BOSTON REGION METROPOLITAN PLANNING ORGANIZATION
Jamey Tesler, MassDOT Secretary and CEO and MPO Chair
Tegin L. Teich, Executive Director, MPO Staff

TECHNICAL MEMORANDUM

DATE: **March 6, 2013; Revised August 15, 2021**
TO: **MOVES Stakeholders**
FROM: **Anne McGahan, Mark Scannell, and Bruce Kaplan**
Central Transportation Planning Staff
RE: **MOVES Emission Factors and Travel Demand Model Application**

This memorandum outlines the assumptions and process for developing mobile source emission factors using the US Environmental Protection Agency's (EPA) Motor Vehicle Emission Simulator (MOVES) emission model for the Commonwealth of Massachusetts. MOVES is an emission modeling system that estimates mobile source emissions for criteria air pollutants and greenhouse gases (GHG). The MOVES model creates mobile source emissions estimates by running either in the *emission rate mode* or *inventory mode*. Because the Massachusetts Department of Transportation (MassDOT) chose to use emission factors in conjunction with the travel demand model, MOVES must be run in the emission rate mode. Using this mode, the Central Transportation Planning Staff (CTPS), MassDOT, and the Massachusetts Department of Environmental Protection (MassDEP) worked to develop a process to translate more than 23 million output records into a format that could be applied to the travel demand model to determine running emissions.

The first part of this memorandum explains the steps taken in March 2013 to develop the process. The second part discusses the ongoing process of developing mobile source emission factors and their application in the travel demand model. The emission factors are used for statewide transportation conformity work and all other air quality work done by MassDOT, CTPS, and the metropolitan planning organizations (MPO) in Massachusetts.

1 INITIAL PROCESS TO DEVELOP FACTORS IN EMISSION RATE MODE (MARCH 2013)

The following outlines the method that MassDEP and CTPS used in March 2013 to develop emission factors from the MOVES model output, which were then used to develop emission rates (measured in grams per distance) for inputs to the travel demand model. Initially, MassDEP ran the MOVES 2010b model for

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the year 2012 in the emission rate mode (as opposed to the inventory mode) for Middlesex County. Middlesex County was chosen as the representative county for the Boston Region MPO given its size and location in eastern Massachusetts. Inputs to the MOVES 2010b model were developed by MassDEP.

Once this method was perfected and approved by MassDEP and EPA, a similar process was used to develop emission rates for rural communities in western Massachusetts. Hampden County was selected to represent rural western communities in the MOVES model.

Both of the data sets for eastern and western Massachusetts were used to develop 2016 and future year emission factors using the version of the emission model, MOVES 2014a.

In November 2020, EPA updated the 2014b MOVES model to what is now the most current version—MOVES 3. The process for developing emission factors using the output files from the 2014b version of MOVES is the same process used for developing the MOVES 3 emission factors. Emission factors were updated in summer 2021 using MOVES 3, and are now available to be used in the Statewide Travel Demand Model to produce emissions for on-road sources.

1.1 MassDEP MOVES Output Files

In 2012, CTPS staff received a number of output files for Middlesex County from MassDEP. The MOVES model was run for Middlesex as a representative county in eastern Massachusetts because it would have taken too much time to run the model for the entire state. Three specific types of files provided emission rates under the categories outlined below:

- *Rates per Distance*: This file provides information in grams per vehicle per distance and presents the exhaust and evaporative emissions that occur while the vehicles are on “real roads.” These rates are applied to the outputs of the travel demand model by link. (These rates are referred to as *running emissions* in this memorandum.)
- *Rates per Vehicle*: This file provides information in grams per vehicle and presents the emissions from vehicle starts and extended idling, and some evaporative emissions (permeation and liquid leaks) from parked vehicles. These rates are multiplied by the total vehicle population for a specific area. (These rates are referred to as *stationary emissions* in this memorandum.)
- *Rates per Profile*: This file provides information in grams per vehicle and presents the vapor venting emissions from parked vehicles as rate per vehicle. These rates are also multiplied by the total vehicle population for

a specific area. (These rates are referred to as *stationary emissions* in this memorandum.)

CTPS received one *Rate per Profile* file, one *Rate per Vehicle* file, and 13 *Rate per Distance* files for each of the following vehicle types:

- Motorcycle—Vehicle Type 11
- Passenger car—Vehicle Type 21
- Passenger truck—Vehicle Type 31
- Light commercial truck—Vehicle Type 32
- Intercity bus—Vehicle Type 41
- Transit bus—Vehicle Type 42
- School bus—Vehicle Type 43
- Refuse truck—Vehicle Type 51
- Single unit short-haul truck—Vehicle Type 52
- Single unit long-haul truck—Vehicle Type 53
- Motor home—Vehicle Type 54
- Combination short-haul truck—Vehicle Type 61
- Combination long-haul truck—Vehicle Type 62

1.2 Running Emissions—Rate Per Distance

The running emission factors were derived from the *Rate per Distance* file. The 13 *Rate per Distance* files included a total of 23,176,706 records. CTPS staff met with staff of the MassDOT Office of Transportation Planning and MassDEP on December 4, 2012, to discuss the initial assumptions for translating those records into factors that could be applied to the travel demand model to determine running emissions. The first step was to determine the appropriate records to use for developing emission factors. The staffs reviewed the following data fields to create a set of records pertinent to the emission factor development:

- Days of the week
- Months of the year
- Emissions process
- Pollutant type
- Time of day
- Vehicle type
- Roadway type
- Speed bins
- Fuel type

Rate Per Distance Assumptions

Days of the Week

Weekday and weekend information was provided in MassDEP's MOVES output files. The travel demand model forecasts weekday travel only, so only the weekday records were used.

