

# **Methods to Find the Cost-Effectiveness of Funding Air Quality Projects**

*For Evaluating  
Motor Vehicle Registration Fee Projects  
and  
Congestion Mitigation and  
Air Quality Improvement (CMAQ) Projects*

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California Environmental Protection Agency

 **Air Resources Board**



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*The methods handbook was initially prepared by the California Air Resources Board (ARB) in cooperation with the California Department of Transportation (Caltrans) and the California Air Pollution Control Officers Association (CAPCOA). Updates have been prepared by Air Resources Board staff. The principal author is Pam Burmich, Air Pollution Specialist. Current ARB staff contact is Jeff Weir, (916) 445-0098, jweir@arb.ca.gov.*

**FOR COPIES** of this handbook, see the ARB or Caltrans websites at [www.arb.ca.gov/planning/tsaq/eval/eval.htm](http://www.arb.ca.gov/planning/tsaq/eval/eval.htm) or [www.dot.ca.gov/hq/transprog/reports/Official\\_CMAQ\\_Web\\_Page.htm](http://www.dot.ca.gov/hq/transprog/reports/Official_CMAQ_Web_Page.htm), or call the ARB's Transportation Strategies Group at (916) 322-0285. The handbook is also available as a Microsoft Access file that allows the user to enter the appropriate inputs and calculates emission reductions and cost-effectiveness automatically.

The primary changes in this edition of the handbook are the updating of emission factors and example calculations using ARB's motor vehicle emissions model, EMFAC2002.

# Methods to Find the Cost-Effectiveness of Funding Air Quality Projects

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# Methods to Find the Cost-Effectiveness of Funding Air Quality Projects

## Introduction

Millions of dollars are provided each year to regional and local jurisdictions to help fund projects that reduce emissions from motor vehicles and assist the implementation of transportation measures in regional clean air plans. Two major sources of this funding are the California Motor Vehicle Registration Fee (MV Fees) Program and the federal Congestion Mitigation and Air Quality Improvement (CMAQ) Program.

To ensure that public health benefits are maximized, it is important that projects funded be the most cost-effective at reducing emissions. To achieve this goal, cost-effectiveness evaluations should be used to prioritize projects before final funding decisions are made.

*The cost-effectiveness of an air quality project is based on the amount of pollution it eliminates for each dollar spent.* This document is a “methods handbook” to help estimate the cost-effectiveness of some of the most widely implemented transportation-related air quality projects:

Cleaner off-road vehicles	Signal coordination
Cleaner on-road vehicles	Bicycle facilities
New bus service	Telecommuting programs
Vanpools and shuttles	Ridesharing and pedestrian facilities
Cleaner street sweepers	

For each project type, the methods handbook includes:

- A list of the information needed to evaluate cost-effectiveness.
- “Defaults” that may be used when data are not available.
- Formulas to calculate vehicle emission reductions for three major pollutants:

- Reactive organic gases (ROG)
  - Nitrogen oxides (NO<sub>x</sub>)
  - Particulate Matter (PM<sub>10</sub>)

Emission factor tables are included for various vehicle and project types.

- Formula to calculate cost-effectiveness
- Sample evaluation to aid in using the method

## Cost-Effectiveness

Cost-effectiveness for MV Fees and CMAQ projects should be expressed as dollars spent per pound of pollutant reduced (ROG + NO<sub>x</sub> + PM<sub>10</sub>). Cost-effectiveness is typically based on total project costs, including capital investments and operating costs. However, for the purposes of this document, cost-effectiveness is based on clean air funding dollars. Project funding generally covers only the incremental additional costs of a cleaner engine or vehicle.

The funding dollars are amortized over the expected project life using a discount rate. The amortization formula yields a capital recovery factor, which, when multiplied by the funding, gives the annual funding for the project over its expected lifetime. The discount rate reflects the opportunity cost of public funds for the clean air programs. This is the level of earning that could be reasonably expected by investing public funds in various financial instruments, such as U.S. Treasury securities. Cost-effectiveness is determined by dividing annualized funds by annual emission reductions (ROG + NO<sub>x</sub> + PM<sub>10</sub>).

The following table gives capital recovery factors that may be used to annualize funding dollars according to project life. The capital recovery factors below are calculated to two decimal places using a discount rate of 3 percent.

<b>Project Life</b>	<b>Capital Recovery Factor for discount rate of 3%</b>
1 year	1.03
3 years	0.35
5 years	0.22
7 years	0.16
10 years	0.12
12 years	0.10
15 years	0.08
20 years	0.07

## Defaults

The methods in this handbook call for monitored data and information inputs that may not be readily available. Defaults are provided for each method based on local and national travel surveys, surveys conducted by local air districts, research projects funded by the Air Resources Board (ARB) and air districts, and ARB guidance documents. Local data should be used in place of defaults when data are available. Emission factors are based on certification testing and ARB's statewide mobile source inventory.

## Federal CMAQ Reporting Requirements

*Carbon monoxide.* Federal Highway Administration (FHWA) requests that CO emission reductions be reported for CMAQ projects. California's MV Fee Program does not request CO information. CO is a localized pollutant and not a regional pollution problem. Most projects using CMAQ and MV Fee dollars are funded primarily to reduce regional ozone and PM<sub>10</sub> and have little impact on localized CO hot spots.

Signal coordination projects, however, may be targeted at specific CO hot spots in CO nonattainment areas. CO emission factors are included in this edition in order to report to FHWA on these types of CMAQ projects. Reporting CO emission reductions should be limited to targeted projects located in CO nonattainment or maintenance areas.

In addition, CO emissions are several orders of magnitude larger than ozone precursors. CO overwhelms cost-effectiveness ratios unless CO emission reductions are scaled back significantly, typically by a factor of seven. This adjustment should be made when using cost-effectiveness ratios as a basis for funding decisions. Another option is to consider CO projects separately from ozone precursor projects.

*Kilograms.* FHWA requests that emission reductions from CMAQ projects be reported in kilograms per day. The methods handbook therefore includes formulas to convert pounds per year of emission reductions to kilograms per day.

### Infrastructure Projects

Supporting infrastructure may be necessary for some kinds of emission reducing projects to be successful. Examples of infrastructure projects are alternative-fueled vehicle refueling stations, electric vehicle recharging facilities, public education programs, multi-modal transit infrastructure projects, and automated transit schedule information. Because infrastructure projects are difficult to evaluate for cost-effectiveness, they are not included in this handbook. However, they should be evaluated with respect to their consistency with clean air plans. Funding priorities can be structured to include supporting projects.

### Mobile Source Emission Reduction Credits

The methods handbook should not be used to determine mobile source credits which can be sold or traded. For procedures on how to generate these credits, please refer to the Air Resources Board document, Mobile Source Emission Reduction Credits Guidelines.

Air Resources Board regulations require new motor vehicles (including transit buses) to meet progressively more stringent emission standards. Emission reductions associated with the natural replacement of older vehicles with newer, cleaner models are included in motor vehicle emission inventories in clean air plans, and thus are not surplus emission reductions.

### Contact

If you have any questions about the methods handbook, air quality cost-effectiveness analysis of transportation-related projects, or the evaluation of future-year projects for which the emission factor tables may not be best suited, please contact Jeff Weir, Transportation Strategies Group, Air Resources Board, at (916) 445-0098 or [jweir@arb.ca.gov](mailto:jweir@arb.ca.gov).

## On-Road Cleaner Vehicle Purchases and Repowering

**Project definition:** The purchase of a motor vehicle that is certified to be less polluting than a typical new vehicle (cleaner purchase) or an engine replacement that transforms a vehicle into a less polluting one (cleaner repower). Since natural replacement of older vehicles or engines with newer, cleaner ones (fleet turnover) is accounted for in clean air plans, in order to claim emission reductions from the project, the vehicles purchased must emit less pollution than conventional new vehicles meeting current emission standards.

**Note:** Recent but limited studies indicate further PM10 and formaldehyde reductions can be obtained from particulate filters and oxygen catalysts on natural gas vehicles.

**How emissions are reduced:** Emission reductions are the emissions associated with a new, more polluting vehicle minus the emissions associated with a new, less polluting vehicle.

**Need to know:**

Funding dollars

Annual vehicle miles traveled (VMT)

Engine certification rates or cleaner vehicle classification

<b>Inputs</b>	<b>Default</b>	<b>Units</b>	<b>Comments</b>
Funding Dollars ( <b>Funding</b> )		dollars	
Effectiveness Period ( <b>Life</b> )		years	Suggested defaults are: Cleaner heavy-duty transit or urban bus - 12 Electric bus - 18, School bus - 20, Heavy-duty trucks - 10, Medium-duty vehicles - 10, Light-duty vehicles - 8 Light-duty electric vehicles - 10
Annual Vehicle Miles Traveled ( <b>VMT</b> )		annual miles	Suggested defaults: Transit bus - 40,000 mi/yr School bus - 15,000 mi/yr Heavy-duty truck – 70,000 mi/yr (line haul truck)

**Emission Factor Inputs** (Example is for Class 8 truck)

	<b>Default</b>	<b>Units</b>	<b>Default</b>	<b>Units</b>
	<b>Before Emission Factor</b>		<b>After Emission Factor</b>	
ROG Factor		g/mi		g/mi
NOx Factor	5.8	"	3.74	"
PM10 Factor	0.3	"	0.06	"

For heavy-duty emission factors, see Table 5. For medium-duty vehicle and light-duty emission factors, see Table 2 and Table 7. Select the factors that best represent your project.

Benefits for on-road heavy-duty engines are usually based on NOx and PM emissions only. (Defaults: The “Before” emission factors represent a typical new Class 8 truck. The “After” emission factors represent a 1.8 g/bhp-hr NOx + NMHC Class 8 truck. For electric buses use 0 as the default value.)

**Formulas****Units**

Annual Emission Reductions (ROG, NO<sub>x</sub>, and PM<sub>10</sub>) =  
 (VMT)\*[(Before Emission Factor) - (After Emission Factor)]/454      lbs/year

Capital Recovery Factor (CRF) =  $\frac{(1 + i)^n (i)}{(1 + i)^n - 1}$

where:       $i$  = discount rate (Assume 3 percent)  
                $n$  = project life

Cost-Effectiveness of  
 Funding Dollars = (CRF \* Funding) / (ROG + NO<sub>x</sub> + PM<sub>10</sub>)      dollars/lb

*Note: The Federal Highway Administration requests that emission reductions from CMAQ projects be reported as kilograms/day. The conversion is  
 (lbs per year) / [(2.2)\* (365)] = kilograms/day*

**On-Road Cleaner Vehicle Purchases and Repowering**      **(Optional Method)**

Emissions can also be calculated using emission factors in units of g/bhp-hr multiplied by annual fuel consumption and an energy consumption factor. The default for the energy consumption factor is 18.5 hp-hr/gal. In the formula above, substitute annual gallons of fuel in place of **VMT**. Substitute emission rates in units of g/bhp-hr multiplied by 18.5 in place of the **Before Emission Factor** and the **After Emission Factor**.

**Purchase Cleaner Line Haul Trucks**

A line haul trucking company proposes to purchase 3 heavy-duty (Class 8) line haul trucks equipped with CNG engines certified to 1.8 g/bhp-hr NOx + NHMC.

**Inputs to calculate cost-effectiveness:**

Funding Dollars (Funding) = \$60,000

(Funding is usually limited to the incremental project cost -- the difference between the cost of the cleaner truck and a typical new truck -- or less, to ensure cost-effectiveness of better than \$10/lb.)

Effectiveness Period (Life): 10 years

Annual Vehicle Miles Traveled (VMT): 210,000 miles

**Emissions Factors (From Table 5):**

	"Before" Emission Factor	"After" Emission Factor
ROG Factor	not applicable	not applicable
NOx Factor	5.8 grams/mi	3.74 grams/mi.*
PM10 Factor	0.3 "	0.06 "

\* From Table 5: Assume 80% NOx for 1.8 NOx + NMHC certification, or 1.44 g/bhp-hr. 1.44 x 2.6 (conversion factor) = 3.74 grams/mi

**Calculations:**

Annual Emission Reductions (ROG, NOx, and PM10) =

$$(VMT) * [(Before\ Emission\ Factor) - (After\ Emission\ Factor)]/454$$

**ROG:** 0 lbs. per year reduced

**NOx:** 210,000 \* [(5.80) - (3.74)]/454 = **953 lbs. per year reduced**

**PM10:** 210,000 \* [(0.30) - (0.06)]/454 = **111 lbs. per year reduced**

**Capital Recovery Factor (CRF) =  $\frac{(1 + i)^n(I)}{(1 + i)^n - 1}$**   
(From Table 8)

where: *n* = project life (10 years)  
*i* = discount rate (3%)

$$CRF = \frac{(1 + .03)^{10}(.03)}{(1 + .03)^{10} - 1} = 0.12$$

**Cost-Effectiveness of Funding Dollars** = (CRF \* Funding) / (ROG + NOx + PM10)  
= (0.12 \* 60,000) / (0 + 953 + 111)  
= **\$6.76 per lb.**

**FOR CMAQ PROJECTS ONLY:**

Once emission reductions have been calculated, add them together (0 + 953 + 111 = 1,064) and convert emissions reductions per year to kg/day:

$$\frac{\text{lbs. per year}}{2.2 \text{ lbs./kg} * 365 \text{ days/year}} = \frac{1,064}{2.2 * 365} = 1 \text{ kg/day}$$

## **Off-Road Cleaner Vehicle Purchases and Repowering**

**Project definition:** Replacing uncontrolled diesel engines in off-road equipment, such as agricultural or construction equipment, with lower-emitting, controlled diesel engines or alternative fueled engines. Repowering vehicles with cleaner new engines is done instead of rebuilding the old engine. Diesel engines, rather than alternative fueled engines, are typically used to meet the needs of these applications.

