



# Creating Look-Up Tables to Streamline the Determination of Emission Reductions for CMAQ Projects

## User Guide

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Prepared for

**AASHTO Committee on Environment and Sustainability**

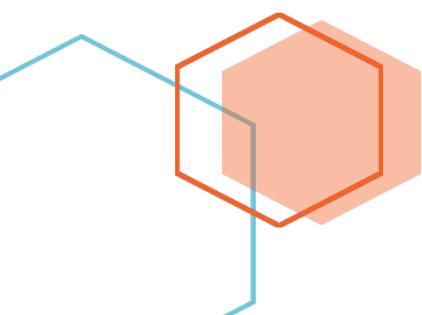
Prepared by

**William Chupp  
Anjuliee Mittelman  
George Noel  
U.S.D.O.T. Volpe Center  
Cambridge, Massachusetts**

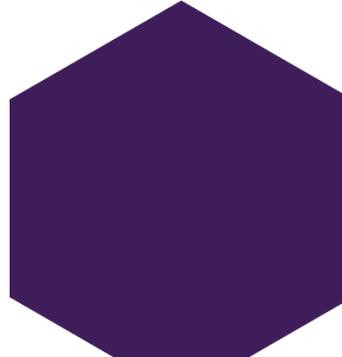
**Leo Tidd  
Louis Berger, U.S., Inc.  
New York, New York**

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SPECIAL NOTE: This report IS NOT an official publication of the National Cooperative Highway Research Program, Transportation Research Board, National Research Council, or The National Academies.



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- *Austina Casey, District of Columbia DOT*
- *S. Natalie Liljenwall, Oregon DOT*
- *Henry Phillips, South Carolina DOT*
- *Allison L. Smith, Kansas DOT*
- *Sue Theiss, Texas DOT*
- *Christopher Voigt, Virginia DOT*
- *Rose Waldman, Colorado DOT*
- *Mark Glaze, FHWA (Liaison)*

The project was managed by Ann Hartell, NCHRP Senior Program Officer.

## Disclaimer

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## Introduction

NCHRP 25-25 Task 108 developed a user-friendly spreadsheet tool for identifying changes in emissions from Congestion Mitigation and Air Quality Improvement (CMAQ) projects/programs. CMAQ was first created under the Intermodal Surface Transportation Efficiency Act (ISTEA) of 1991, and reauthorized under the Transportation Equity Act for the 21st Century (TEA-21), the Safe, Accountable, Flexible, and Efficient Transportation Equity Act: A Legacy for Users (SAFETEA-LU), the Moving Ahead for Progress in the 21st Century Act (MAP-21), and most recently Fixing America's Surface Transportation (FAST) Act.

The tools developed for Task 108 (termed the 'Simplified Toolkit') are independent of the Federal Highway Administration's (FHWA) existing CMAQ Emissions Calculator Toolkit (FHWA Toolkit), but build on the work conducted for the FHWA Toolkit to provide project sponsors an additional option in calculating emissions reductions in an efficient manner. The tools developed in this study may be applied by state departments of transportation, metropolitan planning agencies, and other project sponsors to estimate emission reductions for CMAQ-funded projects in accordance with federal requirements and in keeping with the objective for the study. However, this research is being conducted for NCHRP and therefore the deliverables are by definition not FHWA-products or necessarily FHWA-endorsed products.

The following sections provide an overview of each Project Type Tool, including methodology and inputs required to estimate emissions reductions. The appendix contains example average, low, and high default input values for the Task 108 tools, such as daily vehicle miles traveled (VMT) and intersection delay. The appendix also contains a glossary of emissions modeling terms and a list of abbreviations and acronyms.

## Tool Descriptions and Example Applications

The following sections provide a description of each Project Type Tool, the calculations used to estimate emission reductions, and a description of the inputs required to estimate emissions benefits.

The final spreadsheet includes 15 Project Type Tools:

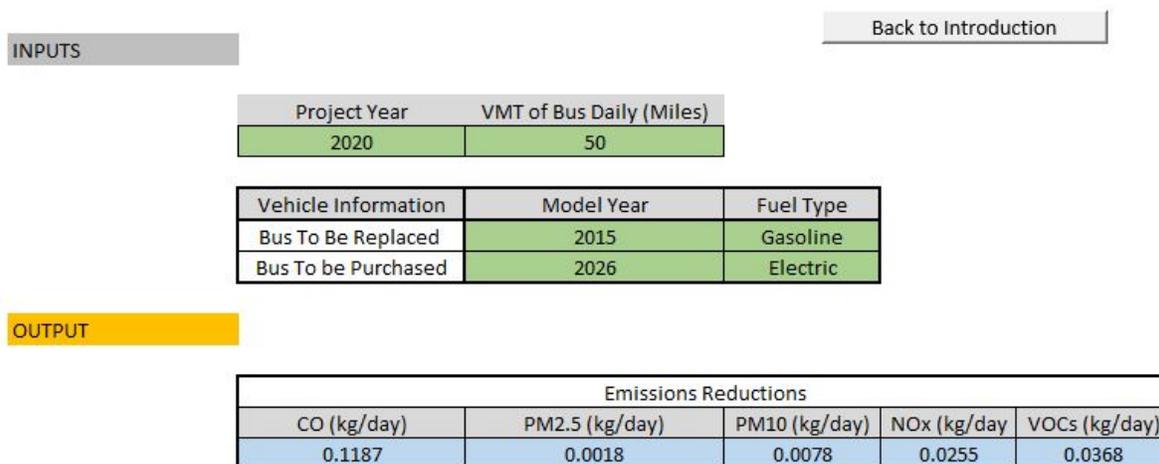
1. Bus Replacement
2. New Transit Buses
3. New Bus Services
4. Diesel Engine Retrofits
5. Diesel Idle Reduction
6. Alternative to Diesel Engines and Engine Replacement
7. Carpooling
8. Vanpooling
9. Bike Lanes, Bike Sharing, Pedestrian Paths
10. Street Sweeping
11. Street Paving
12. Signal Synchronization
13. Intersection Improvements
14. Roundabouts
15. Managed Lanes

## BUS REPLACEMENT

### Description

The Bus Replacement tool calculates emission reductions in kilograms per day (kg/day) by replacing an older diesel, compressed natural gas (CNG), or gasoline transit bus with a newer diesel, CNG, or gasoline transit bus. User input is focused on the number of buses being replaced and the model year of the older and replacement buses. Users may input their own specific bus VMT if available, or use a national default estimate of 50 miles per day. The daily VMT entry should be expressed on a per bus basis. Figure 1 displays a screenshot of the Bus Replacement Tool.

**Figure 1. Bus Replacement Tool**



### Calculation

The Bus Replacement Tool utilizes the equation below to calculate emissions reductions. Emissions reductions are calculated as the difference between the original bus emissions and the replacement bus emissions, where emissions are equal to the emission factor in kg/mile multiplied by the VMT.

$$\text{Emissions Reduction (kg/day)} = [\text{Transit Bus Emission Factor}_{\text{replacement}} \text{ (kg/mile)} \times \text{Annual Transit Bus VMT}_{\text{replacement}} \text{ (mile)} - \text{Transit Bus Emission Factor}_{\text{old}} \text{ (kg/mile)} \times \text{Annual Transit Bus VMT}_{\text{old}} \text{ (mile)}] / 365 \text{ (days/year)}$$

### Inputs

Table 1 lists the Bus Replacement Tool inputs.

**Table 1. Bus Replacement Tool Inputs**

<b>Input</b>	<b>Description</b>
Project Year	Choose the year the old transit bus will be replaced with a new transit bus. Years allowed for the tool range from 2020 to 2040.
Original Transit Bus - Model Year	Type in the model year of the transit bus or buses being replaced
Original Transit Bus - Fuel Type	Choose the fuel type of the new transit bus or buses being replaced. Fuel options include gasoline, diesel, CNG, and electric.
Replacement Transit Bus – Model Year	Type in the model year of the replacement transit bus or buses
Replacement Transit Bus – Fuel Type	Choose the fuel type of the replacement transit bus or buses. Fuel options include gasoline, diesel, CNG, and electric.
VMT of Bus Per Day	Type in the in average daily VMT on a per bus basis.