Months of the Year

Rates are calculated by month. As agreed, staff continued to use data from the January and July months—as was the case when the MOBILE6 emission factors were developed—to be consistent with past modeling methods.

Emissions Process

As described above, the *Rates per Distance* file provides information in grams per vehicle per distance and presents the exhaust and evaporative emissions that occur while the vehicles are on "real roads." Only the running exhaust rates were used to develop emission factors that will be applied to the results of the travel demand model.

Pollutant Type

Emission factors were developed for the following pollutants:

- Carbon monoxide (CO)
- Nitrogen Oxides (NOx)
- Volatile organic compounds (VOCs)
- Atmospheric carbon dioxide (CO_2)
- Primary exhaust particulate matter—10 microns or less (PM_{10}) (total)
- Primary exhaust particulate matter—2.5 microns or less ($PM_{2.5}$) (total)

Time of Day Rates

Rates are calculated by time of day. MassDEP's MOVES outputs included factors for each of the 24 hours on an average January and July day. Staff developed a composite factor for each of the timeframes represented in the travel demand model:

- AM period: 6:00 AM to 9:00 AM
- Midday period: 9:00 AM to 3:00 PM
- PM period: 3:00 PM to 6:00 PM
- Nighttime period: 6:00 PM to 6:00 AM

Staff discussed averaging and weighting rates by time period. Because there was a wider range of NOx rates by time period, passenger vehicles and trucks rates were reviewed to determine the differences in rates per hour, especially for

the nighttime period since it included 12 hours of rates. CTPS used an average rate for the AM, PM, and midday periods. For the nighttime period, an average rate for both passenger vehicles and short-haul trucks was calculated over the 12-hour period and compared to the rates from 6:00 PM to 6:00 AM. Staff determined that the 10:00 PM to 11:00 PM rate was a representative hour of travel and emission rate over the 12-hour nighttime period (see Attachment 1—Time of Day Rates for Passenger Vehicles and Attachment 2—Time of Day Rates for Short-haul Trucks.

Vehicle Type

There are 13 different vehicle types in the MOVES output. The transportation demand model looks at only two—passenger vehicles and commercial vehicles. Transit vehicle emissions are calculated outside of the travel demand model. Staff collapsed the MOVES vehicle types into three categories—passenger vehicles, commercial vehicles, and buses.

Staff initially reviewed vehicle registration data to determine the percentages of vehicle types at the state, MPO, and county levels to identify how to weight the emission factors by vehicle type to develop a composite for passenger and commercial vehicles. Since MassDEP used vehicle population numbers for Middlesex County in the MOVES model, CTPS staff decided to use the Middlesex percentages.

Staff then consolidated the vehicle types into passenger vehicles, commercial vehicles, and buses as follows:

Passenger Vehicles:

- Motorcycle (2.81%)
- Passenger car (64.95%)
- Passenger truck (32.24%)

Commercial Vehicles:

- Light commercial truck (80.92%)
- Refuse truck (0.24%)
- Single unit short-haul truck (13.26%)
- Single unit long-haul truck (0.62%)
- Combination short-haul truck (2.91%)
- Combination long-haul truck (2.05%)

Buses

Emissions from transit vehicles are calculated outside of the travel demand model. The transit bus outputs of the MOVES model can be used to determine

the emission factors for transit buses. The calculation for the stationary emissions (from the *Rates per Profile* and *Rates per Vehicle* files) requires multiplying the factor by the total number of vehicles. However, there needs to be further discussion about how to extract the factors from the *Rates per Distance* file to determine running emission factors when different assumptions are applied (road types, speed bins, time of day, etc.).

Other Vehicles

Some vehicle types were omitted. For example, the travel demand model does not account for school buses, motor homes, or intercity buses, so these were omitted.

Roadway Type

There are five classifications of roadways in the MOVES output. The definitions are as follows:

- *Off network*—All locations where the predominant activity is vehicle starts, parking, and idling (such as parking lots, truck stops, rest areas, freight terminals, and bus terminals)
- *Rural restricted access*—Rural highways that can only be accessed by an on-ramp; this classification corresponds to the classification of rural freeway in the travel demand model
- *Rural unrestricted access*—All other rural roads (arterials, connectors, and local streets); this classification corresponds to the classification of rural arterial in the travel demand model
- *Urban restricted access*—Urban highways that can only be accessed by an on-ramp; this classification corresponds to the classification of urban freeway in the travel demand model
- *Urban unrestricted access*—All other urban roads (arterials, connectors, and local streets); this classification corresponds to the classification of urban arterial in the travel demand model

The off-network rates were not provided and will not be used.

