as part of the balancing procedure:

- Regional HBW attractions are adjusted to match the base-year ratio of total regional HBW attractions to total regional HBW productions with the ratio from the 2000 U.S. census Journey to Work data (1.077).
- External HBW attractions are adjusted to match the base-year ratio of total external HBW attractions to total regional HBW productions with the ratio from the 2000 U.S. census Journey to Work data (.0442).

- External HBW productions are set equal to the difference between the grand total of HBW attractions and the regional HBW productions.

## **TRIP DISTRIBUTION**

The trip distribution model performs the second step in the travel forecasting process. It combines the estimated trip productions and trip attractions prepared by the trip generation model into: an interregional vehicle trip table and an intraregional pick-up/drop-off vehicle trip table to be used as input into the highway assignment model; and intraregional person trip tables to be used as inputs into the mode choice model.

The trip distribution model is made up of three components: a set of internal-external trip distribution models and two sets of intraregional trip distribution models (one for peak travel periods and the other for non-peak travel periods). An overview of the model is presented below.

### **Internal-External Trip Distribution**

Internal-external trip distribution refers to a process in which all internal and external average weekday (AWD) trip ends (trip productions and attractions) are combined into trips using AWD highway impedances, but only the trips with one end in an internal zone and the other end in an external zone are retained. The resultant internal-external trip tables are used as inputs to the highway assignment model. The remaining trip ends are used as inputs to the intra-regional trip distribution model.

The model includes a separate process for each of seven trip purposes: home-based work, home-based personal business, home-based social/recreational, home-based school, home-based pick-up/drop-off, non-home-based work, and non-home-based other. The process undertaken for each purpose consists of the following five steps:

- Convert highway travel times from time period origin-destination format to AWD production-attraction format
- Apply gamma functions to create an initial trip table estimate
- Initiate a three-dimensional balancing process, adjusting the initial trip table to match trip productions, trip attractions, and a trip-length frequency distribution
- Create internal/external vehicular trip tables
- Create intra-regional person trip table productions and attractions

Each of these steps is described below.

#### *Conversion of Highway Travel Times*

Estimates of highway travel times are prepared using the highway assignment model on an origin-destination basis for each time period. In order to use these with the trip productions and attractions from the trip generation model, the highway travel time estimates produced by the

highway assignment are adjusted for each trip purpose by temporal directional factors for each trip purpose from the latest regional household travel survey.

*Applying Gamma Functions*

Gamma functions are estimated using base-year highway travel time estimates and survey trip tables to produce an initial estimate of a model-based trip table. These functions provide an estimate of the number of trips within each cell of the trip table based upon linear regression fitting.

The resultant trip table is referred to as the seed trip table. A trip length frequency distribution is imposed upon the seed trip table by dividing the table into classes of zone pairs. The zone pairs within each class connect a common pair of districts (forming an “interchange”) and fall within a designated range of trip lengths (or “class”). A separate gamma function is used for each interchange. The number of interchanges and classes used for each trip purpose is presented in Table 9.

**TABLE 9  
Number of Interchanges and Classes Used for Each Trip Purpose**

Trip Purpose	Internal-External		Intra-Regional Peak		Intra-Regional Non-Peak	
	Interchanges	Classes	Interchanges	Classes	Interchanges	Classes
HBW	36	250	36	250	36	250
HBPB	36	250	34	228	36	246
HBSR	35	247	33	227	36	244
HBSC	24	229	16	218	16	224
HBPB	25	241	4	49	4	51
NHBW	36	250	36	250	36	249
NHBO	25	244	33	226	36	249

*Three-Dimensional Balancing*

The seed trip table is adjusted through an iterative process in order to match the trip table subtotals as closely as possible to the estimated trip productions, trip attractions, and trip length frequency distribution. Each iteration consists of adjusting all the cells within a dimension (row, column, or class) by the factor needed to match the sum of that dimension to the estimated subtotal in that dimension (productions for row, attractions for column, trip length range trips for class) and then performing the same calculations for the other two dimensions. Since there is more confidence in trip production estimates than in the trip attraction or trip length frequency estimates, the iterative process ends with an exact matching of the trip table production totals to the input trip productions for each purpose.

### *Internal-External Trip Tables*

The portions of the resultant trip table connecting external stations and regional TAZs are saved and adjusted for use in the highway assignment model. Vehicle occupancy data from the latest external travel survey are used to convert the person trips to vehicle trips. Temporal and directional factors from the latest external travel survey are then used to convert the trips from one matrix of AWD trips from production zone to attraction zone to four matrices of time period (AM peak, midday, PM peak, and night) trips from origin zone to destination zone.

### *Intra-Regional Productions and Attractions*

The portions of the resultant trip table connecting regional TAZs are summed by TAZ of production and TAZ of attraction for use in the Intra-Regional Trip Distribution Model. Data from the latest household travel survey are used to split these trip production and trip attraction files into peak-period and non-peak-period files.

### **Intra-Regional Trip Distribution (Peak and Non-Peak)**

Intra-regional trip distribution refers to a process in which all peak-period and non-peak-period intra-regional trip ends are separately combined into trips using composite impedances from the mode choice model. The resultant peak and non-peak intra-regional trip tables are used as inputs to the mode choice model and highway assignment model (home-based pick-up/drop-off trips).

