Application of the EERPAT Greenhouse Gas Analysis Tool in Massachusetts

final

report

prepared for

Massachusetts Department of Transportation

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Cambridge Systematics, Inc.

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1.0 Introduction and Summary

1.1 Study Objectives

The objective of this project is to demonstrate the use of the Federal Highway Administration (FHWA) Energy and Emissions Reduction Policy Analysis Tool (EERPAT) tool for evaluating transportation sector greenhouse gas (GHG) reduction measures in Massachusetts. The results provide information to the Massachusetts Department of Transportation (MassDOT) and other stakeholders about the potential GHG reduction benefits of a variety of transportation emission reduction measures as well as the potential costs of implementing these measures. The project supports the Commonwealth in its efforts to implement the Global Warming Solutions Act (GWSA) of 2008 and to achieve the GHG reduction targets set in the subsequent Clean Energy and Climate Plan (CECP) of 2010 (updated in 2015).[1] The project also supports MassDOT's overall sustainability activities and the State's Healthy Transportation Compact by providing better information on the sustainability benefits of transportation programs and investments.

1.2 Overview of Methods and Assumptions

EERPAT is a tool developed by FHWA for national application, based on the GreenSTEP model first developed in Oregon. EERPAT is a system of disaggregate household-level models that better accounts for interactions between policies than simpler, sketch-level GHG analysis methods. It also accounts for feedback from congestion and costs to travel behavior to account for induced demand. EERPAT synthesizes a statewide set of households and predicts vehicle ownership and use (vehicle-miles of travel) on an individual household basis. Commercial (light and heavy) vehicle travel also is accounted for but is not predicted at the same level of detail. The model is spatially aggregate and does not include a network analysis like a statewide or regional travel demand model. Input data for EERPAT is provided at the metropolitan area level – in this analysis the Metropolitan Planning Organization (MPO) or regional planning association (RPA) region.

For this analysis EERPAT was run using 2015 as the base year and with forecast years of 2020, 2030, 2040, and 2050. The following scenarios were created:[2]

- Scenario B – A "baseline" scenario reflecting current transportation policies and funding in the Commonwealth as of 2015;
- Scenario C – An "additional MassDOT policies" scenario that considers investments that MassDOT could make if additional funding was available; and
- Scenario D – An "additional State and regional policies" scenario that considers other policies that are outside of MassDOT's direct control but could be implemented by the State working with regional agencies and/or municipalities.

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[1] The CECP sets GHG emission reduction targets of 25 percent below 1990 levels in 2020, and 80 percent below 1990 levels in 2050, considering total statewide emissions.

[2] There is no Scenario A. Scenario A was initially left as a placeholder for a "no action" scenario that would include various pre-2015 conditions, but inputs for this concept were not developed.

Each scenario included a variety of policies that can be modeled within EERPAT. The list of policies is shown in Table 1.1. Inputs for most policies are provided in five-year increments; policies are assumed to begin to take effect in 2020, in some cases with a linear phase-in period through 2030 or 2035 as noted. For Clean Buses and Congestion Pricing, two scenarios were modeled, and an additional sensitivity test was done to look at the impacts of high market-driven EV penetration rates. EERPAT also is capable of modeling other policies that were not included. The list of modeled policies was developed based on 1) policies previously identified in the CECP and GreenDOT, and 2) policies with a plausible policy lever for *public-sector implementation* in Massachusetts. The purpose of the study was to examine what additional GHG reductions could be achieved through additional MassDOT or other state agency actions, compared to not taking additional action.[3]

Table 1.1 Greenhouse Gas Reduction Policies

Policy	Scenario B, Current Plans and Policies	Scenario C or D, Additional Policies
Scenario C, Additional MassDOT Policies		
Transit Investment/ Service	Zero per-capita growth (trend)	~1% simple annual increase in per-capita vehicle revenue-miles
Clean Buses	Current Federal standards	All hybrid buses purchased statewide in 2017; electric bus purchasing phased in 2021 to 2029
Bicycle Infrastructure	Estimated increase in bicycling based on 5-year/20-year state and regional plans	Additional investment ($ and facility-miles) to triple bike mode share from current levels by 2030
Travel Demand Management	Current MassRides/Mass Commute participation	Additional funding to reach employers with >100 employees, increasing workforce reached from 25% to 37%
Intelligent Transportation Systems	Funded expansion consistent with ITS strategic plan	Expansion of incident management to all eastern Mass. highway segments; deployment of adaptive signal coordination on 500 more State signals by 2030
Scenario D, Other State and Local Policies		
Land Use/Smart Growth	Current MPO forecasts	At least 80% of new households locate in mixed-use areas in 2020 to 2030; 90% in 2030+
Electric Vehicles	California 10% ZEV rule through 2025, flatline thereafter[a]	$25 million in additional annual State subsidies to increase sales through 2030
Mileage-Based Fee	None	VMT fee of 0.6 c/mi

[3] Eco-driving (driving practices that save fuel) is an example of a policy that was not modeled. It is likely that eco-driving will become more prevalent as in-vehicle feedback devices such as fuel economy meters become more widespread. However, people's driving practices were not viewed as a something that MassDOT could have a significant influence over. Similarly, car-sharing is viewed as something that is being driven primarily by private investment and additional state policies would not have a major impact.

Policy	Scenario B, Current Plans and Policies	Scenario C or D, Additional Policies
Congestion Pricing	None	Severely congested: $0.25/mi; Extremely congested: $0.50/mi Existing tolled Boston MPO highways only (alternative policy test – apply to all Boston MPO limited-access highways)
Clean Fuels Standard	EPA Renewable Fuel Standard-2	10% carbon intensity reduction versus gas/diesel by 2030
Parking Pricing	Current conditions, based on 2011 MA household travel survey	Double average cost of parking and % of trips paying for parking by 2035, through requirements or incentives for paid parking

[a] The California program requirements will take effect in Massachusetts in 2018, once the "travel provision" of the ZEV rule (which allows California to count EVs sold in other states) expires.

The analysis is limited by the specific inputs that EERPAT accepts. For example, the inputs related to transit service provision include rate of growth of vehicle-revenue miles (VRM), bus fuel type and efficiency, and rail percent electrification. Policies such as increasing frequency, coverage, or reliability of service, or adding new rail service, could not be modeled except as an increase in VRM. Similarly, land use policies are modeled based on the fraction of households in "mixed-use" versus "single-use" neighborhoods and the amount of population in urban versus rural areas. Policies such as transit-oriented development cannot be explicitly modeled. A unique set of inputs and assumptions had to be created for each policy. These are described in Section 4.0.

EERPAT inputs that were not modified from baseline (Scenario B) conditions include:

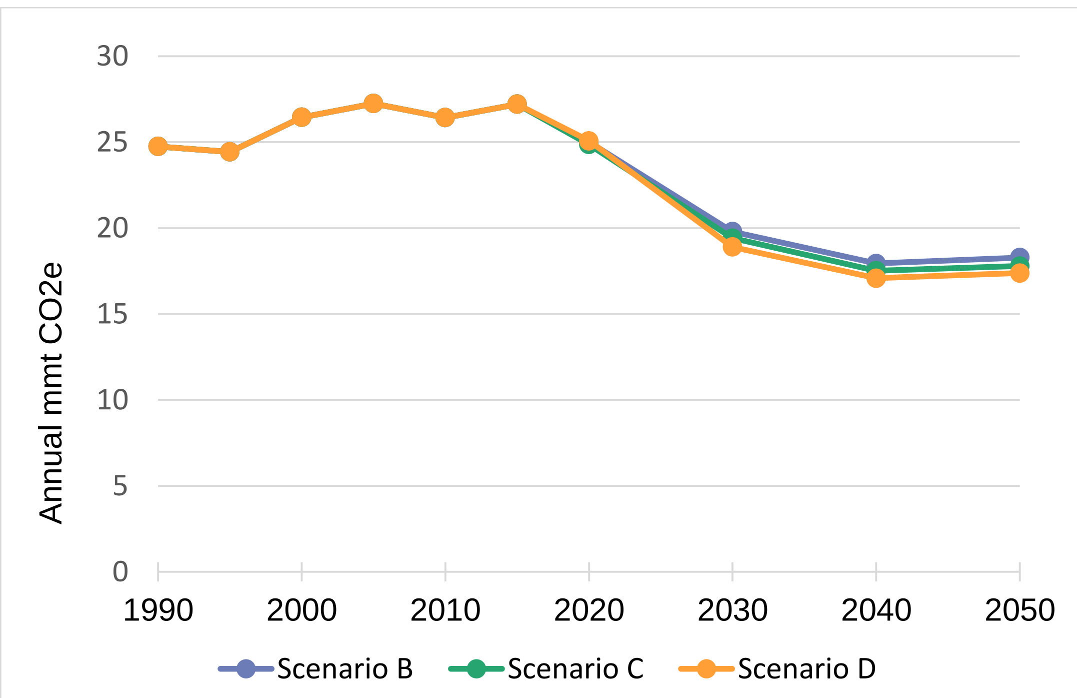
- Land use – urban/rural growth split; urban area growth rate (urbanized land area);
- Transportation supply – percent electrified rail;
- Transportation supply – growth in freeway and arterial lane miles (no growth is assumed under any scenario);
- Vehicle fleet – auto/light truck proportions;
- Vehicle fleet – proportion of commercial service vehicles that are light trucks and distribution of powertrain types for commercial vehicles;
- Use of "light vehicles" other than bicycles;
- Pricing – fuel and electricity costs (including taxes) and carbon prices;
- Degree to which congestion affects the efficiency of different types of vehicles;
- TDM – participation and effectiveness for individualized marketing programs;
- ITS – Level of deployment of freeway ramp metering and arterial access management;

- GHG emission factors for electricity and ethanol (neither are included in the Commonwealth's transportation sector accounting against GWSA targets);
- Parking – percent of employees parking at work, and participation in cash-out programs;
- Eco-driving participation and effectiveness;
- Car-sharing participation;
- Pay-as-you-drive insurance; and
- Low-rolling resistance tires.

1.3 Summary of Key Findings

Figure 1.1 shows direct, on-road transportation emissions, in million metric tons of carbon dioxide equivalent (mmt CO_2e) per year. Historical data for 1990 to 2010 are from the Commonwealth's inventory, and forecast data for 2015 to 2050 are from EERPAT.

Figure 1.1 Massachusetts On-Road Direct Transportation Emissions Under Baseline and Additional Policies Scenarios



Note: Scenario C in this chart includes hybrid buses transitioning to electric for the "clean buses" policy. Scenario D includes congestion pricing only on existing Boston area tolled highways. Emissions from electricity generation are not included.

Scenario B, the baseline scenario, shows a rapid decrease between 2015 and 2030 with a much smaller decline by 2040 and a slight increase in the last decade to 2050. The decline is driven primarily by Federal fuel efficiency standards (through Model Year 2025 for light-duty vehicles and Model Year 2018 for heavy-duty vehicles), with some state and local policy impacts. Scenario C, MassDOT policies and investments, shows an additional decrease of about 0.4 mmt CO_2e or 2 percent of on-road emissions in 2030 and beyond. Scenario D, other state and local policies, shows an additional decrease (versus Scenario B) of about 0.9 mmt CO_2e or 5 percent of on-road emissions.

Table 1.2 summarizes daily VMT and annual CO_2e emissions under each scenario. The decline in emissions comes despite increasing VMT. Scenario C reduces VMT more than Scenario D, since Scenario C emphasizes investments to encourage travel by modes other than automobile. Scenario D reduces VMT slightly through pricing policies, but there may be some offsetting “rebound” effect as the cheaper cost of electricity (for EV owners) encourages additional driving. The table shows emissions changes compared with 1990 as well as 2015 levels, although the statewide GHG reduction targets based on 1990 levels are not applied to specific sectors. Scenario D+ EV Growth is a sensitivity test that includes the same policies but assumes electric vehicle “market transformation” consistent with California Air Resources Board scenarios showing penetration of electric vehicles increasing to over 80 percent of new vehicle market share after 2040. Emissions decrease much more rapidly under this scenario, although there will be some offsetting emissions from the electricity sector.

Table 1.2 Summary of VMT, GHG, and Electricity Changes

	1990	2015	2020	2030	2040	2050
VMT, million miles/day						
Scenario B		151.5	157.4	167.2	176.5	184.2
Scenario C		151.5	156.5	164.4	172.9	179.5
Scenario D		151.5	157.1	166.4	176.0	183.7
Percentage Difference						
C versus B			-0.6%	-1.7%	-2.1%	-2.6%
D versus B			-0.2%	-0.5%	-0.3%	-0.3%
Percentage Change versus 2015						
Scenario B			3.9%	10.4%	16.6%	21.6%
Scenario C			3.3%	8.5%	14.1%	18.5%
Scenario D			3.7%	9.9%	16.2%	21.3%
GHG emissions, mmt/year CO_2e[a]						
Scenario B	24.7	27.2	25.0	19.8	17.9	18.3
Scenario C	24.7	27.2	24.9	19.4	17.5	17.8
Scenario D	24.7	27.2	25.1	18.9	17.1	17.4
Scenario D + EV growth			25.0	18.6	14.2	10.6
Percentage Difference						
C versus B			-0.6%	-1.9%	-2.3%	-2.7%
D versus B			0.3%	-4.5%	-4.8%	-4.9%
Percentage Change versus 2015						
Scenario B			-8.1%	-27.2%	-34.1%	-32.8%
Scenario C			-8.6%	-28.7%	-35.6%	-34.6%
Scenario D			-7.8%	-30.5%	-37.2%	-36.1%
Percentage Change versus 1990						
Scenario B			1.0%	-20.0%	-27.5%	-26.1%
Scenario C			0.5%	-21.6%	-29.2%	-28.1%
Scenario D			1.3%	-23.6%	-31.0%	-29.8%
Transportation Electricity Consumption, MWh/day[b]						
Scenario B			1,318	3,838	5,476	5,959
Scenario C			1,353	3,909	5,582	6,099
Scenario D			1,355	3,982	5,838	6,405
Scenario D + EV growth			1,355	4,891	16,763	32,841

[a] GHG emissions are direct emissions for the transportation sector only; emissions from electricity generation are not included.

[b] Includes electrified urban rail and plug-in consumption by EVs and PHEVs, but not electric buses.

Table 1.3 summarizes the policies tested and outcomes in terms of GHG reduction. Individual policies were run only for 2030, since EERPAT requires a separate model run for each year (the 2040 and 2050 model runs were conducted with all policies). The reduction also is shown as a percentage of on-road transportation emissions. Finally, cost estimates are shown for each policy along with the rough annual cost per metric ton of emissions reduced. These include implementation costs only (capital and operating) and do not include costs or cost savings to travelers, other social costs and benefits, or revenue from pricing policies. The assumptions behind the cost estimates are detailed in Section 6.0. Because of the uncertainties in the analysis the cost per ton estimates should be considered order-of-magnitude only. EERPAT provides outputs of household transportation cost changes but these were not investigated in this analysis. Figure 1.2 shows each policy plotted on a chart of impact (emission reductions) versus cost per ton. Policies to the right have a larger impact and policies towards the bottom of the chart have a lower cost per unit of emission reduction.

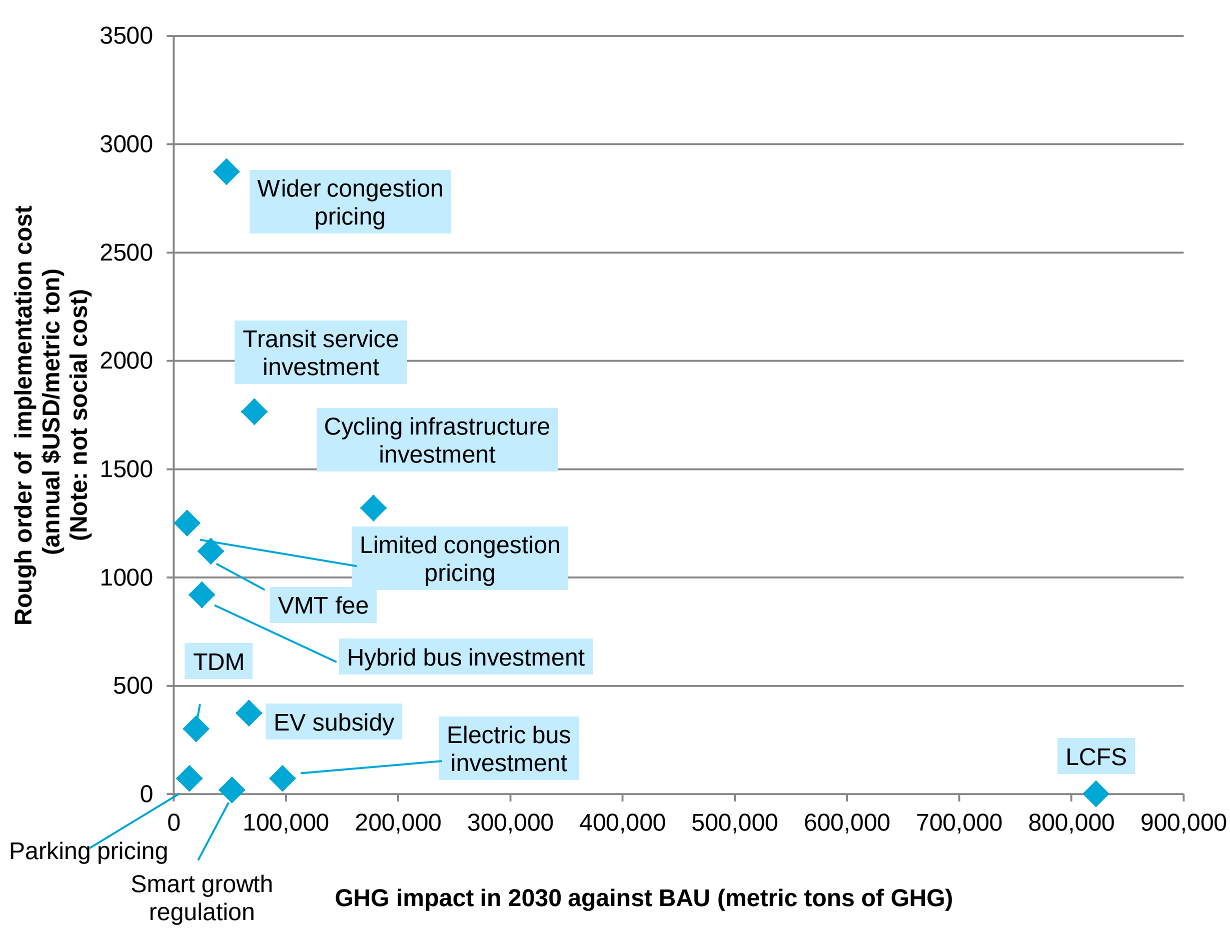
Table 1.3 GHG Reductions and Estimated Costs of Individual Policies

Policy	Change in 2030 GHG Emissions, Metric Tons[a]	Percentage of On-road Emissions	Approximate Cost, $million/ year[b]	Order-of-Magnitude Annual Cost per Ton
MassDOT Policies				
Transit Investment/Service	-73,000	-0.37%	127	$1,700
Clean Buses – Hybrid	-25,000	-0.13%	23	$920
Clean Buses – Hybrid & Electric	-98,000	-0.50%	7	$71
Bicycle Infrastructure	-180,000	-0.91%	91	$510
Travel Demand Management	-20,000	-0.10%	6	$300
Intelligent Transportation Systems	+3,000	+0.01%	20	NA
Other State and Local Policies				
Land Use/Smart Growth	-53,000	-0.27%	<1	$19
Electric Vehicles (subsidy impacts)	-68,000	-0.34%	25	$370
Mileage-Based Fee	-34,000	-0.17%	37	$1,100
Congestion Pricing: Existing Tolled Highways	-12,000	-0.06%	15	$1,300
Congestion Pricing: All Boston Area Highways	-48,000	-0.24%	135	$2,800
Clean Fuels Standard	-831,000	-4.20%	<1	$1
Parking Pricing	-14,000	-0.07%	<1	$71

[a] Direct, in-state, transportation sector emissions only.

[b] Implementation costs only (capital and net operating).

Figure 1.2 Magnitude of Impact versus Cost-Effectiveness



In Scenario C, the largest benefits are seen from bicycle infrastructure investment, transit service increases, and clean buses. TDM program expansion produced smaller benefits. ITS expansion produced a very small negative impact, likely due to induced vehicle-travel (an increase in travel which may occur due to a reduction in travel time or congestion). Note that bicycle mode shares are provided as an input to the model and are not forecast by EERPAT.