Speed Bins

Speeds in the travel demand model were consolidated to match the speed bins in the output of MOVES. The CTPS travel demand model does not use speeds higher than the posted speed limit. MOVES produces rates for vehicles traveling faster than 70 miles per hour. It is possible that some speed bins may not be used.

Fuel Type

The fuel types in the *Rate per Distance* file include gasoline, diesel, compressed natural gas, liquid petroleum gas, and electricity. MassDEP shared information about vehicle fuel type distribution based on data from the state's vehicle inspection and maintenance program. Because gasoline and diesel-powered vehicles are the most prevalent, MassDEP only used the data for gasoline and diesel fuel types for modeling purposes.

Staff spoke with Chris Porter from Cambridge Systematics regarding how hybrid vehicles could be accounted for in future year rates. Hybrids are held to the same vehicle tailpipe standards as gas- and diesel-powered vehicles, so the only real issue is the number of zero-emission or electric vehicles. As discussed, the number of those vehicles will depend upon the availability of infrastructure to accommodate the vehicles in the future. The main issue associated with hybrid vehicles is fuel economy. Hybrids are accounted for in the vehicle mix for Corporate Average Fuel Economy standards, which will be increasing in the future; some vehicles will have a higher miles-to-gallon ratio and others lower to average out to the standard.

It may be necessary to use different usage rates for the fuel types in the future years.

Rate Per Distance Process

The assumptions described above were applied to the 23,176,706 records to yield 6,144 emission factors that were used as input into a macro developed for post processing the outputs from the travel demand model. The macro calculated the total emissions for the 164-community modeled area in eastern Massachusetts. The process to arrive at the 6,144 emission factors took three steps:

Step 1: Reduce the data to only the months, days, process, and pollutants being considered.

2 months of data (January and July only) *multiplied by*

1 day class (weekday only) *multiplied by*

24 hours per day *multiplied by*

1 process (running exhaust only) *multiplied by*

6 pollutants (CO, NO_X, VOC, CO_2, PM_{10} and $PM_{2.5}$ only) *multiplied by*

4 road types *multiplied by*

16 speed bins *multiplied by*

9 vehicle types

Resulting in 165,888 factors (18,432 factors for each of the 9 vehicle types)

Step 2: Collapse 24 hours into four aggregate model periods.

The correspondence between the four aggregate model periods and the hours of day are as follows:

- AM peak period = hours 7-9
- Midday time period = hours 10-15
- PM peak period = hours 16-18
- Nighttime period = hour 23 (which is representative of the 12-hour time period)

Multiply 165,888 factors by 4/24 (24 hourly periods becoming four aggregate model time periods)

Resulting in 27,648 factors (**3,072 factors for each of the 9 vehicle types)**

Step 3: Collapse nine source types into two aggregate vehicle types (passenger and commercial vehicles).

- Passenger (sourceTypeID 11,21,31)
- Commercial (sourceTypeID 32,51,52,53,61,62)

Multiply 27,648 factors by 2/9 (nine source types becoming two aggregate vehicle types)

Resulting in 6,144 factors

These factors were used to post process the travel demand model data to determine the total emissions for the 164 communities in the CTPS model area.

1.3 Stationary Emissions—Rate Per Vehicle

Rate Per Vehicle Assumptions

A portion of the stationary emission factors were derived from the *Rate Per Vehicle* files. The assumptions for determining the appropriate records to use in developing emission factors were the same for this category of stationary emissions as they were for the running emissions:

- Days of the week
- Months of the year

- Pollutant type

As in the development of running emissions, composite rates were developed by collapsing the following classifications:

- Time of day
- Vehicle type

Unlike the *Rate per Distance* calculations, the *Rate per Vehicle* calculations take into account emissions from multiple processes. The file provides information in grams per vehicle and presents the emissions from vehicle starts and extended idling, and some evaporative emissions (permeation and liquid leaks) from parked vehicles. The specific emission processes that are used from this file are as follows:

- Start exhaust
- Evaporative permeation
- Evaporative fuel leaks
- Crankcase start exhaust
- Crankcase extended idle exhaust
- Refueling displacement vapor loss
- Refueling spillage loss
- Extended idle exhaust

Emission processes that were not accounted for include the following:

- Brakewear
- Tirewear
- Crankcase running exhaust

Rate Per Vehicle Process

The first three steps for calculating rate per vehicle are similar to the steps described for calculating rate per distance.