The model includes a separate process for each of seven trip purposes: home-based work, home-based personal business, home-based social/recreational, home-based school, home-based pick-up/drop-off, non-home-based work, and non-home-based other. Similar to the Internal-External Trip Distribution Model, the process undertaken for each purpose consists of the following three steps:

- Convert composite impedance estimates from time period to peak and non-peak format
- Apply gamma functions to create an initial trip table estimate
- Initiate a three-dimensional balancing process, adjusting the initial trip table to match trip productions, trip attractions, and a trip-length frequency distribution

The results of these steps are then processed to final form in the following two steps:

- Create pick-up/drop-off vehicular trip tables
- Create intra-regional person trip tables

The five steps are described below.

### *Conversion of Composite Impedances*

Estimates of purpose-specific composite impedances are prepared using the mode choice model for origin-destination TAZ pairs for each time period. In order to use these with the intra-



regional trip productions and attractions from the Internal-External Trip Distribution Model, the composite impedance estimates produced by the mode choice model are adjusted for production-attraction TAZ pairs for each trip purpose by temporal factors for each trip purpose from the latest regional household travel survey.

### *Applying Gamma Functions*

Gamma functions are estimated using base-year composite impedance estimates and trip tables to produce an initial estimate of a model-based trip table. These functions provide an estimate of the number of trips within each cell of the trip table based upon linear regression fitting.

The resultant trip table is referred to as the seed trip table. A trip length frequency distribution is imposed upon the seed trip table by dividing the table into classes of zone pairs. The zone pairs within each class connect a common pair of districts (forming an “interchange”) and fall within a designated range of trip lengths (or “class”). A separate gamma function is used for each interchange. The number of interchanges and classes used for each trip purpose is presented in Table 9 (above).

### *Three-Dimensional Balancing*

The seed trip table is adjusted through an iterative process to match the trip table subtotals as closely as possible to the estimated trip productions, trip attractions, and composite impedance range frequency distribution. This process is the same as the one used in the Internal-External Trip Distribution Model. Since there is more confidence in trip production estimates than in the trip attraction or trip length frequency estimates, the iterative process ends with an exact matching of the trip table production totals to the input trip productions for each purpose.

### *Pick-Up/Drop-Off Vehicular Trip Tables*

Since they are all assumed to be vehicular trips, the resultant trip tables for the home-based pick-up/drop-off purpose are converted directly to vehicular trip tables so that they can be used in the highway assignment model. Vehicle occupancy data from the latest household travel survey are used to convert the person trips to vehicle trips. Temporal and directional factors from the latest household travel survey are then used to convert the trips from matrices of peak period and non-peak period trips from production zone to attraction zone to matrices of time period (AM peak, midday, PM peak, and night) trips from origin zone to destination zone.

### *Intra-Regional Person Trip Tables*

The resultant trip tables for the other purposes are then prepared. Data from the latest household travel survey are used to split these peak-period and non-peak period files into AM peak, midday, PM peak, and night person trip tables. These trip tables are then used as inputs to the mode choice model.

## MODE CHOICE

### Overview

Mode choice is the third step in travel demand forecasting and in CTPS's regional travel demand model. It is the process in which the trips from distribution are split between the various available modes of the transportation network.

CTPS developed multinomial logit mode choice models by trip purpose using 1991 Household Travel Survey data, travel impedances obtained from highway and transit networks, 1990 and 2000 U.S. census data, and a variety of other data sources. The mode choice models estimate modal splits for four trip purposes: 1) home-based work and work-related (HBW); 2) home-based other (HBO), which includes home-based shopping, personal business, social, recreation, and other miscellaneous purposes; 3) home-based school (HBSC); and 4) non-home-based (NHB). These models have been calibrated and validated. The mode choice models are applied, by purpose, to the distributed trip tables that result from the trip distribution model.

The mode choice models split the trip purposes among six modes: 1) walk-access transit, 2) drive-access transit, 3) single-occupancy vehicles, 4) high-occupancy vehicles with two persons, 5) high-occupancy vehicles with three or more persons (for the HBW trip purpose only), and 6) a pure walk mode. Specific sub-mode selection (i.e., local bus, express bus, light rail, commuter rail, etc.) occurs during the transit assignment process.

The mode choice models estimate mode splits for intra-regional trips only (trips contained within the model boundaries). They estimate mode shares for both interzonal trips (from one zone to another zone) and intra-zonal trips (from and to the same zone); however, intra-zonal trips are only split between the walk and auto modes. Transit splits are not estimated for intra-zonal trips.

### Variables

The following are brief descriptions of the variables the mode choice models use to estimate mode splits:

*Nest coefficient:* Represents the degree of interactivity between the modes within the nest and other modes or nests. The value ranges between 0 and 1, with 1 indicating that transfers to and from other modes are as likely as transfers to and from modes within a nest. A value of 0 indicates there would be no transfer between the nest modes and other modes.

*In-vehicle travel time (IVTT):* Represents time spent in the modal vehicle during a given trip. For the shared-ride modes, in-vehicle and out-of-vehicle time are functions of drive-alone time. This variable is often considered in conjunction with value of time (VOT).

*Out-of-vehicle time:* Includes all walk, boarding, and wait time.

*Drive-access time:* Represents driving time between a trip end and a transit station parking lot.

*Terminal time:* Represents the time it takes to access a vehicle at the production end of a trip and the time it takes to get from a vehicle to a destination at the attraction end of a trip.