**How emissions are reduced:** Emission reductions are the difference between the emissions associated with an older rebuilt, more polluting engine minus the emissions associated with the less polluting new engine. Emission reductions are primarily NOx reductions.

**Need to know:**

Funding dollars

Annual vehicle operating hours

Horsepower

Engine load factor

<b>Inputs</b>	<b>Default</b>	<b>Units</b>	<b>Comments</b>
Funding Dollars ( <b>Funding</b> )		dollars	
Effectiveness Period ( <b>Life</b> )	10	years	
Annual Vehicle Operating Hours ( <b>OperHrs</b> )		annual hours	Operating hours range: Agricultural Equipment 110 - 814 Construction Equipment 130-1836
Horsepower ( <b>HP</b> )		bhp	
<b>Load</b>			Load range: Agricultural Equipment 0.38 - 0.7 Construction Equipment 0.43-0.78

### **Emission Factor Inputs**

	<b>Default</b>	<b>Units</b>	<b>Default</b>	<b>Units</b>
	<b>Before Emission Factor</b>		<b>After Emission Factor</b>	
ROG Factor	0.88	g/bhp-hr	0.22	g/bhp-hr
NOx Factor	11.0	"	4.72	"
PM10 Factor	0.55	"	0.19	"

For off-road vehicle emission factors, see Table 6. The "Before Emission Factor" represents the old diesel engine. The "After Emission Factor" represents a new diesel or cleaner engine. Select the factors that best represent your project. (Defaults are for replacing a 1985-1987 diesel engine in the 121-175 horsepower range with a cleaner 2004 engine.)

**Formulas****Units**

Annual Emission Reductions (ROG, NO<sub>x</sub>, and PM<sub>10</sub>) = lbs/year

$$(\text{OperHrs}) * (\text{HP}) * (\text{Load}) * [(\text{Before Emission Factor}) - (\text{After Emission Factor})] / 454$$

$$\text{Capital Recovery Factor (CRF)} = \frac{(1 + i)^n (i)}{(1 + i)^n - 1}$$

where:  $i$  = discount rate (Assume 3 percent)  
 $n$  = project life

Cost-Effectiveness of

$$\text{Funding Dollars} = (\text{CRF} * \text{Funding}) / (\text{ROG} + \text{NO}_x + \text{PM}_{10}) \quad \text{dollars/lb}$$

*Note: The Federal Highway Administration requests that emission reductions from CMAQ projects be reported as kilograms/day. The conversion is*

$$(\text{lbs per year}) / [(2.2) * (365)] = \text{kilograms/day}$$

*Off-road vehicles are generally not eligible for CMAQ funds, with the exception of off-road construction vehicles used for road projects.*

**Off-Road Cleaner Vehicle Purchases and Repowering (Optional Method)**

Annual operating hours (**OperHrs**), horsepower (**HP**), and Load (**L**) can be replaced in the formula with annual fuel consumption in gallons per year multiplied by an energy consumption factor expressed as hp-hr/gal. The default for the energy consumption factor is 18.5 hp-hr/gal. In the formula above, substitute annual gallons of fuel in place of **OperHrs**. Substitute 18.5 in place of **HP\*Load**.



## Cleaner Street Sweeper Purchases

**Project definition:** The purchase of an alternative-fueled street sweeper in lieu of a typical diesel powered street sweeper. Street sweepers frequently have two engines: a main (on-road) engine and a smaller auxiliary (off-road) engine. Both engines can be powered with alternative-fuels. Also, street sweepers that meet the certification requirements of the South Coast Air Quality Management District's Rule 1186 have improved road dust collection efficiency and generate less PM10 during sweeping activities when compared to non-certified equipment.

**How emissions are reduced:** Emission reductions are the difference between the emissions associated with operating a typical new diesel sweeper compared to one that uses cleaner, alternative fuels. There are additional PM10 emission reductions associated with sweeper operations if the sweeper is PM10 efficient and certified to Rule 1186. The methodology provides default PM10 benefits to account for Rule 1186-certified sweepers.

(There are additional benefits associated with a reduction in entrained road dust from vehicular traffic subsequent to sweeping operations; however, these benefits are difficult to quantify due to variability in roadway conditions and traffic volumes. Typically, alternative-fueled sweepers will be cost effective without consideration of these benefits.)

### **Need to know:**

Funding dollars

Annual fuel usage

Engine certification rates

Annual miles swept

<b>Inputs</b>	<b>Default</b>	<b>Units</b>	<b>Comments</b>
Funding Dollars ( <b>Funding</b> )		dollars	
Effectiveness Period ( <b>Life</b> )	10	years	
Annual Gallons of Fuel Used for the Main Engine ( <b>Main Fuel</b> )		gallons per year	Fuel usage for the main (on-road) engine. Default is 2/3 of total fuel usage for the vehicle. (Default for total fuel usage is 30 gal/day for 250 days/yr or 7500 annual gallons.)
Annual Gallons of Fuel Used for the Auxiliary Engine ( <b>Aux Fuel</b> )		gallons per year	Fuel usage for the auxiliary engine. Default is 1/3 of total fuel usage for the vehicle. If there is no auxiliary engine, enter zero.
Annual Miles Swept ( <b>Miles Swept</b> )		miles per year	

### Emission Factor Inputs for the Main Engine

	Default		Units	Default		Units
	Main EF Before			Main EF After (optional certification rate) (alternative-fueled)		
ROG Factor	N/A		g/bhp-hr	N/A		g/bhp-hr
NOx Factor	2.1		g/bhp-hr	1.44		g/bhp-hr
PM10 Factor	0.1		g/bhp-hr	0.053		g/bhp-hr

Benefits are usually based on NOx and PM10 emissions. The "Main EF Before" factors represent the old diesel engine. The "Main EF After" factors represent a new diesel or cleaner engine. Select the factors that best represent the project. Defaults shown for "Main EF Before" are based on baseline emission factors for heavy-duty trucks 14,001 to 33,000 lbs (see Table 5 -- 4.8 grams per mile / 2.3 conversion factor = 2.1 g/bhp-hr). For "Main EF After," use the g/bhp-hr certification rate of the new, cleaner engine. Defaults for "Main EF After" assume that the new engine is certified to 1.8 g/bhp-hr NOx + NHMC (assume 80% NOx -- 1.44 g/bhp-hr) and 0.053 g/bhp-hr for PM.

Similarly, the emission factors below represent diesel versus alternative-fueled auxiliary engine emissions. The defaults for "Aux EF Before" are from Table 6 and are based on the off-road diesel engine (50 – 175 hp) NOx emission standard of 4.72 g/bhp-hr for year 2004. "Aux EF After" factors assumes an engine that is certified to an optional 4.0 g/bhp-hr NOx + NHMC (assume 95% NOx – 3.8 g/bhp-hr).

The methodology allows for potential benefits from cleaner off-road auxiliary engines to be included should they occur. If the auxiliary engine is an on-road engine, then the defaults are the same as for the main engine shown in the table above.

### Emission Factor Inputs for the Auxiliary Engine

	Default		Units	Default		Units
	Aux EF Before			Aux EF After		
	Off-Rd	On-Rd		Off-Rd	On-Rd	
ROG Factor	N/A	N/A	g/bhp-hr	N/A	N/A	g/bhp-hr
NOx Factor	4.72	N/A	g/bhp-hr	3.80	N/A	g/bhp-hr
PM10 Factor	N/A	N/A	g/bhp-hr	N/A	N/A	g/bhp-hr

### Emissions Benefit Factor for Rule 1186-Certified Sweepers

Rule 1186-certified street sweepers tested in July of 1999 had an average entrainment value of 109 milligrams per meter (mg/meter). During those same evaluations, the non-certified street sweepers had an entrainment value of 340 mg/meter. Based on these evaluations, the net benefit of using a Rule 1186-certified street sweeper is 231 mg/meter; however, this value has been reduced to account for the fact that the silt loadings used in the test are greater than typical paved road loadings. With this reduction factor and the appropriate conversion, the net benefit from using Rule 1186-certified street sweepers is estimated at **0.05 pounds/mile** of street sweeping. This benefit factor is used in the formula below to calculate reductions from sweeping with Rule 1186-certified street sweeping.

**Formulas**

Units

Annual ROG, NO<sub>x</sub>, and PM<sub>10</sub> Emission Reductions from the Cleaner Engines  
(**Engine Reductions**) =

$$[\text{Main Fuel} * (\text{Main EF Before} - \text{Main EF After}) + \text{Aux Fuel} * (\text{Aux EF Before} - \text{Aux EF After})] * 18.5/454$$

lbs/year

(Note: The factor, 18.5 hp-hr/gallons, is the energy consumption factor.)

Additional PM<sub>10</sub> Emission Reductions from Rule 1186-Certified Sweepers  
(**Sweeping Reductions**) =

$$\text{Miles Swept} * 0.05$$

lbs/year

Annual Emission Reductions (**ROG, NO<sub>x</sub>, and PM<sub>10</sub>**) =  
Engine Reductions + Sweeping Reductions

lbs/year

$$\text{Capital Recovery Factor (CRF)} = \frac{(1 + i)^n (i)}{(1 + i)^n - 1}$$

where:  $i$  = discount rate (Assume 3 percent)  
 $n$  = project life

Cost-Effectiveness of

$$\text{Funding Dollars} = (\text{CRF} * \text{Funding}) / (\text{ROG} + \text{NO}_x + \text{PM}_{10})$$

dollars/lb

*Note: The Federal Highway Administration requests that emission reductions from CMAQ projects be reported as kilograms/day. The conversion is  
(lbs per year) / [(2.2) \* (365)] = kilograms/day*

## Cleaner Street Sweepers

### EXAMPLE

#### **Purchase of Rule 1186-certified, CNG Street Sweeper**

A city purchases a street sweeper certified to Rule 1186 that uses compressed natural gas (CNG). The sweeper has a GVWR of 32,000 lbs with a main on-road engine plus an on-road auxiliary engine (150 hp). The new engines are certified to 1.8 g/bph-hr for NOx + NMHC (assume 80% NOx - 1.44 g/bhp-hr) and 0.053 g/bph-hr PM. The cost difference between a new cleaner sweeper and a new typical diesel sweeper is \$40,000.

#### **Inputs to calculate cost-effectiveness:**

Funding Dollars (Funding) = \$40,000

Effectiveness Period (Life): 10 years

Annual Gallons of Fuel Used by the Main Engine (Main Fuel): 5,000 gallons per year

Annual Gallons of Fuel Used by the Auxiliary Engine (Aux Fuel): 2,500 gallons per year

Annual Miles Swept (Miles Swept): 10,000 miles (40 miles/day \* 250 days/year)

Energy Consumption Factor: 18.5 hp-hr/gallons

#### **Emissions Factors for Main Engine:**

	<u>Main EF Before</u>	<u>Main EF After</u>
ROG Factor	not applicable	not applicable
NOx Factor	2.1 grams/ bhp-hr	1.44 grams/ bhp-hr
PM10 Factor	0.1 grams/ bhp-hr	0.053 grams/ bhp-hr

#### **Emissions Factors for Auxiliary Engine:**

	<u>Aux EF Before</u>	<u>Aux EF After</u>
ROG Factor	not applicable	not applicable
NOx Factor	2.10 grams/ bhp-hr	1.44 grams/ bhp-hr
PM10 Factor	0.10 grams/ bhp-hr	0.053 grams/ bhp-hr

#### **Calculations**

Annual ROG, NOx, and PM10 Emission Reductions from the Cleaner Engines (Engine Reductions) =

$$[\text{Main Fuel} * (\text{Main EF Before} - \text{Main EF After}) + \text{Aux Fuel} * (\text{Aux EF Before} - \text{Aux EF After})] * 18.5/454$$

**ROG: 0**

**NOx: [5,000 \* (2.1 - 1.44) + 2,500 \* (2.1 - 1.44)] \* 18.5/454 = 202 lbs. per year reduced**

**PM10: [5,000 \* (0.1 - 0.053) + 2,500 \* (0.1 - 0.053)] \* 18.5/454 = 14 lbs. per year reduced**

Annual PM10 Emission Reductions from Sweeping (Sweeping Reductions) =

$$\text{Miles Swept} * 0.05$$

**PM10: 10,000 \* 0.05 = 500 lbs. per year reduced**

Annual Emission Reductions (ROG, NOx, and PM10) =

= Engine Reductions + Sweeping Reductions

ROG = 0 lbs. per year reduced

NOx = 202 lbs. per year reduced

PM10 = 514 lbs. per year reduced

Capital Recovery Factor (CRF) =  $\frac{(1+i)^n(i)}{(1+i)^n - 1}$   
(From Table 8)

where:  $i$  = discount rate (assume 3 percent)

$n$  = project life (10 years)

$$\text{CRF} = \frac{(1 + .03)^{10}(.03)}{(1 + .03)^{10} - 1} = 0.12$$

Cost-Effectiveness of Funding Dollars = (CRF \* Funding)/(ROG + NOx + PM10)

$$= (0.12 * 40,000) / (202 + 514)$$

$$= \$ 6.70 \text{ per lb.}$$

**FOR CMAQ PROJECTS ONLY:**

Once emissions reductions have been calculated, add them together (0+ 202 + 514 = 716) and

convert emissions reductions to kg/day:  $\frac{\text{lbs. per year}}{2.2 \text{ lbs./kg} * 365 \text{ days/year}} = \frac{716}{2.2 * 365} = 1 \text{ kg/day}$

## Operation of New Bus Service

**Project definition:** New, extended, and increased-frequency routes with cleaner vehicles provide new hours of bus service per year and serve additional people. These are fixed-route services implemented by transit agencies or school districts. Cleaner buses should be used in bus service expansions in order to achieve emission reductions from the project. For example, an urban transit bus with a diesel engine (4.0 g/bhp-hr NO<sub>x</sub>) needs to operate at capacity (40 bus riders) in order to offset the NO<sub>x</sub> emissions associated with the bus itself. Cleaner buses (i.e., 1.8 g/bhp-hr NO<sub>x</sub> + NMHC) will offset bus emissions with half as many bus riders.