In Scenario D, the dominant policy in 2030 is a clean fuels standard. Electric vehicles also have a significant impact if a more optimistic market penetration assumption is made. The impact of land use policies is modest, in part due to the relatively low level of forecast statewide population growth (six percent between 2020 and 2030 and three percent between 2030 and 2040), although benefits should increase over time. The mileage-based fee impact is fairly modest reflecting the modest value of the fee. The small parking pricing impact probably reflects the limited extent to which parking currently is paid; therefore doubling paid parking has a very limited statewide effect although it may have larger localized impacts.

One advantage of EERPAT is that it considers interactions between different policies in terms of how they affect household travel. Under Scenario C, the collective impacts of all policies implemented together are slightly higher than the additive impacts of individual policies (-1.94 versus -1.86 percent), suggesting minor synergistic benefits. In contrast, under Scenario D, the combined impacts are lower than the sum of individual impacts (-4.52 versus -4.98 percent).

1.4 Evaluation of the EERPAT Tool

This analysis provides insights into the EERPAT tool's strengths and limitations. The tool has some noteworthy advantages compared to other tools available for GHG strategy analysis, including:

- Due to its household microsimulation structure, EERPAT is a more sophisticated tool than spreadsheet-based, sketch-plan methods that are commonly used to evaluate GHG policies.
- It includes a much broader range of policies than can be tested using a travel demand model.
- The household-level of analysis provides for consideration of how demographic factors such as household size, structure, age, and income influence travel in different ways.
- While the tool is non-spatial, it considers differences in baseline and policy inputs across regions of the State.
- It considers induced travel – increased amounts of travel resulting from reductions in travel costs and congestion.
- It is capable, to some extent, of considering interactive effects among policies.
- Once the tool is populated with data and calibrated, it is fairly simple to adjust inputs, run the tool, and compare outputs.

EERPAT also has a number of limitations. Some noted in this application include:

- The level of effort to initially set up EERPAT for a new state is not insignificant. Input data requirements are fairly substantial; submodels need to be estimated and the model needs to be calibrated.
- The tool works at an aggregate regional spatial level and is not suitable for project-level analysis.
- The built-in methods for each policy vary in their sophistication and the required inputs do not always align with policies that an agency may want to test. For example, transit-oriented development cannot be explicitly analyzed, and estimates of bicycle use and electric vehicle uptake must be made off-line and provided as model inputs.
- Policies affecting freight and other commercial vehicle travel cannot be explicitly modeled (although FHWA is sponsoring work to improve the freight component).
- The carbon pricing input only affects VMT, not fuel economy or carbon content, and therefore does not fully represent the impacts of a carbon pricing policy.

Enhancements to the tool are planned which should continue to increase its value and relevance to practitioners interested in transportation GHG strategy analysis.

1.5 Suggestions for Additional Analysis

This analysis has just scratched the surface in terms of testing EERPAT's capabilities. Some additional analyses that might be of interest include:

- Testing individual policy impacts in other years (e.g., 2040, 2050);
- Running a scenario that includes all MassDOT and other state and local policies combined;
- Examining differences in impacts by geographic area, income group, etc.;
- Examining model output for household costs/savings;
- Testing the effects of different global input assumptions (e.g., income growth, fuel prices, shift of existing households into mixed-use areas) on baseline emissions as well as policy effectiveness;
- Impacts of additional policies not tested, such as highway expansion, or of reductions in transit service (or highway capacity) if insufficient funding is available to maintain current levels of per-capita capacity or service;
- Using life-cycle emission factors to look at life-cycle GHG impacts;
- Looking at how impacts might scale depending upon the magnitude of policy application (e.g., VMT fee); and
- Designing inputs to test the effects of other potential future developments, such as increased eco-driving through automated and connected vehicles, or to test sensitivity to input parameters such as EV range.

1.6 Overview of the Remainder of this Report

The remainder of this report is organized as follows:

- Section 2.0 describes the scope of the analysis (geographic, temporal, and emissions covered);
- Section 3.0 discusses the process for estimating EERPAT's required submodels;
- Section 4.0 details the creation of the various model and scenario input files;
- Section 5.0 describes the process and data sources for calibrating the model; and
- Section 6.0 discusses cost estimates and assumptions for each policy.

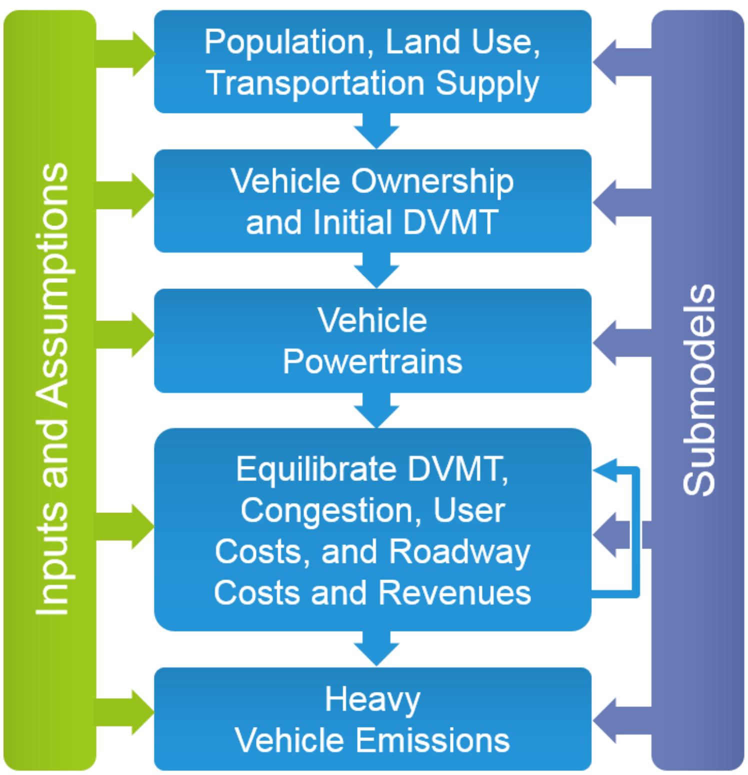
2.0 Overview of EERPAT and Scope of the Analysis

2.1 The EERPAT Tool

Model Design and Flow. EERPAT is a system of disaggregate household-level models, which also are known as the submodels. The submodels are linked together by a main R script and perform separate calculations sequentially with inputs and assumptions to produce the final outputs. Figure 2.1 shows a conceptual overview of the model flow. (A much more detailed flowchart showing the internal logic of the model is included in the EERPAT User's Guide.) The blue boxes in the middle identify the major steps in the model execution process, which are carried out by different submodels. Among the submodels, six of them would require reestimation for a new application (see Section 3.0). Therefore, the sequence of using EERPAT is:

1. Prepare the input data (see Section 4.0);
2. Reestimate the submodels (see Section 3.0); and
3. Run the main script that links all submodels.

Figure 2.1 Conceptual Model Flow



Model Versions. EERPAT version 3.0 was applied for this analysis. Version 3.0 was a beta version not available to the public at the time of the analysis. At the beginning of the project only version 2.0 was available, so some submodels were estimated using version 2.0. Because of the differences between the two versions, CS has made a number of modifications to the model scripts of the beta version 3.0 to ensure that the earlier work done with version 2.0 can be successfully integrated. The biggest change was made to the household income submodel (see Section 3.2).

Staff from the Central Transportation Planning Staff (the technical staff for the Boston MPO) assisted with baseline data preparation and submodel estimation. Brian Gregor of Oregon Systems Analytics, the developer of GreenSTEP, served as an advisor. The tool was still under development and the documentation available at the time of the tool's application was still in draft form; staff from RSG, the developers of EERPAT, were helpful in answering questions about aspects of the tool that were still being developed or documented. RSG also incorporated the adjustments made for the Massachusetts model into a version 3.0 with a graphical user interface (GUI) to make application easier for Massachusetts users.

2.2 Scope of the Analysis

Sources Covered. EERPAT synthesizes a statewide set of households and predicts vehicle ownership and use (vehicle-miles of travel) on an individual household basis. Commercial (light and heavy) vehicle travel also is accounted for but is not explicitly modeled; rather it is "factored up" to match statewide VMT estimates for light and heavy vehicles. Urban bus and rail are included (including commuter rail), but intercity passenger and freight rail is not. Marine and air are not included. Electrification of urban rail is considered, but electric buses are not.

Geographic Scope. EERPAT originally has three main geographic units for analysis – Counties, Economic Regions, and Metropolitan Statistical Areas (MSA). Because counties have little meaning as a jurisdiction or analysis unit in Massachusetts, Metropolitan Planning Organization (MPO)/Regional Planning Agency (RPA) boundaries were used instead of counties as the basis for preparing input data. Because MSAs are county-based areas, MPO/RPA boundaries were used to replace MSAs as well. Therefore, for the application in Massachusetts, data were provided mainly at two geographic levels – MPO/RPA and Economic Regions.

- **MPO/RPA:** There are 13 of these used in the EERPAT; their abbreviations in the EERPAT input files are shown in Table 2.1. This table also shows the names of the corresponding MPO/RPA and transit agency (used for developing transit data inputs from the National Transit Database). The Boston region was split into three parts to allow for greater geographic specificity in inputs for this region.[4]

- **Economic Regions:** These are identical to MPOs for the application in Massachusetts, except for the combination of Berkshire and Franklin MPOs. Economic Regions are used only for the household income model estimation.

[4] The split was also made to avoid potential problems in running the tool for areas over two million population, as was encountered in an early application in King County, although according to the tool developers this should no longer be a problem.

Table 2.1 Analysis Regions

EERPAT MPO/RPA Region Name	EERPAT Abbreviation	Regional Planning Agency	Transit Agency
Berkshire	Berk	Berkshire County RPC	Berkshire Regional Transit Authority (RTA)
Boston Region 1 (Suffolk County)	Bos1	Suffolk	Massachusetts Bay Transit Authority (MBTA)
Boston Region 2 (Essex, Middlesex, Worcester Counties)	Bos2	Boston MPO/ Metropolitan Area Planning Council	MBTA, Cape Ann TA, MetroWest RTA
Boston Region 3 (Norfolk, Plymouth Counties)	Bos3	Boston MPO/ Metropolitan Area Planning Council	MBTA
Cape Cod and Islands	Cape	Cape Cod Commission, Martha's Vineyard Commission, Nantucket Planning and Economic Development Commission	Cape Cod RTA
Central Massachusetts	Cent	Central Massachusetts RPC	Worcester RTA
Franklin	Fran	Franklin Regional Council of Governments (COG)	
Merrimack Valley	Merr	Merrimack Valley Planning Commission	Merrimack Valley RTA
Montachusett	Mont	Montachusett RPC	Montachusett RTA
Northern Middlesex	Nort	Northern Middlesex COG	Lowell RTA
Old Colony	Oldc	Old Colony Planning Commission	Brockton Area Transit
Pioneer Valley	Pion	Pioneer Valley Planning Commission	Pioneer Valley TA
Southern Massachusetts	Sout	Southern Massachusetts Planning and Economic Development District	Southeastern RTA, Greater Attleboro-Taunton RTA

Table 2.2 is the crosswalk table as an input to EERPAT. Note that the field titles remain the same, but the values under "County" and "Msa" are MPO names.

Table 2.2 Geographic Crosswalk

County	Region	Msa
Berk	BerkFran	Berk
Bos1	Bos1	Bos1
Bos2	Bos2	Bos2
Bos3	Bos3	Bos3
Cape	Cape	Cape
Cent	Cent	Cent
Fran	BerkFran	Fran
Merr	Merr	Merr
Mont	Mont	Mont
Nort	Nort	Nort
Oldc	Oldc	Oldc
Pion	Pion	Pion
Sout	Sout	Sout

In addition to the above mentioned geographies, there are a few land-use related input files[5] of EERPAT that group the MPO/RPA-level data into three development types – Metropolitan Area, Town, and Rural – based on population density. The amount of population in each development type, as provided in urban_rural_growth_splits.csv, is shown in Table 2.3. Furthermore, there is one input file that specifically contains household data of urban mixed-use areas by MPO/RPA. Mixed-use areas are defined based on population and employment densities (see Section 4.2.21).

Table 2.3 Metropolitan, Town, and Rural Population Fractions

County (EERPAT Region)	Metropolitan	Town	Rural
Berk	68.40%	1.20%	30.40%
Bos1	99.90%	0.10%	0.00%
Bos2	97.50%	0.10%	2.40%
Bos3	98.10%	0.10%	1.80%
Cape	89.90%	0.60%	9.50%
Cent	83.60%	1.10%	15.30%
Fran	45.60%	5.20%	49.20%
Merr	95.00%	0.10%	4.90%

[5] See Sections 4.1.11, 4.1.12, 4.2.35, and 4.2.36.

County (EERPAT Region)	Metropolitan	Town	Rural
Mont	72.90%	1.50%	25.70%
Nort	96.80%	0.10%	3.10%
Oldc	94.30%	0.30%	5.40%
Pion	86.60%	0.90%	12.50%
Sout	86.60%	0.70%	12.70%

Temporal Scope. EERPAT was run using 2015 as the base year and with forecast years of 2020, 2030, 2040, and 2050. Historical year data also were provided back to 1990, but pre-2015 data were typically either the default values provided in EERPAT or the 2015 level. Since the analysis was forward-looking, no effort was made to develop accurate historic data. The exception is for model-year specific vehicle fuel economy data, which are important because older model vehicles continue to influence the model outputs in future evaluation years.

Scope of Emissions Covered. Consistent with the Commonwealth's GWSA accounting protocols, only direct emissions from the transportation sector are included. Biodiesel is included in, but ethanol is not. Emissions from the generation of electricity are not included. "Upstream" (well-to-pump) emissions also are not included, as these typically are generated in other sectors and/or outside the Commonwealth's boundaries. Life-cycle benefits of carbon sequestration in biofuels production are not captured.

3.0 Estimating Submodels[6]

The EERPAT tool consists of a set of submodels that perform separate calculations in a specific order. Among the submodels, six of them required reestimation based on Massachusetts data. This section describes the modifications and updates made to the submodels and the input data used to reestimate them. This process needs to be carried out only for a new application and before running the main scripts in version 2 of EERPAT. In version 3 (beta at the time of this writing), the process is partially internalized into the main scripts. For users in Massachusetts, there should be no need to redo this process in the near future.

3.1 Household Age Structure Model

Estimation of this model required replacing Oregon population inputs with data for Massachusetts. As the base year of the model for Massachusetts is 2013, 2000 Census Public Use Microsample (PUMS) data were replaced with 2011 American Community Survey (ACS) PUMS statistics. The 2011 PUMS was used in place of the 2013 PUMS due to the redrawing of the Public Use Microsample Area (PUMA) boundaries in 2012. The Census Bureau did not regeocode older ACS household addresses when the 2012 ACS PUMS files were generated. Thus, 2012 and later PUMS have two sets of PUMAs: 2000 Census PUMA codes for households surveyed in 2011 and earlier, and 2010 Census PUMA codes for households surveyed in 2012 and later. The 2011 PUMS was used here for simplicity. The PUMS files are in the 'hh_age_model/data/pums' subfolder.

Model fit was tested against Census population counts by age by MPO for 2000 and 2010 (pop_by_age_2000.csv and pop_by_age2010.csv in the hh_age_model/data/pop_forecasts subfolder). Although not used in model estimation, population by age group in 2005 also was estimated.

3.2 Household Income Model

Estimation of the model required replacing both PUMS and Bureau of Economic Analysis (BEA) personal income input files. The data obtained from BEA are in a series of reports tabulating estimated population and total personal income by county by year. Estimating the same statistics by MPO required making the dubious assumption that per capita income is constant across an entire county.

This model is estimated by region (see the geographic correspondence file hh_income_model/data/county_to_region.csv). For Massachusetts, each MPO (MPO subregion for Boston) is a region by itself except for Berkshire and Franklin counties, which were combined. PUMS data are allocated to region using the lookup table hh_income_model/data/pums_areas.csv. For the most part each PUMA could be assigned to a single MPO where most of its population fell in the MPO. This was not the case for Berkshire and Franklin counties, which were therefore combined into a single region for the purpose of household income modeling.

[6] The work documented in this section was primarily performed by Central Transportation Planning Staff. Paul Reim of CTPS contributed to the description. Submodels were initially estimated in EERPAT v2.0, which was the version available at the time of project initiation; adjustments to the model script were later made to read v2.0 submodels into v3.0. The edits to the income and vehicle age model scripts were done by Brian Gregor.

The fit of the household income model against observed household income data from the Census was not particularly good initially. The income model estimation script was therefore revised to replace parameters derived from Oregon data with parameters estimated from the Massachusetts data. This results in a better fitting income model. The key changes are:

- Computing a power transformation for the Massachusetts data which minimizes the skew of the income distribution;
- Computing a dispersion factor (to match the tails of the income distribution) to minimize the difference between the mean of the modeled household income and mean of the observed household income for the sample population; and
- Using all of the sample population to estimate the model, rather than only households having incomes of $150,000 or less.

The last of these has been an important change for the latest version of GreenSTEP so that average per capita incomes calculated from model outputs match the input value. EERPAT and previous versions of GreenSTEP have underestimated household income.

An additional adjustment to the income model was made as the statewide average per capita income calculated from the Census PUMS data is significantly lower than the BEA statewide average per capita income. Since the model is estimated from the Census PUMS data, it also will produce lower predictions than the BEA average. In the case of Massachusetts, the model and PUMS state averages are about 23 percent less than the BEA state average. To correct this, a scaling value was estimated so that the model produces a statewide average which is the same as the BEA statewide average. The modeled average is within a tenth of a percent of the BEA statewide average. Regional averages differ by as much as 7 percent. It is to be expected that the variation would be greater at the regional level because of the simplicity of the model and adjustment factors are estimated at the State level.

3.3 Household Daily VMT Model

Only two changes needed to be made before estimating this submodel. The consumer price index data file (hh_travel_model/data/cpi.csv) was replaced with statistics for the Boston metropolitan area for 1969 to 2014. The model script 'estimate_ave_hh_travel_model.r' was edited to exclude the coefficients for the west, midwest and south Census region dummy variables.

3.4 Non-motorized Vehicle Model

Similarly to the household daily VMT model description above, the script for this submodel, (light_vehicle_model/estimate_light_vehicle_model_current.r) required edits to exclude the west, midwest and south Census region dummy variables.

3.5 Vehicle Fleet Models

There are two vehicle fleet submodels: the light truck model and the vehicle age model. Before estimating these models, two scripts were run to prepare input data files.

3.5.1 Massachusetts Vehicle Registrations

A text file of individual vehicle registrations, identified by age, MPO of registration and vehicle type (auto, light truck) was extracted from a 2013 extract from the Massachusetts Registry of Motor Vehicles (RMV) registration database. An R binary data file (MaVehSmry..RData) was generated from this text file by a short R script (make_mass_rmv_binary.r).[7]

3.5.2 Generate NHTS Extracts and Vehicle Crosstabs

The R script 'veh_fleet_model/create_estimation_datasets.r' summarizes Massachusetts registration data and National Household Travel Survey (NHTS) household and vehicle data for input to the light truck and vehicle age models. Edits to this script include:

- Changing the reference to local vehicle registration data;
- Using Northeast region NHTS records instead of West; and
- Change output file names from WestVeh..RData and WestHH..RData to EastVeh..RData and EastHH..RData.

3.5.3 Light Truck Model

The script 'veh_fleet_model/estimate_light_truck_model.r' was edited to change the references to the western region NHTS datasets (WestHh..RData, WestVeh..RData) to the northeast region data files described in section 1.5.2 (EastHh..RData, EastVeh..RData).

3.5.4 Vehicle Age Model

The script 'veh_fleet_model/estimate_vehicle_age_model.r' was edited as described above to reference the northeast region NHTS data. Also edited was the reference to local income data in collapsing NHTS income categories into those used in the model. This income data file (veh_fleet_model/data/massachusetts_incomes.csv) was derived from 2000 Census data since the NHTS survey was conducted in 2001.

Execution of this script initially generated errors. The problem appeared to be a result of negative proportions in the vehicle age tables. These were introduced by the spline smoothing routines. This was solved by defining a new function "smoothCumDist" which carries out the spline smoothing of cumulative probability distributions, calculating the corresponding regular distributions, and removing negative values. Defining this function also enabled redundant code to be eliminated.

[7] The prepared input data to EERPAT are at aggregate level.

3.6 Truck Travel Model

The script 'truck_travel/truck_bus_mpg_model.r' updates the TruckBusAgeDist.AgTy.RData table that will be incorporated into GreenSTEP_.RData. The input file "truck_bus_ages.csv" was updated based on 2013 Massachusetts RMV data and National Transit Database (NTD) statistics.