*Fare:* Represents the transit fare, in dollars, a transit rider will pay to use the system.

*Auto cost:* Represents auto operating and toll costs. Also included is one-half of any applicable parking costs (because such costs are calculated on the basis of a one-way trip.) Also, for shared-ride modes, total costs are divided by the appropriate auto occupancy.

*Household size:* Represents the number of persons per household. This estimate is obtained from the Trip Generation sub-model.

*Vehicles/person:* Represents the total number of vehicles per person in a household. Vehicles are forecasted for 2030 using the vehicle availability model described earlier.

*Population density:* Represents total population per acre.

*Percent transit origins/destinations:* Represents the AM peak period transit share of work trip ends within a TAZ, as computed by the home-based work mode-choice model.

## **The Four Trip Purposes**

### *Home-Based Work Model*

Home-based work (HBW) is the only trip purpose for which the mode choice models distinguish between two-person carpools (HOV2) and three-or-more-person carpools (HOV3+). The model specifications are shown in Table 10. Formerly, travel in HOV lanes was restricted to HOV3+ vehicles during peak hours. For the past several years, however, any two-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 made before selection of a particular transit mode. The transit coefficients are generic for both walk access (WAT) and drive access (DAT) and include coefficients 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 WAT fare includes the transit fare in dollars. For DAT, costs include the transit fare and half of any parking cost. Population density by traffic zone, in people per acre, is included in walk-access transit, and it is positively correlated: 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

**TABLE 10**  
**Home-Based Work Mode Choice Model Specifications**

	Nest Coeff	Impedance Variables									Socioeconomic Variables		
		IVTT	Terminal Time	Walk Time	Initial Wait	Transfer Wait	Auto Access	Boarding Time	Fare (\$)	Auto Cost (\$)	Population Density	Vehicles/Worker	HHId 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			
HOV2													
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
HOV3+													
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-Access 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-Access 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	

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 11. The model is similar to the HBW mode choice model, except for the following three differences. First, since there is only one shared-ride mode, HOV2+, household size is only a parameter for this one mode. Second, the vehicles per person in a household is used, as opposed to vehicles per worker. Finally, a distance dummy equal to one if the trip distance is less than a mile, zero otherwise, is 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.

#### *Non-Home-Based Model*

The non-home-based (NHB) model splits work trips and non-work trips. The model specifications are shown in Table 12. 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 that is SOV is a variable in the drive alone mode. The percentage is taken from the results of the HBW mode choice model 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.

#### *Home-Based School Model*

The home-based school (HBSC) model was re-estimated and restructured in 2004 to allow for compatibility of the HBSC purpose with the Federal Transit Administration's Summit program. The previous HBSC model had one nest—all motorized modes. The revised HBSC model has two nests—transit and highway. The revised HBSC model specifications are shown in Table 13.

### **Pre-Assignment Procedure**

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 format (except for NHB trips, where they are the same). This is done using factors from the 1991 Household Travel Survey.

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. Because the HBW HOV mode includes 2-person and 3-person-plus HOVs, the occupancy factor for the

**TABLE 11**  
**Home-Based Other Mode Choice Model Specifications**

	Nest Coeff	Impedance Variables								Socioeconomic Variables				
		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				
HOV2+														
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-Access 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-Access 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 12**  
**Non-Home-Based Work Mode Choice Model Specifications**

	Nest Coefficient	Impedance Variables								Socioeconomic Variables			
		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
HOV2+													
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-Access 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-Access 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			

**TABLE 13**  
**Home-Based School Mode Choice Model Specifications**

	Nest Coefficient	Impedance Variables							Population Density
		IVTT	Terminal Time	Walk Time	Wait Time	Drive Access Time	Fare (\$)	Auto Cost (\$)	
Drive Alone									
Top Level	0.5559	-0.0305	-0.0904					-0.1803	
Application Level		-0.0548	-0.1626					-0.3244	
Ratio to IVTT (\$/hr)		1.0000	2.9672					\$10.14	
HOV2+									
Top Level	0.5559	-0.0305	-0.0904					-0.1803	
Application Level		-0.0548	-0.1626					-0.3244	
Ratio to IVTT (\$/hr)		1.0000	2.9672					\$10.14	
Walk									
Top Level	1			-0.0791					
Application Level				-0.0791					
Ratio to IVTT (\$/hr)									
Walk-Access Transit									
Top Level	0.5559	-0.0305		-0.0791	-0.0791		-0.1803		0.0150
Application Level		-0.0548		-0.1423	-0.1423		-0.3244		0.0270
Ratio to IVTT (\$/hr)		1.0000		2.5967	2.5967		\$10.14		-0.4927
Drive-Access Transit									
Top Level	0.5559	-0.0305	-0.0904	-0.0791	-0.0791	-0.0762	-0.1803	-0.1803	0.0150
Application Level		-0.0548	-0.1626	-0.1423	-0.1423	-0.1371	-0.3244	-0.3244	0.0270
Ratio to IVTT (\$/hr)		1.0000	2.9672	2.5967	2.5967	2.5018	\$10.14	\$10.14	-0.4927

HOV2 mode is exactly 2 persons per vehicle. The exact values for 2-person-plus and 3-person-plus HOVs are the following:

Home-based work trips    HOV3+ = 3.373  
Home-based other trips    HOV2+ = 2.404  
Home-based school trips    HOV2+ = 2.788  
Non-home-based trips      HOV2+ = 2.385

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

- Truck – The truck trip tables that have been used up to the present are based on survey data.
- External Through – This matrix consists of 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, 2000 census Journey to Work data, and traffic counts.
- Taxi – The taxi vehicle trip table was originally developed from a 1993 survey and has since been revised several times based upon a factoring process. However, there has been no update of travel pattern data to create a true updated trip table.
- Logan Airport SOV and HOV – This trip table is developed from a separate modeling procedure, which was developed based on a Massport survey.