## NEW TRANSIT BUSES

### Description

The New Transit Buses tool calculates the emissions reductions in kilograms per day (kg/day) when a new transit bus is purchased and passenger vehicle (passenger cars and passenger trucks) VMT is reduced due to the bus purchase. Figure 2 displays a screenshot of the New Transit Buses Tool.

**Figure 2. New Transit Buses Tool**

INPUTS		Purchased Bus		
Project Year	Model Year	Fuel Type	Bus VMT (miles)	
2026	2025	Electric	50	

Passenger Vehicle	
One way trips diverted	Average Trip Distance (miles)
650	6

Emissions Reductions				
CO (kg/day)	PM2.5 (kg/day)	PM10 (kg/day)	NOx (kg/day)	VOCs (kg/day)
8.5338	0.0329	0.1328	0.5244	0.3470

### Calculation

The emissions benefits for the New Transit Buses Tool are calculated using the equation below. Emission reductions are determined as the reduction in passenger vehicle emissions by the new bus VMT. Passenger vehicle emissions are calculated as emission factor in kg/mile times the number of trips diverted times the average trip distance in miles.

$$\text{Emissions Reduction (kg/day)} = \text{Passenger Vehicle Emission Factor (kg/mile)} \times \text{Passenger Vehicle Trips Diverted} \times \text{Passenger Vehicle Average Trip Distance (mile)} - \text{Transit Bus Emission Factor (kg/mile)} \times \text{Transit Bus VMT (mile)}$$

## Inputs

Table 2 lists the New Transit Buses Tool inputs.

**Table 2. New Transit Buses Tool Inputs**

Input	Description
Project Year	Choose the year the bus will be purchased and deployed. Years allowed for the tool range from 2020 to 2040.
New Transit Bus - Model Year	Type in the model year of the new transit bus or buses being purchased and deployed
New Transit Bus - Fuel Type	Choose the fuel type of the new transit bus or buses being purchased and deployed. Fuel options include gasoline, diesel, CNG, and electric.
New Transit Bus - New Transit Bus VMT	Type in the daily VMT that the new transit bus or buses will be operating
Passenger Vehicles – Trips Diverted	Enter number of one way passenger trips diverted by the new bus services per day
Passenger Vehicles – Average Trip Distance	Type in the average passenger vehicle trip distance

## NEW BUS SERVICES

### Description

The New Bus Services tool calculates the emissions reductions in kilograms per day (kg/day) when additional bus services are added and passenger vehicle (passenger cars and passenger trucks) VMT is reduced. Figure 3 displays a screenshot of the New Bus Service Tool.

**Figure 3. New Bus Services Tool**

INPUTS		Back to Introduction			
Project Year	Buses		Passenger Cars		
	Before VMT (miles)	After VMT (miles)	One Way Trips Diverted	Average Trip Distance (mi)	
2025	50	100	650	6	

OUTPUT				
Emissions Reductions				
CO (kg/day)	PM2.5 (kg/day)	PM10 (kg/day)	NOx (kg/day)	VOCs (kg/day)
8.9833	0.0304	0.1314	0.4148	0.3598

### Calculation

The emissions benefits for the New Bus Services Tool are calculated using the equation below. Emissions reductions are determined as the reduction in passenger vehicle emissions by the new bus services, taking into account the transit emissions before and after the project. Passenger vehicle emissions are calculated as the emission factor in kg/mile times the number of trips diverted times the average trip distance in miles.

$$\text{Emissions Reduction (kg/day)} = \text{Passenger Vehicle Emission Rate (kg/mile)} \times \text{Number of Passenger Vehicle Trips Diverted} \times \text{Average Passenger Vehicle Trip Distance (mile)} - \text{Transit Bus Emission Rate (kg/mile)} \times [\text{Transit Bus VMT}_{\text{after}}(\text{mile}) - \text{Transit Bus VMT}_{\text{before}}(\text{mile})]$$

## Inputs

Table 3 lists the New Bus Services Tool inputs.

**Table 3. New Bus Services Tool Inputs**

Input	Description
Project Year	Choose the year the bus will be purchased and deployed. Years allowed for the tool range from 2020 to 2040.
Transit Bus Daily VMT before service expansion	Type in the daily VMT of the transit bus service before expansion
Transit Bus Daily VMT after service expansion	Type in the daily VMT of transit bus service after expansion
Passenger Vehicle Trips Diverted	Enter number of one way passenger trips diverted by the new bus services per day
Passenger Vehicle Average Trip Distance	Type in the average one-way passenger vehicle trip distance

## DIESEL ENGINE RETROFITS

### Description

The Diesel Engine Retrofits Tool calculates the emissions reductions in kilograms per day (kg/day) when a retrofit technology is applied to diesel vehicle. Figure 4 displays a screenshot of the Diesel Engine Retrofits Tool.

**Figure 4. Diesel Engine Retrofits Tool**

INPUTS				
Project Year	Vehicle Type	Model Year	Daily VMT (miles)	
	Refuse Truck		68	
Retrofit Type				
OUTPUT				
Emissions Reductions				
CO (kg/day)	PM2.5 (kg/day)	PM10 (kg/day)	NOx (kg/day)	VOCs (kg/day)
#N/A	#N/A	#N/A	#N/A	#N/A

### Calculation

The emissions benefits for the Diesel Engine Retrofits Tool are calculated using the equation below. The control efficiency of the retrofit is the percentage reduction in emissions and the pollutants impacted will vary depending on the retrofit.

$$\text{Emissions Reduction (kg/day)} = \text{Emission Factor (kg/mile)} \times \text{Control Efficiency of Retrofit} \times \text{Daily VMT (kg/mile)}$$

## Inputs

Table 4 lists the Diesel Engine Retrofits Tool inputs.

**Table 4. Diesel Engine Retrofits Tool Inputs**

Input	Description
Project Year	Choose the year the vehicle will be retrofitted. Years for the tool range from 2020 to 2040.
Vehicle Type	Select a vehicle type from the drop down list
Model Year	Type in the model year of the vehicle being retrofitted
Daily VMT	Type in the daily VMT of the vehicle being retrofitted
Retrofit Type	Choose the type of retrofit being applied to the vehicle from the drop down list. Retrofit types include Diesel Oxidation Catalyst, Diesel Oxidation Catalyst + Closed Crankcase Ventilation, Diesel Oxidation Catalyst + Diesel Particulate Filter, Diesel Particulate Filter, Exhaust Gas Recirculation + Diesel Particulate Filter, and Selective Catalytic Oxidation + Diesel Particulate Filter

## DIESEL IDLE REDUCTION

### Description

The Diesel Idle Reduction Tool calculates the emissions reductions in kilograms per day (kg/day) when implementing idle reduction technology reduces emission associated with truck hotelling. Note this tool is specific to combination long-haul trucks. Figure 5 displays a screenshot of the Diesel Idle Reduction Tool.

**Figure 5. Diesel Idle Reduction Tool**

INPUTS				Back to Introduction	
Project Year	Activity Type Annual	Total Annual Fleet Activity (hours or vehicles)	Hotelling Mode		
2026	Hotelling Hours	2000	Extended Idle		

OUTPUT				
Emissions Reductions				
CO (kg/day)	PM2.5 (kg/day)	PM10 (kg/day)	NOx (kg/day)	VOCs (kg/day)
0.0000	0.0000	0.0000	0.0000	0.0000

### Calculation

The emissions reductions for the Diesel Idle Reduction Tool are calculated using the equation below, using hotelling hours, operating hours or truck population as the activity input. The tool will automatically convert operating hours or truck population to hotelling hours, based on national default truck activity for the particular project year. Federal regulations mandate that long-haul truck drivers rest (hotelling time) 8 hours for every 10 operating hours.

$$\text{Emissions Reduction (kg/day)} = [\text{Emission Rate}_{\text{extended idle}} (\text{gram/hour}) \times \text{Annual Activity (hours)} - \text{Emission Rate}_{\text{Hotelling Mode}} (\text{gram/hour}) \times \text{Annual Activity (hours)}] / [1000 (\text{gram/kg}) \times 365 (\text{day/year})]$$

Note that emission rates for some hotelling modes are delineated based on ‘model year group’. These groups are from EPA’s updated emission rates for extended idle and diesel auxiliary power units (APUs).<sup>1</sup>

<sup>1</sup> Updated emission rates for extended idle & auxiliary power units (APUs). January 2017. <https://www.epa.gov/sites/production/files/2017-01/documents/emission-rates-extended-idle-aux-power-units.pdf>

## Inputs

Table 5 lists the Diesel Idle Reduction Tool inputs.