**How emissions are reduced:** Emission reductions result from the decrease in emissions associated with auto trips replaced by the new bus service after adjusting for the added bus emissions and auto access to the transit stop.

### **Need to know:**

Funding dollars

Number of operating days per year

Average daily ridership of new service (usually less than 100% occupancy)

Average length of auto trips replaced

Percent of riders who drive to the bus service

Annual VMT for the new bus service

<b>Inputs</b>	<b>Default</b>	<b>Units</b>	<b>Comments</b>
<b><i>For the Bus Service</i></b>			
Funding Dollars ( <b>Funding</b> )		dollars	
Effectiveness Period ( <b>Life</b> )	1	years	Years project is funded.
Days ( <b>D</b> )	260	days (of operation)/year	Suggested defaults are weekday services - 260 days, daily services - 365 days, school bus services - 180 to 200 days
Ridership ( <b>R</b> )		total trips (bus rider trips)/day	If 50 bus riders make a commute round trip each day, that's 100 bus rider trips per day. (50 bus riders x 2 trips)
Annual Bus VMT ( <b>Bus VMT</b> )		annual miles traveled	
<b><i>For Auto Travel Reduced</i></b>			
Adjustment ( <b>A</b> ) on Auto Trips for transit dependent	0.50		This default factor equals the portion of transit riders who reduce a vehicle trip. The default for commuter bus service is 0.83

<b>Inputs</b>	<b>Default</b>	<b>Units</b>	<b>Comments</b>
Auto Trip Length (L)	9	miles one direction/trip	Length of average auto trips reduced. Other suggested defaults are work trip bus services - 16 mi., school bus - 3 mi.
<i>For Auto Travel Added to Access Bus Service</i>			
Adjustment (AA) on Auto Trips for Auto Access to and from transit service	0.1*		This default factor equals the portion of riders who drive to the transit service. The default factor for long-distance commuter service is 0.8.
Trip Length (LL) for Auto Access to and from transit	2	miles one direction/trip	The default for long-distance bus service is 5 miles.

\* The Auto Access default has been decreased from 0.25 to 0.1. Recent transit rider surveys conducted in Sacramento, Fresno, and Monterey indicate a lower auto access trip rate for regular transit routes.

#### **Emission Factor Inputs for Auto Travel**

	<b>Default</b>	<b>Units</b>	<b>Default</b>	<b>Units</b>
	<b>Auto Trip End Factor</b>		<b>Auto VMT Factor</b>	
ROG Factor	1.481	grams/trip	0.392	grams/mile
NOx Factor	0.645	"	0.491	"
PM10 Factor	0.015	"	0.218	"

For average auto emission factors, see Table 3. Use factors that correspond to the life of the project. Defaults are for a project life of 1-5 years.

#### **Emission Factor Inputs for Bus Travel**

	<b>Default</b>	<b>Units</b>
	<b>Bus VMT Factor</b>	
ROG Factor	0.50	grams/mile
NOx Factor	6.20	grams/mile
PM10 Factor	0.025	"

For typical diesel bus emission factors through model year 2002, see Table 1. For model years after 2002, use actual engine certification factors or, if not available, use Table 5. For buses meeting optional standards, or for alternative fueled buses, see Table 5. For commuter express diesel bus service, see Table 1 -- use appropriate year and "45 mph" column. (Defaults are for a CNG transit bus certified to the 1.8 g/bhp-hr NOx + NMHC standard.)

**Formulas****Units**

$$\text{Annual Auto Trips Reduced} = [(D)*(R)*(A)]*[1 - (AA)]$$

trips/year

$$\text{Annual Auto VMT Reduced} = [(D)*(R)*(A)]*[(L) - (AA)*(LL)]$$

miles/year

$$\text{Annual Emission Reductions (ROG, NO}_x\text{, and PM}_{10}\text{)} =$$

lbs/year

$$\begin{aligned} &[(\text{Annual Auto Trips Reduced})*(\text{Auto Trip End Factor}) \\ &+ (\text{Annual Auto VMT Reduced})*(\text{Auto VMT Factor}) \\ &- (\text{Bus VMT})*(\text{Bus VMT factor})]/454 \end{aligned}$$

$$\text{Capital Recovery Factor (CRF)} = \frac{(1 + i)^n (i)}{(1 + i)^n - 1}$$

where:  $i$  = discount rate (Assume 3 percent)  
 $n$  = project life

Cost-Effectiveness of

$$\text{Funding Dollars} = (\text{CRF} * \text{Funding}) / (\text{ROG} + \text{NO}_x + \text{PM}_{10})$$

dollars/lb

*Note: The Federal Highway Administration requests that emission reductions from CMAQ projects be reported as kilograms/day. The conversion is*  
 $(\text{lbs per year}) / [(2.2) * (365)] = \text{kilograms/day}$

**Commuter Express CNG Bus Service**

An 80-mile subscription commute bus service operates using five, 40-passenger compressed natural gas (CNG) buses.

**Inputs to calculate cost-effectiveness:**

Funding Dollars (Funding): \$180,000

Effectiveness Period (Life): 2 years

Days of use/year (D): 252

Daily Ridership (R): 40 passengers \* 5 buses \* 2 ways = 200 \* 2 = 400 bus riders or trips/day

Annual Bus VMT (Bus VMT): 201,600 (5 buses \* 80 miles one-way \* 2 ways \* 252 days = 201,600 VMT)

Adjustment (A) on Auto Trips for transit dependent: 0.83

Auto Trip Length (L): 80 miles in one direction

Adjustment (AA) on Auto Trips for Auto Access to and from transit: 0.80

Trip Length (LL) for Auto Access to and from transit: 5 miles one-way.

**Emissions Factors for Auto Travel (From Table 3):**

	Auto Trip End Factor	Auto VMT Factor
ROG Factor	1.481 grams per trip	0.392 grams per mile
NOx Factor	0.645 "	0.491 "
PM10 Factor*	0.014 "	0.218 "

Note: 1-5 year emission factors are used since project life is 2 years, and "Commute" auto trip end factors are used since this project reduces commute trips.

**Emissions Factors for Clean Bus Travel**

(2004 natural gas buses certified to 1.8 g/bhp-hr standard NOx + NMHC. See Table 5.):

	Bus VMT Factor
ROG Factor	0.50 grams per mile
NOx Factor	6.20 "
PM10 Factor	0.025 "

**Calculations:**

$$\begin{aligned}
 \text{Annual Auto Trips Reduced} &= [(D)*(R)*(A)]*[1-(AA)] \\
 &= [252 * 400 * 0.83]*[1-0.80] \\
 &= 16,733 \text{ annual auto trips} \\
 \text{Annual Auto VMT Reduced} &= [(D) *(R)*(A)] * [(L) - (AA) * (LL)] \\
 &= [252 * 400 * 0.83] * [80-0.80*5] \\
 &= [83,664] * [80-4] \\
 &= 6,358,464 \text{ annual miles}
 \end{aligned}$$

**Annual Emission Reductions = (lbs. per year)**

$$[(\text{Annual Auto Trips Reduced}) * (\text{Auto Trip End Factor}) + (\text{Annual Auto VMT Reduced}) * (\text{Auto VMT Factor}) - (\text{Bus VMT}) * (\text{Bus VMT Factor})] / 454$$

**ROG:**  $[(16,733 * 1.481) + (6,358,464 * 0.392) - (201,600 * 0.50)] / 454 = 5,323 \text{ lbs. per year}$

**NOx:**  $[(16,733 * 0.645) + (6,358,464 * 0.491) - (201,600 * 6.20)] / 454 = 4,147 \text{ lbs. per year}$

**PM10:**  $[(16,733 * 0.014) + (6,358,464 * 0.218) - (201,600 * 0.025)] / 454 = 3,043 \text{ lbs. per year}$

**Capital Recovery Factor (CRF) =**  $\frac{(1 + i)^n(i)}{(1 + i)^n - 1} = 0.52$  *n = project life (2 years)*  
*i = discount rate (3%)*

**Cost-Effectiveness of Funding Dollars =**  $(\text{CRF} * \text{Funding}) / (\text{ROG} + \text{NOx} + \text{PM10})$   
 $= (0.52 * 180,000) / (12,513) = \$7.48 \text{ per lb.}$

**FOR CMAQ PROJECTS ONLY:**

Once emissions reductions have been calculated, add them together (5,323 + 4,147 + 3,043 = 12,513) and convert emissions reductions to kg/day:

$$\frac{\text{lbs. reduced per year}}{2.2 \text{ lbs./kg} * 365 \text{ days/year}} = \frac{12,513}{2.2 * 365} = 16 \text{ kg/day}$$

## Vanpools and Shuttles

**Project definition:** Projects are commuter vanpools; tourist or shopping shuttles; or rail feeders to work sites, homes, or schools. Services are operated by transit agencies, local governments, transportation management associations (TMAs), private businesses, etc. In most cases, the shuttle service must reduce long-distance auto trips or be a cleaner vehicle in order to reduce emissions cost effectively.

**How emissions are reduced:** Emission reductions result from the decrease in emissions associated with auto trips replaced by the vanpool or shuttle service after adjusting for the increase in emissions associated with the shuttle vehicle itself and auto access trips.

**Need to know:**

Funding dollars

Number of operating days per year

Average daily ridership of new service (usually less than 100% occupancy)

Average length of auto trips replaced

Percent of riders who drive to the vanpool or shuttle service

Daily VMT for the new shuttle service

<b>Inputs</b>	<b>Default</b>	<b>Units</b>	<b>Comments</b>
<b><i>For the Vanpool/Shuttle</i></b>			
Funding Dollars ( <b>Funding</b> )		dollars	
Effectiveness Period ( <b>Life</b> )	1	years	Years project is funded.
Days ( <b>D</b> )	250	days (of operation)/year	Suggested defaults are weekday vanpools - 250 days, weekday shuttles - 260, daily services - 365 days, school services - 180 to 200 days
Ridership ( <b>R</b> )		total trips (riders)/day	One-way trips by riders (or number of boardings) per day
Annual Van/Shuttle VMT ( <b>Van VMT</b> )		annual miles	
<b><i>For Auto Travel Reduced</i></b>			
Adjustment ( <b>A</b> ) on Auto Trips	0.83		This factor equals the portion of riders who did NOT previously use transit, vanpools, or carpools. The default (0.83) is the adjustment for long-distance, commuter vanpool service. For new rail feeders, use 0.3 for the adjustment factor A.
Auto Trip Length ( <b>L</b> )	35	miles one direction/trip	Suggested defaults are vanpools - 35 mi., shuttle trips - 16 mi.

<b>Inputs</b>	<b>Default</b>	<b>Units</b>	<b>Comments</b>
<i>For Auto Travel Added to Access Vanpool/Shuttle</i>			
Adjustment ( <b>AA</b> ) for Auto Access to and from vanpool/shuttle	0.75		Enter the percentage of riders who drive to the vanpool/shuttle service. The default (0.75) is for long-distance vanpools. For rail feeders, use 0.5..
Trip Length ( <b>LL</b> ) for Auto Access to and from vanpool/shuttle	5	miles one direction/trip	The default (5 mi) is for long-distance van pools. For rail feeders, use 2 mi.

#### **Emission Factor Inputs for Auto Travel**

	<b>Default</b>	<b>Units</b>	<b>Default</b>	<b>Units</b>
	<b>Auto Trip End Factor</b>		<b>Auto VMT Factor</b>	
ROG Factor	1.719	grams/trip	0.470	grams/mile
NOx Factor	0.721	"	0.602	"
PM10 Factor	0.014	"	0.218	"

For auto emission factors, see Emission Factors Menu, Tables 3 and 3A. For projects with a 1-year life, use Table 3A. For projects with a life of 2-20 years, use Table 3. Defaults are for a 1-year project (2004), Table 3A.

#### **Emission Factor Inputs for Van/Shuttle Travel**

	<b>Example</b>	<b>Units</b>
	<b>Van VMT Factor</b>	
ROG Factor	0.14	grams/mile
NOx Factor	0.20	"
PM10 Factor	0.27	"

To select emission factors for van / shuttle travel:

- For model years 1995-2003, refer to Table 7, "Medium-Duty Emission Factors for Vanpools/Shuttles".
- For model years 2004+, refer to Table 2, "Cleaner Vehicle Emission Factors".

Example is for a medium-duty van (weight 8,501 - 10,000 lbs), certified as an ultra-low-emission vehicle (ULEV), model year 2004.