- Drive-Access-Transit Auto Access – DAT trips are determined through the station choice model, which is a part of the mode choice process. Each DAT trip requires a vehicle access trip.
- Internal–External SOV and HOV – The internal–external trip tables are generated through the trip distribution process.
- Pick-Up/Drop-Off SOV and HOV – The pick-up/drop-off (PUDO) tables are those trips in which a person is dropped off at his or her 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.

## **TRIP ASSIGNMENT**

Trip assignment is the fourth step in the travel demand forecasting process and in CTPS's regional travel demand model. Trip assignment is the process by which each trip in the trip tables resulting from the mode choice model is assigned to a specific submode (for example, bus or rapid transit) and a specific route. The CTPS model uses one or the other of two distinct assignment procedures, depending upon whether the trip has been split to a transit or highway mode.

### **Highway Assignment Routine**

The highway assignment implemented in EMME is an equilibrium assignment. The fundamental assumption underlying such an assignment procedure is that each user of the highway network will choose the route that he or she perceives to be the best. The assignment is an aggregate assignment in that traffic volumes on any given link are an aggregate number, as opposed to being associated with a specific trip. There are several inputs used by the EMME equilibrium assignment procedure. The key inputs are the highway demand matrices, the volume delay function, and the highway network:

- Highway demand matrices

The demand matrices that the highway assignment procedure uses as an input are the demand matrices that result from mode choice and distribution. These are origin-destination matrices of single-occupancy vehicles, trucks, taxis, internal-external trips, through trips, and high-occupancy vehicles.

- Volume-delay function

The function used in the highway assignment procedure is a volume-delay function, which, when applied in the context of a highway assignment, changes the speeds users of the network experience based upon the volumes on the network. The volume-delay function employed in the CTPS regional model is a variation on the so-called Bureau of Public Roads (BPR) function. Developed by its now defunct namesake, the BPR function is a widely used and validated volume-delay function that is parabolic in shape and takes the form:

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

The CTPS regional model is segmented by time periods. For each time period, the BPR function is altered to reflect the number of hours in that period.

- Highway network

The highway network is an abstract digital representation of the real highway network in eastern Massachusetts. For future-year scenarios, the highway network depicts roadway links that are planned in addition to the existing highway network. The base-year highway network is a depiction of the eastern Massachusetts highway network as it existed in the year 2000. The highway network in the base and future years includes information about number of lanes, free-flow speeds, and capacity (in vehicles per lane per hour). Freeways typically have a free-flow speed of 60 miles per hour, are three lanes, and have a capacity of 1,950 vehicles per lane per hour. Smaller arterials typically have a free-flow speed of 30 to 45 miles per hour, are coded as having one or two lanes, and have a capacity of 900 to 1,000 vehicles per lane per hour. Such parameters are consistent with widely accepted traffic engineering principles and the Transportation Research Board's *Highway Capacity Manual*.

The highway assignment procedure performs a multi-class generalized cost equilibrium auto assignment. The multi-class assignment runs an assignment for the demand matrices of three modes, SOV, HOV, and trucks, from the vehicle trip tables for each class, which are assigned by time period. Tolls affect the assignment and are stored on the network.

The highway assignment procedure is iterative in that the assignment is calculated repeatedly, in order to mathematically optimize assignment results. The CTPS regional model is set to run to 30 iterations before stopping. The assignment also considers another stopping criterion known as 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 origin-destination pair would have exactly the same time. The default relative gap is .5%, but CTPS employs .01% so that a more accurate assignment will result.

Another stopping criteria is 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 Assignment Routine**

The transit assignment used in EMME is a multi-path assignment based on the calculation of optimal transit strategies for system users. A transit strategy is roughly analogous to a path in highway assignment. The major difference between a strategy and a path is that a strategy may employ different modes, which in real terms is the equivalent of a transfer between modes. The transit assignment allows for users of the transit system switching within the transit network

between various available transit modes in order to reach their destination. In basic terms, the transit assignment algorithm examines at each node in the transit network, and for each transit network user, what transit service is optimal, given the origin and destination node pairs. This algorithm is repeated until the transit user arrives at the final destination. Like the highway assignment procedure, the transit assignment procedure utilizes several key inputs to estimate a transit assignment. Three of the key inputs are the transit demand matrices, the transit functions and the transit network:

- Transit demand matrices

The transit demand matrices are just that, matrices of trips that have been split into the transit mode because the utility of their trip suggests transit may be an attractive mode choice for their particular origin destination pair.

- Functions

The function used in the transit assignment procedure depicts the relative levels of attractiveness between the variety of sub-modes available in the eastern Massachusetts transit network. Costs are translated to time assuming a value of time of \$12 per hour (using 1991 dollars) and doubling the out-of-vehicle time before adding it to in-vehicle time.