Step 1: As described above, the rate per distance input provided by MassDEP was split into 13 individual files, differentiated by source type. In the case of rate per vehicle, the input was provided in a single file, containing records for all source types. To facilitate a process similar to that used for rate per distance, this single file was split into nine individual files, corresponding to those source types being considered. During this processing, the data were further reduced to only the months, days, and pollutants being considered. Unlike rate per distance processing, there was no attempt to limit the selection based on process type. For all but the *combination long-haul truck* source type, records for the following process types were returned:

- Start exhaust

- Evaporative permeation
- Evaporative fuel leaks
- Crankcase start exhaust
- Refueling displacement vapor loss
- Refueling spillage loss

For the *combination long-haul truck* source type, no evaporative permeation or fuel leak records were returned. This is likely because this class of vehicle is exclusively diesel fueled and thus, because of the properties of the fuel, these trucks produce no significant evaporative emissions. However, records were returned for *crankcase extended idle exhaust* and *extended idle exhaust* processes.

For all but the *single unit short-haul truck* and *combination long-haul truck* source types, this process returned 720 records. These record sets seem consistent across source type, but do not represent every possible combination of month, day, hour, pollutant, and process. For the *single unit short-haul truck* source type only 501 records were returned, while 1,152 records were returned for the *combination long-haul truck* source type. These record totals are much smaller than those produced by the rate per distance process since speed bins and road types are not considered in stationary emissions.

Step 2: Collapse 24 hours into four aggregate model periods as described in the rate per distance process above.

Step 3: Collapse nine vehicle types into two aggregate vehicle types (passenger and commercial vehicles) as described in the rate per distance process above.

The product of Steps 1 through 3 is a table of rate per vehicle emissions rates. This table contains 328 records of which 120 pertain to passenger vehicle rates and 208 pertain to commercial vehicle rates. This table has the following format:

- Months of the year
- Time of day
- Vehicle type
- Pollutant type
- Process type
- Emissions rate

Step 4: The actual rate per vehicle stationary emissions were calculated by multiplying the emissions rates in the rate table by the corresponding registration totals (passenger or commercial) for the 164-municipality study area. Total passenger and commercial registrations for this modeled area were derived from state registration data. The following is a summary of the registration types used in the estimation of passenger and commercial vehicle totals:

Passenger Vehicles (3,074,504 total passenger vehicles):

- Motorcycle (71,757)
- Passenger auto (1,814,871)
- Commercial auto (15,265)
- Light truck (401,868)
- Sport utility vehicle (770,743)

Commercial Vehicles (178,599 total commercial vehicles)

- Sport utility vehicle (11,418)
- Light truck (124,033)
- Heavy truck (4,223)

Emissions were then aggregated to the reporting level by collapsing the table to only include results by month, period of day, and pollutant type.

1.4 Stationary Emissions—Rate Per Profile

Rate Per Profile Assumptions

The final portion of the stationary emission factors were derived from the *Rate per Profile* files. The assumptions for determining the appropriate records to use in developing emission factors were the same for this category of stationary emissions as they were for the rate per vehicle stationary emissions and the running emissions.

The *Rates per Profile* file provides information in grams per vehicle and presents the vapor venting emissions from parked vehicles. The specific outputs from this file are for the *evaporative fuel vapor venting* process.

Rate Per Profile Process

As mentioned, the first three steps for calculating rate per profile are similar to the steps described above for calculating the rate per distance and rate per vehicle.

Step 1: As described above, input was provided in a single file, containing records for all source types. This single file was split into nine individual files, corresponding to those source types being considered. As before, the data

were further reduced to only the months, days, and pollutants being considered. In a departure from the previous processes, months were not identified explicitly in the rate per profile data. Instead, months seems to be implied by the “temperatureProfileID” field. Values in this field are in the format “2501700<n>00,” where “n” seems to represent the ordinal month number.

For all but the *combination long-haul truck* source type, this process returned 48 records (2 months x 24 hours x 1 pollutant x 1 process) for each source type. The limited number of records returned is a reflection of the fact that only one pollutant of interest (VOC) and a single process (evaporative fuel vapor venting) were included in the input file. In the case of the *combination truck* source type, no records were returned. As mentioned above, this is likely because this class of vehicle is exclusively diesel fueled and thus, because of the properties of the fuel, these trucks produce no significant evaporative emissions.

Step 2: Collapse 24 hours into four aggregate model periods as described in the rate per distance process above.

Step 3: Collapse nine vehicle types into two aggregate vehicle types (passenger and commercial vehicles) as described in the rate per distance process above.

The product of Steps 1 through 3 is a table of rate per profile emissions rates. This table contains 16 records (2 months x 4 time periods x 2 vehicle types x 1 pollutant x 1 process) of which eight pertain to passenger vehicle rates and eight pertain to commercial vehicle rates. This table has the following format:

- Months of the year
- Time of day
- Vehicle type
- Pollutant type
- Process type
- Emissions rate

Step 4: The actual rate per profile stationary emissions were calculated by multiplying the emissions rates in the rate table by the previously referenced registration totals (passenger or commercial).

Emissions were then aggregated to the reporting level by collapsing the table to only include results by month, period of day, and pollutant type.