4.0 Creation of Inputs

This section describes the data sources and assumptions used to create the input files for EERPAT as applied in Massachusetts. Section 4.1 describes the basic fixed inputs for the model. Section 4.2 describes the scenario inputs (inputs that can be varied to test GHG impacts).

4.1 Model Inputs

4.1.1 arterial_lane_miles.csv

File description: this files summarizes base year arterial lane miles by metropolitan area (MPO).

Source(s): The data source is MassDOT *Road Inventory Year-End Report 2014*.

4.1.2 ave_rural_pop_density.csv

File description: This file lists population density (per square mile) of the rural portions of each MPO.

Source(s): This file was prepared by CTPS. It was created by: multiplying 2010 rural population at the town level (from the 2010 Census) by the ratio of the 2013 Census population estimate for each town to its 2010 Census population count; summarizing the total 2013 estimated rural population by MPO; and dividing the estimated MPO rural population count by the land area of rural areas in the MPO.

4.1.3 county_groups.csv

File description: This file contains a table associating MPOs with economic regions (Region) and metropolitan areas (MPO/RPA).

Source(s): The file was prepared by CTPS. The "regions" are identical to MPO except for the combination of Berkshire and Franklin counties for the household income model estimation. The "VmtAdjustment" column is used in calibration (see Section 5.0).

4.1.4 freeway_lane_miles.csv

File description: this file summarizes base year freeway lane miles by metropolitan area (MPO).

Source(s): Data source is MassDOT *Road Inventory Year-End Report 2014*.

4.1.5 global_values.txt

File description: This file contains global run parameters that are not defined elsewhere in input files, including:

- Base year;
- Cost multiplier;
- Base year annual light vehicle VMT;

- Base year annual truck VMT;
- Transit vehicle-mile adjustment;
- Truck VMT growth multiplier;
- Megajoules per gallon;
- U.S. to metric conversion factors;
- Factor to convert DVMT to annual VMT;
- Base cost per mile of travel;
- Default budget proportion;
- Factor to estimate commercial service VMT from household VMT;
- Value of time;
- Name of census region; and
- State.

Source(s): Many of the parameters are applicable in any state and thus do not need to be changed from their default values. The parameters that do need changes include base year annual VMT for light vehicles and trucks. They were updated based on Highway Statistics (2013). The factor to estimate commercial service VMT from household VMT was updated to 0.09, a typical proportion of commercial vehicle travel of total vehicle travel. The transit vehicle mile adjustment that converts transit revenue miles to vehicle miles was updated based on calculation of data from NTD. In addition, base year, name of census region, and state name were updated.

4.1.6 hh_dvmt_to_road_dvmt.csv

File description: This file is a table of factors to convert metropolitan household and commercial service vehicle daily VMT to metropolitan roadway light vehicle daily VMT by metropolitan area. The values are approximations of the proportion of household and commercial service vehicle daily VMT that take place inside the metropolitan area and that therefore contributes to metropolitan area congestion.

Source(s): MassDOT provided average daily traffic (ADT) by county for both 2010 and 2011. Daily household VMT was estimated from the 2010 to 2011 Massachusetts Household Travel Survey (MAHTS). The survey days for the households in the survey sample were almost evenly split between 2010 and 2011, so the averages of the 2010 and 2011 ADTs were used for the denominator of the daily VMT factors. Both household and total VMT were summarized by MSA, as defined by the Census Bureau based on county boundaries, before calculating the factors. The factors were adjusted to MPO/RPA-level factors based on the geographic correspondence between MSAs and MPO/RPA areas.

4.1.7 mpo_base_dvmt_parm.csv

File description: This file contains base year proportion of total state heavy truck VMT taking place in each metropolitan area (PropTruckDvmt), and proportions of daily VMT on freeways and arterials for each metropolitan area (FwyArtProp).

Source(s): For **PropTruckDvmt,** the data sources include Highway Statistics (2013, table VM-4) and VMT by RPA (MPO) provided by MassDOT. MassDOT VMT data do not have sufficient classified counts to support MPO-level estimates of vehicle class breakdown; therefore, state-level proportion of heavy trucks (single-unit and combination) in urban areas out of total heavy truck VMT from Highway Statistics reporting were applied to VMT data by MPO.

For **FwyArtProp,** the data source is MassDOT VMT by functional class by MPO.

4.1.8 pop_forecasts/pop_by_age_XXXX.csv

File description: this file contains population estimates/forecasts by MPO and age cohort from 1990 to 2050 in five-year increments.

Source(s): Population data for 1990 and 1995 were from the Census Bureau's intercensal estimates. Population data for 2000, 2005 and 2010 were created by CTPS. Population data for the rest of the future years were developed based on UMass Donahue Institute's population projections (2015 to 2035).

4.1.9 transit_revenue_miles.csv

File description: This file is a table of the relative growth rate of annual bus and rail vehicle-revenue miles (VRM) compared to population growth by metropolitan area. A value of 1.0 indicates that VRM is growing at the same rate as population.

Source(s): The source is the "Service" table from the National Transit Database (NTD, 2013), where "Vehicle Revenue Miles" data for each transit agency in Massachusetts was obtained. "Motor Bus (MB)," "Commuter Bus (CB)," and "Trolley Bus (TB)" were included in the analysis of "Bus" mode. "Light Rail (LR)," "Heavy Rail (HR)" and "Commuter Rail (CR)" were included in the analysis of "Rail" mode. The revenue miles of each agency were then distributed to each of the MPOs based on the facility route miles breakdown by MPO derived from spatial analysis of GIS data from MassDOT and CTPS. (GIS layers of MBTA's and regional transit agencies' service routes were obtained from MassGIS; MPO boundaries were derived based on CTPS data.) For the two transit agencies for which such data are not available, Southeastern Regional Transit Authority (SRTA) and Plymouth & Brockton Street Railway Company (PBSR), the breakdown was estimated based on analysis of route maps. Finally, town-level population data from the Census (2010, the most recently available) were aggregated to the MPO level and used to calculate the per capita revenue miles.

Growth rates were first estimated based on the trend in 2005 to 2012 NTD data. This showed a slight decline in VRM per capita for the MBTA and a slight increase for other RTAs, so in Scenario B the future growth rates were set to 1.0.

4.1.10 truck_bus_fc_dvmt_split.csv

File description: This file contains base year proportions of truck and bus daily VMT by functional class in each metropolitan area (MPO/RPA).

Source(s): The data sources are Highway Statistics (2013, table VM-4)[8] and VMT by functional class by MPO developed by MassDOT. The proportions of truck and bus VMT out of total VMT on each type of functional class (freeway, arterial, others) were computed first based on Highway Statistics. The proportions were then used to calculate the truck and bus VMT figures by multiplying the MassDOT-developed VMT by functional class by MPO. Once VMT figures of each functional class within each MPO for truck and bus were obtained, the percentage breakdown was calculated. The equations used to calculate the proportions of trucks are presented below. Similar equations were applied for buses.

% of Truck VMT on freeway = Total Truck VMT on freeway / Total VMT on freeway

% of Truck VMT on arterial = Total Truck VMT on arterial / Total VMT on arterial

% of Truck VMT on others = Total Truck VMT on arterial / Total VMT on others

Truck VMT on freeway by MPO = VMT on freeway by MPO x % of Truck VMT on freeway

Truck VMT on arterial by MPO = VMT on freeway by MPO x % of Truck VMT on arterial

Truck VMT on others by MPO = VMT on freeway by MPO x % of Truck VMT on others

% of Truck VMT on freeway by MPO = Truck VMT on freeway by MPO /

(Truck VMT on freeway by MPO +

Truck VMT on arterial by MPO +

Truck VMT on others by MPO)

4.1.11 ugb_areas.csv

File description: This file is a table of geographic areas contained within urban boundaries defining metropolitan areas and other urban (town) areas by MPO.

Source(s): This file was prepared by CTPS. Because there are no defined urban growth boundaries in Massachusetts, this file lists the area (in square miles) of each MPO falling in metropolitan and town urban areas as defined by population density thresholds used by the Census Bureau.

4.1.12 urban_rural_pop_splits.csv

File description: This file is a table of proportions of population located in the metropolitan, town, and rural portions of each county in the base year.

[8] Trucks include single-unit trucks and combination trucks in Highway Statistics.

Source(s): This file was derived from 2010 Census counts, as no source of data could be identified to determine if population changes over the past five years resulted in different splits.

4.1.13 adj_veh_own.csv

File description: This file contains the adjustment factors for vehicle ownership.

Source(s): The values in the file were set to zero at the beginning. The adjustment factors were developed later for model calibration in a "trial-and-error" process. See section 5.2 for more details.

4.1.14 GreenSTEP_.RData

GreenSTEP_.RData is an R binary object containing all of the estimated submodels. In version 2, it needs to be created/updated using an R script (make_GreenSTEP.r) if any of the submodels are reestimated, and then be moved to the model directory to ensure successful execution of the main script. In version 3.0 (beta at the time of this writing), the process has been internalized. As a result, GreenSTEP_.RData no longer needs to be created separately by running the R script.

4.1.15 HtProb.HtAp.RData (.csv)

File description: This is an object that is part of GreenSTEP_.RData. It contains a data table used in the population synthesis model to associate person information with household information. In version 3 of EERPAT, the main scripts will read the data directly in.csv format to create the GreenSTEP_.RData.

Source(s): This object is a product of the Household Age Model (3.1). It was converted from.RData format to.csv format, and then moved into the Model Inputs folder.

4.1.16 TruckBusAgeDist.AgTy.RData (.csv)

File description: This is an object that is part of GreenSTEP_.RData. It contains a data table of truck and bus age distributions that is used in the calculation of truck and bus average fuel economy. In version 3 of EERPAT, the main scripts will read the data directly in.csv format to create the GreenSTEP_.RData.

Source(s): This object is a product of the Truck Travel Model (3.6). It was converted from.RData format to.csv format, and then moved into the Model Inputs folder.

4.1.17 VehProp_.RData (.csv)

File description: This is an object that is part of GreenSTEP_.RData. It contains a cumulative distribution of auto and light truck ages (AgCumProp.AgTy.RData), and auto and light truck age distributions by income category (AgIgProp.AgIgTy-Auto.RData and AgIgProp.AgIgTy-LtTruck.RData). In version 3 of EERPAT, the main scripts will read the data directly in.csv format to create the GreenSTEP_.RData.

Source(s): AgCumProp.AgTy.RData, AgIgProp.AgIgTy-Auto.RData and AgIgProp.AgIgTy-LtTruck.RData are products of the Vehicle Fleet Model (3.5). They were converted from.RData format to.csv format, and then moved into the Model Inputs folder.

4.1.18 HsldXXXX.RData

File description: These files are **not** user created; they are *created by the model* during a model run from the pop_forecasts/pop_by_age_XXXX.csv files. At the beginning of a model run, the model checks to see if the HsldXXXX.RData files exist and will not overwrite them if they do exist. Therefore, if the analyst updates the files in the pop_forecasts directory and wants those changes to be reflected in the synthesized population used in subsequent model runs, the HsldXXXX.RData files should be deleted.

4.1.19 income_dispersion_factors.csv

File description: This file is **not** user created. When EERPAT is run for the base year, the revised income model will calculate the MPO-specific dispersion (scaling) factors to calibrate the modeled income estimations. This file is auto-generated for base year and then applied in future years, so users do not need attend to it.

4.2 Scenario Inputs

4.2.1 age_adj.csv

File description: This is a table of vehicle age adjustment factors (varied around 1.0) by vehicle type and year.

Sources: The age distribution was adjusted to simulate potential impacts of electric vehicle (EV) requirements on vehicle fleet age. Specifically, requirements for manufacturers to produce and sell EVs are likely to lead to higher vehicle costs, at least in the short run, as manufacturers recoup the higher costs of developing and producing these vehicles. Higher new vehicle costs lead to a reduction in new vehicle sales as consumers hold on to older vehicles longer. The adjustment was increased from 1.0 in 2015 to 1.038 in 2030 and beyond, for automobiles and light trucks. See phev_characteristics.csv for further description of the basis for this adjustment. The effect of the adjustment is to increase on-road emissions by about one percent in 2030; this would occur under all scenarios since the primary effect is the cost impact of the California ZEV requirement that is included in the baseline as well as scenarios.

4.2.2 auto_lighttruck_fuel.csv

File description: A table of fuel type proportions for automobiles and light trucks, including: 1) proportion diesel; 2) proportion compressed natural gas (CNG); 3) proportion of gasoline that is ethanol; and 4) proportion of diesel that is biodiesel. Proportions are expressed on an energy basis – gasoline gallons equivalent (GGE) or British thermal units (BTU).

Current levels and baseline forecast: The AEO 2015 – Transportation Sector Energy Use by Fuel Type Within a Mode was used to calculate auto/light truck diesel and CNG values. The same values were used for auto and light truck because the AEO 2015 table does not split these values. The ethanol proportion of gasoline was calculated from gasoline and fuel ethanol Massachusetts State data from the U.S. Energy Information Administration (EIA) – State Energy Data 2013: Consumption.[9] Similarly, biodiesel

[9] Table CT2. Primary Energy Consumption Estimates, Selected Years, 1960-2013, Massachusetts (Trillion BTU). Accessed from <http://www.eia.gov/state/seds/sep_use/total/pdf/use_MA.pdf>.

proportions were calculated from transportation sector national consumption of biodiesel[10] and distillate fuel oil from the EIA Monthly Energy Review July 2015.[11] Lastly, the biodiesel proportion of diesel fuel value was estimated for 2022 based on information in the U.S. Environmental Protection Agency (EPA) Regulatory Impact Assessment (RIA) for the Renewable Fuel Standard-2 (RFS-2).[12] This value was used for years 2025 to 2050. Values used are shown in Table 4.1.

Table 4.1 Values in auto_lighttruck_fuel.csv

Year	AutoPropDiesel	AutoPropCng	LtTrkPropDiesel	LtTrkPropCng	GasPropEth	DieselPropBio
1990	0.003	0.001	0.003	0.001	0	0
1995	0.003	0.001	0.003	0.001	0	0
2000	0.003	0.001	0.003	0.001	0	0
2005	0.003	0.001	0.003	0.001	0.050	0
2010	0.003	0.001	0.003	0.001	0.072	0
2015	0.006	0.001	0.006	0.001	0.071	0.029
2020	0.011	0.001	0.011	0.001	0.101	0.070
2025	0.019	0.001	0.019	0.001	0.131	0.112
2030	0.027	0.001	0.027	0.001	0.131	0.112
2035	0.033	0.002	0.033	0.002	0.131	0.112
2040	0.037	0.002	0.037	0.002	0.131	0.112
2045	0.037	0.002	0.037	0.002	0.131	0.112
2050	0.037	0.002	0.037	0.002	0.131	0.112

Scenarios: This file was not modified for the scenarios. A low-carbon fuel standard in Scenario D was modeled using the composite fuel characteristics (fuel_co2.csv).

4.2.3 auto_lighttruck_mpg.csv

File description: A table of estimates and forecasts of average fuel economy for automobiles and light trucks by vehicle model year in miles per gallon. Measured in gasoline equivalent gallons, the fuel economy is the average for new vehicles sold in the year and is the same for all fuel types. This file is used to test alternative development scenarios such as improved technology and/or fuel economy standards that lead to higher fuel economies.

Current levels and baseline forecast: Default values were maintained for years preceding 2005, but no higher than the AEO 2005 value. AEO 2008 values were then used as inputs for years 2005 to 2008, AEO

[10] Table 10.2b Renewable Energy Consumption: Industrial and Transportation Sectors (Trillion BTU). Accessed from: http://www.eia.gov/totalenergy/data/monthly/pdf/sec10.pdf.

[11] Table 3.8c Heat Content of Petroleum Consumption: Transportation and Electric Power Sectors (Trillion BTU). Accessed from: http://www.eia.gov/totalenergy/data/monthly/pdf/sec3_26.pdf.

Also available here: http://www.eia.gov/beta/MER/index.cfm?tbl=T03.08C#/?f=A.

[12] U.S. Environmental Protection Agency (2010). Renewable Fuel Standard Program (RFS2) Regulatory Impact Analysis. EPA-420-R-10-006.

2012 Early Release for 2009, AEO 2013 for 2010 and 2011 values, and AEO 2015 for years after 2012. Values after 2005 represent energy efficiency for an "on-road new light-duty vehicle" as reported by the AEO – Transportation Sector Key Indicators and Delivered Energy Consumption tables. This value is about 13 percent lower than the "New Light-Duty Vehicle CAFE Standard" shown in the same table. There is a discontinuity in the AEO data (3.3 mpg increase for passenger cars) between model years 2010 and 2011 which may reflect changes in methodology or assumptions implemented beginning with year 2011.

After the initial inputs were developed as described above, the mpg values were further adjusted as part of the model calibration process. This adjustment was applied after income, auto ownership, and total VMT were calibrated. Efficiency values for all years and vehicle types were reduced by 17.3 percent so that model output closely matched estimates of total motor fuel use in 2013 as reported in Table MF-21 of FHWA's Highway Statistics (see Section 5.0, Model Calibration). Table 4.2 shows the pre- and post-calibration fuel efficiency values. Values before 2005 are the same as far back as 1983. Values after 2034 are the same as 2034.

Table 4.2 Values in auto_lighttruck_mpg.xlsx

	Precalibration		Postcalibration	
Model Year	Auto	Light Truck	Auto	Light Truck
2005	24.5	18.0	20.3	14.8
2006	25.3	18.7	20.9	15.4
2007	25.3	18.7	20.9	15.4
2008	25.2	18.8	20.9	15.5
2009	25.8	20.1	21.3	16.6
2010	29.1	21.5	24.1	17.8
2011	29.8	21.8	24.6	18.0
2012	29.6	22.0	24.5	18.1
2013	29.8	22.1	24.6	18.2
2014	30.2	22.5	25.0	18.5
2015	30.2	22.7	25.0	18.8
2016	30.7	23.1	25.4	19.1
2017	32.1	23.6	26.5	19.5
2018	32.8	23.9	27.1	19.8
2019	34.4	26.1	28.5	21.6
2020	36.1	26.5	29.8	21.9
2021	37.7	27.2	31.2	22.4
2022	39.6	28.2	32.8	23.3
2023	41.6	29.5	34.4	24.3
2024	42.6	30.8	35.2	25.5
2025	44.6	32.3	36.9	26.6
2026	44.9	32.4	37.1	26.7
2027	45.0	32.5	37.2	26.8

	Precalibration		Postcalibration	
Model Year	Auto	Light Truck	Auto	Light Truck
2028	45.0	32.5	37.3	26.8
2029	45.1	32.5	37.3	26.8
2030	45.1	32.6	37.3	26.9
2031	45.2	32.6	37.4	26.9
2032	45.2	32.7	37.4	27.0
2033	45.3	32.7	37.4	27.0
2034 +	45.3	32.7	37.5	27.0

Scenarios: This input parameter was not varied.

4.2.4 bus_fuels.csv

File description: This file contains a table of estimates and forecasts of the proportions of fuels used by the transit system for each forecast year and metropolitan area. For each metropolitan area, the following proportions are specified: 1) proportion of gasoline; 2) proportion of CNG; 3) biodiesel proportion of diesel fuel; and 4) ethanol proportion of gasoline used. The future values may be varied to test alternative bus fueling scenarios such as investment in CNG-fueled buses.

Current levels and baseline forecast: Data for the 12 transit agencies in Massachusetts were obtained from the National Transit Database. The data were then converted from thousand gallons of fuel to gallons of gasoline equivalents (see Table 4.3) to calculate proportions of energy consumption by each system's fixed route service. Data from energy consumption tables (T.17) for 2008 were used for years 1990 to 2010, and from the 2013 table for years 2015 to 2050. The ethanol proportion of gasoline was assumed to be the same as for motor fuels consumed by light-duty vehicles as reported by SEDS (see auto_lighttruck_fuel.csv). The proportion of biodiesel was set to zero except for the Cape region where it was set to 1. The proportion of CNG was set to 0.03 in the Boston region, 0.09 in the Northern Middlesex region, and zero elsewhere. Nine regions had a non-zero gasoline proportion.

Table 4.3 Fuel Conversion Factors to Gallons to Gasoline Equivalents

Fuel Type	Fuel Measurement Unit	Conversion Factor	GGE Calculation
B100	Gallons	1.066	GGE = B100 gal x 1.066
CNG @ 3,000 psi	Gallons @ 3,000 psi	0.239	GGE = CNG gal @ 3000 psi x 0.239
CNG	Hundred cubic feet	0.877	GGE = CNG ccf x 0.877
Diesel	Gallons	1.155	GGE = Diesel gal x 1.155
E85	Gallons	0.734	GGE = E85 gal x 0.734
Electricity	kWh	0.031	GGE = Electricity kWh x 0.031
LNG	Gallons @ 14.7 psi and -234˚F	0.666	GGE = LNG gal x 0.666
LPG	Gallons	0.758	GGE = LPG gal x 0.758

Source: Department of Energy Efficiency and Renewable Energy. Accessed from: http://www1.eere.energy.gov/vehiclesandfuels/epact/fuel_conversion_factors.html.