<b>Formulas</b>	<b>Units</b>
Annual Auto Trip Reduced = [(D) * (R) * ( A )]*[1-(AA)]	trips/year
Annual Auto VMT Reduced = [(D) * (R) * ( A )]* [(L) - (AA)*(LL)]	miles/year
Annual Emission Reductions (ROG, NO <sub>x</sub> , and PM10) =	lbs/year

$$\begin{aligned} & [(\text{Annual Auto Trips Reduced}) * (\text{Auto Trip End Factor}) \\ & + (\text{Annual Auto VMT Reduced}) * (\text{Auto VMT Factor}) \\ & - (\text{Van VMT}) * (\text{Van VMT Factor}) ] / 454 \end{aligned}$$

$$\text{Capital Recovery Factor (CRF)} = \frac{(1 + i)^n (i)}{(1 + i)^n - 1}$$

where:  $i$  = discount rate (Assume 3 percent)  
 $n$  = project life

$$\text{Cost-Effectiveness of Funding Dollars} = (\text{CRF} * \text{Funding}) / (\text{ROG} + \text{NO}_x + \text{PM10}) \quad \text{dollars/lb}$$

*Note: The Federal Highway Administration requests that emission reductions from CMAQ projects be reported as kilograms/day. The conversion is (lbs per year) / [(2.2) \* (365)] = kilograms/day*

**Suburban Vanpool/Carpool Park-and-Ride Lots** **(Method Variation)**

Provision of park-and-ride lots may encourage the formation of vanpools and carpools. The emission reduction benefits from park-and-ride lots can be calculated using the above Vanpools and Shuttles methodology plus the following calculation to estimate Ridership (**R**).

$$\text{Ridership (R)} = (\text{Parking}) * (\text{Lot Utilization}) * (2 \text{ commute trips/day})$$

Where:

**Parking** is the number of parking spaces for a new parking lot or the number of added spaces to an existing lot. **Lot Utilization** is the estimated lot utilization rate from monitored data OR use 0.75 as a default. Also, when using the vanpool/shuttle methodology for park-and-ride lots, the default for Adjustment (**AA**) for Auto Access to and from vanpool/shuttle should be 0.9 instead of 0.5.

**Long-Distance Commuter Vanpools**

This project subsidizes 10 long-distance commute vanpools. On average, each vanpool carries 11 people to work. The average distance to work is 48 miles. The vans used are 2004 model year ULEVs, 8501-10,000 lbs.

**Inputs to calculate cost-effectiveness:**

Funding Dollars (Funding): \$33,000

Effectiveness Period (Life): 1 year

Days of use/year (D): 250

Daily Ridership (R): 11 passengers \* 10 vans \* 2 ways = 220 riders or trips/day

Annual Van VMT (Van VMT): 240,000 (If you don't know the van mileage, you can estimate it:  
10 vans \* 2 ways \* 250 days \* 48 miles one-way = 240,000)

Adjustment (A) on Auto Trips: 0.83

Auto Trip Length (L): 48 miles in one direction

Adjustment (AA) on Auto Trips for Auto Access to and from vanpool: 0.75

Trip Length (LL) for Auto Access to and from vanpool: 5 miles one-way

**Emissions Factors for Auto Travel (From Table 3):**

	Auto Trip End Factor	Auto VMT Factor
ROG Factor	1.719 grams per trip	0.470 grams per mile
NOx Factor	0.721 "	0.602 "
PM10 Factor	0.014 "	0.218 "

Note: Used 1-year (2004) emission factors from Table 3A since project life is 1 year, and "Commute" auto trip end factors are used since this project reduces commute trips.

**Emissions Factors for Van Travel (From Table 2, ULEV, 8501-10,000 lbs.):**

	Van VMT Factor
ROG Factor	0.14 grams per mile
NOx Factor	0.20 "
PM10 Factor	0.27 "

**Calculations:**

$$\begin{aligned}
 \text{Annual Auto Trips Reduced} &= [(D)*(R)*(A)]*[1-(AA)] \\
 &= [250 * 220 * 0.83]*[1-0.75] \\
 &= 11,413 \text{ annual auto trips reduced} \\
 \text{Annual Auto VMT Reduced} &= [(D) *(R)*(A)] * [(L) - (AA) * (LL)] \\
 &= [250 * 220 * 0.83] * [48-0.75*5] \\
 &= [45,650] * [48-3.75] \\
 &= 2,020,013 \text{ annual auto VMT reduced}
 \end{aligned}$$

**Annual Emission Reductions = (lbs. per year)**

$$[(\text{Annual Auto Trips Reduced}) * (\text{Auto Trip End Factor}) + (\text{Annual Auto VMT Reduced}) * (\text{Auto VMT Factor}) - (\text{Van VMT}) * (\text{Van VMT factor})] / 454$$

**ROG:**  $[(11,413 * 1.719) + (2,020,013 * 0.470) - (240,000 * 0.14)] / 454 = 2,060 \text{ lbs. per year reduced}$

**NOx:**  $[(11,413 * 0.721) + (2,020,013 * 0.602) - (240,000 * 0.20)] / 454 = 2,591 \text{ lbs. per year reduced}$

**PM10:**  $[(11,413 * 0.014) + (2,020,013 * 0.218) - (240,000 * 0.27)] / 454 = 828 \text{ lbs. per year reduced}$

**Capital Recovery Factor (CRF) =**  $\frac{(1+i)^n(i)}{(1+i)^n - 1} = 1.03$  *where n = project life (1 year)*  
(From Table 8) *and i = discount rate (3%)*

**Cost-Effectiveness of Funding Dollars =**  $(\text{CRF} * \text{Funding}) / (\text{ROG} + \text{NOx} + \text{PM10})$   
 $= (1.03 * 33,000) / (5,479) = \$6.20 \text{ per lb.}$

**FOR CMAQ PROJECTS ONLY:**

Once emissions reductions have been calculated, add them together  
(2,060 + 2,591 + 828 = 5,479) and convert emissions reductions to kg/day:

$$\frac{\text{lbs. reduced per year}}{2.2 \text{ lbs./kg} * 365 \text{ days/year}} = \frac{5,479}{2.2 * 365} = 7 \text{ kg/day}$$

## Signal Coordination

**Project definition:** Improvements to signal timing that reduce overall vehicle stops and delays and that give transit vehicles priority. These include traffic signal synchronization, interconnection, improved timing projects, and transit signal priority projects. (Signal timing and other actions that increase traffic speeds and flows to the detriment of overall traffic performance or that offer a significant inducement to travel by auto are not air quality beneficial. Speeds higher than 36 mph begin to increase NO<sub>x</sub> emissions and may also discourage walking and bicycling. These results may be counterproductive to meeting clean air goals.)

**How emissions are reduced:** Emission reductions in reactive organic gases (ROG) and nitrogen oxides (NO<sub>x</sub>) are associated with increasing average traffic speeds to up to 36 mph. (NO<sub>x</sub> emissions start increasing when average speeds are over 36 mph.)

Travel growth degrades project performance over time. Traffic flow improvements that occur immediately after implementation of the project decline to no improvement by the end of the effectiveness period. As a result, the methodology averages speed improvements over the effectiveness period by taking one-half of the first day benefits.

### **Need to know:**

Funding dollars

Number of operating days per year

Traffic volumes for the congested periods of the day

Length of the roadway segment impacted by the project

Before and after average traffic speeds

The following information may need to be entered separately for each road segment and congested period (i.e. AM peak and PM peak) affected by the project. Vehicle speeds should correspond to the specified traffic volume. If the project includes multiple connected segments entered as one project, traffic volume should be the average volume of the segments, not the aggregate volume.

<b>Inputs</b>	<b>Default</b>	<b>Units</b>	<b>Comments</b>
Funding Dollars ( <b>Funding</b> )		dollars	
Effectiveness Period ( <b>Life</b> )	5	years	
Days ( <b>D</b> )	250	operating days per year	Default equals weekdays.
Length ( <b>L</b> ) of congested roadway segment		miles	Length of roadway that is impacted by the project.
Traffic Volume during congested period ( <b>Congested Traffic</b> )		trips per day	Traffic volumes during congested period.

### Emission Factor Inputs

	Example (20 mph)	Units	Example (24 mph)	Units
	Before Speed Factor		After Speed Factor	
ROG Factor	0.37	grams/mile	0.31	grams/mile
NOx Factor	1.15	"	1.09	"
PM10 Factor	0.04	"	0.04	"

**Emission Factors** are dependent on the **before-project** and **after-project** average traffic speeds. To select emission factors for various speeds, refer to Table 4 at the end of the document. The factors above are for before-project speed 20 mph and after-project speed 24 mph for a 1-5 year project.

Use measured “before” and “after” average speeds. If speeds are unknown, average traffic speed can be estimated using the segment length (L) and a travel time (T) for vehicles passing through the segment. (Speed = L/T).

### Formulas

Annual Project VMT (**VMT**) = (D) \* (L) \* (Congested Traffic) Units  
miles/year

Annual Emission Reductions (ROG, NOx, and PM10) = Units  
lbs/year  
 $0.5 * [(VMT) * (Before\ Speed\ Factor - After\ Speed\ Factor)] / 454$

*Note: Initial speed improvements decline to zero improvement by the end of the effectiveness period. In order to account for this, the emission reduction equation reduces initial emission reduction benefits by one half.*

Capital Recovery Factor (CRF) =  $\frac{(1 + i)^n (i)}{(1 + i)^n - 1}$

where:  $i$  = discount rate (Assume 3 percent)  
 $n$  = project life

### Cost-Effectiveness of

Funding Dollars = (CRF \* Funding) / (ROG + NOx + PM10) dollars/lb

*Note: The Federal Highway Administration requests that emission reductions from CMAQ projects be reported as kilograms/day. The conversion is*  
 $(lbs\ per\ year) / [(2.2) * (365)] = kilograms/day$

**Traffic Signal Coordination**

The City's master traffic signal controller was replaced with a new controller with expanded capacity, allowing 15 more intersections to be coordinated.

**Inputs to Calculate Cost-Effectiveness:**

- Funding Dollars (Funding): \$50,000
- Effectiveness Period (Life): 5 years
- Days of use/year (D): 250
- Length of congested roadway segment (L): 2.50 miles
- Traffic Volume during congested period (Congested Traffic): 38,400 trips per day
- Before Speed: 28 mph
- After Speed: 33 mph

**Emissions Factor Inputs (From Table 4):**

	Before Speed Factor	After Speed Factor
ROG Factor	0.26 grams per mile	0.22 grams per mile
NOx Factor	1.04 "	1.01 "
PM10 Factor	0.03 "	0.03 "

**Calculations:**

$$\text{Annual Project VMT (VMT)} = (D) * (L) * (\text{Congested Traffic})$$

$$= 250 * 2.50 * 38,400 = 24,000,000 \text{ annual miles}$$

**Annual Emission Reductions (ROG, NOx, and PM10) in lbs. per year**

$$= [(.50) * (\text{VMT}) * (\text{Before Speed Factor} - \text{After Speed Factor})] / 454 \text{ grams per lb.}$$

$$\text{ROG: } [(0.50 * 24,000,000) * (0.26 - 0.22)] / 454 = \mathbf{1,057 \text{ lbs. per year}}$$

$$\text{NOx: } [(.50 * 24,000,000) * (1.04 - 1.01)] / 454 = \mathbf{793 \text{ lbs. per year}}$$

$$\text{PM10: } [(.50 * 24,000,000) * (0.03 - 0.03)] / 454 = \mathbf{0 \text{ lbs. per year}}$$

$$\text{Capital Recovery Factor (CRF)} = \frac{(1 + i)^n(i)}{(1 + i)^n - 1} = .22 \quad \text{where } n = \text{project life (5 years)}$$

(From Table 8) and i = discount rate (3%)

**Cost-Effectiveness**

$$\text{of Funding Dollars} = (\text{CRF} * \text{Funding}) / (\text{ROG} + \text{NOx} + \text{PM10}) = [.22 * 80,000] / 1,850$$

$$= \mathbf{\$9.51 \text{ per lb.}}$$

**FOR CMAQ PROJECTS ONLY:**

Once emissions reductions have been calculated, add them together (1,057 + 793) and convert emissions reductions to kg/day:  $\frac{\text{lbs. reduced per year}}{2.2 \text{ lbs./kg} * 365 \text{ days/year}} = \frac{1,850}{2.2 * 365} = \mathbf{2 \text{ kg/day}}$

## **Bicycle Facilities**

**Project definition:** Bicycle paths (Class 1) or bicycle lanes (Class 2) that are targeted to reduce commute and other non-recreational auto travel. Class 1 facilities are paths that are physically separated from motor vehicle traffic. Class 2 facilities are striped bicycle lanes giving preferential or exclusive use to bicycles. Bike lanes should meet Caltrans' full-width standard depending on street facility type.

**How emissions are reduced:** Emission reductions result from the decrease in emissions associated with auto trips replaced by bicycle trips for commute or other non-recreational purposes.

### **Need to know:**

Funding dollars

Number of operating days per year

Average length of bicycle trips

Average daily traffic volume on roadway parallel to bicycle project

City population

Project class (1 or 2)

Types of activity centers in the vicinity of the bicycle project

Length of bicycle path or lane

<b>Inputs</b>	<b>Default</b>	<b>Units</b>	<b>Comments</b>
Funding Dollars ( <b>Funding</b> )		Dollars	
Effectiveness Period ( <b>Life</b> )	15	Years	Class 1 projects - 20 years Class 2 projects - 15 years
Days ( <b>D</b> )	200	Days of use/year	Consider local climate in number of days used.
Average Length ( <b>L</b> ) of bicycle trips	1.8	Miles per trip in one direction	Default is based on the National Personal Transportation Survey
Annual Average Daily Traffic ( <b>ADT</b> )		Trips per day	Two-direction traffic volumes on roadway parallel to bike project. MAXIMUM IS 30,000.
Adjustment ( <b>A</b> ) on ADT for auto trips replaced by bike trips from the bike facility.	.0020		See Adjustment Factors table on the next page. Adjustments are based on facility class, ADT, project length, and community characteristics.
Credit ( <b>C</b> ) for Activity Centers near the project.	.0005		See Activity Centers table on the next page.