2 ONGOING PROCESS TO DEVELOP FACTORS IN EMISSION RATE MODE

2.1 Emission Factor Development

Currently, inputs for the emission model (MOVES 3) are developed by CTPS in coordination with MassDOT and MassDEP. CTPS uses these input files in the MOVES 3 emission model to develop emission factors for eastern and western Massachusetts. These factors are then used in conjunction with the Statewide Travel Demand Model.

The previous model, MOVES 2014b, was used during the development of the Long-Range Transportation Plans (LRTP) for the MPOs in Massachusetts, which were adopted in 2015 and updated in 2016 to document the GHG analysis that was done for the Commonwealth. In 2016, due to the recent court ruling regarding the 1997 ozone standard, the MPOs in the Commonwealth were required to perform ozone air quality conformity analyses for their latest plans. A consultation meeting was held in April 2018. Those in attendance included the Federal Highway Administration, EPA, MassDEP, MassDOT, and MPOs. The parties involved decided to use the latest factors developed in 2016 since all believed that the Commonwealth would be well within the emission budgets set for the 1997 standard and that these factors would be conservative. They agreed that the factors would be updated next when the MPOs adopted their new LRTPs in spring 2019.

In February 16, 2018, further guidance was issued as a result of the United States Court of Appeals for the District of Columbia Circuit in *South Coast Air Quality Mgmt. District v. EPA* ("*South Coast II*," 882 F.3d 1138), which held that transportation conformity determinations must continue to be done in areas that were designated either as nonattainment or maintenance areas for the 1997 ozone National Ambient Air Quality Standards (NAAQS) and attainment for the 2008 ozone NAAQS when the 1997 ozone NAAQS was revoked.

According to the guidance, both Eastern and Western Massachusetts, along with several other areas across the country, were defined as orphan nonattainment areas—areas that were designated as nonattainment areas for the 1997 ozone NAAQS at the time of its revocation (80 FR 12264, March 6, 2015) and as attainment areas for the 2008 ozone NAAQS in EPA's original designation rule for this NAAQS (77 FR 30160, May 21, 2012). As of February 16, 2019, conformity determinations are required in these areas; however, regional emissions analyses are not required. Therefore, emission factors were not updated as part of the 2019 LRTPs.

The latest emission factors were updated in summer 2021 using the MOVES 3 emission model. These factors are now available for use in the Statewide Travel Demand Model.

2.2 Application of Running Emission Factors to Travel Demand Model

When conducting the MPOs' LRTP regional air quality conformity determinations, CTPS links the Statewide Travel Demand Model with the aforementioned running emission factors produced by the MOVES model and develops estimates of emissions from public transportation vehicles.

On-Road Emissions

The calibrated Statewide Travel Model set estimates traffic volumes, average highway speeds, vehicle-miles traveled (VMT) and vehicle-hours traveled. One of the outputs of the model sets' highway assignment routines is VMT on individual roadway segments, while another output is average speed on individual roadway segments. Pollutant emission factors (see below for the listed emissions) per VMT were developed for different speeds on different roadway types for different times of the day and times of the year using EPA's MOVES emissions modeling software. These emissions factors were arranged into cross-classification tables, according to the following component elements:

- Speed
- Roadway type
- Urban classification
- Vehicle type
- Time of day
- Time of year

Given that each roadway segment has an associated average speed, as well as roadway classification, emissions were generated by the application of the appropriate emission factors to each segment's particular (truck or passenger vehicle) VMT. The emissions factors employed in the calculation of these emissions were for a summer month (July), with the exception of the factors for carbon monoxide, which use a winter month (January); in this manner, the most conservative estimate of ozone precursors was computed. Car and truck emissions were estimated in this analysis for the following:

- Carbon monoxide (CO)
- Carbon dioxide (CO_2)
- Nitrogen oxides (NOx)
- Volatile organic compounds (VOCs)
- Sulfur oxides (SO_x)
- Particulate matters ($PM_{2.5}$ and PM_{10}).

Public Transportation Vehicle Emissions

Massachusetts has a significant number of public transportation vehicles that are not accounted for in the methodology described above. In order to account for public transportation vehicles, a second analysis was undertaken. This section summarizes the methodology used to estimate emissions for each of three public transportation modes:

- Passenger commuter rail
- Bus
- Water transportation

Because the rapid transit lines draw electricity from a third track or catenaries, they draw their power from a stationary source, namely a power plant that may or may not be locally sited. Because of the difficulty in quantifying emissions associated with transportation sources from stationary sources and to eliminate the possibility of double counting emissions, no estimates were made for stationary power generators, such as power plants.

Passenger Commuter Rail Emissions

Estimates of emissions from the commuter rail system in eastern Massachusetts are based upon the factors received by CTPS from the EPA Office of Transportation and Air Quality and are documented on its website: https://www.epa.gov/regulations-emissions-vehicles-and-engines/regulations-emissions-locomotives. The fleet average emission factors for all locomotives by year are presented in the EPA guidance and are shown in grams per gallon. These factors are translated into vehicular emission rates per train mile by assuming a fixed fuel consumption rate of 3.7 gallons per mile and one locomotive per train (based upon a survey of Boston commuter rail operations).