**Table 5. Diesel Idle Reduction Tool Inputs**

Input	Description
Project Year	Choose the year that the diesel idle reduction is being applied The range of this tool is from 2020 to 2040.
Activity Type Annual	Select either hotelling hours, operating hours or population
Total Fleet Activity	Enter either the number of hotelling hours, operating hours or population of vehicles that diesel idle reduction is being applied on an annual basis
Hotelling Mode	Select the type of hotelling mode that is being applied for diesel idle reduction from the drop down menu. Options include Extended Idle, Diesel APU, Battery APU, Direct-Fired (D-F) Heater, Truck Stop Electrification (TSE), and Engine-Off

## ALTERNATIVE TO DIESEL ENGINES AND ENGINE REPLACEMENT

### Description

The Alternative to Diesel Engines and Engine Replacement Tool calculates the emissions reductions in kilograms per day (kg/day) when replacing diesel vehicles with alternative fuel vehicles. Figure 6 displays a screenshot of the Alternative to Diesel Engines and Engine Replacement Tool.

**Figure 6. Alternative to Diesel Engines and Engine Replacement Tool**

INPUTS				
Project Year	Vehicle Type	Original Model Year	Daily VMT (miles)	
2023	Passenger Truck	2015	30	
Replacement Model year		Replacement Fuel Type		
2023		Diesel		
OUTPUT				
Emissions Reductions				
CO (kg/day)	PM2.5 (kg/day)	PM10 (kg/day)	NOx (kg/day)	VOCs (kg/day)
0.03739	0.00016	0.00017	0.01667	0.00112

### Calculation

The emissions reductions for the Alternative to Diesel Engines and Engine Replacement Tool are calculated using the equation below. The AFLEET<sup>2</sup> emission rate is the MOVES diesel emission factor (kg/mile) multiplied by an AFLEET alternative fuel factor.

$$\text{Emissions Reduction (kg/day)} = \text{Emission Factor}_{\text{diesel}} \text{ (kg/mile)} \times \text{Daily VMT (miles)} - \text{Emission Factor}_{\text{AFLEET}} \text{ (kg/mile)} \times \text{Daily VMT (miles)}$$

The tool applies a 5 percent loss in effectiveness of start and running emission reductions when closed crankcase ventilation is utilized, based on guidance provided with the EPA's Diesel Emissions Quantifier tool.<sup>3</sup>

<sup>2</sup> Department of Energy, <https://greet.es.anl.gov/index.php?content=registration&from=afleet>

<sup>3</sup> Environmental Protection Agency's (EPA) Diesel Emissions Quantifier (DEQ) calculator tool.<sup>3</sup>

## Inputs

Table 6 lists the Alternative to Diesel Engines and Engine Replacement Tool inputs.

**Table 6. Alternative to Diesel Engines and Engine Replacement Tool**

Input	Description
Project Year	Type in the year that the diesel vehicle is being replaced. The range for this tool is from 2020 to 2040.
Vehicle Type	Choose a vehicle type from the drop down menu.
Old Model Year	Type in the model of the diesel vehicle that is being replaced
New Model Year	Type in the model year of the new vehicle
New Fuel Type	Choose the fuel type of the new vehicle
Daily VMT	Type in the daily VMT of the new vehicle

## CARPOOLING

### Description

The Carpooling Tool calculates the emissions reductions in kilograms per day (kg/day) for the reduction in VMT associated with carpools. Figure 7 displays a screenshot of the Carpooling Tool.

**Figure 7. Carpooling Tool**

INPUT				
Project Year	Participating Vehicles	Distance to Pickup Locations (miles)	Passengers per Carpool Vehicle	
2023	8000	4	3	
Average One Way Distance (miles)				
25.2				
OUTPUT				
Emissions Reductions				
CO (kg/day)	PM2.5 (kg/day)	PM10 (kg/day)	NOx (kg/day)	VOCs (kg/day)
887.5372	4.0616	17.8988	57.7400	10.0870

### Calculation

The emissions reductions for the Carpooling Tool is calculated using the equation below. The number of passengers per carpool vehicle in the equation does not include the driver.

$$\text{Emissions Reduction (kg/day)} = \text{Passenger Vehicle Emission Factor (kg/mile)} \times \text{Number of Vehicles Participating in Carpool} \times \text{Passengers per Carpool Vehicle} \times [\text{Average Daily Roundtrip Commute Distance (miles)} - \text{Average Distance to Pick up Locations (miles)}]$$

## Inputs

Table 7 lists the carpooling tool inputs.

**Table 7. Carpooling Tool Inputs**

Input	Description
Project Year	Type in the year that carpool is occurring. The range for this tool is from 2020 to 2040.
Number of Vehicles Participating in the carpool	Type in the number of vehicles participating in the carpool
Average Distance to carpool pickup locations	Type in the average distance in miles to centralized carpool pickup locations. Enter 0 if the carpool is not centralized
Passenger per carpool vehicle	Type in the passengers per carpool vehicle and do not include the driver
Average Commute Distance	Type in the average roundtrip commute distance. The national average commute distance is provided as a default option

## VANPOOLING

### Description

The Vanpooling Tool calculates the emissions reductions in kilograms per day (kg/day) for the reduction in VMT associated vanpools. Figure 8 displays a screenshot of the Vanpooling tool.

**Figure 8. Vanpooling Tool**

INPUTS				
Project Year	Vehicle Type	Fuel Type	Model year	
Participating Vehicles	Distance to Pickup Locations (miles)	Passengers per Vanpool Vehicle	Average Trip Distance (miles)	
380	4	5	25.2	
Note: Input "0" if pickup locations are not centralized.				
OUTPUT				
Emissions Reductions				
CO (kg/day)	PM2.5 (kg/day)	PM10 (kg/day)	NOx (kg/day)	VOCs (kg/day)
#N/A	#N/A	#N/A	#N/A	#N/A

### Calculation

The emissions reductions for the Vanpooling Tool is calculated using the equation below. The number of passengers per carpool vehicle in the equation does not include the driver.

$$\begin{aligned}
 \text{Emissions Reduction (kg/day)} = & \text{Passenger Vehicle Emission Rate (kg/mile)} \times \text{Number of Vehicles} \\
 & \text{Participating in Vanpool} \times \text{Passengers per Vanpool Vehicle} \times \text{Average Daily Roundtrip Commute} \\
 & \text{Distance (miles)} - \text{Vanpool Vehicle Emission Rate (kg/mile)} \times \text{Average Daily Commute Distance (miles)}
 \end{aligned}$$

## Inputs

Table 8 lists the Vanpooling Tool inputs.

**Table 8. Vanpooling Tool Inputs**

Input	Description
Project Year	Type in the year that vanpool is occurring. The range for this tool is from 2020 to 2040.
Number of Vehicles Participating in the vanpool	Type in the number of vehicles participating in the vanpool
Average Distance to vanpool pickup locations	Type in the average distance in miles to centralized vanpool pickup locations. Enter 0 if the vanpool is not centralized
Passenger per vanpool vehicle	Type in the passengers per vanpool vehicle and do not include the driver
Average Commute Distance	Type in the average roundtrip commute distance. The national average commute distance is provided as a default option
Vehicle Type	Select one of the vanpool vehicle type options from the drop down menu
Fuel Type	Select a fuel type for the Vanpool Vehicle from the dropdown list
Model Year	Type in the Model Year of the Vanpool Vehicle

## BICYCLE AND PEDESTRIAN IMPROVEMENT PROJECTS

### Description

The Bicycle and Pedestrian Improvement Projects Tool calculates the emissions reductions in kilograms per day (kg/day) when the implementation of a bicycle-pedestrian improvements project reduces passenger vehicle VMT. This tool may be used for pedestrian paths, bike lanes, bike sharing, and other incentive projects that divert passenger vehicle trips. Figure 9 displays a screenshot of the Bicycle and Pedestrian Improvement Projects Tool.