- Transit network

The transit network is an abstract digital representation of the real transit network in eastern Massachusetts. For future-year scenarios, the transit network depicts transit links that are planned in addition to the existing transit network. The base-year transit network is a depiction of the eastern Massachusetts transit network as it existed in the year 2000. The transit network includes every commuter rail line, rapid transit line, bus route, and ferry route in eastern Massachusetts. The bus routes run on the highway network, and their run times are influenced by roadway traffic congestion. Among other things, the transit network in the base and future years includes information about vehicle headways, wait times, transit run times, and fares. The assignment algorithm takes into consideration all of these elements in calculating a transit assignment.

Additionally, the transit network represents and accounts for park-and-ride facilities. Park-and-ride nodes provide connections between the highway and transit networks via a walk link. As a result, drive-access transit trips use both the highway and the transit networks.

The transit network is augmented by a data input known in EMME as a line. This input contains many of the features unique to a given sub-mode such as run time, headways, and station stopping details. There is a different line file for each time period represented by the CTPS model.

Another major element of the transit network is so-called walk links. Some walk links serve as transfers between sub-modes. Other walk links serve as transfers between modes (see park-and-ride information above) but the vast majority of walk links are so-

called walk-access links. All walk links have a hard-coded speed of 3 miles per hour.

### *Walk-access estimation*

Walk-access links are an abstract representation of all of the walking routes transit users utilize in eastern Massachusetts to access the transit system. In other words, they are an aggregate abstraction of the sidewalks, roadways, backyards, driveways, and shortcuts people use to walk to the transit system.

The walk-access estimation process is an automated process that involves three steps. The first step builds paths and distances on a walk network roadway geographic information system (GIS) coverage that is created from the most recent statewide digital line graph (DLG) coverage of the roadway network. The roadways that are suitable for walking within the study area are then cut from that coverage. The path building and distance skimming between transit stops and zones is calculated on this coverage. The latest set of transit stops from the EMME databank are then imported into a GIS environment. The distances between stops and zones are then calculated from this coverage. Up to two walk links are created between each TAZ and the stations and stops on each transit line, with no links over one mile. Transfer links are created to connect all stations and stops within a quarter-mile walk.

## **Fare Coding**

In addition to time, one of the key modeled metrics is cost. In the case of transit, user costs are captured by fares that are coded onto the network. The CTPS regional model allows for testing of a variety of complicated fare schemes. A significant portion of the fare information in the model is coded onto walk links. This makes intuitive sense because transit users often pay for access to the system at the end of their walk to access the system—at the turnstile, entrance to the bus, gate to the ferry, etc. The fares coded onto walk links are called boarding fares. The other kind of fare coding allowed for is zonal-based fare information. This type of fare structure is implemented with long-haul services such as commuter rail and express buses and is imposed on segments of the transit path.

## **Path-Building Conventions**

As mentioned earlier, the transit assignment implemented in EMME is a multi-path assignment based on the computation of optimal strategies. An optimal strategy is one that minimizes the total expected perceived travel time for a transit system user. In order to reflect the fact that time is perceived by the transit system user differently depending on the portion of the trip being considered, weighting factors have been developed and applied to different portions of the transit trip. For example, transit riders perceive time spent waiting for a transit vehicle as more onerous than time spent traveling in a vehicle. The values shown in Table 14 are currently being used for the purposes of developing transit skims for mode choice and for building optimal strategies in transit assignment.

The values in the table apply both to walk-access transit and drive-access transit and to all sub-modes. They are all relative to in-vehicle time. Although these values theoretically 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 14**  
**Current Pathbuilding Parameter Values**

<b>Parameter</b>	<b>Value</b>
Initial wait time factor	2
Transfer wait time factor	2
Transfer penalty	2.45
Bus boarding penalty	7
Walk-access time factor	2
Walk speed	3.0 mph
Fare factor	1.0

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### **AIR QUALITY ANALYSIS**

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The mobile-source emissions of alternative transportation scenarios can be forecasted and analyzed using the CTPS travel demand forecasting model in conjunction with U.S. Environmental Protection Agency (EPA) emissions rates that are developed by the EPA Mobile software. The model estimates traffic volumes, average highway speeds, vehicle miles traveled, and vehicle hours traveled. The EPA Mobile software develops emission factors by pollutant and speed for different years based on, among other things, assumptions about fleet fuel efficiency. Using these tools, reasonable estimates of emissions from mobile sources can be developed for various years and network conditions.

The procedure described above is used to estimate emissions from cars and trucks of carbon monoxide (CO), nitrogen oxides (NO<sub>x</sub>), volatile organic compounds (VOCs), carbon dioxide (CO<sub>2</sub>), and particulate matter. Emissions from commuter rail diesel locomotives and MBTA buses and some automobile emissions associated with park-and-ride lots are estimated off model.

In the South Coast Rail analysis, as in most transit studies, the emission factors and roadway networks remained constant between the no-build and build alternatives, and the observed emission changes are due to mode shifts from auto to transit that result in lower VMT and possibly lower congested speeds on the roadway network.