The number of train miles is estimated from a breakdown of track mileage by train line and community. Train mileage is a function of the train frequency data garnered from current and proposed commuter rail schedules. Multiplying the train miles per day by the vehicular emissions per train mile yields the estimated vehicular emissions per day in eastern Massachusetts for each pollutant.

Bus Emissions

Bus emissions estimates are based upon a survey of all of the fixed-route bus operations in the model area and the bus manufactures' information on vehicle type and fuel type. This includes all bus service operated by regional transit authorities, including the Massachusetts Bay Transportation Authority, and private bus carriers. The analysis includes a summary of vehicle miles and fuel type (including the electric portion of dual-mode routes) for each bus route by year. Emissions of each pollutant were calculated by multiplying the appropriate

emission factor (based on fuel type) by the miles traveled by buses on each route. These results were summed for all routes on a daily basis.

Water Transportation Emissions

Water transportation emission estimates are based upon a survey of water transportation operators, boat manufacturers' information, and guidance from EPA's April 2009 report titled "Current Methodologies in Preparing Mobile Source Port-Related Emission Inventories Final Report" by ICF International. The water transportation services examined consist of the following water taxi and ferry routes:

- Boston Harbor water taxis routes
- Rowes Wharf to Logan Airport
- Hingham to Boston
- Charlestown to Long Wharf
- Lovejoy to World Trade Center
- Hull routes
- Quincy routes

Each water transportation route was identified with a boat, a specific engine type, number of engines, and horsepower.

Final Step

The last step is to combine the total emissions estimated for motor vehicle emissions in the model area with that of the emissions estimate for public transportation to derive a regional total estimate by county and by MPO for the Commonwealth of Massachusetts.

The Boston Region Metropolitan Planning Organization (MPO) operates its programs, services, and activities in compliance with federal nondiscrimination laws including Title VI of the Civil Rights Act of 1964 (Title VI), the Civil Rights Restoration Act of 1987, and related statutes and regulations. Title VI prohibits discrimination in federally assisted programs and requires that no person in the United States of America shall, on the grounds of race, color, or national origin (including limited English proficiency), be excluded from participation in, denied the benefits of, or be otherwise subjected to discrimination under any program or activity that receives federal assistance. Related federal nondiscrimination laws administered by the Federal Highway Administration, Federal Transit Administration, or both, prohibit discrimination on the basis of age, sex, and disability. The Boston Region MPO considers these protected populations in its Title VI Programs, consistent with federal interpretation and administration. In addition, the Boston Region MPO provides meaningful access to its programs, services, and activities to individuals with limited English proficiency, in compliance with U.S. Department of Transportation policy and guidance on federal Executive Order 13166.

The Boston Region MPO also complies with the Massachusetts Public Accommodation Law, M.G.L. c 272 sections 92a, 98, 98a, which prohibits making any distinction, discrimination, or restriction in admission to, or treatment in a place of public accommodation based on race, color, religious creed, national origin, sex, sexual orientation, disability, or ancestry. Likewise, the Boston Region MPO complies with the Governor's Executive Order 526, section 4, which requires that all programs, activities, and services provided, performed, licensed, chartered, funded, regulated, or contracted for by the state shall be conducted without unlawful discrimination based on race, color, age, gender, ethnicity, sexual orientation, gender identity or expression, religion, creed, ancestry, national origin, disability, veteran's status (including Vietnam-era veterans), or background.

A complaint form and additional information can be obtained by contacting the MPO or at http://www.bostonmpo.org/mpo_non_discrimination.

To request this information in a different language or in an accessible format, please contact

Title VI Specialist
Boston Region MPO
10 Park Plaza, Suite 2150
Boston, MA 02116
civilrights@ctps.org

By Telephone:
857.702.3702 (voice)

For people with hearing or speaking difficulties, connect through the state MassRelay service:

- **Relay Using TTY or Hearing Carry-over:** 800.439.2370
- **Relay Using Voice Carry-over:** 866.887.6619
- **Relay Using Text to Speech: 8**66.645.9870

For more information, including numbers for Spanish speakers, visit https://www.mass.gov/massrelay

ATTACHMENT 1

Passenger Cars (sourceTypeID =21) / 24 Hours / Oxides of Nitrogen (pollutantID=3) / Urban Restricted (roadTypeID=4) / 22.5MPH <= Speed <