**Figure 9. Bicycle and Pedestrian Improvement Projects Tool**

INPUTS					
Project Year	Daily Reduction in Trips	Avg Trip Distance (miles)			
2025	500	2			

OUTPUT					
Net Reduction in VMT:		1000		miles	
Emissions Reductions					
CO (kg/day)	PM2.5 (kg/day)	PM10 (kg/day)	NOx (kg/day)	VOCs (kg/day)	
3.9577	0.0111	0.0387	0.2724	0.2587	

### Calculation

The emissions reductions for the Bicycle and Pedestrian Improvement Projects Tool are calculated using the equation below.

$$\text{Emissions Reduction (kg/day)} = \text{Emission Rate (kg/mile)} \times \text{Net Reduction in Daily VMT (miles)}$$

where:

$$\text{Net Reduction in Daily VMT} = \text{Average Trip Distance} \times \text{Reduction in Trips per Day}$$

Note that VMT reduction from a mode shift is best calculated using a travel demand model (TDM). See FHWA's CMAQ Toolkit Bicycle-Pedestrian Improvements User Guide for TDM resources and examples of simplified methodologies.<sup>4</sup>

<sup>4</sup> See Appendix B (Travel Demand Modeling Resources):

[https://www.fhwa.dot.gov/environment/air\\_quality/cmaq/toolkit/bikeped\\_userguide.cfm#toc531083408](https://www.fhwa.dot.gov/environment/air_quality/cmaq/toolkit/bikeped_userguide.cfm#toc531083408)

## Inputs

Table 9 lists the Bicycle and Pedestrian Improvement Projects Tool inputs.

**Table 9. Bicycle and Pedestrian Improvement Projects Tool Inputs**

Input	Description
Project Year	Type in the year that the bicycle or pedestrian path project is to be built. The range for this tool is from 2020 to 2040.
Reduction in Trips Per Day	Type in the reduction in trips per day due the construction of the pedestrian path or bike lanes.
National Average Trip Distance	A default value of 2.494 miles per trip is applied. The user may edit this value.

## STREET SWEEPING

### Description

The Street Sweeping Tool calculates the emissions reductions in kilograms per day (kg/day) for fugitive dust emissions of PM<sub>10</sub> and PM<sub>2.5</sub>. Only PM<sub>10</sub> and PM<sub>2.5</sub> emissions will be reduced with this tool and CO, NO<sub>x</sub>, VOC emission may increase due to the street sweeper emissions. Figure 10 displays a screenshot of the Street Sweeping Tool.

**Figure 10. Street Sweeping Tool**

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INPUTS				
Project Year	Sweeper Fuel			
Sweeper Gross Weight (pounds)	Sweeper Model Year			
Roadway Type	Heavy Duty Percentage			
	10			
Annual VMT on the Subject Road				
Total VMT (miles)	Sweeper VMT (miles)			
500000	5000			
OUTPUT				
Emissions Reductions				
CO (kg/day)	PM2.5 (kg/day)	PM10 (kg/day)	NOx (kg/day)	VOCs (kg/day)
0.0000	0.0000	0.0000	0.0000	0.0000

### Calculation

The emissions reductions for the Street Sweeping Tool are calculated using the equation below.

$$\text{Emissions Reduction (kg/day)} = \text{Fugitive Dust Emissions}^5 \text{ (kg/day of Only PM}_{10} \text{ and PM}_{2.5}) \times \text{CE} - \text{Street Sweeper Emissions (kg/day)}$$

where CE is the control efficiency of street sweeping (i.e., percentage fugitive dust reduction).

Fugitive dust emissions were determined from EPA’s AP-42 Compilation of Air Emission Factors.<sup>6</sup> Fugitive dust emissions on paved roads were calculated as:

<sup>5</sup> Fugitive dust calculations based on EPA’s AP-42 Compilation of Emission Factors methodology for Paved Roads: <https://www.epa.gov/air-emissions-factors-and-quantification/ap-42-compilation-air-emissions-factors>

<sup>6</sup> EPA’s AP-42: <https://www3.epa.gov/ttnchie1/ap42/ch13/>

$$E = k \times sL^{0.91} \times W^{1.02}$$

where:

E = paved road dust emission factor (g/VMT),

k = particle size multiplier (g/VMT),

sL = road surface silt loading (g/m<sup>2</sup>) (dimensionless in equation), and

W = average weight (tons) of all vehicles traveling the road (dimensionless in equation).

The paved road dust emission factor (E) was multiplied by the Sweeper VMT input to determine ‘Fugitive Dust Emissions’, which is used in the emissions reduction equation above.

The particle size multiplier is equal to 7.3 and 1.8 for PM<sub>10</sub> and PM<sub>2.5</sub>, respectively. The average weight is determined by a weighted average considering the source mass of MOVES vehicle types. The silt loading is a function of road type (selected by the user).

The reduction in fugitive dust emissions is determined by applying a control efficiency (fraction of dust removed) to the fugitive PM<sub>2.5</sub> and PM<sub>10</sub> emissions. The Task 108 tool uses the national default efficiency from AP-42 (0.79), which assumes vacuum sweeping of paved roads twice per month.

Street sweeper emissions include brake and tire wear emissions from MOVES and exhaust emissions based on EPA’s Emission Standards for Heavy-Duty Highway Engines and Vehicles.<sup>7</sup>

## Inputs

Table 10 lists the Street Sweeping Tool required inputs.

**Table 10. Street Sweeping Tool Inputs**

Input	Description
Project Year	Type in the year that the street sweeper is being utilized. The range for this tool is from 2020 to 2040.
Total Traffic VMT on the Road	Type in the total VMT on the roadway segment(s) the street sweeper is operating
Total Sweeper VMT on the Road	Type in the street sweeper VMT on the roadway segments that the street sweeper is operating.
Roadway Type	Choose the roadway type from the dropdown menu the street sweeper is operating on.
Sweeper Fuel	Choose the fuel the street sweeper is using from the drop down menu.
Sweeper Gross Weight	Choose the street sweeper gross vehicle weight from the drop down menu
Sweeper Model Year	Type in the street sweeper model year
Heavy Duty Percentage	Enter a heavy-duty traffic percentage between 0 and 100.

<sup>7</sup> EPA Emission Standards for Heavy-Duty Highway Engines and Vehicles. <https://www.epa.gov/emission-standards-reference-guide/epa-emission-standards-heavy-duty-highway-engines-and-vehicles>

## STREET PAVING

### Description

The Street Paving Tool calculates the emissions reductions in kilograms per day (kg/day) when paving an unpaved road. Figure 11 displays a screenshot of the Street Paving Tool. Emissions reductions consider both fugitive dust emissions and any change in running emissions of the fleet due to a speed change after paving.

**Figure 11. Street Paving Tool**

#### INPUTS

Project Year	Roadway Type	Roadway Length (mi)	Average Hourly Flow
2024	Rural Unrestricted Access	0.5	1000 vph

Conditions Before Paving			Speed After Paving
Road Surface Material	Moisture Condition	Speed (mph)	Speed (mph)
Dirt	Typical	33	38

#### OUTPUT

Emissions Reductions				
CO (kg/day)	PM2.5 (kg/day)	PM10 (kg/day)	NOx (kg/day)	VOCs (kg/day)
1.8519	770.5373	7721.1101	0.7340	0.0585

### Calculation

The emissions reductions for the Street Paving Tool are calculated using the equation below:

$$\text{Emissions Reduction (kg/day)} = \text{Fugitive Dust}^8 \text{ (kg/day of Only PM}_{10} \text{ and PM}_{2.5}) \times \text{CE} + \text{Reduction in Running Emissions from Speed Change (kg/day)}$$

where CE is the control efficiency of street paving (i.e., percentage fugitive dust reduction).