Scenarios: In Scenario C, the biodiesel proportion was increased from 0 to 0.1 in 2020 and 0.2 in 2025 and beyond, reflecting full deployment of biodiesel fuel in buses throughout the State. Since the analysis is only accounting for direct, not life-cycle, emissions, the apparent impact of biodiesel on CO_2 emissions is negligible (even though the fuel may have life-cycle benefits), and biodiesel is not listed as a separate policy in the summary output tables.

4.2.5 carshare.csv

File description: This file shows the availability of car-share vehicles in terms of the population per car-share vehicle in medium- (4,000 to 10,000 people per square mile) and high-density (>10,000 people per square mile) portions of metropolitan areas.

Current levels and baseline forecast: The high-density default rate from EERPAT of 4,500 people per vehicle was used in the Boston 1, Boston 2, and Boston 3 metro areas. The medium-density default rate of 50,000 people per vehicles was used in the other metro areas. These rates are only applied by the model to the segments of population in areas meeting the respective density thresholds.

Scenarios: The values in this file were not varied.

4.2.6 comm_service_fuel.csv

File description: This file provides fuel type proportions (diesel, CNG, ethanol, and biodiesel) for commercial service automobiles and light trucks.

Current levels and baseline forecast: Light truck diesel proportions were taken from the AEO 2015 values for commercial light trucks, at 42.0 percent in 2015 and increasing to 45.3 percent in 2040 and beyond. Other proportions were the same as for passenger cars and light trucks (see auto_lighttruck_fuel.csv).

Scenarios: The values in this file were not varied.

4.2.7 comm_service_lttruck_prop.csv

File description: This file provides the proportion of commercial service vehicles that are light trucks for each forecast year.

Current levels and baseline forecast: Light commercial service vehicles are assumed to be made up of 43.9 percent light trucks, the same proportion as for light passenger vehicles in Massachusetts, based on 2013 data from the Registry of Motor Vehicles.

Scenarios: The values in this file were not varied.

4.2.8 comm_service_pt_prop.csv

File description: This file provides the distribution of commercial service vehicle power train types by vehicle type and model year.

Current levels and baseline forecast: The proportions of commercial service vehicles that are hybrid-electric (HEV) and electric (EV) powertrain were set to the same proportions as for passenger vehicles in the baseline forecast.

Scenarios: The proportions of commercial service vehicles that are HEV and EV powertrain were set to the same proportions as for passenger vehicles in each respective scenario.

4.2.9 cong_efficiency.csv

File description: This file specifies the degree to which congestion (lower speed driving) affects the efficiency of vehicles.

Current levels and baseline forecast: The default values of 0.5 were not modified.

Scenarios: The default values of 0.5 were not modified.

4.2.10 congestion_charges.csv

File description: This file contains the cost to light-duty vehicles for driving in congested conditions in dollars per vehicle mile. Costs are specified for each metropolitan area (MPO/RPA area in this analysis); each analysis year; each of two road types (freeway and arterial); and each of two congestion levels (severe and extreme).

Current levels and baseline forecast: Current and baseline forecast congestion charges are set to zero.

Scenarios: In Scenario D, congestion pricing is tested at a level of $0.25/mi for severely congested conditions and $0.50/mi for extremely congested conditions. Congestion pricing is applied only in the Boston MPO planning area, and specifically only in the Boston 1 and Boston 2 study regions where tolled highways currently are found. Two alternatives are tested: (D1) where congestion pricing is only "applied" to currently tolled highways, and (D2) where congestion pricing is applied to all highways meeting the congestion thresholds.

The toll rates are set based on a review of 14 congestion-priced roadway facilities in the U.S. This review found an average low cost (at minimum congestion levels) of $0.12 per mile, and an average high cost (at maximum congestion levels) of $0.82 per mile. Values of $0.25 to $0.50 per mile were viewed as representative.

To adjust the tolls in scenario D1 to consider only currently tolled highways, data were obtained from CTPS on the percentage of highway VMT occurring on tolled facilities (for links with over 20,000 AADT per lane – a level where high levels of congestion are likely to occur). Based on model data for 2020, these percentages were 7.4 percent in the Boston 1 region and 17.9 percent in the Boston 2 region. For example, the average charge experienced by all users in the region was set at $0.25 * 0.074 = $0.0368 for severely congested conditions in Boston 1.

4.2.11 costs.csv

File description: This file contains a table with information on various unit costs in year 2013 dollars for each forecast year. It includes unit costs for the following: 1) average cost of gasoline and diesel fuels;

2) average cost of electricity per kWh; 3) cost of VMT taxes; 4) cost of carbon taxes; and 5) average cost of gasoline and diesel fuel taxes. The data in this file may be used to test variable travel cost scenarios.

Current levels and baseline forecast: Transportation sector electricity and motor gasoline prices were obtained from AEO 2015 "Energy prices by Sector and Source" tables using the reference case. Values from data tables, which were reported in 2013 dollars, were then converted from $/million BTU to $/gal for gasoline, and $/kWh for electricity (1 gal of gasoline: 124,000BTU, 1 kWh of electricity: 3,412 BTU).[13] For transportation electricity prices, AEO 2015 costs were multiplied by a factor of 1.5 to estimate Massachusetts costs based on recent data on electricity costs for Massachusetts and the nation from the EIA electricity data browser.[14] Secondly, Massachusetts and U.S. gas prices were compared with data from the EIA,[15] and found to be almost identical. Lastly, Federal and State gasoline tax rates were obtained from FHWA's Highway Statistics 2013 (Tables FE-101A and MF-205). Values were converted to 2001 dollars using a deflator of 25.5 percent per the Bureau of Labor Statistics. Fuel costs, electricity costs, and the gas tax value (state + Federal) are shown in Table 4.4.

Table 4.4 Values in costs.csv (Selected)

	Values in 2013$			Inflation Adjusted to 2001$		
Year	FuelCost	KwhCost	GasTax	FuelCost	KwhCost	GasTax
1990	1.63	0.15	0.39	1.21	0.11	0.29
1995	1.17	0.15	0.39	0.87	0.11	0.29
2000	1.47	0.15	0.39	1.09	0.11	0.29
2005	2.12	0.15	0.39	1.58	0.11	0.29
2010	2.43	0.15	0.39	1.81	0.11	0.29
2015	3.29	0.15	0.42	2.45	0.11	0.32
2020	2.82	0.16	0.42	2.10	0.12	0.32
2025	3.04	0.17	0.42	2.26	0.12	0.32
2030	3.30	0.17	0.42	2.45	0.13	0.32
2035	3.64	0.17	0.42	2.71	0.13	0.32
2040	4.04	0.19	0.42	3.01	0.14	0.32
2045	4.37	0.19	0.42	3.26	0.14	0.32
2050	4.70	0.20	0.42	3.50	0.15	0.32

Scenarios: In Scenario D, a VMT fee of 0.6 cents per mile was tested beginning in 2020, using the "Vmttax" column in the input file.

[13] Environment and Ecology. (2015) *Energy Units and Calculators.* Website, accessed from http://environment-ecology.com/what-is-energy/90-energy-units-and-calculators.html.

[14] Average Retail Price of Electricity 2001-2014. Accessed from http://www.eia.gov/electricity/data/browser/#/topic/7?agg=0,1&geo=vvvvvvvvvvvvo&endsec=vg&freq=A&start=2001&end=2014&ctype=linechart&ltype=pin&rtype=s&maptype=0&rse=0&pin=.

[15] U.S. EIA- Petroleum and Other Liquids (2015). Weekly Retail Gasoline and Diesel Prices (Dollars per Gallon, Including Taxes) Accessed from <http://www.eia.gov/dnav/pet/pet_pri_gnd_dcus_nus_a.htm>.

4.2.12 eco_tire.csv

File description: This file contains information on the proportion of households participating in eco-driving practices, the proportion of households that use low-rolling resistance tires, and the efficiency gains from each practice.

Current levels and baseline forecast: The EERPAT default files assume participation increases from 0 in 2010 to 100 percent in 2035, which could result from supportive vehicle technology such as in-vehicle fuel economy feedback. The assumed benefit is 3 percent for eco-driving and 1 percent for low-rolling resistance tires. These values were not modified.

Scenarios: Implementation of eco-driving practices was not included in the policy scenarios so this input file was not adjusted.

4.2.13 ev_characteristics.csv

File description: This file contains information on electric vehicles for each vehicle model year. This information includes the average vehicle range between charges; the proportion of PHEVs + EVs sold that are EVs (PropEV); and the average power efficiency in miles per kilowatt hour (mpkwh). The data are repeated for automobiles and light trucks.

Current levels and baseline forecast: Range was set to 75 miles in 2015, increasing to 200 in 2030, considering automaker statements that 200-mile vehicles will be available as early as 2017. The proportion of PHEVs and EVs that are EVs was set to 26 percent in 2015, increasing to 35 percent in 2020 and 40 percent in 2025, based on estimates found in California Air Resources Board (CARB) spreadsheets and other sources suggesting that full EVs will make up about 30 to 40 percent of plug-in vehicles at least in the short term. Efficiency was taken from the Argonne National Laboratory's GREET.net model, version 2014, interpolating between values for 2013, 2020, and 2030. GREET projects EV efficiency increasing from 2.65 mi/kwh in 2013 to 3.23 in 2020 and 3.74 in 2030 (automobiles), with corresponding values of 1.88, 2.38, and 2.57 for light trucks.

Scenarios: Scenario D modeled higher rates of PHEV and EV penetration compared to Scenario B. However, no values in the ev_characteristics file were changed. Instead, the overall fraction of new vehicles that are PHEVs and EVs was adjusted in the phev_characteristics file.

4.2.14 fuel_co2.csv

File description: This is a table of "pump-to-wheels" CO2 equivalent emissions by fuel type in grams per megajoule (g/MJ) of fuel energy content. Fuel types included are as follows: 1) ULSD (ultra low-sulphur diesel), 2) biodiesel, 3) RFG (reformulated gasoline), 4) CARBOB (CARB oxygenated blend – gasoline formulated to be blended with ethanol), 5) ethanol, and 6) CNG. The table also provides an option (final column) for a "composite" emission factor representing the average emissions rate across all fuel types. If this column is provided, the fuel-specific emission factors are ignored.

Current levels and baseline forecast: Default values by fuel type were maintained for Scenario B, with the exception that ethanol emissions were set to zero since these emissions are not included in the transportation emissions that the Commonwealth counts towards GWSA targets. Diesel fuel is assumed to be all ULSD, and gasoline is assumed to be all RFG. Note that these emissions are direct emissions only and do not include upstream (well-to-pump) emissions from fuel production and transport. Since biodiesel is included in the Massachusetts inventory and has a direct emissions factor only slightly lower than ULSD (76.8 versus 77.2 g CO_2/MJ), biodiesel will have a negligible impact on the model results.

Scenarios: Scenario C used the same values as for Scenario B. Scenario D includes a low-carbon fuel standard policy. To model this standard, the composite emission factor option was used. In 2015 and prior years, the composite emission factor is the combination of the individual fuel emission factors (ULSD, RFG, and ethanol) weighted by the percent of fuel in use based on AEO data (gasoline is 73.7 percent of gasoline + diesel fuel by energy content in 2013; ethanol is 7.1 percent of gasoline, increasing to 13.1 percent in 2025). After 2015, the emission factor is progressively reduced until it is 10 percent lower than the combined diesel/ gasoline/ ethanol factor, i.e.:

$$g/MJ\ (2030) = 77.2\ g/MJ * 0.243 + 75.7\ g/MJ * 0.737 * (1 - 0.131) = 62.2\ g/MJ$$

4.2.15 fwy_art_growth.csv

File description: This file contains information about rates of freeway lane mile growth and arterial lane mile growth relative to population growth for each metropolitan area.

Current levels and baseline forecast: Current transportation plans in Massachusetts do not include any significant freeway or arterial expansions, so relative growth rates are set to zero.

Scenarios: Roadway capacity expansion is not included in the test scenarios.

4.2.16 heavy_truck_fuel.csv

File description: This file contains a table of fuel type proportions for heavy trucks. Fuel types captured are proportion gasoline, proportion CNG, ethanol proportion of gasoline, and biodiesel proportion of diesel used. File may be used to test alternative fuel scenarios by varying the future shares of non-diesel fuels.

Current levels and baseline forecast: Baseline shares of gasoline and CNG data were obtained from AEO 2015 – Freight Transportation Energy Use (2013 to 2040) table. Year 2012 AEO values were used for baseline 2010 proportions. Ethanol proportions are obtained from EIA-SEDS data for Massachusetts (2005 to 2020) and are assumed to be the same as for light-duty vehicles. Biodiesel proportions increase from 2.9 percent in 2015 to 7.0 percent in 2020 and 11.2 percent in 2020 and beyond. This is based on Cambridge Systematics estimates of the amount of biodiesel needed to meet EPA RFS2 standards.

Scenarios: Values of this input were not varied by scenario.

4.2.17 hev_characteristics.csv

File description: This gives information on hybrid electric vehicles and light trucks. It includes the proportion of internal-combustion engine (ICE) and HEV autos manufactured during the year that are HEVs and their efficiency in miles per gallon.

Current levels and baseline forecast: The HEV proportions were taken from AEO forecasts, which show HEVs increasing to a maximum of 8 percent of the automobile fleet in 2040 and 0.8 percent of the light truck fleet. We assume that HEV is just one technology that auto manufacturers will use to meet Federal fuel economy standards, and do not explicitly model differences in HEVs as compared to other ICE vehicles.

Therefore, average fuel economy is the same as in the auto_lighttruck_mpg input file. (Note that in EERPAT the assumed proportion of HEVs will affect the benefits of policies that affect congestion, such as congestion pricing and operations deployment, since HEVs show less efficiency benefit between congested and uncongested conditions.)

Scenarios: Values of this input were not varied by scenario.

4.2.18 hvy_veh_mpg_mpk.csv

File description: This file contains estimates and forecasts of average fuel economy and power economy in miles per gallon of gasoline-equivalent (mpgge) and miles per kilowatt hour (mpkwh) for heavy vehicles (heavy truck, bus, train) by vehicle model year. The fuel economy is the average for new vehicles sold in the year, and is the same for all fuel types.

Current levels and baseline forecast: Initial data for this table were obtained from two sources, the NTD (using Massachusetts system data) for buses, and AEO (using national data) for trucks. Model defaults were maintained for years preceding 2010. Baseline truck and bus values for 2010 and 2011 were obtained from AEO 2013, while the 2015 Heavy Truck – Technology and Fuel Type table was used for years following 2012. Train mpkwh values were obtained from NTD 2013 energy consumption data for heavy rail, light rail, and trolley buses operated by the MBTA, by dividing total vehicle-miles by total kilowatt-hours consumed. Bus fuel economy was increased by 9.7 percent over the 2014 to 2018 period to account for the MY 2014 to 2018 heavy-duty GHG/fuel efficiency standards (forecast truck fuel economy from the AEO already accounts for these standards).

In the model calibration process, adjustments were made to the inputs to better match fuel consumption outputs with AEO and NTD data. Bus fuel economy was reduced by 20.8 percent for all model years while train efficiency was increased by 73.3 percent. This led to reaching a maximum average bus fuel economy of 4.2 mpgge in 2018 and beyond and a train efficiency of 0.21 mpkwh.

Scenarios: In Scenario C2, average bus fuel economy was increased by 20 percent starting in MY 2017, compared with Scenario B, under the assumption that all new buses purchased would have hybrid-electric drivetrains. Scenario C1 was intended to model a phase-in of electric buses over the 2021 to 2030 period. Since electric buses cannot be explicitly modeled in EERPAT, but electricity emissions are not included in the inventory, the average fuel economy of new buses was increased such that it rose to a high of 600 mpgge in 2030, which is large enough to produce essentially zero emissions. The increase was set to reflect a linear phase-in of electric bus purchase, increasing from 10 percent of new bus purchases statewide in 2021 to 100 percent in 2030.

4.2.19 light_vehicles.csv

File description: This file contains input data for the non-motorized vehicle model. Light vehicles may include bicycles, and also electric bicycles, Segways, and similar vehicles that are small, light-weight and can travel at bicycle speeds or slightly higher. For each region the following inputs are required:

- TargetProp – Non-motorized vehicle ownership rate (average ratio of non-motorized vehicles to driver age population).

- Threshold – SOV tour mileage threshold used in the SOV travel proportion model. Mileage in SOV tours less than or equal to this threshold is considered possible to divert to travel by non-motorized vehicles.

- PropSuitable – Proportion of SOV travel within the tour mileage threshold that is considered suitable for non-motorized vehicle travel.

Current levels and baseline forecast: In this analysis, only bicycles are explicitly considered. Rather than modeling non-motorized ownership separately, TargetProp was set to 1.0 and PropSuitable was then determined from actual levels of bicycling as observed in the 2011 Massachusetts Household Travel Survey, based on analysis of the survey data by CTPS. "Threshold" was set to 9.0 (equivalent to an upper bound of a 4.5 mile one-way trip for an out-and-back tour). The 2011 statewide bicycle mode share is 5.4 percent of tours (4.2 percent of miles) for tours less than 4.5 miles, compared to 0.6 percent of tours (0.3 percent of miles) for tours greater than 4.5 miles. There were too few bicycle tour observations in most regions to reliably determine bicycle mode shares by region. Therefore, two proxies were tested to make adjustments to mode share by region: 1) percent of people with a working bicycle available; and 2) percent of competitive tours (miles of travel in tours <4.5 miles). The percent of competitive tours was used because it appeared to give more realistic results. For example, the observed mode share in Suffolk County (City of Boston) is one of the highest (8.4 percent) whereas it is only 2.9 percent – lower than other parts of the Boston region – using bicycle availability as the scaling factor. The bicycle tour data from the household survey and calculated scaling factors and regional mode shares (PropSuitable) are shown in Table 4.5. For example, for the CMRPC region:

Bike-competitive miles = 189,373 / (189,373 + 2,259,420) = 7.7%

Scale factor = CMRPC / statewide bike-competitive miles = 7.7% / 8.9% = 0.87

Table 4.5 Bicycle Tour Data from Household Travel Survey

						Estimated Bike Mode Share (Tours <4.5 mi)	
RPA	Usable Bicycle Available	Total Tours in Survey	Miles in Tours <4.5 mi (All Modes)	Miles in Tours >4.5 mi (All Modes)	Bike-competitive Miles	Scaled by Bike Availability	Scaled by Bike-competitive Miles
BCRPC	43%	268	51,032	400,521	11%	4.7%	5.3%
CCC	49%	361	71,345	731,074	9%	5.3%	4.2%
CMRPC	37%	1,238	189,373	2,259,420	8%	4.0%	3.7%
FRCOG	48%	262	17,630	277,638	6%	5.2%	2.8%
Suffolk	27%	705	139,800	648,992	18%	2.9%	8.4%
MAPC-N	41%	3,633	473,155	3,954,755	11%	4.5%	5.1%
MAPC-S	41%	1,838	184,209	2,255,090	8%	4.5%	3.6%
MRPC	41%	546	57,575	1,125,343	5%	4.4%	2.3%
MVC	75%	29	11,532	15,104	43%	8.2%	10.0%
MVPC	33%	709	103,658	1,110,717	9%	3.6%	4.0%
NMCOG	39%	741	78,090	1,163,509	6%	4.3%	3.0%

RPA	Usable Bicycle Available	Total Tours in Survey	Miles in Tours <4.5 mi (All Modes)	Miles in Tours >4.5 mi (All Modes)	Bike-competitive Miles	Estimated Bike Mode Share (Tours <4.5 mi) Scaled by Bike Availability	Estimated Bike Mode Share (Tours <4.5 mi) Scaled by Bike-competitive Miles
NPEDC	70%	12	2,458	2,392	51%	7.7%	10.0%
OCPC	34%	613	108,427	1,303,700	8%	3.8%	3.6%
PVPC	42%	1,400	206,619	1,581,334	12%	4.6%	5.5%
SRPEDD	37%	1,103	203,982	2,571,674	7%	4.1%	3.5%
Statewide	**39%**	**13,458**	**1,898,885**	**19,401,263**	**8.9%**	**4.2%**	**4.2%**
Miles by Bicycle			83,549	65,315			
Bicycle Share			4.2%	0.3%			

The right hand column of the above table is used for the base-year (2015 and prior) PropSuitable values for Scenario B, with minor adjustments to combine RPAs into the model analysis regions. For forecast years in Scenario B, adjustments were made to account for the expected impacts of bicycle facilities (on-road, or “lanes,” and off-road, or “paths”) specified in regional plans, including long-range transportation plans and five-year capital improvement programs or transportation improvement programs. This information, based on a review of plans and programs conducted in the summer of 2015, is shown in Table 4.6. This table also shows assumptions (based on this plan/program review) about the percent of planned miles that are funded. For the long-range (20-year) plans, all are assumed to be funded except for the Cape region, which had a very high number of miles of planned bicycle facilities. This needed to be adjusted so the model would not produce unreasonably high mode share estimates. Blank cells represent values that could not be determined from existing plans.