yearID	monthID	dayID	period	hourID	pollutantID	processID	sourceTypeID	fuelTypeID	roadTypeID	avgSpeedBinID	ratePerDistance	avgRateperTime
2012	2	5	6 pm to 6 am	1	3	1	21	0	4	6	0.371948	
2012	2	5	6 pm to 6 am	2	3	1	21	0	4	6	0.371949	
2012	2	5	6 pm to 6 am	3	3	1	21	0	4	6	0.371948	
2012	2	5	6 pm to 6 am	4	3	1	21	0	4	6	0.371949	
2012	2	5	6 pm to 6 am	5	3	1	21	0	4	6	0.371947	
2012	2	5	6 pm to 6 am	6	3	1	21	0	4	6	0.371949	0.37195
2012	2	5	6 am to 9 am	7	3	1	21	0	4	6	0.371948	
2012	2	5	6 am to 9 am	8	3	1	21	0	4	6	0.371947	
2012	2	5	6 am to 9 am	9	3	1	21	0	4	6	0.371948	0.37195
2012	2	5	9 am to 3 pm	10	3	1	21	0	4	6	0.371948	
2012	2	5	9 am to 3 pm	11	3	1	21	0	4	6	0.371947	
2012	2	5	9 am to 3 pm	12	3	1	21	0	4	6	0.371948	
2012	2	5	9 am to 3 pm	13	3	1	21	0	4	6	0.371948	
2012	2	5	9 am to 3 pm	14	3	1	21	0	4	6	0.371948	
2012	2	5	9 am to 3 pm	15	3	1	21	0	4	6	0.371823	0.37193
2012	2	5	3 pm to 6 pm	16	3	1	21	0	4	6	0.371665	
2012	2	5	3 pm to 6 pm	17	3	1	21	0	4	6	0.371947	
2012	2	5	3 pm to 6 pm	18	3	1	21	0	4	6	0.371949	0.37185
2012	2	5	6 pm to 6 am	19	3	1	21	0	4	6	0.371949	
2012	2	5	6 pm to 6 am	20	3	1	21	0	4	6	0.371947	
2012	2	5	6 pm to 6 am	21	3	1	21	0	4	6	0.371949	
2012	2	5	6 pm to 6 am	22	3	1	21	0	4	6	0.371949	
2012	2	5	6 pm to 6 am	23	3	1	21	0	4	6	0.371948	
2012	2	5	6 pm to 6 am	24	3	1	21	0	4	6	0.371949	

ATTACHMENT 1

Passenger Cars (sourceTypeID =21) / 24 Hours / Oxides of Nitrogen (pollutantID=3) / Urban Restricted (roadTypeID=4) / 22.5MPH <= Speed < 27.5MPH (avgSpeedBinID=6)

yearID	monthID	dayID	period	hourID	pollutantID	processID	sourceTypeID	fuelTypeID	roadTypeID	avgSpeedBinID	ratePerDistance	avgRateperTime
2012	7	5	6 pm to 6 am	1	3	1	21	0	4	6	0.302998	
2012	7	5	6 pm to 6 am	2	3	1	21	0	4	6	0.306002	
2012	7	5	6 pm to 6 am	3	3	1	21	0	4	6	0.308280	
2012	7	5	6 pm to 6 am	4	3	1	21	0	4	6	0.309892	
2012	7	5	6 pm to 6 am	5	3	1	21	0	4	6	0.311077	
2012	7	5	6 pm to 6 am	6	3	1	21	0	4	6	0.312434	0.30887
2012	7	5	6 am to 9 am	7	3	1	21	0	4	6	0.313576	
2012	7	5	6 am to 9 am	8	3	1	21	0	4	6	0.312627	
2012	7	5	6 am to 9 am	9	3	1	21	0	4	6	0.306630	0.31094
2012	7	5	9 am to 3 pm	10	3	1	21	0	4	6	0.303411	
2012	7	5	9 am to 3 pm	11	3	1	21	0	4	6	0.310581	
2012	7	5	9 am to 3 pm	12	3	1	21	0	4	6	0.312534	
2012	7	5	9 am to 3 pm	13	3	1	21	0	4	6	0.319761	
2012	7	5	9 am to 3 pm	14	3	1	21	0	4	6	0.320064	
2012	7	5	9 am to 3 pm	15	3	1	21	0	4	6	0.320104	0.31441
2012	7	5	3 pm to 6 pm	16	3	1	21	0	4	6	0.320106	
2012	7	5	3 pm to 6 pm	17	3	1	21	0	4	6	0.320093	
2012	7	5	3 pm to 6 pm	18	3	1	21	0	4	6	0.319932	0.32004
2012	7	5	6 pm to 6 am	19	3	1	21	0	4	6	0.319537	
2012	7	5	6 pm to 6 am	20	3	1	21	0	4	6	0.312474	
2012	7	5	6 pm to 6 am	21	3	1	21	0	4	6	0.310852	
2012	7	5	6 pm to 6 am	22	3	1	21	0	4	6	0.307705	
2012	7	5	6 pm to 6 am	23	3	1	21	0	4	6	0.304559	
2012	7	5	6 pm to 6 am	24	3	1	21	0	4	6	0.300671	