<sup>8</sup> Fugitive dust calculations based on EPA's AP-42 Compilation of Emission Factors methodology for Unpaved Roads: <https://www.epa.gov/air-emissions-factors-and-quantification/ap-42-compilation-air-emissions-factors>

## Inputs

Table 11 lists the Street Paving Tool required inputs.

**Table 11. Street Paving Tool Inputs**

Input	Description
Project Year	Type in the year that the road is paved. The range for this tool is 2020 to 2040.
Road Surface Before Paving	Select gravel or dirt from the drop-down menu.
Moisture Condition Before Paving	Select typical or dry from the drop-down menu.
Roadway Type	Select urban or rural / restricted or unrestricted access from the drop-down menu.
Speed Before Paving	Enter a speed between 0 and 75 mph.
Speed After Paving	Enter a speed between 0 and 75 mph.
Length of the Roadway	Enter the length of the road to be paved.
Average Hourly Flow	Enter the hourly traffic flow on the road.

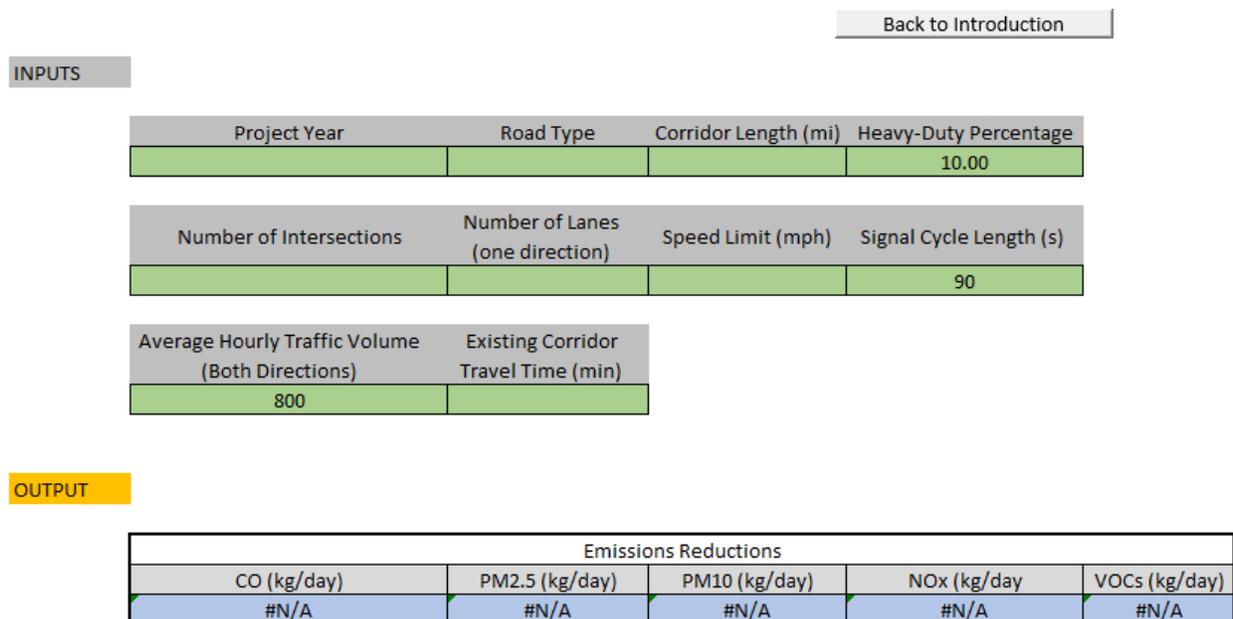
## SIGNAL SYNCHRONIZATION

### Description

The Signal Synchronization Tool calculates the emissions reductions in kilograms per day (kg/day) for projects that coordinate the timing of multiple traffic signals along a corridor. Figure 12 displays a screenshot of the Signal Synchronization Tool.

Emission reductions are estimated from the change in running emissions due to improved travel time along the corridor. The improved travel time is calculated based on the change in delay at each signal along the corridor and the effect of traffic volume on travel time and speed.

**Figure 12. Signal Synchronization Tool**



### Calculation

The emissions reductions for the Signal Synchronization Tool are calculated using the equation below.

$$\text{Emissions Reduction (kg/day)} = [(\text{Emission Rate}_{\text{before}} - \text{Emission Rate}_{\text{after}} \text{ (kg/mi)}) \times \text{Corridor Length (mi)} \times \text{Average Hourly Traffic Volume (veh/hr)} \times 24 \text{ hr/day}]$$

The delay reduction methodology used in this tool was derived from TRB’s Highway Capacity Manual.<sup>9</sup> Please refer to the manual for detailed equations and assumptions.

<sup>9</sup> Equation 18-20 in Chapter 18: Signalized Intersection, Highway Capacity Manual, Transportation Research Board National Academy of Sciences, Washington DC, 2010.

## Inputs

Table 12 lists the Signal Synchronization Tool required inputs.

**Table 12. Signal Synchronization Tool Inputs**

Input	Description
Analysis Year	Type in the year that the road is paved. The range for this tool is 2020 to 2040.
Road Type	Select urban or rural from the drop-down menu.
Corridor Length	Enter the length of the corridor.
Number of Intersections	Enter the number of intersections along the corridor.
Number of Lanes	Enter the number of lanes along the corridor for one direction only.
Speed Limit	Enter the average speed limit posted along the corridor. The upper limit of the tool is 75 mph.
Signal Cycle Length	Enter the average length of the signal cycles along the corridor in seconds.
Average Hourly Traffic Volume	Input the AAHT volume along the corridor for both directions.
Existing Travel Time	Enter the travel time along the corridor prior to the synchronization project.
Heavy Duty Percentage	Enter a heavy-duty traffic percentage between 0 and 100.

## INTERSECTION IMPROVEMENTS

### Description

The Intersection Improvements Tool estimates emission reductions for a single intersection with any of the following improvements. It is intended for a standard four-way intersection.

- installing a new traffic signal in place of a previous two-way stop or four-way stop
- creating a new phase (dedicated left-turn or right-turn signal), and
- increasing capacity (left-lane only) in an intersection with a left-turn phase

Emission reductions are estimated by calculating the reduction in idling emissions from the delay at the intersection after project implementation and subtracting it from the existing delay at the intersection.

Figure 13 displays a screenshot of the Intersection Improvements Tool.

**Figure 13. Intersection Improvements Tool**

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**INPUTS**

Existing Conditions					
Project Year	Area Type	Business District	Existing Signalization	Truck Percentage (%) (Both Roads)	
			Signalized	10	
Average Hourly Traffic Volume (both directions)	Lanes (one direction)	Existing Delay per vehicle per approach (sec)	Existing Left-turn Phase	Existing Right-turn Phase	
Roadway 1	800	40			
Roadway 2	800	40			

Proposed Conditions			
Left-Turn Lanes to Add (one direction)	Left-Turn Phase Added	Right-Turn Phase Added	
Roadway 1			
Roadway 2			

Signal Cycle Length (sec)
90

**OUTPUT**

Emissions Reductions				
CO (kg/day)	PM2.5 (kg/day)	PM10 (kg/day)	NOx (kg/day)	VOCs (kg/day)
#N/A	#N/A	#N/A	#N/A	#N/A

### Calculation

The emissions reductions for the Intersection Improvements Tool are calculated using the equation below:

$$\text{Emissions Reduction (kg/day)} = \text{Emission Rate (kg/hr)} \times \text{Total Intersection Delay Reduction (hr/day)}$$

The delay reduction methodology used in this tool was derived from TRB’s Highway Capacity Manual.<sup>10</sup> Please refer to the manual for detailed equations and assumptions.

## Inputs

Table 13 lists the Intersection Improvements Tool required inputs.