Table 4.6 Planned Bicycle Facility Investment Data

	Existing Miles			Planned Miles: 5 Years				5-Year Funded	Planned Miles: 20 Years				20-Year Planned
Region	**Paths**	**Lanes**	**P+L**	**Paths**	**Lanes**	**P+L**	**% fund**	**mi P+L**	**Paths**	**Lanes**	**P+L**	**% fund**	**mi P+L**
Berk	11					11	73%	8			11	100%	11
Bos1	55		55	14	68	82	75%	62			301	100%	301
Bos2				9	4	13					52	100%	52
Bos3				9	3	12					48	100%	48
Cape			515			283	5%	14			1,131	5%	57
Cent	0	0	0									100%	0
Fran	5	2	7		5	5	100%	5			5	100%	5
Merr	13	0	13	7		7	63%	4	26		26	100%	26
Mont	25	0	25	32		32	13%	4	32		32	100%	32
Nort	25	5	30	11		11	100%	11	11		11	100%	11
Oldc	12	2	14	0	0	0						100%	0
Pion			81				100%	0				100%	0
Sout	19	50	69	87	155	242	12%	28	87	155	242	100%	242
State	**165**	**59**	**809**	**169**	**235**	**697**		**136**	**156**	**155**	**1,859**		**785**

The number of new miles of facility needed to be combined with an estimate of the new annual bicycle-miles of travel per new facility-mile. This value was set at 126,000 new annual bicycle-miles per facility-mile. The source of this value is an estimate from a prior analysis for MassDOT[16] of the amount of new bicycling that would be required to go from a baseline mode share of 0.6 percent (representative of suburban areas in the State, based on MAHTS data) to a mode share of 2.0 percent if a comprehensive network of facilities were built out. The previous analysis used a much higher value (increase to 10 percent) for high-density urban areas (at least 10,000 persons per square mile), which would result in a much higher increase in bicycling per unit investment. However, this would only be appropriate for the urban core of Boston 1 region and a small part of other regions, so the suburban value was viewed as more representative for a statewide estimate. The amount of new five-year funded miles in Table 4.6 was assumed to be implemented by 2020, and the amount of new 20-year planned miles shown in that table was assumed to be implemented by 2035.

Scenarios: Scenario C assumed that additional investment is made to triple bicycle mode share from current (2015) levels by 2030. For the EERPAT input file this meant tripling the 2015 “PropSuitable” value for each region by 2030, assuming a linear increase in the interim years (2020 and 2025).

[16] 1) “Analysis of Mode Shift, Greenhouse Gas, Health, and Equity Benefits of 2014-2018 Capital Investment Program.” Memorandum from Chris Porter, Marc Cutler, and Joe Zissman, Cambridge Systematics, to Jennifer Slesinger and Steve Woelfel, MassDOT, December 31, 2014. 2) Porter, C. et al. “Health Benefits of the MassDOT Capital Investment Program.” Presented at Moving Active Transportation to Higher Ground, Washington, D.C., April 2015.

4.2.20 lttruck_prop.csv

File description: This file contains targets for the proportion of the passenger vehicle fleet that is light trucks in each forecast year.

Current levels and baseline forecast: 2013 Massachusetts RMV data were used for 2010 and earlier years (averaging 43.9 percent statewide, varying from a low of 37.5 percent in the Boston 1 region to 49.7 percent in the Berkshire region). Values of "NA" were entered for 2015 and later years, allowing the tool to use values computed from its vehicle type model based on household characteristics.

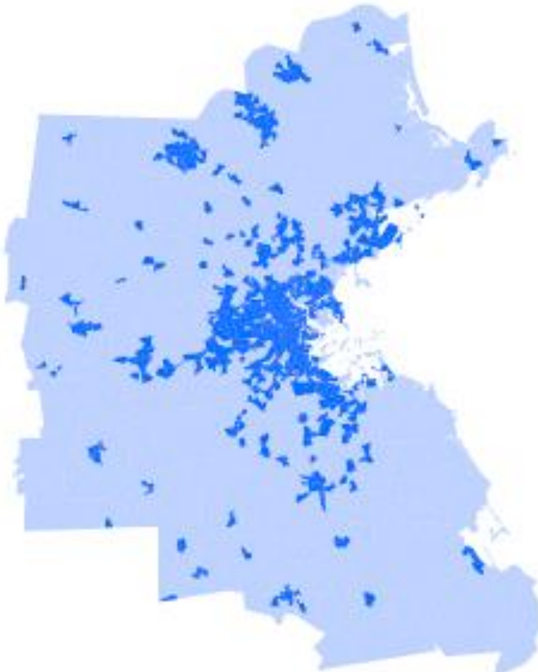
Scenarios: Values for this input were not modified in the scenarios.

4.2.21 metropolitan_urban_type_proportions.csv

File description: This file contains the proportion of households located in urban mixed-use areas by metropolitan area and forecast year.

Current levels and baseline forecast: Current levels and baseline forecast data are developed based on the statewide model, which provides projections of population, household and employment by traffic analysis zone (TAZ) for years 2020, 2030 and 2040. Urban mixed-use areas are defined as TAZs with a population density of at least 2,000 persons per square mile and an employment density (service and retail only) of at least 500 per square mile. The definition was determined by overlaying mixed-use area definitions at different residential and employment thresholds on map imagery of the State (using Google Earth) and applying judgment to identify the set of thresholds that best represented alignment with mixed-use neighborhoods. Figure 4.1 shows the current mixed-use areas in eastern Massachusetts identified based on these criteria (only Eastern Massachusetts data were available at the time the mixed-use definition was developed).

Figure 4.1 Mixed-Use TAZs in Eastern Massachusetts



Scenarios: Under Scenario D, it was assumed that State and local policies and incentives would be implemented so that at least 80 percent of new households (housing units added) would be located in mixed-use areas in 2020 through 2030, and at least 90 percent after 2030. The change in households forecast in mixed-use and non-mixed-use areas was calculated for 2020 to 2030 and 2030 to 2040.[17] In regions where 80 or 90 percent of the change was not already in mixed-use areas, new households were reallocated from the non-mixed-use to mixed-use areas. The new increments were added to the baseline number of households by area type at the beginning of the 10-year period and the percentage of each region's households in mixed-use areas recomputed. Table 4.7 shows the households by region in 2020, 2030, 2040 and the total percent in mixed-use areas in 2020 and 2040.

Table 4.7 Household Growth in Mixed-Use Areas

Region	2020 HHs	2020 % in mixed-use	2020 to 2040 new HHs	2020 to 2040 new HHs in MX: Scenario B	2020-2040 new HHs in MX: Scenario D	2040 % in mixed-use
Berk	55,424	18.7%	299	705	295[a]	19.1%
Bos1	325,427	91.2%	49,846	47,551	47,551	91.7%
Bos2	720,725	57.9%	83,684	69,166	70,647	60.7%
Bos3	290,760	35.0%	32,282	19,246	26,877	38.3%
Cape	107,929	5.1%	(6,694)	(2,072)	-	4.1%

[17] While mixed-use areas are all assumed to be "urban" – metropolitan or town – rather than rural, the change in households is based on all households. As shown in Table 2.3, nearly all of the analysis regions are predominantly urban so limiting the policy to urban population only would not have a meaningful effect on the analysis.

Region	2020 HHs	2020 % in mixed-use	2020 to 2040 new HHs	2020 to 2040 new HHs in MX: Scenario B	2020-2040 new HHs in MX: Scenario D	2040 % in mixed-use
Cent	227,607	33.2%	23,431	7,926	19,530	34.8%
Fran	29,778	16.0%	(227)	(954)	351	14.4%
Merr	131,542	44.6%	12,964	7,041	10,821	46.8%
Mont	92,762	18.7%	3,679	(73)	3,024	19.0%
Nort	113,223	36.2%	12,572	6,897	10,674	40.1%
Oldc	132,821	24.4%	11,838	5,121	9,670	26.1%
Pion	245,463	35.6%	10,198	5,624	8,520	36.8%
Sout	251,227	36.3%	14,733	8,201	12,386	37.6%
State	2,724,688	45.5%	248,605	174,379	220,346	48.1%

[a] The change for Berk looks slightly greater in Scenario B in this table than Scenario D because of the way the adjustments were applied to account for negative population growth (as projected in the Berk region for the 2030 to 2040 period, but not 2020 to 2030). Baseline forecasts include a loss of 406 households in non-mixed-use areas over the 2020 to 2040 period.

4.2.22 ops_deployment.csv

File description: This file gives the level of deployment of four different operations programs relative to average deployment levels in similarly sized metropolitan areas. The four operations programs are freeway ramp metering, freeway incident management, arterial traffic signal coordination, and arterial access management. A value of 0.5 means that the deployment is average for that size metropolitan area. A value of 0 means that there is no deployment of the program. A value of 1 means that the program is deployed to a level that achieves the maximum possible benefit from the program.

Current levels and baseline forecast: There is no source of information to directly develop these inputs. Current and baseline forecast levels were estimated using professional judgment considering information from the U.S. DOT ITS Deployment Database (as reported by MassDOT and a few Massachusetts cities and towns),[18] the MassDOT Highway Division Status of ITS Deployment (April 2014), the MassDOT ITS Strategic Plan (July 2013), and other information provided directly by MassDOT. Table 4.8 shows the most recent Deployment Database survey results for Massachusetts. Information on deployment by region of the State was very limited so the same deployment levels were assumed for all regions.

- Freeway ramp metering – This is not practiced in Massachusetts, therefore a value of “0” was entered for all regions.
- Freeway incident management – MassDOT has an active incident management program that involves monitoring roadways, detecting incidents, making notifications, documenting the sequence of response, deploying resources, responding to the scene, recovering operations, learning lessons, and conducting after action reviews. The Highway Operations Center (HOC) in South Boston is the central hub for statewide operations. Coverage of technology to support incident management along limited-access

[18] http://www.itsdeployment.its.dot.gov/Results.aspx, queried July 2015.

highways varies but is being expanded rapidly by MassDOT. In 2012 MassDOT initiated a significant investment program in roadside Portable Variable Message Signs (VMS) and Camera Message Boards. The implementation of programmed and planned ITS Corridor projects will expand the existing miles of highway coverage with ITS (primarily closed circuit television and overhead VMS) by 247 miles, a 174 percent increase over existing ITS coverage since 2012 (Figure 4.2). A value of 0.4 was entered for recent values (2000 to 2010) assuming the program is comparable to many other states' programs but without full deployment. The value was increased to 0.5 in 2015 and 0.6 in 2020 and beyond to account for initiatives underway and planned.

- Arterial traffic signal coordination – Limited evidence is available to describe how Massachusetts compares to other states on this factor. Data from MassDOT show that 41 percent of signals operated by the State (588 of 1,432) currently are part of an interconnect system.[19] Similar data do not readily exist for local jurisdictions. However the City of Boston does employ an extensive system of cameras for monitoring traffic flow as well as actuated signal controls. The ITS Deployment Database notes that adaptive signal control currently is not used, although MassDOT has three corridors in the planning stage. Deployment of other arterial management technologies also is limited. A baseline value of 0.2 was assigned for this factor, increasing to 0.25 in the future.

- Arterial access management – While some arterials in Massachusetts are access-controlled, use of this technique is relatively limited compared to many states due largely to geometric and environmental constraints. There are no significant initiatives underway to implement access management more extensively. A baseline value of 0.2 was assigned now and in the future.

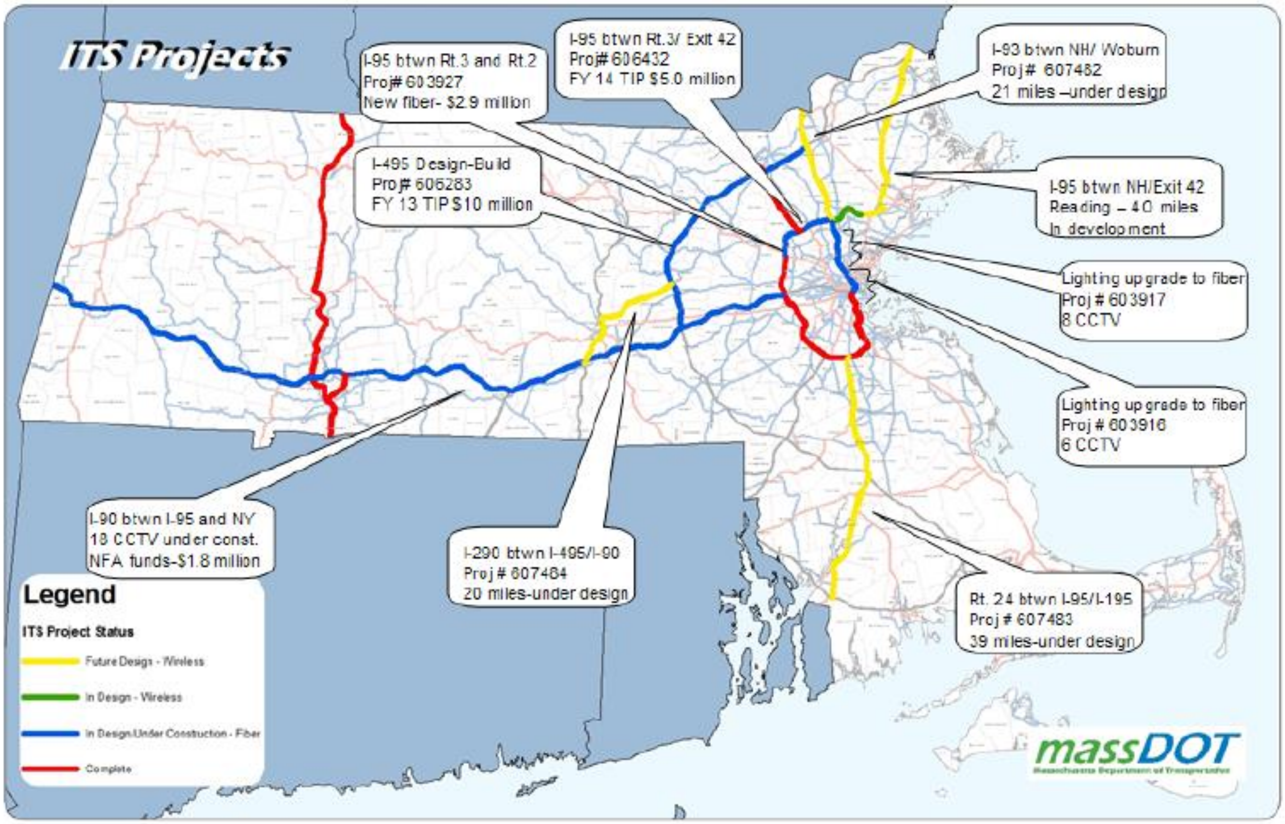
Table 4.8 ITS Deployment Database Survey Results

	Mass Highway	Boston City	Cambridge City	Lynn City	Newton City	Weymouth Town
Arterial Management						
Centerline arterial miles operated by your agency	6,778				250	202
Total number of arterial centerline miles with real-time traffic data collection technologies (does not include CCTV)	0	0	0		0	
Number of these miles where real-time traffic data are collected using roadside infrastructure such a loops, radar, detectors, or video imaging detector systems	0	0	0		0	
Number of these miles where real-time traffic data are collected by vehicle probes, using technology such as toll tag readers, cell phones, etc.	0	0	0		0	
Number of pretimed signalized intersections	71	220	110	70	20	4

[19] Email from James Danila, MassDOT – Highway Division, July 31, 2015.

	Mass Highway	Boston City	Cambridge City	Lynn City	Newton City	Weymouth Town
Number of semiactuated signalized intersections	644	575	24	0	65	
Number of fully actuated signalized intersections	715	50	1		10	6
Number of signalized intersections equipped with CCTV cameras for the purpose of monitoring traffic flow	20	195	0	0		
Does your agency use adaptive signal control technology (ASCT) as an operational strategy to improve coordinated signal timing?	No –3 systems in design	No	No	No		
Does your agency participate in a regional program managed by the State DOT, MPO or other regional authority that actively coordinates traffic signals on arterials of regional significance across jurisdictional boundaries?	No	No	No	No	No	No
Number of signalized intersections that allow for signal priority for transit vehicles	22	30	0		0	
Incident Management						
Number of arterial centerline miles patrolled by service patrol	0	0	0		0	202
Number of arterial centerline miles covered by the following incident detection/verification methods: 1) computer algorithms, 2) CCTV, 3) Other	0	20- CCTV	0		0	
Integrated corridor management						
Have you identified corridor(s) for the purpose of integrating operations across multiple transportation facilities (including freeways, major arterials, and public transit networks) in order to actively manage travel demand and capacity in the corridor as a whole?	No	No	No	1 and no follow up answers	No	No
Centerline arterial miles operated by your agency	6,778				250	202

Figure 4.2 Completed and Planned ITS Infrastructure



Source: MassDOT Highway Division Status of ITS Deployment (April 2014).

Scenarios: Scenario C assumes more aggressive deployment of incident management and signal coordination technologies. This might include technological strategies such as more widespread deployment of coordinated adaptive signal control, variable speed limits, and variable message signs, as well as institutional strategies such as improved coordination of signal timing across agencies and city/town boundaries (e.g., MassDOT Highway, Department of Conservation and Recreation, municipalities). In this scenario, the deployment value for incident management was increased to 0.8 by 2030, and the value for signal coordination was increased to 0.5. Freeway incident management was assumed to be expanded to all highway segments identified in the MassDOT ITS Strategic Plan, which includes most limited-access highways east of Worcester. Some level of signal coordination (adaptive or synchronized across a corridor) was assumed to be deployed for an additional 500 signals under MassDOT's control.

4.2.23 optimize.csv

File description: This file contains information on the proportion of households that optimize the use of their vehicles to minimize fuel consumption (i.e., using the most fuel efficient vehicle for the most travel).

Current levels and baseline forecast: This policy was not tested; therefore all input values were set to zero.

Scenarios: Values of this input were not varied by scenario.

4.2.24 other_ops.csv

File description: This file contains effects of delay-reducing operations programs other than those modeled in ops_deployment.csv.

Current levels and baseline forecast: This strategy was not tested; therefore all input values were set to zero.

Scenarios: Values of this input were not varied by scenario.

4.2.25 parking.csv

File description: This file is a table of parking policies such as workplace parking charges for each MPO and each forecast year. Specifically, the inputs include:

- Proportion of employees working where parking is not free, who use the parking they have to pay for versus finding a free parking spot in the neighborhood;
- Proportion of employees who pay for parking at work;
- Proportion of employment parking that is converted from being free to pay under a “cash-out buy-back” type of program;
- Proportion of other parking that is not free; and
- Average daily parking cost.

Current levels and baseline forecast: Massachusetts Household Travel Survey (2010/2011) data were used to estimate the percentage of work/non-work trips that are charged for parking and average daily parking cost. The first input is not available in the survey. It is assumed that 100 percent of the employees who have to pay for parking at work actually pay. Data related to the “cash-out buy-back” program may be updated with MassRIDES data.

- **Percentage of paid parking:** Work and non-work trips were distinguished by the “primary trip purpose” in the survey. The trips that were reported as “work/job,” “all other activities at work” or “work business related” were classified as “work” trips, whereas the others were “non-work” trips. Then, the two types of trips were aggregated by MPO regions respectively.
- **Average daily parking cost:** First, parking cost data in the survey were converted to per-day charges as they were reported in various units from hourly rate to annual rate. After the conversion, the outliers with extremely high or unrealistically low values were removed from the calculation. The identification of outliers was based on prevalent average parking cost in each city. Additionally, since parking costs in Boston downtown are generally higher than other regions, a table of parking price ranges in downtown

Boston was assembled using data from a parking cost tracking site[20] and applied to identify the high-end outliers. Finally, with outliers removed, average daily parking cost was calculated for each MPO region.