<b>ADJUSTMENT FACTORS</b>				
<b>BIKE FACILITY CLASS</b>	<b>AVERAGE DAILY TRAFFIC (ADT)</b>	<b>LENGTH OF BIKE PROJECT (one direction)</b>	<b>ADJUSTMENT FACTORS FOR CITIES WITH POP. ≥ 250,000 and non-university towns &lt; 250,000</b>	<b>ADJUSTMENT FACTORS FOR UNIVERSITY TOWNS WITH POP. &lt; 250,000</b>
Class 1 (bike path) & Class 2 (bike lane)	ADT ≤ 12,000 vehicles per day	≤ 1 mile	.0019	.0104
		>1 & ≤ 2 miles	.0029	.0155
		> 2 miles	.0038	.0207
Class 1 (bike path) & Class 2 (bike lane)	12,000 < ADT ≤ 24,000 vehicles per day	≤ 1 mile	.0014	.0073
		>1 & ≤ 2 miles	.0020	.0109
		> 2 miles	.0027	.0145
Class 2 bike lane	24,000 < ADT ≤ 30,000 vehicles per day Maximum is 30,000	≤ 1 mile	.0010	.0052
		>1 & ≤ 2 miles	.0014	.0078
		> 2 miles	.0019	.0104

When evaluating the impact of a new bike project, it is important to consider the location of the bike facility. What types of destinations are accessible from the project? How many of these activity centers are within one-half mile of the facility? How many are within a quarter of a mile? Examine the activity centers in the vicinity of the project and compare them to the list below. Select the credit factor that corresponds to the number of activity centers in the surrounding area.

<b>ACTIVITY CENTERS CREDITS</b>		
<i>Types of Activity Centers: Bank, church, hospital or HMO, light rail station (park &amp; ride), office park, post office, public library, shopping area or grocery store, university or junior college.</i>		
<b>Count your activity centers. If there are...</b>	<b>Credit (C)</b>	<b>Credit (C)</b>
	<b>Within 1/2 mile</b>	<b>Within 1/4 mile</b>
Three (3)	.0005	.001
More than 3 but less than 7	.001	.002
7 or more	.0015	.003

#### **Emission Factor Inputs for Auto Travel**

	<b>Default</b>	<b>Units</b>	<b>Default</b>	<b>Units</b>
	<b>Auto Trip End Factor</b>		<b>Auto VMT Factor</b>	
ROG Factor	1.020	grams/trip	0.266	grams/mile
NOx Factor	0.458	"	0.319	"
PM10 Factor	0.016	"	0.219	"

For average auto emission factors, see Table 3. Use factors that correspond to the life of the project: 11-15 year factors for Class 2 facilities and 16-20 year factors for Class 1 facilities. Defaults are for a project life of 15 years.

**Formulas**

$$\text{Annual Auto Trip Reduced} = (D) * (ADT) * (A + C)$$

**Units**

trips/year

$$\text{Annual Auto VMT Reduced} = (\text{Auto Trips}) * (L)$$

miles/year

$$\text{Annual Emission Reductions (ROG, NO}_x\text{, and PM}_{10}\text{)} =$$

lbs./year

$$\begin{aligned} & [(\text{Annual Auto Trips Reduced}) * (\text{Auto Trip End Factor}) \\ & + (\text{Annual Auto VMT Reduced}) * (\text{Auto VMT Factor})] / 454 \end{aligned}$$

$$\text{Capital Recovery Factor (CRF)} = \frac{(1 + i)^n (i)}{(1 + i)^n - 1}$$

where:  $i$  = discount rate (Assume 3 percent)  
 $n$  = project life

Cost-Effectiveness of

$$\text{Funding Dollars} = (\text{CRF} * \text{Funding}) / (\text{ROG} + \text{NO}_x + \text{PM}_{10})$$

dollars/lb.

*Note: The Federal Highway Administration requests that emission reductions from CMAQ projects be reported as kilograms/day. The conversion is*  
 $(\text{lbs. per year}) / [(2.2) * (365)] = \text{kilograms/day}$

**Documentation:** Adjustment factors were derived from a limited set of bicycle commute mode split data for cities and university towns in the southern and western United States (Source: FHWA National Bicycling And Walking Study, 1992). This data was then averaged and multiplied by 0.7 to estimate potential auto travel diverted to bikes. On average, about 70% of all person trips are taken by auto driving (Source: 2000-01 Statewide Travel Survey), and it is these trips that can be considered as possible auto trips reduced. Finally, this number was multiplied by 0.65 to estimate the growth in bicycle trips from construction of the bike facility. Sixty-five percent represents the average growth in bike trips from a new bike facility as observed in before and after data for bike projects in U.S. DOT's "A Compendium of Available Bicycle and Pedestrian Trip Generation Data in the United States." Benefits are scaled to reflect differences in project structure, length, traffic intensity, community size, and proximity of activity centers. The scale has been adapted from a method developed by Dave Burch of the Bay Area Air Quality Management District (BAAQMD).

**Note 1:** Because ADT represents vehicles passing a single point, it may neglect vehicles that travel only a short distance on the corridor and, as a result, underestimate total vehicle trips. Therefore, the number of vehicles diverted to bicycles may be underestimated in this method. If actual vehicle trips in the corridor are known, this number should be used in place of ADT.

**Note 2:** Bicycle usage data is limited. From the data currently available, a positive correlation has been observed between the percentage of an area's arterials that have full width bike lanes, and the percentage of commuters who bike to work. Simply put, more bike lanes are associated with more bike commuting. More specifically, for an area with a given ratio of bike lanes to arterials, we observe that roughly one-fourth of that ratio is equal to the percentage of commuters that bike to work. More research and data are needed to confirm this relationship and to clarify the causes of this positive correlation.

**Class 2 Bikeway Facility**

The new Class 2 bike lanes are a critical link in the city bike system, allowing residents bicycle access to education, employment, shopping, and transit. Within one-quarter mile of the project, there is a college, a shopping center, a light rail station, and an office building. The project includes installation of new pavement, signage, and Class 2 bike lane striping along both sides of 1.13 miles of arterials. This is primarily a college town, with a population of 128,000.

**Inputs to Calculate Cost-Effectiveness:**

Funding Dollars (**Funding**): \$40,000

Effectiveness Period (**Life**): 15 years

Days (**D**): 200

Average Length (**L**) of bicycle trips: 1.8 miles

Annual Average Daily Traffic (**ADT**): 20,000

Adjustment (**A**) on ADT for auto trips replaced by bike trips from the bike facility: 0.0109

Credit (**C**) for Activity Centers near the project: 0.002

**Emissions Factors (From Table 3, for a 15-year Life):**

	Auto Trip End Factor	Auto VMT Factor
ROG Factor	1.020 grams/trip	0.266 grams/ mile
NOx Factor	0.458	0.319
PM10 Factor	0.016	0.219

**Calculations:**

$$\begin{aligned} \text{Annual Auto Trip Reduced} &= (D) * (ADT) * (A + C) \\ &= (200) * (20,000) * (0.0109 + 0.002) \\ &= 51,600 \end{aligned}$$

$$\begin{aligned} \text{Annual Auto VMT Reduced} &= (\text{Auto Trips}) * (L) \\ &= (51,600) * (1.8) \\ &= 92,880 \end{aligned}$$

**Annual Emission Reductions (ROG, NOx and PM10) in lbs. per year**

$$\begin{aligned} &= [(\text{Annual Auto Trips Reduced}) * (\text{Auto Trips End Factor}) \\ &\quad + (\text{Annual Auto VMT Reduced}) * (\text{Auto VMT Factor})] / 454 \\ \text{ROG:} &\quad [(51,600 * 1.020) + (92,880 * 0.266)] / 454 = \mathbf{170 \text{ lbs. per year}} \\ \text{NOx:} &\quad [(51,600 * 0.458) + (92,880 * 0.319)] / 454 = \mathbf{117 \text{ lbs. per year}} \\ \text{PM10:} &\quad [(51,600 * 0.016) + (92,880 * 0.219)] / 454 = \mathbf{47 \text{ lbs. per year}} \end{aligned}$$



## Telecommunications

**Project definition:** Programs and equipment that enable teleconferencing, or telecommuting from home or a neighborhood center.

**How emissions are reduced:** Emissions are reduced when auto trips are replaced with (1) home-based telecommuting, (2) teleconferencing, or (3) shorter auto trips to a neighborhood telecommuting center.

**Need to know:**

Funding dollars

Work weeks per year

Weekly one-way auto trips eliminated (i.e., home-work trips or work-meeting trips)

Average length of auto trips eliminated

(i.e., distance from home to work or from work to meeting)

Weekly one-way auto trips to telesite

Average length of auto trips to telesite

<b>Inputs</b>	<b>Default</b>	<b>Units</b>	<b>Comments</b>
Funding Dollars ( <b>Funding</b> )		dollars	
Effectiveness Period ( <b>Life</b> )	5	years	If no equipment was purchased, enter the number of years funding is available.
<b><i>Inputs for Trips Eliminated</i></b>			
Auto Trips ( <b>T</b> ) eliminated		trips one-way/week	Examples: (1) For home-based telecommute projects--the number of auto trips eliminated to and from the workplace per week. (2) For teleconferencing projects--the number of auto trips eliminated to and from the meeting site during an average week. (3) For telecommute center--the number of auto trips that had been made to the worksite before using the telecenter.

<b>Inputs</b>	<b>Default</b>	<b>Units</b>	<b>Comments</b>
Length ( <b>L</b> ) of Auto Trips eliminated	16	miles one direction/trip	Examples: (1) For telecommuting--average distance from home to work (default is 16 miles), (2) For teleconferencing--average distance from work to meeting site. (3) For telecenter--average distance from home to worksite before using telecenter
Weeks ( <b>W</b> )	50	weeks (of operation)/year	Examples: (1) Home-based telecommute --50 weeks, (2) Teleconferencing--52 weeks. (3) Telecenter--50 weeks.
<b>Inputs for Trips Added</b>			
New Auto Trips ( <b>New T</b> )		trips one-way/week	Examples: (1) For home-based telecommuting, enter 0. (2) For teleconference, enter number of auto trips to and from the teleconference site. (3) For telecenter, enter the number of auto trips to and from the telecenter for a week.
New Auto Trip Length ( <b>New L</b> )		miles one direction/trip	Examples: (1) For home-based telecommuting, enter 0. (2) For teleconference--average distance from home to center. (3) For telecenter--average distance from work to teleconference center.

#### **Emission Factor Inputs for Auto Travel**

	<b>Default</b>	<b>Units</b>	<b>Default</b>	<b>Units</b>
	<b>Auto Trip End Factor</b>		<b>Auto VMT Factor</b>	
ROG Factor	1.481	grams/trip	0.392	grams/mile
NOx Factor	0.645	"	0.491	"
PM10 Factor	0.015	"	0.218	"

For auto emission factors, see Emission Factors Menu, Tables 3 and 3A. For projects with a 1-year life, use Table 3A. For projects with a life of 2-20 years, use Table 3. Defaults are for a project life of 5 years, using the "1-5 Years" column of Table 3.

**Formulas****Units**

$$\text{Annual Auto Trips Reduced} = W * [(T) - (\text{New } T)]$$

trips/year

$$\text{Annual Auto VMT Reduced} = W * [(T)*(L) - (\text{New } T)*(\text{New } L)]$$

miles/year

$$\begin{aligned} \text{Annual Emission Reductions (ROG, NO}_x, \text{ and PM}_{10}) = & \\ & [(\text{Annual Auto Trips Reduced}) * (\text{Auto Trip End Factor}) \\ & + (\text{Annual Auto VMT Reduced}) * (\text{Auto VMT Factor})] / 454 \end{aligned}$$

lbs/year

$$\text{Capital Recovery Factor (CRF)} = \frac{(1 + i)^n (i)}{(1 + i)^n - 1}$$

where:  $i$  = discount rate (Assume 3 percent)  
 $n$  = project life

$$\begin{aligned} \text{Cost-Effectiveness of} & \\ \text{Funding Dollars} = & (\text{CRF} * \text{Funding}) / (\text{ROG} + \text{NO}_x + \text{PM}_{10}) \end{aligned}$$

dollars/lb

*Note: The Federal Highway Administration requests that emission reductions from CMAQ projects be reported as kilograms/day. The conversion is*  
 $(\text{lbs per year}) / [(2.2) * (365)] = \text{kilograms/day}$

(Note: If the project includes both home-based telecommuting as well as teleconferencing or telecenters, then the formula should be run separately for each aspect of the project.)

**County Probation Videophone Project**

A videophone-interviewing project is implemented by the County Probation Department. Videophone equipment is installed for \$33,000 at the branch probation offices and two detention centers. Videophone interviewing of 5,000 inmates per year saves 200 one-way trips per week to and from detention centers (a distance of 29 miles on average).

**Inputs to calculate cost-effectiveness:**

- Funding Dollars (Funding): \$33,000
- Effectiveness Period (Life): 5 years
- One-Way Auto Trips Eliminated Per Week (T): 200
- Length (L) of Auto Trips Eliminated: 29 miles one-way
- Weeks (W) = 50 weeks
- New Auto Trips (New T): 0
- New Auto Trip Length (New L): not applicable

**Emissions Factors for Auto Travel (From Table 3):**

	Auto Trip End Factor	Auto VMT Factor
ROG Factor	1.481 grams per trip	0.392 grams per mile
NOx Factor	0.645	0.491
PM10 Factor	0.015	0.219

Note: 1-5 year emission factors are used since project life is 5 years, and "Commute" auto trip end factors are used since this project reduces commute trips.