**Table 13. Intersection Improvements Tool Inputs**

Input	Description
Project Year	Type in the year that the road is paved. The range for this tool is 2020 to 2040.
Area Type	Select rural or urban from the drop-down menu.
Business District	Select yes or no from the drop-down menu to indicate if intersection is in a business district.
Existing Signalization	Use the drop-down menu to indicate whether the existing intersection is signalized or signalized.
Truck Percentage	Enter the percentage of truck traffic on both roads of the intersection.
Average Hourly Traffic Volume	Enter the hourly traffic volume in both directions for each road.
Lanes	Input the number of lanes, considering one direction only for each road.
Delay	Input the existing delay per vehicle for one direction of each road at the intersection.
Left-Turn Lanes to Add	Input the number of left-turn lanes to be added, considering one direction only.
Left-Turn Phase Added	Select yes or no from the drop-down menu to indicate whether a left-turn phase will be added.
Right-Turn Phase Added	Select yes or no from the drop-down menu to indicate whether a right-turn phase will be added.
Signal Cycle Length	Enter the average length of signal cycles at the intersection.

<sup>10</sup> Equation 18-20 in Chapter 18: Signalized Intersection, Highway Capacity Manual, Transportation Research Board National Academy of Sciences, Washington DC, 2010.

## ROUNDBABOUTS

### Description

The Roundabouts Tool calculates the emissions reductions in kilograms per day (kg/day) when installing a roundabout in place of a traditional signalized or un-signalized intersection. It is intended for a single or double lane roundabout that has either three- or four- approach directions. Emission reductions are estimated based on the reduction in idling emissions due to the roundabout. Figure 14 displays a screenshot of the Roundabouts Tool.

**Figure 14. Roundabouts Tool**

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**INPUTS**

	Existing Conditions				
	Evaluation Year	Area Type	Business District	Truck Percentage	
			10.00	4	
	Average Hourly Traffic Volume (vehicles)	Lanes	Typical Existing Delay (sec/veh)	Existing Left-turn %	Existing Right-turn %
Approach 1	250		55	15	33
Approach 2	250		55	15	33
Approach 3	250		55	15	33
Approach 4	250		55	15	33

Proposed Conditions	
Number of Circulating Roundabout	1
	Please input approaches in CLOCKWISE direction for existing intersection. Location of the first approach does not matter, only that the order is in a clockwise direction

**OUTPUT**

Emissions Reductions				
CO (kg/day)	PM2.5 (kg/day)	PM10 (kg/day)	NOx (kg/day)	VOCs (kg/day)
#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!

### Calculation

The emissions reductions for the Roundabouts Tool is calculated using the equation below.

$$\text{Emissions Reduction (kg/day)} = \text{Emission Rate (kg/hr)} \times \text{Total Intersection Delay Reduction (hr/day)}$$

The delay reduction methodology used in this tool was derived from TRB’s Highway Capacity Manual.<sup>11</sup> Please refer to the manual for detailed equations and assumptions.

<sup>11</sup> Chapter 21: Roundabouts, Highway Capacity Manual, Transportation Research Board, National Academy of Sciences, Washington DC, 2010.

## Inputs

Table 14 lists the Roundabouts Tool required inputs.

**Table 14. Roundabouts Tool Inputs**

Input	Description
Project Year	Type in the year that the roundabout project is implemented. The range for this tool is 2020 to 2040.
Area Type	Select urban or rural from the drop-down menu.
Business District	Select yes or no from the drop-down menu
Truck Percentage	Enter a heavy-duty traffic percentage between 0 and 100.
Average Hourly Traffic Volume	Input the AAHT volumes for three or four approaches.
Delay	Input the existing delay per vehicle for each approach.
Existing Left-turn %	Input the percent of traffic for each approach that takes a left turn at the existing intersection.
Existing Right-turn %	Input the percent of traffic for each approach that takes a right turn at the existing intersection.
Number of Circulating Lanes	Enter the number of lanes in the proposed roundabout.

## MANAGED LANES

### Description

The Managed Lanes Tool calculates the emissions reductions in kilograms per day (kg/day) when adding a new managed lane facility (e.g., high-occupancy vehicle or HOV lane) to a highway. Figure 15 displays a screenshot of the Managed Lanes Tool.

**Figure 15. Managed Lanes Tool**

#### INPUTS

Project Year	Hours Operating Per Day	Facility Length (mi)	Highway Type	Heavy Duty Percentage (%)
	8			10

All inputs below should be per hour per lane

Traffic Flow Information	BEFORE		AFTER	
	Managed Lanes	General Purpose Lanes	Managed Lanes	General Purpose Lanes
Average Hourly Traffic Flow (vehicles/hour)	0	2500	1000	1500
Average Hourly Speed (mph)	0	50	65	55
Number of Lanes	0			

NOTE: If managed lanes do not exist Before or After the project, put 0 for average hourly traffic flow, average speed, and number of lanes under the managed lanes column in the "Before" section above

#### OUTPUT

Emissions Reductions				
CO (kg/day)	PM2.5 (kg/day)	PM10 (kg/day)	NOx (kg/day)	VOCs (kg/day)
#N/A	#N/A	#N/A	#N/A	#N/A

### Calculation

The emissions reductions for the Managed Lanes Tool is calculated using the equation below.

$$\text{Emissions Reduction (kg/day)} = (E_{ML,before} + E_{GP,before}) - (E_{ML,after} + E_{GP,after})$$

where:

*ML* = managed lane; *GP* = general purpose lane; and

*E* = Average Hourly Traffic Flow (volume/hr) x Length of Facility (mi) x Number of Lanes x Emission Rate (kg/mi) x Hours Operated (hr/day)

For new managed lane facilities, the net emissions are composed of emissions resulting from:

- Traffic on the general purpose lanes before project completion,
- Traffic on the general purpose lanes after completion, and
- Traffic on the new managed lane(s).

Methodology used in this tool is based on National Collaborative Highway Research Program (NCHRP 03-96) research on managed lanes that was added to the Highway Capacity Manual in 2012.<sup>12</sup> Please refer to the manual for detailed equations and assumptions.

## Inputs

Table 15 lists the Managed Lanes Tool required inputs. Values for the last three inputs (traffic flow, speed, and number of lanes) are required for the managed lanes and general purpose lanes before and after project implementation.

**Table 15. Managed Lanes Tool Inputs**

Input	Description
Project Year	Type in the year that the new managed lane is implemented. The range for this tool is 2020 to 2040.
Hours Operating Per Day	Enter the number of hours each day the facility will be in use.
Length of the Facility	Enter the length of the new managed lane(s) in miles.
Highway Type	Select urban or rural from the drop-down menu.
Heavy Duty Percent Fleet Mix	Enter the percent of the fleet made up of heavy-duty vehicles.
Average Hourly Traffic Flow	Enter the hourly traffic flow for the managed lanes and general purpose lanes before and after the project.
Average Hourly Speed	Enter average speed for the managed lanes and general purpose lanes before and after the project in mph.
Number of Lanes	Input the number of managed lanes and general purpose lanes before and after the project.

<sup>12</sup> National Academies of Sciences, Engineering, and Medicine (NASEM), 2012, *Analysis of Managed Lanes on Freeway Facilities*. Washington, DC: The National Academies Press (<https://doi.org/10.17226/22677>).

## Appendix

### DEFAULT INPUT DATA

The table below provides example inputs (recommended default, low, and high values) for the NCHRP Task 108 tools. The recommended default inputs are based on national averages drawn from various sources. See reference column and additional detail below for descriptions of how default values were developed. Default inputs are pre-filled in the Simplified Toolkit spreadsheet, and can be re-loaded into the relevant input cells using the “Reset Defaults” button on each tool input tab. The list of default inputs covers every tool input to the extent possible. Note that certain inputs are inherently project specific. For example, it was assumed that the user would choose inputs such as diesel retrofit type and fuel type. Other inputs, such as existing corridor travel time, are highly area-specific and depend on factors such as corridor length and number of intersections.