- **Weighting Adjustment:** An adjustment was made to the calculations based on the person weight developed in the survey to adjust the relative importance of survey responses to correct the potential bias from the different probabilities of selection of respondents.[21]

Scenarios: In Scenario D, it was assumed that the application of paid parking would be expanded throughout the State. This could be done through State requirements and/or incentives for municipalities to require paid parking in new development, and or charges on parking supply, in appropriate areas where a market could be realized for parking. This policy application was assumed to have the following impacts:

- Double the proportion of trips paying for parking by 2035, and triple it by 2050, compared to current levels; and
- Double the average cost of paid parking compared to current levels, by 2035.

Table 4.9 shows the average parking cost, proportion of work trips with paid parking, and proportion of other trips with paid parking under Scenario D. Since very few trips currently include paid parking and the average cost is low, even tripling the amount of trips where parking is paid still leads to only a small percentage of statewide trips paying a small average cost.

Table 4.9 Paid Parking Assumptions in Scenario D

Region	2015	2020	2025	2030	2035	2040	2045	2050	2015	2020
Average Parking Cost (PkgCost)										
Berkshire	$0.57	$0.71	$0.85	$0.99	$1.13	$1.13	$1.13	$1.13	$0.57	$0.71
Boston Region 1	$2.34	$2.92	$3.51	$4.09	$4.67	$4.67	$4.67	$4.67	$2.34	$2.92
Boston Region 2	$0.88	$1.10	$1.32	$1.53	$1.75	$1.75	$1.75	$1.75	$0.88	$1.10
Boston Region 3	$0.63	$0.79	$0.95	$1.11	$1.27	$1.27	$1.27	$1.27	$0.63	$0.79
Cape Cod and Islands	$1.09	$1.37	$1.64	$1.91	$2.19	$2.19	$2.19	$2.19	$1.09	$1.37
Central Massachusetts	$0.57	$0.71	$0.86	$1.00	$1.14	$1.14	$1.14	$1.14	$0.57	$0.71
Franklin	$0.43	$0.53	$0.64	$0.75	$0.85	$0.85	$0.85	$0.85	$0.43	$0.53
Merrimack Valley	$0.38	$0.48	$0.57	$0.67	$0.77	$0.77	$0.77	$0.77	$0.38	$0.48
Montachusett	$0.32	$0.40	$0.49	$0.57	$0.65	$0.65	$0.65	$0.65	$0.32	$0.40
Northern Middlesex	$0.58	$0.72	$0.86	$1.01	$1.15	$1.15	$1.15	$1.15	$0.58	$0.72
Old Colony	$0.33	$0.41	$0.49	$0.57	$0.66	$0.66	$0.66	$0.66	$0.33	$0.41
Pioneer Valley	$1.21	$1.51	$1.81	$2.11	$2.42	$2.42	$2.42	$2.42	$1.21	$1.51

[20] http://boston.bestparking.com/neighborhoods/financial-district-parking.

[21] Massachusetts Travel Survey 2010 to 2011.

Region	2015	2020	2025	2030	2035	2040	2045	2050	2015	2020
Southern Mass.	$0.49	$0.61	$0.73	$0.85	$0.97	$0.97	$0.97	$0.97	$0.49	$0.61
Proportion of Work Trips with Paid Parking (PropWrkChrgd)										
Berkshire	0.4%	0.5%	0.6%	0.7%	0.8%	0.9%	1.1%	1.2%	0.4%	0.5%
Boston Region 1	6.4%	8.0%	9.6%	11.2%	12.8%	14.9%	17.1%	19.2%	6.4%	8.0%
Boston Region 2	2.8%	3.5%	4.2%	4.9%	5.6%	6.5%	7.5%	8.4%	2.8%	3.5%
Boston Region 3	0.3%	0.3%	0.4%	0.5%	0.5%	0.6%	0.7%	0.8%	0.3%	0.3%
Cape Cod and Islands	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Central Massachusetts	3.4%	4.3%	5.1%	6.0%	6.9%	8.0%	9.1%	10.3%	3.4%	4.3%
Franklin	0.5%	0.6%	0.7%	0.8%	0.9%	1.1%	1.3%	1.4%	0.5%	0.6%
Merrimack Valley	0.2%	0.2%	0.3%	0.3%	0.4%	0.4%	0.5%	0.6%	0.2%	0.2%
Montachusett	0.4%	0.5%	0.6%	0.7%	0.8%	0.9%	1.0%	1.2%	0.4%	0.5%
Northern Middlesex	0.8%	1.0%	1.2%	1.4%	1.6%	1.9%	2.2%	2.5%	0.8%	1.0%
Old Colony	0.5%	0.7%	0.8%	0.9%	1.1%	1.2%	1.4%	1.6%	0.5%	0.7%
Pioneer Valley	2.4%	3.0%	3.6%	4.2%	4.8%	5.6%	6.4%	7.2%	2.4%	3.0%
Southern Mass.	0.5%	0.6%	0.7%	0.8%	0.9%	1.1%	1.2%	1.4%	0.5%	0.6%
Proportion of Other Trips with Paid Parking (PropOthChrgd)										
Berkshire	0.1%	0.1%	0.1%	0.2%	0.2%	0.2%	0.2%	0.3%	0.1%	0.1%
Boston Region 1	1.2%	1.5%	1.8%	2.1%	2.4%	2.8%	3.2%	3.6%	1.2%	1.5%
Boston Region 2	0.8%	1.0%	1.2%	1.4%	1.6%	1.9%	2.2%	2.4%	0.8%	1.0%
Boston Region 3	0.5%	0.7%	0.8%	0.9%	1.1%	1.2%	1.4%	1.6%	0.5%	0.7%
Cape Cod and Islands	0.4%	0.5%	0.5%	0.6%	0.7%	0.8%	1.0%	1.1%	0.4%	0.5%
Central Massachusetts	0.4%	0.5%	0.6%	0.7%	0.7%	0.9%	1.0%	1.1%	0.4%	0.5%
Franklin	0.4%	0.5%	0.6%	0.7%	0.8%	0.9%	1.0%	1.1%	0.4%	0.5%
Merrimack Valley	0.1%	0.2%	0.2%	0.2%	0.3%	0.3%	0.4%	0.4%	0.1%	0.2%
Montachusett	0.3%	0.4%	0.5%	0.6%	0.7%	0.8%	0.9%	1.0%	0.3%	0.4%
Northern Middlesex	0.5%	0.6%	0.7%	0.8%	1.0%	1.1%	1.3%	1.5%	0.5%	0.6%
Old Colony	0.4%	0.6%	0.7%	0.8%	0.9%	1.0%	1.2%	1.3%	0.4%	0.6%
Pioneer Valley	0.5%	0.7%	0.8%	0.9%	1.1%	1.2%	1.4%	1.6%	0.5%	0.7%
Southern Mass.	0.3%	0.4%	0.5%	0.6%	0.7%	0.8%	0.9%	1.0%	0.3%	0.4%

4.2.26 payd.csv

File description: This file contains information describing pay-as-you-drive (PAYD) insurance participation and costs, including the proportion of households that buy pay-as-you-drive insurance and the rate in cents per mile.

Current levels and baseline forecast: This policy was not tested; therefore all input values were set to zero.

Scenarios: Values of this input were not varied by scenario.

4.2.27 per_cap_inc.csv

File description: This file contains information on statewide average per capita income by forecast year in year 2013 dollars.

Current levels and baseline forecast: Historical data of per capita personal income were obtained from Bureau of Economic Analysis for the years from 1990 to 2014. The income data were adjusted by inflation obtained from Bureau of Labor Statistics. Since the trend over the years changes, the compounded annual growth rates of a 20-year period (1990 to 2010) and of a 10-year period (2000 to 2010) were computed respectively as two future growth rates, representing two different prospects of personal income growth for sensitivity analysis (Figures 4.3 and 4.4).

Figure 4.3 Inflation-Adjusted Per Capita Personal Income over 20-Year Period

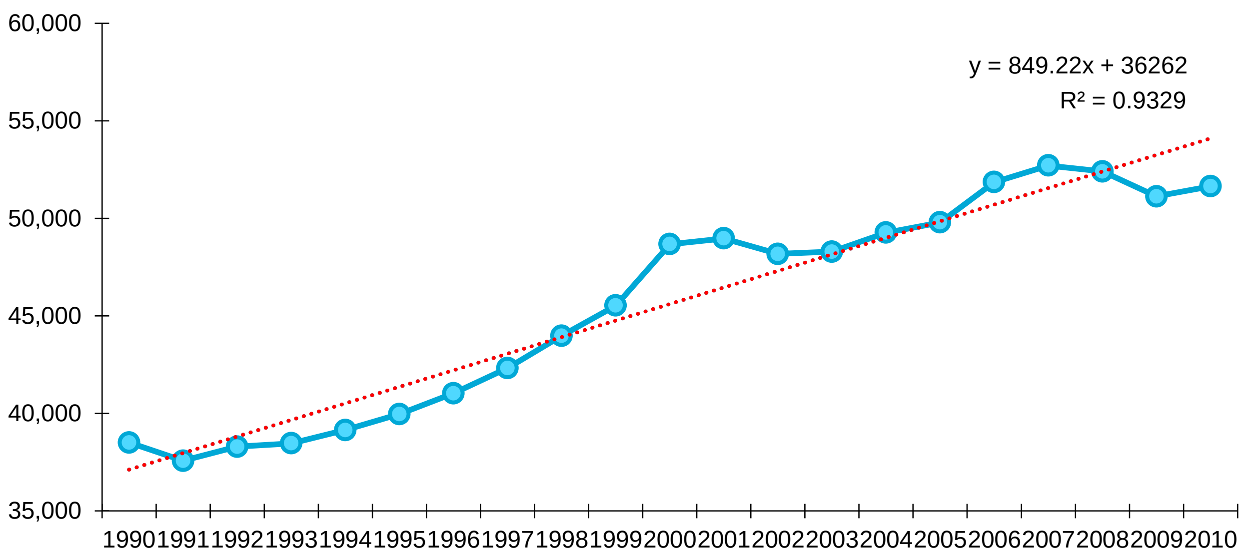
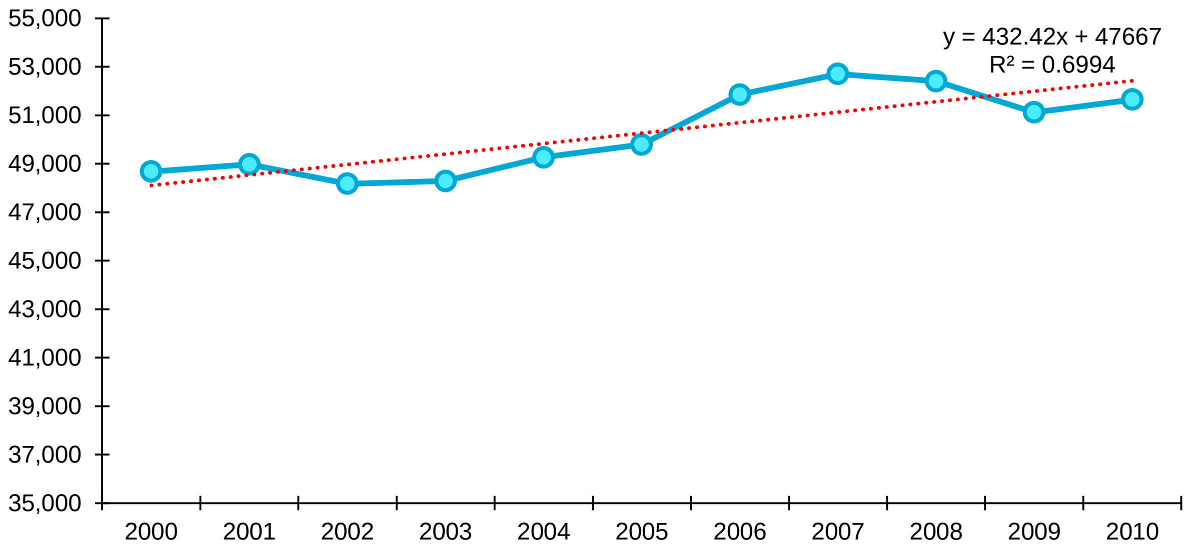


Figure 4.4 Inflation-Adjusted Per Capita Personal Income over 10-Year Period



Scenarios: Values of this input were not varied by scenario.

4.2.28 phev_characteristics.csv

File description: This file contains information on plug-in hybrid electric vehicles (PHEV) for each vehicle model year. This information includes the average vehicle range (between nightly charges) using batteries only; the proportion of autos sold that are either PHEVs or EV; the average power efficiency in mpkwh traveled on electricity; and the average fuel efficiency in mpg traveled on gasoline. The data are repeated for automobiles and light trucks.

Current levels and baseline forecast: The all-electric range was set to 25 miles reflecting a mix of PHEVs with ranges typically between 10 and 40 miles. AEO 2015 values of the proportion of fleet that is EV's + PHEVs were used for model years through 2014. After 2015, this proportion was increased, reaching a high of 15.4 percent in 2025 (just over 54,000 vehicles sold in that year), to represent compliance with California Air Resources Board's 10 percent ZEV rule, using data from an ARB-developed spreadsheet entitled, "ZEV Regulation Fleet Scenario – 10% Requirement." (The percentage is higher than 10 because PHEVs do not get a full ZEV credit.) Note that this is one scenario for compliance with the 10 percent rule, and other compliance scenarios representing different mixes of vehicle technology are possible. Because this scenario is modeling only minimum compliance with the regulatory standard, no further increase in PHEV/EV penetration is assumed beyond 2025.

Gasoline mpg was set to be the same as for a conventional internal combustion engine vehicle (see: auto_lighttruck_mpg.csv). Electric-use efficiency was set to be the same as for an EV (see: ev_characteristics.csv).

Scenarios: In Scenario D1, it is assumed that the State provides an additional subsidy of $25 million per year to incentivize EV/PHEV purchases. The new state incentive is assumed to be needed to overcome the difference in vehicle costs including purchase costs (based on ARB data[22]) offset by five years of fuel savings. This "net premium" is estimated to be about $10,000 in 2025. In essence, the analysis is assuming that EVs and conventional vehicles will have comparable performance in other respects, and that the main barrier to consumers adopting EVs on a widespread basis is the cost differential. The subsidy is assumed to be provided to vehicle manufacturers to cover the incremental cost of an EV as compared to a conventional internal combustion engine vehicle. In essence, the analysis is assuming that EVs and conventional vehicles will have comparable performance in other respects, and that the main barrier to consumers adopting EVs on a widespread basis is the cost differential. The subsidy would only be provided for each vehicle that is sold above and beyond the number needed to meet the 10 percent ZEV requirement.

The subsidy therefore leverages another 2,518 PHEV and EV sales in that year (Table 4.10). After 2030, the price differential continues to fall closer to zero. The subsidy model is discontinued at this point because it would ultimately lead to a number of vehicle sales approaching infinity, which is unrealistic. Instead the impact is continued at 2030 levels indefinitely.

Table 4.10 Incremental Cost Assumptions for EVs

Table Header	2016	2020	2025	2030	2035
Incremental capital cost					
EV	$27,406	$22,524	$16,422	$10,320	$4,218
PHEV	$19,162	$15,252	$10,365	$5,477	$590
Net incremental cost considering 5 year fuel savings					
EV	$21,948	$17,585	$12,296	$6,729	$1,090
PHEV	$16,624	$12,973	$8,493	$3,873	$-
Average	$18,025	$14,594	$9,927	$4,950	$411
Impacts of MA Subsidy					
Additional new vehicles	1,387	1,713	2,518	5,050	N/A
% of total sales	0.4%	0.5%	0.7%	1.4%	N/A

The analysis also accounts for the potential impacts of higher vehicle prices on new vehicle sales in all scenarios. It is assumed that vehicle manufacturers spread out the additional costs of complying with the California 10 percent rule (which is included in Scenario B) over all vehicles sold. With the 10 percent rule in place, the average purchase price in 2025 of any new light vehicle therefore increases from $33,000 (2015, based on Kelley Blue Book) to $34,529. An elasticity of sales with respect to price of -1.0 is assumed.[23] Sales decline by 4.6 percent and the average age of the vehicle fleet increases proportionately as people hold on to vehicles longer. This age adjustment was fed back into the EERPAT model through the age_adj.csv input, for all scenarios.

Scenarios B and D1 assume that the regulations and incentives provided through 2025 are not enough to get PHEVs and EVs "over the hump" to being widely marketable and cost-competitive. Scenario D2 is a

[22] California Air Resources Board. "Emissions Data" – Compliance Cost Sheet. http://www.arb.ca.gov/msprog/clean_cars/clean_cars_ab1085/clean_cars_ab1085.htm.

[23] EPA MY2017–2015 GHG/FE stds RIA p. 8-1, citing earlier sources.

hypothetical scenario in which the technology is assumed to take off and PHEV and EV sales continue on an upward trajectory without further State subsidy after 2025. This trajectory is based on an ARB scenario that shows the proportion of PHEV/EV sales increasing to 30 percent in 2030, and continuing to increase to a maximum of 87 percent in 2045 and beyond.

4.2.29 power_co2.csv

File description: This file contains a table of county-specific average pounds of CO_2e generated per kilowatt hour of electricity consumed by the end user by forecast year. Emissions rates in this file are end-user values rather than source values, thus, they include power transmission loss effects representing full CO_2e emissions for EVs.

Current levels and baseline forecast: This analysis measured only emissions from the transportation sector. Electricity emissions are not included in the transportation sector and therefore are not included in the analysis. All values were set to zero.

Scenarios: Values were set to zero for all scenarios.

4.2.30 regional_inc_prop.csv

File description: This file relates the ratios of average per capita income for each region of the State to the overall statewide average per capita income.

Source(s): Data prepared by CTPS based on outputs of the GreenSTEP household income model.

Scenarios: Values of this input were not varied by scenario.

4.2.31 run_parameters.txt

File description: This is a text file that identifies whether the scenario is a base scenario or not, what the name of the base scenario is, and what forecast years to run the model for. The forecast years to choose from are between 1990 and 2050 in increments of five years.

4.2.32 speed_smooth_ecodrive.csv

File description: This file contains four types of values characterizing speed smoothing and ecodriving programs, including the portions of maximum freeway and arterial speed smoothing benefits, and the portions of light and heavy vehicle drivers that eco-drive (redundant with the eco_tire input).

Current levels and baseline forecast: Speed smoothing was not tested; therefore all input values were set to zero.

Scenarios: All input values were set to zero.

4.2.33 tdm.csv

File description: This file contains a table of factors identifying the proportion of metropolitan area employees or households that participate in travel demand management (TDM) programs in each metropolitan area by forecast year. The values are from 0 to 1 where 1 means that everyone in the entire metropolitan area participates. The TDM parameters are as follows:

- PropWrkEco – the proportion of employees participating in employee commute option programs;
- ImpPropGoal – percentage of households participating in an individualized marketing program;
- EcoReduction – reduction in commute daily VMT by households participating in employee commute option programs; and[24]
- ImpReduction – reduction in daily VMT by households participating in individualized marketing programs.

Current levels and baseline forecast: Individualized marketing programs were not analyzed in this study so the values for participation and VMT reduction were set to zero. A variety of data sources were investigated to create the employee commute option inputs.

There is an active set of TDM programs in Massachusetts. MassRIDES, run by MassDOT, works with both employers and commuters within the Commonwealth to promote the use of commute options. 12 Transportation Management Associations (TMA) provide similar services in specific areas and are associated under the MassCommute umbrella[25]. Program statistics for MassRIDES and MassCommute were obtained through MassDOT, including number of member employers, employees served through these employers, and the number of employers taking advantage of specific measures offered through each program (e.g., vanpool, guaranteed ride home). The number of employees also served was compared to the total number of employees at firms in the State, as obtained from a CTPS database. The statistics are shown in Table 4.11. Statewide, about one-quarter of workers currently are covered through either MassRIDES or MassCommute. Table 4.12 shows the percent of specific TDM strategies offered by MassRIDES employer partners (some partners offer more than one strategy).

Table 4.11 TDM Program Coverage

Region/Program	Members[a]	Employees Served[a]	Total Employers in Region	Total Employees in Region	Employer Coverage	Employee Coverage
MassCommute TMAs – MAPC	221	279,138	133,674	1,853,141	0.2%	15.1%
MassCommute TMAs – MVPC	69	7,573	11,532	145,374	0.6%	5.2%
MassRIDES (statewide)	336	515,821	N/A	3,199,467	N/A	16.1%
MassRIDES + MassCommute	627	802,532	N/A	3,199,467	N/A	25.1%

[a] Average of four quarters in 2014.

[24] Specifically, this value was interpreted as the average commute VMT reduction across the set of workers exposed to TDM programs (i.e., at worksites where TDM programs are offered) – not for the set of workers actually taking advantage of these programs and changing their commute pattern.