**Calculations:**

$$\begin{aligned} \text{Annual Auto Trips Reduced} &= (W)*[(T) - (\text{New T})] \\ &= 50 * (200-0) = 10,000 \\ \text{Annual Auto VMT Reduced} &= (W)*[(T)*(L) - (\text{New T})*(\text{New L})] \\ &= (50)*[(200)*(29) - 0] = 290,000 \end{aligned}$$

**Annual Emission Reductions (ROG, NOx, and PM10)**

$$\begin{aligned} &= [( \text{Annual Auto Trips Reduced} ) * (\text{Auto Trip End Factor}) \\ &\quad + ( \text{Annual Auto VMT Reduced} ) * (\text{Auto VMT Factor})] / 454 \end{aligned}$$

- ROG:**  $[(10,000 * 1.481) + (290,000 * 0.392)] / 454 = 283 \text{ lbs. per year}$
- NOx:**  $[(10,000 * 0.645) + (290,000 * 0.491)] / 454 = 328 \text{ lbs. per year}$
- PM10:**  $[(10,000 * 0.015) + (290,000 * 0.219)] / 454 = 140 \text{ lbs. per year}$

Capital Recovery Factor(CRF)=  $\frac{(1+i)^n(i)}{(1+i)^n - 1}$  = 0.22  
(From Table 8)

where n= project life (5 years)  
and i = discount rate (3%)

Cost-Effectiveness of Funding Dollars = (CRF \* Funding) / (ROG + NOx + PM10)  
=(0.22\*33,000) / (750) = **\$ 9.68 per lb.**

**FOR CMAQ PROJECTS ONLY:**

Once emissions reductions have been calculated, add them together (283 + 328 + 140 = 750) and convert emissions reductions to kg/day:

$$\frac{\text{lbs. reduced per year}}{2.2 \text{ lbs./kg} * 365 \text{ days/year}} = \frac{750}{2.2 * 365} = 1 \text{ kg/day}$$

## Ridesharing and Pedestrian Facilities

**Project definition:** Ridesharing programs replace drive-alone auto trips by encouraging carpooling and other less polluting modes of travel. Pedestrian facilities replace auto trips by providing or improving pedestrian access. An example is a pedestrian passageway over several lanes of heavy traffic providing safe walking access to adjacent activity centers.

**How emissions are reduced:** Ridesharing reduces emissions when drive-alone auto trips are replaced with less polluting modes of travel. Pedestrian facilities reduce emissions when auto trips are replaced by walking.

**Need to know:**

Funding dollars

Work weeks or operating weeks per year

Weekly one-way auto trips eliminated

Average length of auto trips eliminated

<b>Inputs</b>	<b>Default</b>	<b>Units</b>	<b>Text Comments</b>
Funding Dollars ( <b>Funding</b> )		dollars	
Effectiveness Period ( <b>Life</b> )	1	year	Ridesharing: Enter 1 year. Pedestrian: Enter 20 years.
<b><i>Inputs for Trips Eliminated</i></b>			
Auto Trips ( <b>T</b> ) eliminated		trips one-way/week	The number of auto trips eliminated per week to and from workplace (for ridesharing) or to and from activity center (for pedestrian projects).
Length ( <b>L</b> ) of Auto Trips eliminated	16	miles one direction/trip	Default (16 mi.) is for ridesharing projects and equals the average distance from home to work. Pedestrian projects should use the average distance of auto trip to adjacent activity center -- one mile is suggested. This is the average distance of pedestrian trips.
Weeks ( <b>W</b> )	52	weeks (of operation)/year	If trips eliminated (T) is based on employee numbers that exclude workers on sick leave, vacations, etc. then (W) equals 52. Otherwise (W) typically equals 50.

<b>Inputs</b>	<b>Default</b>	<b>Units</b>	<b>Text Comments</b>
<b><i>Inputs for Trips Added</i></b>			
Adjustment (A) for Auto Access Trips to transit, vanpools, and carpools  Note: No adjustment is made on Length (L) of Auto Trips eliminated because access trip length is an insignificant portion of annual VMT reduced.	0.7		Adjustment (A) equals the portion of employees who do NOT drive to transit, vanpools, or carpools. Default 0.7 equals the adjustment (A) for areas with average transit use. Use 0.6 for high transit use (i.e., commute transit mode split >10%). Use 1.0 if Method 2 was used to determine Auto Trips (T) eliminated. Use 1.0 for pedestrian projects.

### **Emission Factor Inputs for Auto Travel**

		<b>Units</b>		<b>Units</b>
	<b>Auto Trip End Factor</b>		<b>Auto VMT Factor</b>	
ROG Factor	1.719	grams/trip	0.470	grams/mile
NOx Factor	0.721	"	0.602	"
PM10 Factor	0.014	"	0.218	"

For auto emission factors, see Emission Factors Menu, Tables 3 and 3A. For projects with a 1-year life, use Table 3A. For projects with a life of 2-20 years, use Table 3. Defaults are for 1-year project life (2002) from Table 3A.

### **Formulas**

$$\text{Annual Auto Trips Reduced} = W * T * A$$

**Units**  
trips/year

$$\text{Annual Auto VMT Reduced} = W * T * L$$

miles/year

$$\begin{aligned} \text{Annual Emission Reductions (ROG, NOx, and PM10)} = \\ [(\text{Annual Auto Trips Reduced}) * (\text{Auto Trip End Factor}) \\ + (\text{Annual Auto VMT Reduced}) * (\text{Auto VMT Factor})] / 454 \end{aligned}$$

lbs/year

$$\text{Capital Recovery Factor (CRF)} = \frac{(1 + i)^n (i)}{(1 + i)^n - 1}$$

where:  $i$  = discount rate (Assume 3 percent)  
 $n$  = project life

Cost-Effectiveness of

$$\text{Funding Dollars} = (\text{CRF} * \text{Funding}) / (\text{ROG} + \text{NOx} + \text{PM10})$$

dollars/lb

*Note: The Federal Highway Administration requests that emission reductions from CMAQ projects be reported as kilograms/day. The conversion is (lbs per year) / [(2.2) \* (365)] = kilograms/day*

This method can also be adapted to evaluate **Transportation Management Organizations (TMOs)** if the number of auto trips eliminated by the program is known.

### ***Ridesharing***

### ***(Optional Method 1)***

For ***ridesharing programs*** where the average number of daily peak-period employees and Average Vehicle Ridership (AVR) are known, you can use the following formula to find Auto Trips Eliminated (**T**). Auto Trips Eliminated (**T**) is needed in the above formulas to calculate **Annual Auto Trips Reduced** and **Annual Auto VMT Reduced**.

**T** trips/week =

$$2 \text{ trips/day} * 5 \text{ days/week} * \text{Peak-Period Employees} * \left[ \frac{1}{\text{Baseline AVR}} - \frac{1}{\text{New AVR}} \right]$$

**Notes:** (1) The **New AVR** is the AVR for the current year. The **Baseline AVR** occurred before the ridesharing program was implemented. (2) The number of days/week should be adjusted to the appropriate operating schedule for the company or agency. (3) Sometimes the number of employees in the work force changes over time. In these situations, use the most current number of employees in the formula. (4) The formula is based on the assumption that AVR will revert back to the baseline without an ongoing ridesharing program. Therefore, the benefits of the program include trip reductions from previous years that are maintained, as well as additional new trip reductions. (5) If you want to evaluate a ridesharing program over several years, you should determine trips eliminated (**T**) separately for each year of the analysis period and use the average for (**T**). To do this, you need to know the AVR for each year.

### ***Ridesharing***

### ***(Optional Method 2)***

For ***ridesharing programs*** where a week-long commute travel survey is used, you can use the worksheets provided on the following pages to determine **Annual Auto Trips Reduced** and **Annual Auto VMT Reduced**.

- Calculate (A) number of commute employees, (B) weekly trips, and (C) weekly VMT by plugging your commute travel survey data into the "Weekly Trips and VMT Worksheet" on the next page.
- Calculate **Annual Auto Trips Reduced** and **Annual Auto VMT Reduced** by plugging the totals from the "Weekly Trips and VMT Worksheet" into the "Annual Auto Trips and VMT Reduced Worksheet."
- Enter **Annual Auto Trips Reduced** and **Annual Auto VMT Reduced** in the formulas provided in the original methodology on the previous pages to calculate emission reductions and cost-effectiveness.

**Employer Rideshare Programs  
Weekly Trips and VMT Worksheet**

Commute mode	Employee days/week (from survey)	x	Trips/day factor	=	Trips/week subtotal	x	Access trip correction factor	=	Trips/week
Bicycle			0.0		0.0		--		0.0
Walk			0.0		0.0		--		0.0
Telecommute			0.0		0.0		--		0.0
Compressed work week day off			0.0		0.0		--		0.0
Solo drive (& motorcycle)		x	2.0	=			--	=	
Public transportation			--		--	x	1.0	=	
Carpool (default avo = 2.5)		x	0.8	=		x	1.25	=	
Vanpool (default avo = 8.5)		x	0.24	=		x	5.25	=	
		÷ 5 =			x 16.0 mi. =				
		<b>(A) Commute Employees</b>			<b>(B) VMT/week</b>			<b>(C) Trips/week</b>	

\* Average commute trip length.  
avo = average vehicle occupancy

**Employer Rideshare Programs  
Annual Auto Trips and VMT Reduced Worksheet**

Use Totals (A), (B), and (C) from Weekly Trip and VMT Worksheet

**Annual Auto Trips Reduced**

Trips/week (C)	÷	# of commute employees (A)	=	Weekly trips/ commute employee	Baseline weekly trips/commute employee (Default: 8.7)	-	Weekly trips/ commute employee	=	Weekly trips/ commute employee reduced
	÷		=			-		=	

Weekly trips/commute employee reduced (from row above)	x	50 weeks*	=	Annual trips/ employee reduced	x	Total # of employees**	=	<b>Annual Auto Trips Reduced</b>
	x	50	=		x		=	

**Annual Auto VMT Reduced**

VMT/week (B)	÷	# of commute employees (A)	=	Weekly VMT/ commute employee	Baseline weekly VMT/commute employee (Default: 139)	-	Current year Wkly VMT/ employee	=	Weekly VMT/ commute employee reduced
	÷		=			-		=	

Weekly VMT/commute employee reduced (from row above)	x	50 weeks*	=	Annual VMT/ employee reduced	x	Total # of employees**	=	<b>Annual Auto VMT Reduced</b>
	x	50	=		x		=	

\* A 50-week default is used since the number of commute employees excludes workers on sick leave and vacation. If the worksite is not in operation year-round, adjust the number accordingly.

\*\* If the weekly travel survey includes part-time employees, count them proportionately to their commute days, e.g., an employee working two days a week counts as 0.40 employee (2/5 = 0.40).

Baseline weekly VMT and trips per commute employee is generally calculated from survey data the year before the program started. If baseline figures are not available, use the defaults provided.

Use the Annual Auto Trips Reduced and the Annual Auto VMT Reduced totals from this worksheet in the formula for calculating emission reductions from ridesharing programs.

**Worksheet Calculations**

Auto trips and VMT reduced equal the difference between the trips and VMT per employee before and after the program has been implemented, multiplied by the number of employees at the worksite(s).

**Calculating Annual Auto Trips Reduced**

Using "Weekly Trips and VMT Worksheet," add "employee days/week" for each commute mode and divide the sum by 5 (days) to get "# of commute employees."

Multiply "employee days/week" for each commute mode by the "trips/day factor," and multiply that total by the "access trip correction factor" to get "trips/week" for each commute mode.

Using "Annual Auto Trips and VMT Reduced Worksheet," add the "trips/week" for each commute mode to get total "trips/week." Divide "trips/week" by the "# of commute employees" to get "weekly trips/commute employee."

Subtract "weekly trips/commute employee" from the "baseline weekly trips/commute employee" to obtain "weekly trips/commute employee reduced."

Multiply "weekly trips/commute employee reduced" by 50 weeks to get "annual trips/commute employee reduced."

Multiply "annual trips/commute employee reduced" by the "total # of employees" at the worksite(s) to obtain "annual auto trips reduced."

**Calculating Annual Auto VMT Reduced**

Multiply "employee days/wk" for each commute mode by the "trips/day factor" to get "trips/week subtotal" for each commute mode.

Add "trips/week subtotal" for each commute mode and multiply the sum by the "average commute distance" to get "VMT/week." Divide "VMT/week" by the "# of commute employees" to get "weekly VMT/commute employee."

Subtract "weekly VMT/commute employee" from the "baseline weekly VMT/commute employee" to obtain "weekly VMT/commute employee reduced."

Multiply "weekly VMT/commute employee reduced" by 50 weeks to get "annual VMT/commute employee reduced."

Multiply "annual VMT/commute employee reduced" by the "total # of employees" at the worksite(s) to obtain "annual auto VMT reduced."

***Worksheet Assumptions***

*Average one-way commute trip length:* The 1995 National Personal Transportation Survey indicated the average home-to-work trip is 11-12 miles. Recent commute surveys conducted by the Southern California Association of Governments and RIDES for Bay Area Commuters have estimated the average home-to-work trip to be 16-17 miles. Since surveys of employer Transportation Demand Management (TDM) programs (100+ employees) have also shown a commute distance closer to 16-17 miles, a 16-mile average is used for this methodology.