**Table A1. Default input values for Task 108 tools**

Input	Tool(s)	Recommended Default	Low Value	High Value	Units	References
Average Commute by Transit Distance	New Transit Buses, New Bus Services	6	3	8	Miles	Moovit Insights, public transit tracking app that has insights about public transit data for many U.S. cities. <a href="https://moovitapp.com/insights/en/Moovit_Insights_Public_Transit_Index-commute-distance">https://moovitapp.com/insights/en/Moovit_Insights_Public_Transit_Index-commute-distance</a>
Daily Passenger VMT Reduction	New Transit Buses, New Bus Services	4000	1000	6500	Miles	Values provided for illustrative purposes only; VMT reduction is highly project specific and dependent on local travel behavior and geography.
Daily Passenger Trip Reduction	New Transit Buses, New Bus Services	650	125	2500	Trips	Values provided for illustrative purposes only; VMT reduction is highly project specific and dependent on local travel behavior and geography.

<b>Input</b>	<b>Tool(s)</b>	<b>Recommended Default</b>	<b>Low Value</b>	<b>High Value</b>	<b>Units</b>	<b>References</b>
Daily VMT - Transit Bus	Bus Replacement, New Bus Services, New Transit Buses	50	30	150	Miles	FHWA's Highway Statistics 2015: <a href="https://www.fhwa.dot.gov/policyinformation/statistics/2015/">https://www.fhwa.dot.gov/policyinformation/statistics/2015/</a>
Daily VMT - Passenger Car (single vehicle)	Diesel Engine Retrofits, Alternative to Diesel Engine/Engine Replacement	30	10	100	Miles	FHWA's Highway Statistics 2015
Daily VMT - Passenger Truck (single vehicle)	Diesel Engine Retrofits, Alternative to Diesel Engine/Engine Replacement	30	10	100	Miles	FHWA's Highway Statistics 2015
Daily VMT - Refuse Truck (single vehicle)	Diesel Engine Retrofits, Alternative to Diesel Engine/Engine Replacement	68	25	200	Miles	FHWA's Highway Statistics 2015
Daily VMT - School Bus (single vehicle)	Diesel Engine Retrofits, Alternative to Diesel Engine/Engine Replacement	30	10	100	Miles	FHWA's Highway Statistics 2015
Daily VMT - Light Commercial Truck (single vehicle)	Diesel Engine Retrofits, Alternative to Diesel Engine/Engine Replacement	30	10	100	Miles	FHWA's Highway Statistics 2015
Daily VMT - Single Unit Short-Haul Truck (single vehicle)	Diesel Engine Retrofits, Alternative to Diesel Engine/Engine Replacement	35	15	110	Miles	FHWA's Highway Statistics 2015

<b>Input</b>	<b>Tool(s)</b>	<b>Recommended Default</b>	<b>Low Value</b>	<b>High Value</b>	<b>Units</b>	<b>References</b>
Daily VMT - Single Unit Long-Haul Truck (single vehicle)	Diesel Engine Retrofits, Alternative to Diesel Engine/Engine Replacement	185	100	550	Miles	FHWA's Highway Statistics 2015
Daily VMT - Combination Unit Short-Haul Truck (single vehicle)	Diesel Engine Retrofits, Alternative to Diesel Engine/Engine Replacement	35	15	110	Miles	FHWA's Highway Statistics 2015
Daily VMT - Combination Unit Long-Haul Truck (single vehicle)	Diesel Engine Retrofits, Alternative to Diesel Engine/Engine Replacement	185	100	550	Miles	FHWA's Highway Statistics 2015
Total Fleet Activity - Annual Operating Hours (single vehicle)	Diesel Idle Reduction	2,500	1,300	3,100	Hours per Year	Estimates for illustrative purposes only; total fleet activity can vary widely depending on road type and location.
Reduction in Trips Per Day	Bicycle and Pedestrian Improvement Projects	500	100	20000	Trips	Values provided for illustrative purposes only; trip diversion values vary widely and are project-specific. It is recommended that users run their own travel demand model to generate these inputs.
National Average Trip Distance	Bicycle and Pedestrian Improvement Projects	2.5	1.5	5	Miles	Analysis of 2009 National Household Transportation Survey (NHTS) survey data
Distance to Pickup Locations	Carpooling and Vanpooling	4	2	6	Miles	FHWA's 2010 Status of the Nation's Highways, Bridges, and Transit: Conditions & Performance

Input	Tool(s)	Recommended Default	Low Value	High Value	Units	References
Passengers Per Carpool Vehicle	Carpooling	3	2	7	Passengers per Vehicle	FHWA's 2010 Status of the Nation's Highways, Bridges, and Transit: Conditions & Performance
National Average Commute Distance	Carpooling	25.2	10	50	Miles	FHWA's 2010 Status of the Nation's Highways, Bridges, and Transit: Conditions & Performance
Passengers Per Vanpool Vehicle	Vanpooling	5	3	15	Passengers per Vehicle	FHWA's 2010 Status of the Nation's Highways, Bridges, and Transit: Conditions & Performance
Total Fleet VMT	Street Sweeping	500,000	100,000	3,000,000	Miles	Estimates for illustrative purposes only; total VMT can vary widely depending on road type and location.
Street Sweeper VMT (single sweeper)	Street Sweeping	5,000	2,000	7,500	Miles	Operating hours estimate based on a street sweeper operating 8 hours per day on weekdays, approximately 6 months out of the year. Using an average speed of 5 mi/hr, this gives a street sweeper VMT of 5,000 miles.
Average Hourly Traffic Volume	Street Paving, Intersection Improvements, Roundabouts, Signal Synchronization	800	200	2000	Vehicles per Hour	Estimates for illustrative purposes only; traffic volume can vary widely depending on road type and location.
Delay, Signalized (per vehicle for one direction)	Intersection Improvements	40	20	80	Seconds per Vehicle	TRB's Highway Capacity Manual (HCM), Sixth Edition. <a href="http://www.trb.org/Main/Blurbs/175169.aspx">http://www.trb.org/Main/Blurbs/175169.aspx</a>
Delay, Unsignalized (per vehicle for one direction)	Intersection Improvements	35	10	50	Seconds per Vehicle	TRB's Highway Capacity Manual (HCM), Sixth Edition.
Delay (per vehicle for each approach)	Roundabouts	55	20	80	Seconds per Vehicle	TRB's Highway Capacity Manual (HCM), Sixth Edition.

Input	Tool(s)	Recommended Default	Low Value	High Value	Units	References
Heavy-Duty Truck Percentage	Intersection Improvements, Roundabouts, Signal Synchronization, Managed Lanes	10	5	20	Percent	Estimates for illustrative purposes only; truck percentage varies widely dependent on road type and location.
Existing Left Turn Percentages (3 Approach)	Roundabouts	15			Percent	Individual intersections vary widely. Average values provided for example purposes only.
Existing Right Turn Percentage (3 Approach)	Roundabouts	85			Percent	Individual intersections vary widely. Average values provided for example purposes only.
Signal Cycle Length	Signal Synchronization	90	30	120	Seconds	TRB's Highway Capacity Manual (HCM), Sixth Edition.
Facility Hours Operating Per Day	Managed Lanes	8	4	24	Hours per Day	Values provided for illustrative purposes only. Please input project-specific data.
Average Hourly Traffic Flow	Managed Lanes	1000	400	2200	Vehicles per Hour	TRB's Highway Capacity Manual (HCM), Sixth Edition.
Average Hourly Speed	Managed Lanes	65	55	75	Miles per Hour	TRB's Highway Capacity Manual (HCM), Sixth Edition.
Total Fleet Activity - Population (number of trucks in city fleet)	Diesel Idle Reduction	10,000			Trucks	Based on retrofitting program in New York City: <a href="http://visionzeronetwork.org/wp-content/uploads/2016/10/CaseStudy_LargeVehicle_Final.pdf">http://visionzeronetwork.org/wp-content/uploads/2016/10/CaseStudy_LargeVehicle_Final.pdf</a>
Existing Left Turn Percentages (4 Approach)	Roundabouts	15	10	20	Percent	Based on USDOT Informational Guide on Roundabouts: <a href="https://www.fhwa.dot.gov/publications/research/safety/00067/000673.pdf">https://www.fhwa.dot.gov/publications/research/safety/00067/000673.pdf</a>