**APPENDIX**

**Operating Plans for Proposed Build Alternatives**

**South Coast Rail Project**

**Vanasse Hangen Brustlin, Inc.**

**South Coast Rail Operation for Each Alternative (DRAFT)**

**List of Alternatives**

Alt. 1A	Attleborough - Diesel	Rail
Alt. 1B	Attleborough - Electric	Rail
Alt. 4A - Local	Stoughton - Diesel - Local	Rail
Alt. 4B - Local	Stoughton - Electric - Local	Rail
Alt. 4C - Local	Stoughton - Diesel - Local - Whittenton Route	Rail
Alt. 4D - Local	Stoughton - Electric - Local - Whittenton Route	Rail
Alt. 5	Rapid Bus Alternative	Bus
Alt. 6	No Build (TSM) Alternative	Bus

**Headway on Branches**

Alternative	AM and PM Peaks	MD and NT
Alt. 1A, 1B - Attleborough	40 min	2 hr
Alt. 4A-Local, 4B-Local, 4C-Local, 4D-Local - Stoughton	40 min	2 hr
Alt. 5 - Rapid Bus Alternative	15 min	1 hr
Alt. 6 - No Build (TSM) Alternative	30 min	Varies*

\* Headways vary for the off-peak hours.

**Travel Time\***

Alternative	Stations***	Northbound**		Southbound**	
		AM	PM	AM	PM
Alt. 1A (Fall River - S.Station)	Battleship Cove (Off Peak Only) - FR Depot - Freetown - E. Taunton - Taunton Depot - Barrowsville - Mansfield - Rt. 128 - Ruggle St. (OB Only) - Back Bay - S. Station	82 min	n/a	n/a	86 min
Alt. 1B (Fall River - S.Station)		72 min	n/a	n/a	74 min
Alt. 1A (New Bedford - S.Station)	Whale's Tooth - King's Hwy - E. Taunton - Taunton Depot - Barrowsville - Mansfield - Rt. 128 - Ruggles St. (OB Only) - Back Bay - S. Station	84 min	n/a	n/a	87 min
Alt. 1B (New Bedford - S.Station)		75 min	n/a	n/a	76 min
Alt. 4A - Local (Fall River - S.Station)	Battleship Cove (Off-Peak Only) - FR Depot - Freetown - E. Taunton - Taunton - Raynham - Easton Village - N. Easton - Stoughton - Canton Ctr - Canton Junction - Rt. 128 - Hyde Park - Ruggle St.(OB Only) - Back Bay - S. Station	83 min	n/a	n/a	85 min
Alt. 4B - Local (Fall River - S.Station)		73 min	n/a	n/a	76 min
Alt. 4C - Local (Fall River - S.Station)	Battleship Cove (Off-Peak Only)- FR Depot - Freetown - E. Taunton - Taunton Depot - Raynham - Easton Village - N. Easton - Stoughton - Canton Ctr - Canton Junction - Rt. 128 - Hyde Park - Ruggle St. (OB Only) - Back Bay - S. Station	94 min	n/a	n/a	96 min
Alt. 4D - Local (Fall River - S.Station)		85 min	n/a	n/a	87 min
Alt. 4A - Local (New Bedford - S.Station)	Whale's Tooth - King's Hwy - E. Taunton - Taunton - Raynham - Easton Village - N. Easton - Stoughton - Canton Ctr - Canton Junction - Rt. 128 - Hyde Park - Ruggle St. (OB Only) - Back Bay - S. Station	85 min	n/a	n/a	86 min
Alt. 4B - Local (New Bedford - S.Station)		76 min	n/a	n/a	78 min
Alt. 4C - Local (New Bedford - S.Station)	Whale's Tooth - King's Hwy - E. Taunton - Taunton Depot - Raynham - Easton Village - N. Easton - Stoughton - Canton Ctr - Canton Junction - Rt. 128 - Hyde Park - Ruggle St. (OB Only) - Back Bay - S. Station	96 min	n/a	n/a	97 min
Alt. 4D - Local (New Bedford - S.Station)		87 min	n/a	n/a	89 min
Alt. 5 - Rapid Bus (FallRiver - S. Station)****	Fall River Depot - Freetown - South Station	91 min	81 min	81 min	88 min
Alt. 5 - Rapid Bus (New Bedford - S, Station)	Whale's Tooth - King's Highway - South Station	103 min	93 min	93 min	99 min
Alt. 5 - Rapid Bus (Taunton Depot - S. Station)	Taunton Depot - South Station	68 min	62 min	62 min	65 min
Alt. 5 - Rapid Bus (Taunton Galleria - S. Station)	Galleria Station - South Station	66 min	60 min	60 min	63 min
Alt. 6 - No Build Alternative (FallRiver - S. Station)*****	Fall River Depot - South Station	84 min	n/a	n/a	66 min
Alt. 6 - No Build Alternative (New Bedford - S. Station)	Fair Haven - Downtown New Bedford - Mt. Pleasant - Taunton - South Station	105 min	95 min	100 min	100 min
Alt. 6 - No Build Alternative (Taunton - S. Station)	GATRA/Bloom Terminal - Dog Track - 106@24 - Boston	86 min	75 min	70 min	75 min

\* Travel times for the rail Alternatives were obtained from SYSTRA and include dwell time.

\*\* Travel times for the rail Alternatives were provided for inbound and outbound without peak designation. Given data were assumed to be the peak direction. However, travel time for the off-peak direction should not differ significantly as long as the train makes the same stops.

\*\*\* The list of stations include all stations that will be operational in the build scenarios.

\*\*\*\* For the Rapid Bus Alternative, travel times have been refined to more accurately mimic the operations based on the CTPS' data, Google Map, and Transportation Studies.