*Trips/day factor:* It is assumed that bicycle, telecommute, compressed work week day off, and walk commute modes do not generate any commute-related vehicle trips. Solo driving and motorcycles generate 2 commute trips per day. Carpools and vanpools generate varying trips/day based on the number of passengers. For example, a person in a carpool that averages 2.5 occupants generates 0.8 trips per day (1 vehicle divided by 2.5 occupants equals 0.4 trips, multiplied by 2 trips equals 0.8 trips per day).

*Default carpool and vanpool factors:* Based on average vehicle occupancy of 2.5 for a carpool and 8.5 for a vanpool. (Source: 1996 Southern California State of the Commute Survey)

*Access trip correction factor:* It is assumed that 50% of public transportation commuters, 50% of vanpoolers, and 10% of carpoolers drive a personal vehicle to the mode access point. (Source: Percentages developed by California Air Resources Board, using 1999 Southern California State of the Commute Survey, Bay Area Air Quality Management District data, and emission reduction analyses of California motor vehicle fee TDM projects.)

Example: A vanpool averaging 8.5 occupants generates 5.25 one-way vehicle trips because 1 van is driven and 4.25 passengers (50%) drive to the vanpool access point. Over five times more one-way trips are generated (5.25 instead of 2) than if there were no access trips, so 5.25 is the access trip correction factor. Access trips are included in trips/week calculations but not VMT/week calculations because they add a significant amount of trips to overall commute travel but a fairly insignificant amount of VMT.

*Default baseline weekly trips and VMT per employee:* 8.7 trips/week, 139 VMT/week. The 1995 National Personal Transportation Survey indicates the average daily commute vehicle trip rate is 1.75. 1.75 multiplied by 5 days per week equals 8.7 trips per week. 8.7 trips per week multiplied by a 16-mile average commute distance equals 139 VMT per week. (Note: Weekly trip and VMT rates per employee are calculated in order to compensate for not having completed surveys from every employee and/or for having a different number of employees in the baseline and current years.)

### County Trip Reduction Program

A county conducts a comprehensive employee trip reduction program, which includes vanpool and carpool programs, telecommuting, compressed work schedules, and guaranteed emergency transportation.

#### Inputs to Calculate Cost-Effectiveness:

Funding Dollars (Funding): \$140,000

Effectiveness Period (Life): 1 year

One-Way Auto Trips Eliminated Per Week (T) Using Optional Method 1:

$$T = 2 \text{ trips/day} * 5 \text{ days/week} * \text{peak period employees} * [1/\text{Baseline AVR} - 1/\text{New AVR}]$$

where baseline AVR is 1.13, new AVR is 1.19, and there are 15,750 peak period employees.

$$\text{Therefore, } T = 2 \text{ trips/day} * 5 \text{ days/week} * 15,750 \text{ peak period employees} * [1/1.13 - 1/1.19] = 6300 \text{ trips}$$

Length (L) of Auto Trips Eliminated: 16 miles

Weeks (W) = 52 weeks

Adjustment (A): 0.7 For auto access trips to transit, vanpools, and carpools

#### Emissions Factors for Auto Travel (From Table 3):

	Auto Trip End Factor	Auto VMT Factor
ROG Factor	1.719 grams per trip	0.470 grams per mile
NOx Factor	0.721	0.602
PM10 Factor	0.014	0.218

Note: 1-5 year emission factors are used since project life is 1 year, and "Commute" auto trip end factors are used since this project reduces commute trips..

#### Calculations:

$$\begin{aligned} \text{Annual Auto Trips Reduced} &= (W) * (T) * (A) \\ &= 52 * 6300 * .7 = 229,320 \end{aligned}$$

$$\begin{aligned} \text{Annual Auto VMT Reduced} &= (W) * (T) * (L) \\ &= 52 * 6300 * 16 \text{ miles} \\ &= 5,241,600 \text{ annual VMT reduced} \end{aligned}$$

#### Annual Emission Reductions (ROG, NOx, and PM10)

$$= [(\text{Annual Auto Trips Reduced}) * (\text{Auto Trip End Factor}) + (\text{Annual Auto VMT Reduced}) * (\text{Auto VMT Factor})] / 454$$

$$\text{ROG: } [(229,320 * 1.719) + (5,241,600 * 0.470)] / 454 = \mathbf{6,295 \text{ lbs. per year}}$$

$$\text{NOx: } [(229,320 * 0.721) + (5,241,600 * 0.602)] / 454 = \mathbf{7,314 \text{ lbs. per year}}$$

$$\text{PM10: } [(229,320 * 0.014) + (5,241,600 * 0.219)] / 454 = \mathbf{2,524 \text{ lbs. per year}}$$

$$\text{Capital Recovery Factor (CRF)} = \frac{(1+i)^n(i)}{(1+i)^n - 1} = 1.03 \quad \text{where } n = \text{project life (1 year)} \\ \text{(From Table 8)} \quad \text{and } i = \text{discount rate (3 \%)}$$

$$\begin{aligned} \text{Cost-Effectiveness of Funding Dollars} &= (\text{CRF} * \text{Funding}) / (\text{ROG} + \text{NOx} + \text{PM10}) \\ &= (1.03 * 140,000) / (16,133) = \mathbf{\$8.94 \text{ per lb.}} \end{aligned}$$

**FOR CMAQ PROJECTS ONLY:**

Once emissions reductions have been calculated, add them together  
(6,295 + 7,314 + 2,524 = 16,133) and convert emissions reductions to kg/day:

$$\frac{\text{lbs. reduced per year}}{2.2 \text{ lbs./kg} * 365 \text{ days/year}} = \frac{16,133}{2.2 * 365} = 20 \text{ kg/day}$$

**Table 1 Diesel Bus Emission Factors**

(through Model Year 2002)

Pollutant	Calendar Year	Model Year	VMT Emission Factor in g/mi	
			Average	45 MPH
<b>ROG</b>	2004	Entire Fleet	1.10	0.64
	2004	1973-83	1.16	0.68
	2004	1984-90	1.15	0.68
	2004	1991-93	1.14	0.67
	2004	1994-95	1.12	0.66
	2004	1996-2001	1.13	0.66
	2004	2002	1.14	0.66
<b>CO</b>	2004	Entire Fleet	4.47	2.36
	2004	1973-83	6.50	3.43
	2004	1984-90	6.05	3.20
	2004	1991-93	3.47	1.83
	2004	1994-95	2.35	1.23
	2004	1996-2001	1.83	0.96
	2004	2002	1.78	0.96
<b>NOx</b>	2004	Entire Fleet	22.79	20.40
	2004	1973-83	29.22	26.16
	2004	1984-90	26.77	23.95
	2004	1991-93	16.10	14.44
	2004	1994-95	18.87	16.90
	2004	1996-2001	19.84	17.77
	2004	2002	12.81	11.55
<b>PM10 - Exhaust</b>	2004	Entire Fleet	0.41	0.24
	2004	1973-83	0.47	0.27
	2004	1984-90	0.44	0.26
	2004	1991-93	0.39	0.24
	2004	1994-95	0.51	0.29
	2004	1996-2001	0.43	0.26
	2004	2002	0.16	0.12
PM10 - Tire Wear	All Years	All Years	0.009	Not Speed Dependent
PM10 - Brake Wear	All Years	All Years	0.013	Not Speed Dependent
PM10 - Road Dust*	All Years	All Years	0.184	Not Speed Dependent

Source: EMFAC2002, Version 2.2 (Apr03), average annual emissions, statewide urban diesel bus fleet, running exhaust emissions only, humidity 50%, temperature 75 degrees F.

\*PM10 Road Dust (paved) emission factor is based on US EPA's Compilation of Air Pollutant Emission Factors (AP-42, January 1995).

For Model Year 2003+ emission factors, use actual engine certification factors or, if not available, use Table 5.

**Table 2 Cleaner Vehicles Emission Factors (2004+)**  
**For Light-Duty and Medium-Duty Vehicles (Chassis Certified)**  
**Based on LEV II Exhaust Emission Standards**

**Baseline Vehicles**

Low-emission light-duty and medium-duty vehicle (LEV) emission factors in grams per mile with 120,000 mile durability					
Weight (lbs.) <sup>1</sup>	ROG	NOx	PM10 <sup>2</sup>		CO
			Exhaust	Total <sup>3</sup>	
0-8500	0.08	0.06	0.01	0.22	3.87
8501-10,000	0.20	0.20	0.12	0.33	6.40
10,001-14,000	0.23	0.40	0.12	0.33	7.30

**Cleaner Vehicles**

Ultra low-emission light-duty and medium-duty vehicle (ULEV) emission factors in grams per mile with 120,000 mile durability					
Weight (lbs.)	ROG	NOx	PM10		CO
			Exhaust	Total	
0-8500	0.05	0.06	0.01	0.22	1.93
8501-10,000	0.14	0.20	0.06	0.27	6.40
10,001-14,000	0.17	0.40	0.06	0.27	7.30

Super ultra low-emission vehicle (SULEV) factors in grams per mile with 120,000 mile durability Partial zero emission vehicle (PZEV) with 150,000 mile durability Advanced technology zero emission vehicle (AT-PZEV) with 150,000 mile durability					
Weight (lbs.)	ROG	NOx	PM10		CO
			Exhaust	Total	
0-8500	0.01	0.02	0.01	0.22	1.00
8501-10,000	0.10	0.10	0.06	0.27	3.20
10,001-14,000	0.12	0.20	0.06	0.27	3.70

Zero-emission light-duty and medium-duty vehicle (ZEV) emission factors in grams per mile					
Weight (lbs.)	ROG	NOx	PM10		CO
			Exhaust	Total	
All weights	0	0	0	0.21	0

**Source:** Based on California Vehicle Exhaust Standards (“LEV II”) for chassis certified vehicles. Factors represent a weighted average of emission standards over a 120,000-mile life; the first 50,000 miles are assessed at the 50,000-mile standard, and the remaining 70,000 miles are assessed at the 120,000-mile standard. The SULEVs exhaust standards apply over the full 120,000 mile life. PZEVs and AT-PZEVs must comply to SULEV standards over 150,000 miles and have near zero evaporative emissions. AT-PZEV must also make use of additional “ZEV-enabling” clean technology such as alternative fuel, electric drive, or other advanced technology systems. The PM10 exhaust factors are based on standards; tire wear and brake wear factors are based on EMFAC2002, version 2.2 (Apr03). The road dust portion of the PM10 factor is based on U.S. EPA’s Compilation of Air Pollutant Emission Factors (AP-42, January 1995). Silt loading and vehicle weight data used as inputs to EPA’s equation are from Improvement of Specific Emission Factors (BACM Project No. 1), Final Report, Midwest Research Institute, March 1996. Vehicle trip reductions may have little, if any effect on road dust emissions from high volume facilities thought to be in equilibrium, i.e., the dust is fully entrained due to the heavy traffic. The road dust PM10 factor, however, may be multiplied times total VMT reductions as it has been scaled down to reflect emissions from lower-volume local and collector roads only.

<sup>1</sup> Gross vehicle weights can be associated with passenger capacity as follows: 5751-8500, roughly 8 passengers; 8501-10,000, roughly 10-15 passengers; 10,001-14,000, roughly 20 passengers or more.

<sup>2</sup> PM10 factors are based on standards for diesel vehicles only. There is no applicable standard for gasoline vehicles; gasoline vehicles are known to emit significantly less PM10.

<sup>3</sup> Total PM10 factors include motor vehicle exhaust, tire wear (0.008 g/m), brake wear (0.013 g/m), and entrained road dust (0.184 g/m).

**Table 3 Average Auto Emission Factors  
(Fleet of Light-Duty Passenger Vehicles, Light-Duty Trucks, and Motorcycles)**

Analysis Period or Project Life	1-5 Years (2004-2008)	6-10 Years (2004-2013)	11-15 Years (2004-2018)	16-20 Years (2004-2023)
<b>ROG</b>				
VMT (g/mile)	0.392	0.318	0.266	0.229
commute trip ends (g/trip end)	1.481	1.223	1.020	0.866
average trip ends (g/trip end)	1.054	0.860	0.714	0.606
<b>NOx</b>				
VMT (g/mile)	0.491	0.390	0.319	0.269
commute trip ends (g/trip end)	0.645	0.547	0.458	0.387
average trip ends (g/trip end)	0.577	0.489	0.411	0.348
<b>PM10</b>				
VMT (g/mile)	0.218	0.219	0.219	0.219
running exhaust only (g/mile)	0.014	0.014	0.014	0.015
tire and brake wear (g/mile)	0.021	0.021	0.021	0.021
road dust (g/mile)	0.184	0.184	0.184	0.184
commute trip ends (g/trip end)	0.015	0.015	0.016	0.016
average trip ends (g/trip end)	0.008	0.008	0.008	0.008
<b>CO</b>				
VMT (g/mile)	4.680	3.795	3.146	2.672
commute trip ends (g/trip end)	13.160	11.120	9.412	8.056
average trip ends (g/trip end)	9.324	7.762	6.525	5.563

**Source:** EMFAC2002, Version 2.2 (Apr03), statewide, average annual emissions, light-duty cars and trucks plus motorcycles. The rate summary model output report (rts) used for commute trip end calculations is based on temperature 75 degrees F and 50% humidity. The VMT factors equal running exhaust plus running losses divided by daily VMT. The average trip end factors equal statewide start emissions plus hot soak emissions divided by daily trips.

The commute trip end factors are based on an “off-model” calculation that equals statewide start emissions for a commute-type pre-start soak distribution plus hot soak emissions divided by daily trips. The commute trip end factors do not reflect the soak distribution used in EMFAC2002. Instead, the factors are calculated using a special commute-type pre-start soak distribution based on an analysis of the 1991 Statewide Travel Survey for all day home-work and work-home trips.