Input	Tool(s)	Recommended Default	Low Value	High Value	Units	References
Existing Right Turn Percentages (4 Approach)	Roundabouts	15	10	20	Percent	Based on USDOT Informational Guide on Roundabouts: <a href="https://www.fhwa.dot.gov/publications/research/safety/00067/000673.pdf">https://www.fhwa.dot.gov/publications/research/safety/00067/000673.pdf</a>
Rural Unpaved Roads Average Speed	Street Paving	33	30	39	Miles per Hour	EPA's AP-42, Unpaved Roads: <a href="https://www3.epa.gov/ttn/chief/ap42/ch13/index.html">https://www3.epa.gov/ttn/chief/ap42/ch13/index.html</a>
Urban Unpaved Roads Average Speed	Street Paving	20			Miles per Hour	EPA's AP-42, Unpaved Roads: <a href="https://www3.epa.gov/ttn/chief/ap42/ch13/index.html">https://www3.epa.gov/ttn/chief/ap42/ch13/index.html</a>
Number of Vehicles Participating in Carpooling	Carpooling	8,000			Vehicles	Based on US Census Bureau statistic of 9% of commuters carpool (assumption: 90% carpool, 10% is vanpool), taking 9% total commuter volume of a mid-sized city (Springfield, MA at 294,000) gives number of commuters, taking 90% and dividing by average number of passengers per vehicle (3) gives 8,000 cars participating in carpools programs per city.
Number of Vehicles Participating in Vanpooling	Vanpooling	380		1500	Vehicles	Assuming 10% of carpoolers participate in vanpool and dividing by the average number of passengers per vehicle (7) gives around 380 vans per city program
Average Hourly Traffic Flow of General Purpose Lanes - After	Managed Lanes	1500	1200	1700	Vehicles per Hour	Estimate from review of California's HOV lane program found at <a href="https://lao.ca.gov/2000/010700_hov/010700_hov_lanes.html">https://lao.ca.gov/2000/010700_hov/010700_hov_lanes.html</a>

Input	Tool(s)	Recommended Default	Low Value	High Value	Units	References
Average Hourly Speed of General Purpose Lanes – Before & After	Managed Lanes	55	45	65	Miles per Hour	Data from University of Utah Evaluation of the Effectiveness of HOV lanes found at <a href="https://www.ugpti.org/resources/reports/downloads/mpc04-158.pdf">https://www.ugpti.org/resources/reports/downloads/mpc04-158.pdf</a>
Average Hourly Traffic Volume	Roundabouts	250	200	800	Vehicles per Hour	Based on USDOT Informational Guide on Roundabouts: <a href="https://www.fhwa.dot.gov/publications/research/safety/00067/000673.pdf">https://www.fhwa.dot.gov/publications/research/safety/00067/000673.pdf</a> Default average value is based on a single lane approach and one circulating lane, with 15% left turn percentage.
Total Fleet Activity - Hotelling Hours (Single Vehicle)	Diesel Idle Reduction	2000	1200	2480	Hours	Estimates for illustrative purposes only; fleet hotelling activity can vary widely depending on location.
Average Hourly Traffic Flow of General Purpose Lanes - Before	Managed Lanes	2500	1600	3900	Vehicles per Hour	TRB’s Highway Capacity Manual (HCM), Sixth Edition.

*Additional notes on default input values:*

Daily VMT estimates by vehicle type were derived from FHWA's Highway Statistics 2015 report. FHWA provides annual vehicle distance travelled in miles by highway category (e.g., rural, urban) and vehicle type (e.g., buses, single-unit trucks, combination trucks). Annual distances were divided by 365 to develop estimates for daily VMT for each vehicle type in the Task 2018 tools.

The average trip distance (one-way) for a transit bus was derived from the American Public Transportation Association's (APTA) 2017 Public Transportation Fact Book. APTA determined the average national trip length by mode for bus, vanpool, commuter rail, ferry boat, and other forms of public transportation. The average distances in the APTA report are comparable to those reported by major metropolitan transit systems, such as the Massachusetts Bay Transportation Authority.<sup>1</sup>

Delay estimates (time spent idling) for intersections and roundabouts were derived from the Transportation Research Board's Highway Capacity Manual (HCM), Sixth Edition. The HCM was also used to develop estimates for signal cycle length and average hourly traffic flow for the Signal Synchronization and Managed Lanes tools, respectively.

Select vanpool and carpool statistics were derived from FHWA's 2010 Status of the Nation's Highways, Bridges, and Transit: Conditions & Performance<sup>2</sup> and the Federal Transit Administration's National Transit Database (NTD).<sup>3</sup>

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<sup>1</sup> MBTA Ridership and Service Statistics 2014:

<https://cdn.mbtace.com/uploadedfiles/documents/2014%20BLUEBOOK%2014th%20Edition%281%29.pdf>

<sup>2</sup> 2010 Conditions and Performance Report: <https://www.fhwa.dot.gov/policy/2010cpr/index.cfm>

<sup>3</sup> NTD 2016 statistics: <https://www.transit.dot.gov/ntd/data-product/2016-service>

## EMISSIONS MODELING GLOSSARY

Common terms in EPA's MOVES model:

**MOVES:** EPA's Motor Vehicle Emissions Simulator. MOVES is a set of modeling tools for estimating emissions produced by onroad and nonroad mobile sources. Most emission rates in the Task 108 tools were calculated by dividing MOVES emission inventories by the appropriate emission-related activity (e.g., extended idle emissions and hotelling hours for extended idle emission rates).

**Fuel type:** broad fuel categories that indicate the fuel vehicles are capable of using; includes diesel, gasoline, CNG, electric.

**Model year group:** a list of years and groups of years corresponding to vehicles with similar emissions performance

**Road type:** distinguishes roadways by population density of geographic area and by type of access, particularly the use of ramps for entrance and exit. The MOVES road types are based on two FHWA distinctions: 1) urban versus rural roadways are distinguished based on land use and human population density, and 2) unrestricted versus restricted are distinguished based on roadway access—restricted roads require the use of ramps.

**Hotelling activity:** type of hotelling or extended rest period; includes extended idle and auxiliary power units (APUs)

**Emissions process:** source of emissions; includes running, start, crankcase, extended idle, and auxiliary power

**Exhaust emissions:** emissions from engine related processes such as fuel combustion, burnt oil, and other particles that exit the tailpipe

**Brake and tire wear emissions:** particulate matter from brakes and tires that can be created by abrasion, corrosion, and turbulence; these particles have different chemical composition and size compared with exhaust particulate matter.

**Fugitive dust emissions:** atmospheric dust generated from open sources, such as unpaved roads and heavy construction operations; dust is generated by pulverization and abrasion of surface materials (e.g., force of wheels) and entrainment of dust particles in turbulent air currents. Street sweeping and paving are two common dust mitigation measures.

## ABBREVIATIONS AND ACRONYMS

AADT	Annual average daily traffic
AFLEET	Alternative Fuel Life-Cycle Environmental and Economic Transportation Tool
APU	Auxiliary power units
CE	Control efficiency
CMAQ	Congestion Mitigation and Air Quality Improvement
CNG	Compressed natural gas
CO	Carbon monoxide
FHWA	Federal Highway Administration
GP	General Purpose lanes
HOV	High-occupancy vehicles
ML	Managed lanes
MOVES	Motor Vehicle Emission Simulator
NCHRP	National Cooperative Highway Research Program
NO <sub>x</sub>	Nitrogen oxide
PM <sub>2.5</sub>	Particulate matter with diameter less than 2.5 micrometers
PM <sub>10</sub>	Particulate matter with a diameter less than 10 micrometers
TDM	Travel demand model
TSE	Truck Stop Electrification
VMT	Vehicle miles traveled
VOCs	Volatile organic compounds