ATTACHMENT 2

Combination Short Haul Trucks (sourceTypeID =61) / 24 Hours / Oxides of Nitrogen (pollutantID=3) / Urban Restricted (roadTypeID=4) / 22.5MPH <= Speed < 27.5MPH (avgSpeedBinID=6)

yearID	monthID	dayID	period	hourID	pollutantID	processID	sourceTypeID	fuelTypeID	roadTypeID	avgSpeedBinID	ratePerDistance	avgRateperTime
2012	2	5	6 pm to 6 am	1	3	1	61	0	4	6	13.450300	
2012	2	5	6 pm to 6 am	2	3	1	61	0	4	6	13.450200	
2012	2	5	6 pm to 6 am	3	3	1	61	0	4	6	13.450300	
2012	2	5	6 pm to 6 am	4	3	1	61	0	4	6	13.450200	
2012	2	5	6 pm to 6 am	5	3	1	61	0	4	6	13.450300	
2012	2	5	6 pm to 6 am	6	3	1	61	0	4	6	13.450200	13.4503
2012	2	5	6 am to 9 am	7	3	1	61	0	4	6	13.450200	
2012	2	5	6 am to 9 am	8	3	1	61	0	4	6	13.450300	
2012	2	5	6 am to 9 am	9	3	1	61	0	4	6	13.450300	13.4503
2012	2	5	9 am to 3 pm	10	3	1	61	0	4	6	13.450300	
2012	2	5	9 am to 3 pm	11	3	1	61	0	4	6	13.450300	
2012	2	5	9 am to 3 pm	12	3	1	61	0	4	6	13.450300	
2012	2	5	9 am to 3 pm	13	3	1	61	0	4	6	13.450200	
2012	2	5	9 am to 3 pm	14	3	1	61	0	4	6	13.450200	
2012	2	5	9 am to 3 pm	15	3	1	61	0	4	6	13.447000	13.4497
2012	2	5	3 pm to 6 pm	16	3	1	61	0	4	6	13.442800	
2012	2	5	3 pm to 6 pm	17	3	1	61	0	4	6	13.450300	
2012	2	5	3 pm to 6 pm	18	3	1	61	0	4	6	13.450200	13.4478
2012	2	5	6 pm to 6 am	19	3	1	61	0	4	6	13.450300	
2012	2	5	6 pm to 6 am	20	3	1	61	0	4	6	13.450300	
2012	2	5	6 pm to 6 am	21	3	1	61	0	4	6	13.450300	
2012	2	5	6 pm to 6 am	22	3	1	61	0	4	6	13.450300	
2012	2	5	6 pm to 6 am	23	3	1	61	0	4	6	13.450200	
2012	2	5	6 pm to 6 am	24	3	1	61	0	4	6	13.450200	

ATTACHMENT 2

Combination Short Haul Trucks (sourceTypeID =61) / 24 Hours / Oxides of Nitrogen (pollutantID=3) / Urban Restricted (roadTypeID=4) / 22.5MPH

yearID	monthID	dayID	period	hourID	pollutantID	processID	sourceTypeID	fuelTypeID	roadTypeID	avgSpeedBinID	ratePerDistance	avgRateperTime
2012	7	5	6 pm to 6 am	1	3	1	61	0	4	6	12.167600	
2012	7	5	6 pm to 6 am	2	3	1	61	0	4	6	12.251500	
2012	7	5	6 pm to 6 am	3	3	1	61	0	4	6	12.315200	
2012	7	5	6 pm to 6 am	4	3	1	61	0	4	6	12.360300	
2012	7	5	6 pm to 6 am	5	3	1	61	0	4	6	12.393400	
2012	7	5	6 pm to 6 am	6	3	1	61	0	4	6	12.431400	11.9764
2012	7	5	6 am to 9 am	7	3	1	61	0	4	6	12.463300	
2012	7	5	6 am to 9 am	8	3	1	61	0	4	6	12.436700	
2012	7	5	6 am to 9 am	9	3	1	61	0	4	6	12.269100	12.3897
2012	7	5	9 am to 3 pm	10	3	1	61	0	4	6	11.969500	
2012	7	5	9 am to 3 pm	11	3	1	61	0	4	6	11.619000	
2012	7	5	9 am to 3 pm	12	3	1	61	0	4	6	11.278200	
2012	7	5	9 am to 3 pm	13	3	1	61	0	4	6	10.943900	
2012	7	5	9 am to 3 pm	14	3	1	61	0	4	6	10.748600	
2012	7	5	9 am to 3 pm	15	3	1	61	0	4	6	10.677800	11.2062
2012	7	5	3 pm to 6 pm	16	3	1	61	0	4	6	10.657300	
2012	7	5	3 pm to 6 pm	17	3	1	61	0	4	6	10.708400	
2012	7	5	3 pm to 6 pm	18	3	1	61	0	4	6	10.847600	10.7378
2012	7	5	6 pm to 6 am	19	3	1	61	0	4	6	11.074300	
2012	7	5	6 pm to 6 am	20	3	1	61	0	4	6	11.346200	
2012	7	5	6 pm to 6 am	21	3	1	61	0	4	6	11.595900	
2012	7	5	6 pm to 6 am	22	3	1	61	0	4	6	11.796600	
2012	7	5	6 pm to 6 am	23	3	1	61	0	4	6	11.929100	
2012	7	5	6 pm to 6 am	24	3	1	61	0	4	6	12.054700	