\*\*\*\*\* For the No Build Alternative, travel times were estimated based on the measure time through bus rides for the peak period/peak direction, the others were estimated based on the current schedules.)

\*\*\*\*\* The build alternatives include station parking constraints at Taunton Station (200 spaces) and Barrowsville Station (264 spaces).

**Park-N-Ride Facilities in No Build Alternative**

P-N-R Facility	Capacity	Fee*
Route 106 near Route 24 (West Bridgewater)	180**	Free
Route 24 Exit 12 Silver City Galleria (Taunton)	211	Free
Oak Street Bloom/GATRA Terminal (Tunton)	160	Free
I-495 Exit 8/Greyhound Track (Raynham)	150	Free
Mt. Pleasant Street (New Bedford)	201	Free
72 Sycamore Street (fairhaven)	28	Free

\* Fee for commuter parking

\*\* Route 106/Route 24 Park-N-Ride currently has a parking capacity of 140 spaces, but there is additional 40 spaces being planned to be added in the near future, and is included in the No Build Alternative.

**Parking Supply at Rail Stations in Build Conditions**

2009 DEIR Planning	
Station	Parking Spaces Provided
N. Easton	519
Easton Village	0
Raynham Park	455
Taunton	200
East Taunton (N)	473
Freetown	183
FR Depot	510
Battelship Cove	0
King's Hwy	0
Whale's Tooth	694
Barrowsville	264
Taunton Depot	737
Stoughton Station	468
Canton Center	0
Mansfield	0
Sharon	0
<b>Total</b>	<b>4503</b>

**Fare**

**Alternatives 1 (Attleboro)**

From \ To	Battleship	FR Depot	Freetown	State Pier	Whale's Tooth	King's Hwy	E. Taunton	Taunton Depot	Barrowsville	Mansfield	Sharon	Canton Jct	Route 128	Hyde Park	Boston
Battleship	-	\$1.61	\$1.61	-			\$1.84	\$1.84	\$1.84	\$2.34	\$2.82	\$3.05	\$3.30	\$3.59	\$4.50
Fall River Depot	\$1.61		\$1.61	-			\$1.84	\$1.84	\$1.84	\$2.34	\$2.82	\$3.05	\$3.30	\$3.59	\$4.50
Freetown	\$1.61	\$1.61	-	-			\$1.84	\$1.84	\$1.84	\$2.34	\$2.82	\$3.05	\$3.30	\$3.59	\$4.50
State Pier	-	-	-	-	\$1.61	\$1.61	\$1.84	\$1.84	\$1.84	\$2.34	\$2.82	\$3.05	\$3.30	\$3.59	\$4.50
Whale's Tooth	-	-	-	\$1.61		\$1.61	\$1.84	\$1.84	\$1.84	\$2.34	\$2.82	\$3.05	\$3.30	\$3.59	\$4.50
King's Hwy	-	-	-	\$1.61	\$1.61		\$1.84	\$1.84	\$1.84	\$2.34	\$2.82	\$3.05	\$3.30	\$3.59	\$4.50
E. Taunton	\$1.84	\$1.84	\$1.84	\$1.84	\$1.84	\$1.84		-	\$1.61	\$1.84	\$2.57	\$2.82	\$3.05	\$3.30	\$4.34
Taunton Depot	\$1.84	\$1.84	\$1.84	\$1.84	\$1.84	\$1.84		-	\$1.61	\$1.84	\$2.57	\$2.82	\$3.05	\$3.30	\$4.34
Barrowsville	\$1.84	\$1.84	\$1.84	\$1.84	\$1.84	\$1.84	\$1.61	\$1.61		\$1.84	\$2.57	\$2.82	\$3.05	\$3.30	\$4.34
Mansfield	\$2.34	\$2.34	\$2.34	\$2.34	\$2.34	\$2.34	\$1.84	\$1.84	\$1.84		\$2.34	\$2.57	\$2.82	\$3.05	\$4.11
Sharon	\$2.82	\$2.82	\$2.82	\$2.82	\$2.82	\$2.82	\$2.57	\$2.57	\$2.57	\$2.34		\$1.84	\$2.34	\$2.57	\$3.39
Canton Jct	\$3.05	\$3.05	\$3.05	\$3.05	\$3.05	\$3.05	\$2.82	\$2.82	\$2.82	\$2.57	\$1.84		\$1.84	\$2.34	\$2.91
Route 128	\$3.30	\$3.30	\$3.30	\$3.30	\$3.30	\$3.30	\$3.05	\$3.05	\$3.05	\$2.82	\$2.34	\$1.84		\$1.84	\$2.68
Hyde Park	\$3.59	\$3.59	\$3.59	\$3.59	\$3.59	\$3.59	\$3.30	\$3.30	\$3.30	\$3.05	\$2.57	\$2.34	\$1.84		\$2.68
Boston	\$4.50	\$4.50	\$4.50	\$4.50	\$4.50	\$4.50	\$4.34	\$4.34	\$4.34	\$4.11	\$3.39	\$2.91	\$2.68	\$2.68	