[25] The number of TMAs is in the process of expanding to 15 during the development of this report.

Table 4.12 MassRIDES Participants – TDM Measures Offered

Measure	Firms That Offer	Percentage of Total Firms
Emergency Ride Home	121	35%
Preferential Parking	67	20%
Employer Provided Incentives/Rewards	20	6%
Shared Vehicles through Employer	23	7%
Transit Subsidy through Employer	42	12%
Vanpool Subsidy through Employer	15	4%
Pretax Payroll Deductions through Employer	36	11%
Parking Cashout through Employer	4	1%
Discounted Parking through Employer	6	2%
Formal Telework Program through Employer	36	11%
Formal Staggered and/or Flex Time through Employer	30	9%
Formal Compressed Work Week through Employer	11	3%
Employer LEED Certification	12	4%
Shuttle Service through Employer	40	12%
Total Firms	**342**	

The 2010/2011 Massachusetts Household Travel Survey also provides some information on TDM programs, but only for availability of and participation in telecommuting and flex time (including 4/40 or 9/80 work weeks). About 24 percent of respondents statewide reported telecommuting, and about 2.7 percent participated in either a 4/40 or 9/80 flex time program.

MassRIDES and MassCommute provide some data on program activity, as observed through the NuRide ridematching, tracking, and incentive program. NuRide reports total riders, active riders, and reduced car trips, VMT, and emissions, for workers registered with NuRide. Program reports were obtained for each region of the State. However, the NuRide data include only a subset of workers taking advantage of any type of TDM offering. For example, the NuRide data report that in 2014 about 3.5 percent of employees served at MassRIDES sites were registered with NuRide; 1.9 percent in 2014 were registered "non-SOV commuters"; and 0.1 percent of all served employees (1.7 percent of NuRide registrants) converted from SOV to non-SOV commute or increased the frequency of non-SOV commuting.

The Center for Urban Transportation Research at the University of South Florida has developed a model called TRIMMS (Trip Reduction Impacts of Mobility Management Strategies) that is intended for evaluating the VMT and emissions impacts of TDM programs if program offerings are known. TRIMMS was run for different sets of program offerings typically provided through MassRIDES and MassCommute. The model estimates a VMT reduction of up to 5.3 percent at affected worksites with a full transit subsidy, or 3.2 to 4.2 percent with other programs, with a number of scenarios showing a 3.5 percent reduction.[26] The model outputs show little variation depending upon the specific set of TDM measures offered.

[26] Programs tested included transit subsidy, vanpool subsidy, flex time, telework, and emergency ride home.

Considering all this information, the statewide average value of PropWrkEco was set at 0.25, reflecting the statewide average exposure rate to TDM programs. However, this was adjusted for each region based on NuRide participation, by comparing total NuRide participants with total employment in that region. The adjustment factors and resulting values of PropWrkEco by region are shown in Table 4.13. It should be noted that NuRide participation is a small fraction of total workers and regional NuRide participation may or may not be proportional to participation in other TDM programs.

Table 4.13 Estimated Employer Commute Program Participation Rates by Region

Region	Total NuRiders	2010 Regional Employment	NuRiders, % of 2010 Employment	Scale Factor	PrpWrkEco
Berkshire	109	60,150	0.18%	0.38	0.09
Boston Regions 1, 2, 3	10,608	1,853,141	0.57%	1.20	0.30
Cape Cod	185	88,596	0.21%	0.44	0.11
Central Massachusetts	1,388	224,059	0.62%	1.30	0.32
Franklin	315	25,684	1.23%	2.57	0.50[a]
Merrimack Valley	316	145,374	0.22%	0.46	0.11
Montachusett	271	77,199	0.35%	0.73	0.18
Northern Middlesex	509	119,332	0.43%	0.89	0.22
Old Colony	328	110,946	0.30%	0.62	0.15
Pioneer Valley	1,086	252,156	0.43%	0.90	0.23
Southern Massachusetts	165	229,400	0.07%	0.15	0.04
Statewide	**15,285**	**3,199,467**	**0.48%**	**1.00**	**0.25**

[a] Participation in the Franklin COG region was capped at 50 percent because the originally estimated level of 64 percent seemed high.

The value for EcoReduction was set to 0.035, indicating an average 3.5 percent reduction in VMT for participating households (workers with TDM programs offered at the workplace). This value is based on the TRIMMS model results and also is consistent with the consultants' professional judgment regarding the magnitude of impact of TDM programs, considering research from across the U.S. The higher TRIMMS values (up to 5.3 percent) were not used because these are based on a full transit subsidy which is only offered by a small percentage of firms.

Scenarios: TDM programs typically target the largest employers, since this will yield the greatest net impact per unit of outreach effort, and since some TDM measures can be more effective at larger sites where there is a critical mass of employees (e.g., ridesharing, vanpool). The data in Table 4.14 show that the average firm size served is about 1,200 in the MAPC region, 100 in the MVPC region, and over 1,500 in the MassRIDES program.

The CTPS employer data for eastern Massachusetts were used to examine the distribution of firms and employees by employer size. Table 4.14 shows this distribution (excluding agriculture and mining, transportation/communications, and wholesale trade activities as these types of employment are less amenable to TDM). About 24 percent of eastern Massachusetts workers are in organizations over 250, representing about 0.4 percent of the State's firms. About 37 percent of workers are in organizations over 100, representing about 1.5 percent of the State's employers. A scenario was therefore created in which the statewide proportion of workers was increased to 37 percent – assuming that all organizations of over 100 people (except for excluded industries) were reached by TDM programs through MassRIDES or MassCommute. Existing TDM participation in each region was increased proportionately (by 37/25 = 1.48) starting in 2020. The resulting values for PropWrkEco are shown in Table 4.15. The value for EcoReduction was left unchanged.

As shown in Table 4.14 there are 3.4 times as many employers in the >100 size range than in the >250 size range in the CTPS data. Multiplying 2014 participation (627) by 3.4 gives a total of about 2,100 employers that would need to be reached to expand the program to the new level.

Table 4.14 Distribution of Eastern Massachusetts Employment by Employer Size

		All	> 50	> 100	> 250	> 500
Eastern MA – Percentage	Employers	83.5%	4.2%	1.5%	0.4%	0.2%
	Employees	87.7%	50.7%	36.6%	24.4%	17.8%
Eastern MA – Total	Employers	148,539	7,474	2,602	773	324
	Employees	2,099,232	1,215,179	875,813	584,334	425,781

Table 4.15 Scenario 1 Values for Employee Commute Program

Region	Baseline PrpWrkEco	Scen 1 PrpWrkEco
Berkshire	0.09	0.14
Boston Region 1 (Suffolk)	0.30	0.44
Boston Region 2 (Essex, Middlesex, Worcester)	0.30	0.44
Boston Region 3 (Norfolk, Plymouth)	0.30	0.44
Cape Cod	0.11	0.16
Central Massachusetts	0.32	0.48
Franklin	0.50	0.74
Merrimack Valley	0.11	0.17
Montachusett	0.18	0.27

Region	Baseline PrpWrkEco	Scen 1 PrpWrkEco
Northern Middlesex	0.22	0.33
Old Colony	0.15	0.23
Pioneer Valley	0.23	0.33
Southern Massachusetts	0.04	0.06
Statewide	**0.25**	**0.37**

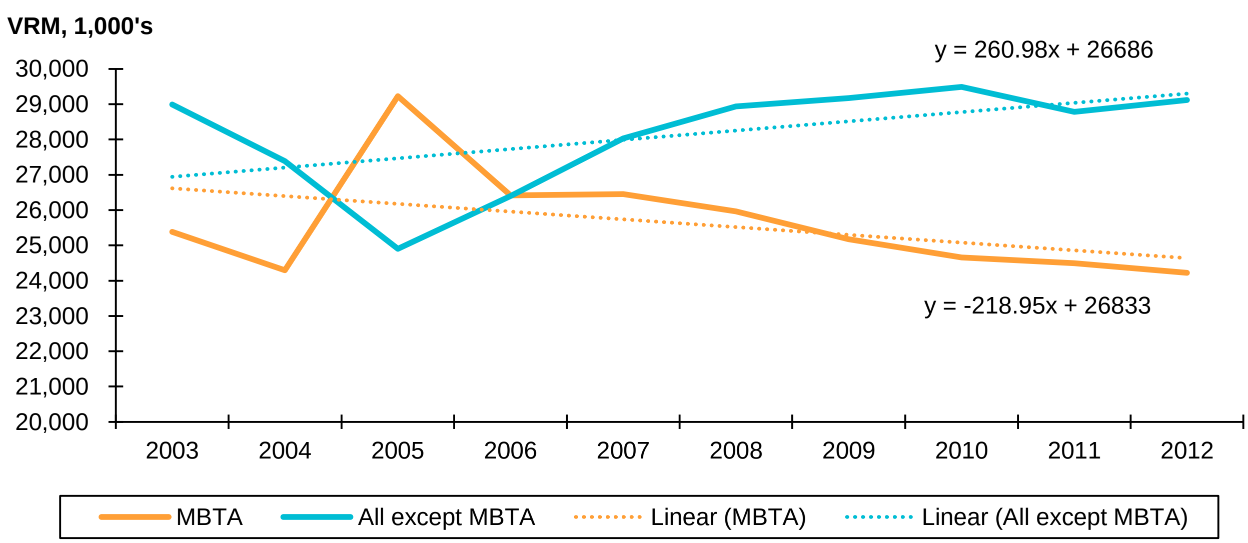
4.2.34 transit_growth.csv

File description: This file contains information about transit revenue mile growth relative to the base year and the proportion of transit revenue mile growth that is electrified rail transit. The file contains one row per metropolitan area for each of the following variables:

- RevMiCapGrowth – the ratio of future transit revenue miles to base year transit revenue miles. A value of one indicates that revenue miles do not grow, stay the same from year to year, less than one means that revenue miles decrease, and more than one means that revenue miles increase. This variable is expressed on a per-capita basis, so that a value of one means that revenue-miles per capita remain constant.
- PctElectric – the proportion of transit revenue miles that are electrified rail transit.

Current levels and baseline forecast: Vehicle revenue-miles for each transit operator in Massachusetts were obtained from the National Transit Database for each year 2003 through 2012. Because the non-MBTA operators are relatively small they were grouped together, so that VRM trends are examined for the MBTA and for other operators. Demand-response services were excluded. MBTA bus services also were evaluated separately from rail. The MBTA showed a modest decline in bus VRM over that period while other operators showed a modest increase (Figure 4.5).

Figure 4.5 Trends in Fixed-Route Bus Vehicle Revenue-Miles



The trendlines were used in combination with MassDOT population estimates and forecasts at 10 year intervals (2000 to 2040) to estimate VRM per capita for each five-year increment required for EERPAT. The Green Line and Silver Line extensions were added starting in 2020 but only increase MBTA VRM by 1.1 percent compared to projections. Since the MBTA showed a declining trendline, it was decided instead to use a flat (1.0) ratio of VMT per capita for the baseline future years. The other RTAs show some growth in VRM per capita, but a baseline ratio of 1.0 also was used for these agencies assuming that further growth in service (beyond the rate of population growth) would not be supported without new revenue sources. A number of RTA and regional planning organization transportation plans include strategies to increase transit service but it is not clear to what extent funding has been identified to implement such increases.

Scenarios: The scenario tested was a simple 1 percent per capita annual increase for the MBTA (increasing by increments of 0.05 per 5-year interval) and a trendline increase for other RTAs. A simple two percent per capita annual increase in VRM per capita for all services also was tested and gave just over double the benefits (166,000 versus 73,000 annual tonnes GHG reduction). The resulting VRM/capita ratios for the baseline and alternative scenarios are shown in Table 4.16. Only the one percent scenario is presented in the final results.

Table 4.16 Transit Growth Scenarios: Ratio of VRM Growth to Population Growth

	2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
Trendline											
MBTA	1.06	1.03	1.00	0.97	0.94	0.90	0.86	0.83	0.81	0.78	0.75
Other RTAs	0.94	0.97	1.00	1.03	1.05	1.08	1.11	1.15	1.18	1.21	1.25
Baseline (Flatline)											
MBTA	1.06	1.03	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Other RTAs	0.94	0.97	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Scenario 1											
MBTA	1.06	1.03	1.00	1.00	1.05	1.10	1.15	1.20	1.25	1.30	1.35
Other RTAs	0.94	0.97	1.00	1.00	1.05	1.08	1.11	1.15	1.18	1.21	1.25
Scenario 2[a]											
MBTA	1.06	1.03	1.00	1.00	1.10	1.20	1.30	1.40	1.50	1.60	1.70
Other RTAs	0.94	0.97	1.00	1.00	1.10	1.20	1.30	1.40	1.50	1.60	1.70

[a] Not included in final results shown in Section 1.0.

4.2.35 ugb_area_growth_rates.csv

File description: This file contains a table of growth rates of urban growth boundary areas relative to urban population growth rates for metropolitan and other urban areas (town) in each MPO.

Current levels and baseline forecast: Urban growth boundaries do not exist in Massachusetts, so all are set to zero. What this effectively means is that there is an urban growth boundary set at the base year extent of urbanization and that this area does not grow over time.

4.2.36 urban_rural_growth_splits.csv

File description: This file contains a table of the proportions of population growth in each MPO that will occur in metropolitan, other urban (town), and rural portions of the county. It is used to allocate population growth by area type and allows the impact of land use policies to be tested.

Current levels and baseline forecast: Population by TAZ for year 2000 and population projections by TAZ for year 2020 prepared by CTPS were the source data to develop this input file. For each TAZ, an area type (i.e., metropolitan, other urban, or rural) was assigned based on the definitions in section 7.1.3 of the EERPAT User's Guide. Some adjustments were made to ensure that the assignments better align with the actual condition in Massachusetts.[27] The difference of population between 2010 and 2020 were then summed by MPO and by area type. The percentages of population growth in each MPO that are projected to occur in metropolitan, other urban and rural areas were calculated respectively. When an area type has negative growth, the respective percentage of growth was set to zero. When all area types of an MPO have negative growth, the area type that has the smallest share of population decline was set to have 100 percent of growth and the others were set to zero so that the sum was 100 percent as required by EERPAT.

[27] If the total population of a TAZ is over 2,500 or if the population density is over 1,000, then it is classified as "metropolitan." If the total population of a TAZ is over 1,000 or if the population density is over 500, then it is classified as "Town" (i.e., other urban). If none of the other conditions is met, the TAZ is classified as "Rural."

5.0 Model Calibration

Once basic inputs for historical and current years were developed, the model was calibrated against known data sources for household income, motor vehicle registrations, VMT, and motor fuel sales.

5.1 Income

This item, specifically the output, inc.CoDt.csv, was calibrated against 2014 income data from the Bureau of Economic Analysis (BEA). Before calibrating, the income output of the model was significantly lower (close to 50 percent) than that from the BEA data. After examining the model scripts, it was found that the main script did not correctly read in the reestimated household income model due to a version control problem. To fix it, a new income model and a new predictIncome function were developed and replaced the existing ones in the scripts. This also enables the calculation of MPO-specific scaling factors (stored in income_dispersion_factors.csv) which allows modeled outputs to be closer to the actual condition. The difference was reduced to about 1.6 percent after the model modifications.

5.2 Vehicle Ownership

This item, specifically the output, VehiclePopulation.csv, was calibrated against 2013 motor vehicle registrations from the Massachusetts Registry of Motor Vehicles. After calibrating income in the previous step, the initial output of the model showed a total of 5,553,064 light vehicles (automobiles and light-duty trucks). This was 15.6 percent higher than the total of 4,802,239 light vehicles registered in the State in 2013. The difference was reduced to 1.0 percent by tweaking the vehicle ownership adjustment factors in the adj_veh_own.csv file. The breakdown of households by the number of vehicles per driving age population in VehPerDrvAgePop.csv was analyzed to help come up with the adjustment factors for the "trial-and-error" process.

5.3 Vehicle-Miles of Travel

The outputs related to VMT, Dvmt.CoDt.csv and CommVehDvmt.CoDt.csv, were calibrated against 2015 daily VMT data provided by MassDOT and FHWA's Highway Statistics 2013. After calibrating the vehicle ownership, the initial output of the model showed a total of 179,248,032 light vehicle daily VMT statewide. This was 24.5 percent higher than the total of 144,005,993 daily VMT as reported by Highway Statistics. At the MPO level, comparing the modeled outputs to VMT data provided by MassDOT, overprediction of the model was found across the State at varying degrees except for the Boston core (see Table 5.1). Overprediction was the greatest in rural areas of central and western Massachusetts and the Cape and islands (Martha's Vineyard and Nantucket). Because of the regional discrepancies, three adjustment factors – rural (0.62), suburban (0.84) and urban core (1.00) – were applied in the *VmtAdjFactor* column in the County_Group.csv file. The difference at the statewide level was reduced to less than 1 percent as a result. For all but one region, the difference was reduced to be around or less than 10 percent.

EERPAT does provide an additional way to make VMT adjustment. The file hh_dvmt_to_road_dvmt.csv can be used to convert household VMT estimated by the model into roadway VMT in metropolitan area. This allows further calibration at the roadway level if good validation targets exist.

Table 5.1 Comparison of Observed and Modeled VMT by Region

Region	Light Vehicle VMT from MassDOT	EERPAT Original Difference	Calibration Area	EERPAT Difference After Calibration
Berkshire	2,266,351	65.9%	rural	10.3%
Boston Region 1	10,160,776	-16.2%	urban core	-6.6%
Boston Region 2	39,371,387	18.7%	suburban	1.6%
Boston Region 3	18,504,534	19.8%	suburban	6.2%
Cape Cod and Islands	4,793,344	59.5%	rural	8.6%
Central Mass.	12,567,439	24.8%	suburban	6.3%
Franklin	1,533,056	39.9%	rural	-6.9%
Merrimack Valley	9,639,535	0.9%	suburban	-14.4%
Montachusett	4,624,892	43.8%	rural	-4.4%
Northern Middlesex	7,140,534	16.9%	suburban	3.6%
Old Colony	6,916,054	13.9%	suburban	-1.0%
Pioneer Valley	10,628,382	56.6%	rural	0.2%
Southern Mass.	14,519,140	20.8%	suburban	1.8%
Statewide	**142,665,423**	**21.6%**		**0.9%**

5.4 Motor Fuel Use

This item, specifically the Fuel and Power Use Summary table produced by the model after model run completes (assembled based on a number of output files), was calibrated against the motor fuel sales data from Highway Statistics 2014 and energy consumption data from NTD 2013. After calibrating the VMT, the initial outputs of the model showed an underprediction of fuel use by light vehicle, bus and heavy truck by about 16 percent overall, as well as an overprediction of electric power use by about 77 percent. By adjusting down the fuel economy of auto, light truck and bus, and adjusting up the energy efficiency of rail in auto_lighttruck_mpg.csv and hvy_veh_mpg_mpk.csv respectively, the difference in terms of fuel use was reduced to 1.2 percent while the difference in terms of power use was reduced to 2.2 percent. The same percentage adjustment was applied to all vehicle types and model years.

5.5 Reasons for Differences in Modeled versus Observed Data

No model is perfect, and any model typically needs to be calibrated against real-world data. Furthermore, the data sources available for calibration are not always perfectly matched to the model outputs. Some potential reasons for the differences in initial model output versus observed data include:

- EERPAT was built on national data (except for submodels estimated on Oregon data, which were reestimated using Massachusetts data). Households in Massachusetts may generate different travel patterns than similar demographics in other states. Lower automobile ownership and VMT could be explained in part by geographic factors such as more compact settlement patterns and better transit service than in most parts of the United States.

- EERPAT VMT is based on household-generated VMT, whereas MassDOT or Highway Statistics reports VMT traveled on roadways within the State. If Massachusetts households were putting more of their mileage on out-of-state roads than out-of-state households were putting on Massachusetts roads, that could help explain why EERPAT estimates higher VMT than HPMS.

- VMT as reported by MassDOT or in Highway Statistics is based on sampling to estimate a statewide VMT inventory and may not be completely accurate. For example, vehicle counts are not done on local roads. There is an adjustment factor to scale up major road VMT to local roads, but it could be too small.

- Cars in Massachusetts could get lower fuel economy than average in the U.S., for example, due to lower travel speeds or more congestion.

- As with VMT, Highway Statistics fuel sales data are based on sales within the State boundaries, not fuel used by Massachusetts households. People might buy more gas in Massachusetts and drive out of state, than buy gas in other states and drive into Massachusetts.

6.0 Policy Costs

Rough cost estimates were made for each policy tested to assist MassDOT in evaluating the implementation costs of policies as compared to their GHG benefits. These cost estimates should be treated as planning-level estimates and are not based on a detailed evaluation. Costs are incremental for Scenario C or D policies as compared to the baseline Scenario B. The costs are public-sector implementation costs; any potential new State revenues also are noted. A full cost-benefit or social cost analysis, considering costs and benefits (monetary and otherwise) to consumers and businesses, was beyond the scope of this effort.

6.1 Scenario C – Additional MassDOT Policies

6.1.1 Transit Investment and Service

Net Public-Sector Cost or Revenue Impact: Scenario C, a 1 percent simple annual growth in VRM per capita for the MBTA and 0.8 percent for other agencies, is estimated to increase annual operating costs (net of additional fare revenues) by $44 million in 2020, $127 million in 2030, and $210 million in 2040. A sensitivity analysis using a 2.0 percent simple annual growth in VRM per capita is estimated to increase net annual operating costs by $87 million in 2020, $262 million in 2030, and $437 million in 2040. Significant additional capital costs would likely be needed to accommodate this increase in service, especially if service is to be expanded during peak periods.

Basis for Cost/Revenue Estimate: Data from the 2013 National Transit Database show a gross operating expense of $16.37 per VRM for MBTA bus and rail, and $6.68 for other RTA buses. The operating cost per VRM was assumed to remain constant under system expansion (which also would imply keeping a similar mix of service types). These costs were applied to the VRM data shown in transit_growth.csv. The NTD data also showed a 40.3 percent statewide average farebox recovery ratio, which was assumed to remain the same after service expansions.

6.1.2 Hybrid and Electric Buses

Net Public-Sector Cost or Revenue Impact: An additional $30 million in additional annual bus purchase costs is estimated for either hybrid or electric buses. Up to $7 million in annual fuel savings are estimated for hybrids (once the entire fleet is converted), increasing up to $23 million for electric buses. Minor capital costs also could be incurred for recharging infrastructure (perhaps $1 to $5 million in one-time expenses).

Basis for Cost/Revenue Estimate: The NTD identifies 1,846 buses and articulated buses in public agency bus fleets across the State in 2014. With an average life span of 12 years, about 150 buses per year need to be replaced on average.

A review of hybrid and diesel bus costs suggests that a 40' diesel bus typically costs around $400,000 and a 40' hybrid bus nearly 50 percent more than that.[28] Electric bus costs were over $1 million recently but appear to be dropping. For example, Proterra cites a cost of $500,000 to $850,000 for a 35' or 40' electric

[28] See, for example, Metropolitan Transportation Commission, FY2011 MTC Transit Capital Priorities Criteria; http://www.therta.com/news/2012/03/new-wrta-buses-to-roll-into-worcester/; and http://media.mlive.com/annarbornews_impact/other/hybrid_bus_report_Oct2014.pdf.

bus[29] and BYD cites a range of about $400,000 to $600,000.[30] For this analysis, it is assumed/that by 2020, electric bus costs will be similar to hybrid buses, around 50 percent more expensive than diesel, or $600,000 each.

Diesel fuel costs are the same as assumed for other modes (see costs.csv). An electricity cost of $0.08/kwh is used.[31] Hybrid buses are assumed to be 20 percent more efficient than diesel buses. An electric bus energy efficiency ratio (GGE–electric/GGE–diesel) of 3.0 is used, which is the ratio assumed for light-duty electric vehicles in a 2011 NESCAUM study of a Low-Carbon Fuel Standard.[32] The cost of recharging stations suitable for bus yards was not investigated, but at a conservative value of $5,000 per station with 500 stations the one-time cost would be $2.5 million.

There is considerable uncertainty in the costs and efficiency associated with electric buses. The technology is evolving rapidly and manufacturers have claimed life-cycle cost savings although this analysis does not show a net savings. Cost savings also will be very sensitive to fuel prices, and any additional maintenance costs or cost savings are not considered.

6.1.3 Bicycle Infrastructure

Net Public-Sector Cost or Revenue Impact: Additional annual investment of $44 million for shared-use paths and $11 million for on-road facilities over the 2015 to 2030 period, for a total of $55 million. This is in addition to investment required to meet 20-year plan estimates of 785 new miles of bicycle facilities as included in Scenario B.

Basis for Cost/Revenue Estimate: The number of miles of new bicycle facilities needed to achieve a tripling of bicycle mode share (Scenario C) were "back-calculated" by estimating the new bicycle miles of travel needed to triple 2011 levels (from CTPS analysis of the MAHTS) to 225 million miles annually statewide, then applying a factor 126,000 new bicycle miles traveled per new facility-mile (see 4.2.19, light_vehicles.csv). The result was a need for about 1,000 miles of new facilities (beyond the 785 miles identified in 20-year plans). This was assumed to include 33 percent off-street paths (331 miles) and 67 percent on-street facilities (673 miles).[33] Unit costs were assigned of $2 million per mile of shared-use path (per CTPS data), and $250,000 per mile of on-road facility, which assumes a mix of bike lanes (typically $10,000 to $50,000 per mile), protected paths ($500,000 to $1 million per mile), and bike boulevards or "neighborways" (around $200,000 to $300,000 per mile).[34] These costs are incremental to other Complete

[29] http://cleantechnica.com/2015/10/05/proterras-diesel-killing-electric-buses-killing-cleantechnica-exclusive-interview/.

[30] https://en.wikipedia.org/wiki/BYD_electric_bus.

[31] Correspondence with Jules Williams, MassDOT, 3/7/2016.

[32] Northeast States for Coordinated Air Use Management (2011). "Economic Analysis of a Program to Promote Clean Transportation Fuels in the Northeast/Mid-Atlantic Region."

[33] The proportion of paths versus on-road facilities identified in five-year plans was 42 percent paths and 58 percent on-road facilities (for facilities with a type identified). It was assumed that this mix would shift over time to include a larger proportion of on-road facilities.

[34] Bushell, M.A.; B.W. Poole, C.V. Zageer, and D.A. Rodriguez (2013). Costs for Pedestrian and Bicyclist Infrastructure Improvements: A Resource for Researchers, Engineers, Planners, and the General Public. Prepared by UNC Highway Safety Research Center for the Federal Highway Administration.

Streets reconstruction costs (CTPS estimates total reconstruction costs for a Complete Streets project of $6 million per mile).[35]

It should be noted that not all plans specified the type of facility, and also the future mix of on-street versus off-street facilities may shift. Furthermore, costs per mile vary widely by facility type. The bicycle investment cost estimate should therefore be viewed as only a very rough (order-of-magnitude) estimate.

The Scenario C investment of an additional 1,000 new facility-miles over 15 years plus 785 miles in Scenario B also can be compared with a total of 9,065 miles of urban arterial and collector streets in Massachusetts.[36]

6.1.4 Travel Demand Management

Net Public-Sector Cost or Revenue Impact: An additional $6 million in annual MassRIDES program expenses are assumed.

Basis for Cost/Revenue Estimate: Scenario B assumes that 25 percent of employees in suitable industries currently are reached by a TDM program (MassRIDES or one of the MassCommute program partners) (see tdm.csv). This is approximately the fraction of employees working at establishments with at least 250 workers. If the program were expanded to reach establishments with at least 100 workers, 37 percent of employees would be reached. There are 3.4 times as many establishments with at least 100 workers as there are with at least 250 workers. Multiplying the current MassRIDES program budget of $2.4 million by 3.4 yields an additional cost of $6 million. This assumes that the program cost is proportional to the number of employers reached. It also assumes that MassDOT's funding for TMAs through MassCommute (a line-item in the MassRIDES budget) can continue to leverage private funds at the same ratio to grow these TMAs.

6.1.5 Intelligent Transportation Systems

Net Public-Sector Cost or Revenue Impact: Expansion of freeway incident management is assumed to require $6 million in annual capital investment over 15 years plus $12 million in annual operating costs. Expanded signal coordination on State roads is assumed to require an annual investment of $2 million per year.

Basis for Cost/Revenue Estimate: Unit-cost estimates are based on a review of the U.S. DOT ITS Joint Program Office ITS Costs Database (http://www.itscosts.its.dot.gov/). Two freeway management system in Arizona cost between $200,000 and $250,000 per mile, including dynamic message signs, Closed Circuit Television cameras, traffic count stations, traffic interchange signal interconnections, fiber optic cable, and the associated communications system. A cost of $250,000 mile was applied to an additional 384 miles of limited-access highway segments in eastern and central Massachusetts identified in the MassDOT 2014 ITS Annual Report as having ITS either "in design" or identified in the ITS Strategic Plan as future corridors. Segment lengths were taken directly from the report for segments in design, and estimated using Google Earth for other segments.

[35] CTPS (2015). The Boston Region's Next Long-Range Transportation Plan - Scenario Planning Results. Accessed from http://www.ctps.org/data/html/plans/lrtp/charting/Charting_Progress_Scenario_Planning/index.html

[36] FHWA Highway Statistics 2013 Table HM-20, Public Road Length – Miles by Functional System.

Another study in the U.S. DOT database identified a general cost for adaptive signal control of approximately $65,000 per intersection. Seven other individual cases showed a range of $18,000 to $82,000 per intersection so the value of $65,000 was viewed as representative. This cost was applied to an additional 500 signals bringing the total with some level of coordination to 1,088 out of the 1,432 signals in the MassDOT inventory.[37] Additional benefits could be achieved on local roadway systems but an inventory of local signals was not available.

The annual operating cost per mile for a freeway management system was estimated as $30,000. This is based on the Moving Cooler study which estimated $18,000 per mile for incident management, $10,000 per mile for traveler information, and $2,000 per mile for dynamic message signs.[38] Annual operating and maintenance costs for traffic signal coordination systems are typically on the order of 10 percent of capital costs.

6.2 Scenario D – Other State and Local Policies

6.2.1 Land Use/Smart Growth

Net Public-Sector Cost or Revenue Impact: Implementation costs for this policy are not estimated but are likely to be modest.

Basis for Cost/Revenue Estimate: Modest state costs may be needed in the form of grants, incentives, or technical assistance to municipalities to assist in revising municipal codes. These planning-related costs are typically small compared to infrastructure investment costs and savings. For example, grants of $25,000 per municipality spread out over a period of 10 years would be less than $1 million per year.

Some long-term savings to municipal road and utility costs may be realized. For example, Burchell (2005) estimated a savings of $2,250 per unit in road, water, and sewer costs for compact versus sprawl development. At this level of cost savings, shifting an additional 30,000 households into mixed-use areas over the 2020 to 2030 timeframe (as proposed in Scenario D) would result in a long-term cost savings of over $60 million.

6.2.2 Electric Vehicles

Net Public-Sector Cost or Revenue Impact: The State is assumed to provide $25 million in annual subsidies to incentivize EV purchases.

Basis for Cost/Revenue Estimate: The $25 million subsidy is a policy assumption regarding the level of subsidy the Commonwealth might be willing to provide. A larger or smaller subsidy pool would allow for a correspondingly greater or lesser effect on EV sales and market penetration. The assumed impact of the subsidy on vehicle sales is described in the section, phev_characteristics.csv.

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[37] For reference, a study in New Jersey found 45 percent of the State's 2,562 traffic signals suitable for some level of interconnected coordination including 33 percent for some level of computerized control. See Allen, A. (2015). "Developing a Traffic Signal System Optimization Plan for New Jersey, USA." *ITE Journal*, September 2015.

[38] Cambridge Systematics (2009). *Moving Cooler: An Analysis of Transportation Strategies for Reducing Greenhouse Gas Emissions.* Prepared for Urban Land Institute. See Appendix C for cost information, which was in turn based on information in the U.S. DOT ITS Costs Database.

6.2.3 Mileage-Based Fee

Net Public-Sector Cost or Revenue Impact: Annual administrative costs of approximately $37 million year in 2030 are estimated. The State would take in approximately $365 million in annual revenue from the fee, although the fee could be designed to be revenue-neutral (by returning revenue to consumers through other channels such as an income or sales tax reduction).

Basis for Cost/Revenue Estimate: The fee level of 0.6 cents per mile was applied to EERPAT output of statewide VMT in 2030 (167 million daily). Administrative costs are estimated to be approximately 10 percent of revenues based on a review of mileage-based pricing program designs.[39] This estimate includes capital costs as well as annual administrative costs. There are low-capital options for a mileage-based fee program design such as annual self-reporting with audits, as well as high-capital options (e.g., on-board monitoring devices) with lower annual administrative costs. Costs may change in the future as technology evolves.

6.2.4 Congestion Pricing

Net Public-Sector Cost or Revenue Impact: Annual administrative costs of approximately $15 million year in 2030 are estimated for D1 (congestion pricing on existing tolled highways) or $135 million for D2 (expanding congestion pricing to all Boston area limited-access highways). The State would take in approximately $146 million in annual revenue under D1, or $1,350 million under D2, although the fee could be designed to be revenue-neutral (by returning revenue to consumers through other channels such as an income or sales tax reduction).

Basis for Cost/Revenue Estimate: EERPAT output shows a total 2030 annual VMT in the Boston area (model regions 1, 2, and 3) of 2,226 million under "severe" congestion and 1,587 million under "extreme" congestion. The congestion prices of $0.25 and $0.50 per mile were applied to these VMT levels respectively. Administrative costs were assumed to be 10 percent of annual revenues as described for the mileage-based fee. Actual administrative costs will depend upon the program design. For example, congestion pricing could be implemented simply by adjusting tolls at existing toll facilities based on time of day. Broader expansion would require installing additional toll gantries or piggybacking on another fee collection system (such as using on-board devices that are used for mileage-based fee monitoring).

6.2.5 Fuel Mix/Carbon Intensity

Net Public-Sector Cost or Revenue Impact: Implementation costs for this policy are not estimated but are likely to be modest.

Basis for Cost/Revenue Estimate: Implementation costs to the State would consist only of administrative and enforcement costs to establish and monitor a crediting system (or link with an existing one such as California's). Potentially higher costs would be borne by fuel producers and/or consumers; the magnitude of the cost will depend upon the difference in production costs between conventional and low-carbon fuels.

[39] For example, the Washington State Road Usage Charge Assessment – Preliminary Business Case Evaluation (2013) evaluated three concepts and finds the present value of application costs ranging from 7 to 13 percent of revenues.

6.2.6 Parking Pricing

Net Public-Sector Cost or Revenue Impact: Implementation costs for this policy are not estimated but are likely to be modest.

Basis for Cost/Revenue Estimate: Implementation costs will depend upon the specific mechanism for implementing parking pricing. In this analysis it is assumed that a requirement is established for municipalities to require paid parking in new developments in appropriate areas. The State would need to monitor municipalities for compliance. Municipal and/or state administrative costs could potentially be recovered if taxes were levied on parking supply. Some cost savings could be realized by developers and property owners from reduced parking needs/demand.

6.3 Comparison of Costs and Effectiveness

Policies can be arrayed based on their implementation costs as compared to their GHG reduction effectiveness. Figure 6.1 arrays policies on a graph with effectiveness on the horizontal axis and cost-effectiveness (based on implementation costs) on the vertical access. This simple cost-effectiveness measure, annual costs in 2030 divided by annual GHG reductions, is shown in Table 6.1. Because of the uncertainly underlying some of the cost and effectiveness estimates these numbers should be cited and used with caution.

Figure 6.1 Magnitude of Impact versus Cost-Effectiveness

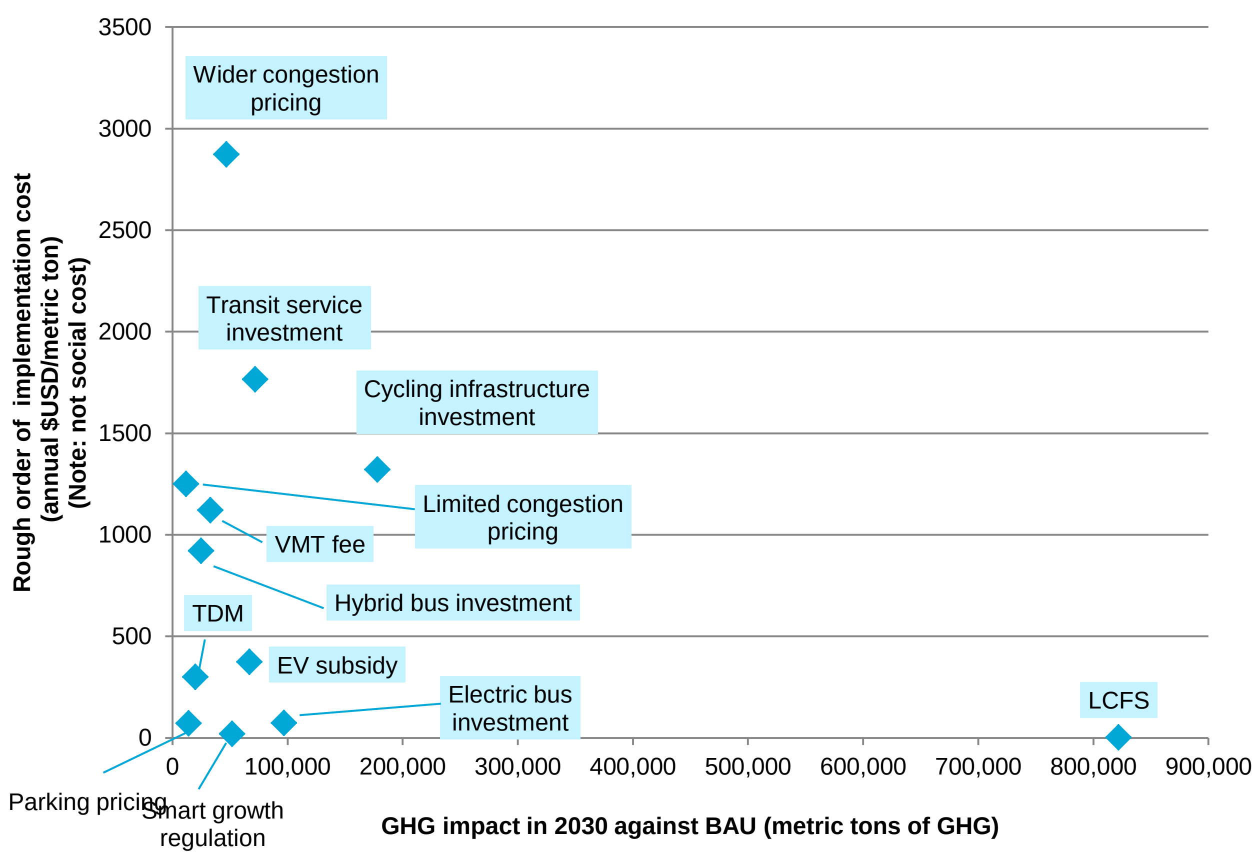

Table 6.1 Cost-Effectiveness Metric for GHG Reduction Policies in 2030

Policy	Annual Implementation Cost, $millions	Tonnes/Year GHG Reduction in 2030	Annual Cost/Tonne
Transit Investment/ Service	127	73,000	$1,700
Clean Buses – Hybrid	23	25,000	$920
Clean Buses – Electric	7	98,000	$71
Bicycle Infrastructure	91	180,000	$510
Travel Demand Management	6	20,000	$300
Intelligent Transportation Systems	20	(3,000)	NA
Land Use/Smart Growth	<1	53,000	$19
Electric Vehicles	25	68,000	$370
Mileage-Based Fee[a]	37	34,000	$1,100
Congestion Pricing – Tolled Highways[a]	15	12,000	$1,300
Congestion Pricing – All Boston Area Highways[a]	135	48,000	$2,800
Clean Fuels Standard	<1	831,000	$1
Parking Pricing	<1	14,000	$71

[a] Revenue from these policies is not included.

The data suggest the following groups of policies:

- Relatively low cost but low impact policies: ITS, TDM, congestion pricing on existing tolled highways, parking pricing;
- Land use is low cost and moderate impact (considering that impact will increase over time);
- Moderate cost, moderate impact policies: EV subsidies, clean buses, and VMT fee;
- Full congestion pricing, transit service, and bicycling are higher cost but higher impact; and
- A low-carbon fuel requirement is potentially low cost with high impact.

Note that pricing policies could be net revenue generators from the State's perspective. This graph is based on implementation costs, not including revenues. Also, many of the policies are "scalable" – higher or lower levels of investment would lead to correspondingly higher or lower GHG reductions.

This analysis shows only a limited snapshot of the costs and benefits of the various policies. Many of these policies may be worthwhile to implement for other reasons, such as accessibility, mobility/time savings, and safety. Furthermore, other social costs and benefits, such as costs or cost savings to travelers or improved air quality or public health, are beyond the scope of this analysis. Transportation policies and investments should be evaluated in a holistic manner; this analysis of GHG benefits provides one piece of information to assist in their evaluation.