**Alternative 4 (Stoughton)**

From \ To	Battleship	FR Depot	Freetown	State Pier	Whale's Tooth	King's Hwy	E. Taunton	Taunton	Whittenton	Raynham	Easton	Stoughton	Canton Ctr	Canton Jct	Route 128	Hyde Park	Boston
Battleship	-	\$1.61	\$1.61	-			\$1.84	\$1.84	\$1.84	\$2.34	\$2.57	\$2.82	\$3.05	\$3.05	\$3.30	\$3.59	\$4.50
FR Depot	\$1.61		\$1.61	-			\$1.84	\$1.84	\$1.84	\$2.34	\$2.57	\$2.82	\$3.05	\$3.05	\$3.30	\$3.59	\$4.50
Freetown	\$1.61	\$1.61	-	-			\$1.84	\$1.84	\$1.84	\$2.34	\$2.57	\$2.82	\$3.05	\$3.05	\$3.30	\$3.59	\$4.50
State Pier	-	-	-	-	\$1.61	\$1.61	\$1.84	\$1.84	\$1.84	\$2.34	\$2.57	\$2.82	\$3.05	\$3.05	\$3.30	\$3.59	\$4.50
Whale's Tooth	-	-	-	\$1.61		\$1.61	\$1.84	\$1.84	\$1.84	\$2.34	\$2.57	\$2.82	\$3.05	\$3.05	\$3.30	\$3.59	\$4.50
King's Hwy	-	-	-	\$1.61	\$1.61		\$1.84	\$1.84	\$1.84	\$2.34	\$2.57	\$2.82	\$3.05	\$3.05	\$3.30	\$3.59	\$4.50
E. Taunton	\$1.84	\$1.84	\$1.84	\$1.84	\$1.84	\$1.84		\$1.61	\$1.61	\$1.84	\$2.34	\$2.57	\$2.82	\$2.82	\$3.05	\$3.30	\$4.34
Taunton	\$1.84	\$1.84	\$1.84	\$1.84	\$1.84	\$1.84	\$1.61		\$1.61	\$1.84	\$2.34	\$2.57	\$2.82	\$2.82	\$3.05	\$3.30	\$4.34
Whittenton	\$1.84	\$1.84	\$1.84	\$1.84	\$1.84	\$1.84	\$1.61	\$1.61		\$1.84	\$2.34	\$2.57	\$2.82	\$2.82	\$3.05	\$3.30	\$4.34
Raynham	\$2.34	\$2.34	\$2.34	\$2.34	\$2.34	\$2.34	\$1.84	\$1.84	\$1.84		\$1.84	\$2.34	\$2.57	\$2.57	\$2.82	\$3.05	\$4.11
Easton	\$2.57	\$2.57	\$2.57	\$2.57	\$2.57	\$2.57	\$2.34	\$2.34	\$2.34	\$1.84		\$1.84	\$2.34	\$2.34	\$2.57	\$2.82	\$3.86
Stoughton	\$2.82	\$2.82	\$2.82	\$2.82	\$2.82	\$2.82	\$2.57	\$2.57	\$2.57	\$2.34	\$1.84		\$1.84	\$1.84	\$2.34	\$2.57	\$3.39
Canton Ctr	\$3.05	\$3.05	\$3.05	\$3.05	\$3.05	\$3.05	\$2.82	\$2.82	\$2.82	\$2.57	\$2.34	\$1.84		\$1.61	\$1.84	\$2.34	\$2.91
Canton Jct	\$3.05	\$3.05	\$3.05	\$3.05	\$3.05	\$3.05	\$2.82	\$2.82	\$2.82	\$2.57	\$2.34	\$1.84	\$1.61		\$1.84	\$2.34	\$2.91
Route 128	\$3.30	\$3.30	\$3.30	\$3.30	\$3.30	\$3.30	\$3.05	\$3.05	\$3.05	\$2.82	\$2.57	\$2.34	\$1.84	\$1.84		\$1.84	\$2.68
Hyde Park	\$3.59	\$3.59	\$3.59	\$3.59	\$3.59	\$3.59	\$3.30	\$3.30	\$3.30	\$3.05	\$2.82	\$2.57	\$2.34	\$2.34	\$1.84		\$2.41
Boston	\$4.50	\$4.50	\$4.50	\$4.50	\$4.50	\$4.50	\$4.34	\$4.34	\$4.34	\$4.11	\$3.86	\$3.39	\$2.91	\$2.91	\$2.68	\$2.68	

**Alternative 5 (Rapid Bus)**

From \ To	Fall River	Freetown	New Bedford	Taunton	Boston
Fall River	-	-	-	-	\$4.50
Freetown	-	-	-	-	\$4.50
New Bedford	-	-	-	-	\$4.50
Taunton	-	-	-	-	\$4.34
Boston	\$4.50	\$4.50	\$4.50	\$4.34	-

\* All fares are based on the 2006 MBTA fare structure.

\*\* All new stations in Fall River and Newbedford were assigned Zone 8.

\*\*\* For the fare per commuter trip calculation, the monthly reduced pass fare was divided into 44 (22 commute day per month, two trips per day).

**Alternative 6 (No Build/TSM)**

From	To	Fare (per trip)	
Fall River	Fall River	Boston	\$5.91
	New Bedford	Taunton	\$2.95
New Bedford	New Bedford	Boston	\$5.68
	Taunton	Boston	\$4.59
Taunton	W. Bridgewater	Boston	\$4.55
	Easton	Boston	\$5.45
	Raynham	Boston	\$5.45
	Taunton	Boston	\$5.45

\* No Build Conditions assumes that the existing commuter buses will continue providing the commuting services.