PM10 VMT factor includes motor vehicle exhaust, tire wear, brake wear, and entrained road dust. The road dust portion of the PM10 factor is based on U.S. EPA’s Compilation of Air Pollutant Emission Factors (AP-42, January 1995). Silt loading and vehicle weight data used as inputs to EPA’s equation are from Improvement of Specific Emission Factors (BACM Project No. 1), Final Report, Midwest Research Institute, March 1996. Vehicle trip reductions may have little, if any effect on road dust emissions from high volume facilities thought to be in equilibrium, i.e., the dust is fully entrained due to the heavy traffic. The road dust PM10 factor, however, may be multiplied times total VMT reductions as it has been scaled down to reflect emissions from lower-volume local and collector roads only.

NOTES: (1) The factors do not include medium-duty vehicles (5751 to 8500 GVW); however, emissions from medium-duty vehicles used as passenger vehicles have an insignificant effect on the average emission factor (1% or less) when added to the emission factors given for light-duty vehicles. (2) Light-duty vehicle emission standards require progressively cleaner fleet average emissions. This accounts for the gradual decrease in fleet average emission factors over time.

**TO USE THE TABLE** to find annual emissions related to travel: 1) select the time period that corresponds to the life of project, 2) multiply annual miles traveled by the VMT factor, 3) multiply the annual number of trips by the trip end factor, 4) add VMT emissions to trip end emissions, 5) divide by 454 grams/lb to get lbs of emissions per year, 6) repeat for each pollutant. (Note: Use the commute trip end factor when analyzing work trips. Use the average trip end factor when analyzing a variety of trip types. The VMT factor is the same in both instances.)

**Table 3A Average Auto Emission Factors**  
**For use with projects with a 1-year project life**  
**(Fleet of Light-Duty Passenger Vehicles, Light-Duty Trucks, and Motorcycles)**

Analysis Period or Project Life	1 Year 2003	1 Year 2004	1 Year 2005
<b>ROG</b>			
VMT (g/mile)	0.523	0.470	0.424
commute trip ends (g/trip end)	1.873	1.719	1.577
average trip ends (g/trip end)	1.364	1.249	1.143
<b>NOx</b>			
VMT (g/mile)	0.686	0.602	0.538
commute trip ends (g/trip end)	0.769	0.721	0.675
average trip ends (g/trip end)	0.695	0.649	0.612
<b>PM10</b>			
VMT (g/mile)	0.218	0.218	0.218
running exhaust only (g/mile)	0.013	0.013	0.013
tire and brake wear (g/mile)	0.021	0.021	0.021
road dust (g/mile)	0.184	0.184	0.184
commute trip ends (g/trip end)	0.014	0.014	0.014
average trip ends (g/trip end)	0.008	0.008	0.008
<b>CO</b>			
VMT (g/mile)	6.190	5.590	5.060
commute trip ends (g/trip end)	16.291	15.008	13.851
average trip ends (g/trip end)	11.834	10.878	10.022

**Source:** EMFAC2002, Version 2.2 (Apr03), statewide, average annual emissions, light-duty cars and trucks plus motorcycles. The rate summary model output report (rts) used for commute trip end calculations is based on temperature 75 degrees F and 50% humidity. The VMT factors equal running exhaust plus running losses divided by daily VMT. The average trip end factors equal statewide start emissions plus hot soak emissions divided by daily trips.

The commute trip end factors are based on an “off-model” calculation that equals statewide start emissions for a commute-type pre-start soak distribution plus hot soak emissions divided by daily trips. The commute trip end factors do not reflect the soak distribution used in EMFAC2002. Instead, the factors are calculated using a special commute-type pre-start soak distribution based on an analysis of the 1991 Statewide Travel Survey for all day home-work and work-home trips.

PM10 VMT factor includes motor vehicle exhaust, tire wear, brake wear, and entrained road dust. The road dust portion of the PM10 factor is based on U.S. EPA’s Compilation of Air Pollutant Emission Factors (AP-42, January 1995). Silt loading and vehicle weight data used as inputs to EPA’s equation are from Improvement of Specific Emission Factors (BACM Project No. 1), Final Report, Midwest Research Institute, March 1996. Vehicle trip reductions may have little, if any effect on road dust emissions from high volume facilities thought to be in equilibrium, i.e., the dust is fully entrained due to the heavy traffic. The road dust PM10 factor, however, may be multiplied times total VMT reductions as it has been scaled down to reflect emissions from lower-volume local and collector roads only.

NOTES: (1) The factors do not include medium-duty vehicles (5751 to 8500 GVW); however, emissions from medium-duty vehicles used as passenger vehicles have an insignificant effect on the average emission factor (1% or less) when added to the emission factors given for light-duty vehicles. (2) Light-duty vehicle emission standards require progressively cleaner fleet average emissions. This accounts for the gradual decrease in fleet average emission factors over time.

**TO USE THE TABLE** to find annual emissions related to travel: 1) select the time period that corresponds to the life of project, 2) multiply annual miles traveled by the VMT factor, 3) multiply the annual number of trips by the trip end factor, 4) add VMT emissions to trip end emissions, 5) divide by 454 grams/lb to get lbs of emissions per year, 6) repeat for each pollutant. (Note: Use the commute trip end factor when analyzing work trips. Use the average trip end factor when analyzing a variety of trip types. The VMT factor is the same in both instances.)

**Table 4 Emission Factors by Speed**

Analysis Period 1-5 years (2004-2008)

<i>Speed (mph)</i>	<i>Grams per Mile</i>				<i>Speed (mph)</i>	<i>Grams per Mile</i>			
	<i>ROG</i>	<i>CO</i>	<i>NOx</i>	<i>PM10 Ex</i>		<i>ROG</i>	<i>CO</i>	<i>NOx</i>	<i>PM10 Ex</i>
<b>5</b>	<b>1.05</b>	<b>11.13</b>	<b>1.73</b>	<b>0.11</b>	<b>35</b>	<b>0.20</b>	<b>4.79</b>	<b>1.00</b>	<b>0.03</b>
6	0.98	10.70	1.68	0.10	36	0.20	4.73	1.00	0.02
7	0.91	10.27	1.62	0.09	37	0.19	4.67	1.01	0.02
8	0.84	9.84	1.57	0.09	38	0.19	4.62	1.01	0.02
9	0.77	9.42	1.52	0.08	39	0.19	4.56	1.01	0.02
<b>10</b>	<b>0.70</b>	<b>8.99</b>	<b>1.46</b>	<b>0.08</b>	<b>40</b>	<b>0.18</b>	<b>4.51</b>	<b>1.01</b>	<b>0.02</b>
11	0.66	8.70	1.43	0.07	41	0.18	4.47	1.02	0.02
12	0.62	8.41	1.39	0.07	42	0.18	4.44	1.03	0.02
13	0.58	8.11	1.35	0.06	43	0.18	4.41	1.04	0.02
14	0.54	7.82	1.32	0.06	44	0.17	4.37	1.04	0.02
<b>15</b>	<b>0.50</b>	<b>7.53</b>	<b>1.28</b>	<b>0.06</b>	<b>45</b>	<b>0.17</b>	<b>4.34</b>	<b>1.05</b>	<b>0.02</b>
16	0.47	7.32	1.25	0.05	46	0.17	4.33	1.07	0.02
17	0.45	7.12	1.23	0.05	47	0.17	4.32	1.08	0.02
18	0.42	6.91	1.20	0.05	48	0.17	4.31	1.10	0.02
19	0.40	6.70	1.18	0.05	49	0.17	4.30	1.11	0.02
<b>20</b>	<b>0.37</b>	<b>6.50</b>	<b>1.15</b>	<b>0.04</b>	<b>50</b>	<b>0.17</b>	<b>4.28</b>	<b>1.12</b>	<b>0.02</b>
21	0.35	6.34	1.14	0.04	51	0.17	4.30	1.15	0.02
22	0.34	6.19	1.12	0.04	52	0.17	4.32	1.17	0.02
23	0.32	6.04	1.10	0.04	53	0.17	4.33	1.19	0.02
24	0.31	5.89	1.09	0.04	54	0.17	4.35	1.21	0.02
<b>25</b>	<b>0.29</b>	<b>5.74</b>	<b>1.07</b>	<b>0.04</b>	<b>55</b>	<b>0.17</b>	<b>4.36</b>	<b>1.24</b>	<b>0.02</b>
26	0.28	5.63	1.06	0.03	56	0.18	4.41	1.27	0.02
27	0.27	5.52	1.05	0.03	57	0.18	4.46	1.31	0.02
28	0.26	5.41	1.04	0.03	58	0.18	4.51	1.34	0.02
29	0.25	5.30	1.03	0.03	59	0.19	4.56	1.37	0.02
<b>30</b>	<b>0.24</b>	<b>5.19</b>	<b>1.02</b>	<b>0.03</b>	<b>60</b>	<b>0.19</b>	<b>4.61</b>	<b>1.41</b>	<b>0.02</b>
31	0.23	5.11	1.02	0.03	61	0.19	4.71	1.46	0.02
32	0.22	5.03	1.01	0.03	62	0.20	4.81	1.51	0.02
33	0.22	4.95	1.01	0.03	63	0.20	4.91	1.55	0.02
34	0.21	4.87	1.01	0.03	64	0.21	5.01	1.60	0.02
					<b>65</b>	<b>0.21</b>	<b>5.11</b>	<b>1.65</b>	<b>0.02</b>

**Source:** EMFAC2002 Version 2.2 (Apr03), annual average emissions, statewide vehicle fleet, 50% humidity, temperature 75 degrees F. ROG includes running exhaust and running evaporative emissions. PM10 Ex includes running exhaust emissions only.

**Table 4 Emission Factors by Speed (Continued)**

Analysis Period 6-10 years (2004-2013)

<i>Speed (mph)</i>	<i>Grams per Mile</i>								
	<i>ROG</i>	<i>CO</i>	<i>NOx</i>	<i>PM10 Ex</i>	<i>Speed (mph)</i>	<i>ROG</i>	<i>CO</i>	<i>NOx</i>	<i>PM10 Ex</i>
<b>5</b>	<b>0.84</b>	<b>9.09</b>	<b>1.44</b>	<b>0.10</b>	<b>35</b>	<b>0.16</b>	<b>3.96</b>	<b>0.83</b>	<b>0.02</b>
6	0.79	8.74	1.39	0.10	36	0.16	3.91	0.83	0.02
7	0.73	8.40	1.35	0.09	37	0.16	3.86	0.83	0.02
8	0.67	8.06	1.30	0.08	38	0.15	3.82	0.83	0.02
9	0.62	7.71	1.26	0.08	39	0.15	3.77	0.84	0.02
<b>10</b>	<b>0.56</b>	<b>7.37</b>	<b>1.21</b>	<b>0.07</b>	<b>40</b>	<b>0.15</b>	<b>3.72</b>	<b>0.84</b>	<b>0.02</b>
11	0.53	7.14	1.18	0.07	41	0.14	3.69	0.84	0.02
12	0.49	6.90	1.15	0.06	42	0.14	3.67	0.85	0.02
13	0.46	6.67	1.12	0.06	43	0.14	3.64	0.86	0.02
14	0.43	6.43	1.09	0.06	44	0.14	3.61	0.86	0.02
<b>15</b>	<b>0.40</b>	<b>6.19</b>	<b>1.06</b>	<b>0.05</b>	<b>45</b>	<b>0.14</b>	<b>3.58</b>	<b>0.87</b>	<b>0.02</b>
16	0.38	6.03	1.04	0.05	46	0.14	3.57	0.88	0.02
17	0.36	5.86	1.02	0.05	47	0.14	3.56	0.89	0.02
18	0.34	5.69	1.00	0.05	48	0.14	3.55	0.91	0.02
19	0.32	5.52	0.98	0.04	49	0.14	3.53	0.92	0.02
<b>20</b>	<b>0.30</b>	<b>5.36</b>	<b>0.95</b>	<b>0.04</b>	<b>50</b>	<b>0.13</b>	<b>3.52</b>	<b>0.93</b>	<b>0.02</b>
21	0.28	5.23	0.94	0.04	51	0.14	3.53	0.95	0.02
22	0.27	5.11	0.93	0.04	52	0.14	3.54	0.97	0.02
23	0.26	4.99	0.91	0.04	53	0.14	3.55	0.99	0.02
24	0.24	4.87	0.90	0.03	54	0.14	3.56	1.01	0.02
<b>25</b>	<b>0.23</b>	<b>4.75</b>	<b>0.89</b>	<b>0.03</b>	<b>55</b>	<b>0.14</b>	<b>3.57</b>	<b>1.03</b>	<b>0.02</b>
26	0.22	4.65	0.88	0.03	56	0.14	3.61	1.05	0.02
27	0.21	4.56	0.87	0.03	57	0.14	3.65	1.08	0.02
28	0.21	4.47	0.86	0.03	58	0.15	3.69	1.11	0.02
29	0.20	4.38	0.85	0.03	59	0.15	3.72	1.14	0.02
<b>30</b>	<b>0.19</b>	<b>4.29</b>	<b>0.85</b>	<b>0.03</b>	<b>60</b>	<b>0.15</b>	<b>3.76</b>	<b>1.17</b>	<b>0.02</b>
31	0.18	4.23	0.84	0.03	61	0.15	3.84	1.21	0.02
32	0.18	4.16	0.84	0.03	62	0.16	3.91	1.25	0.02
33	0.17	4.09	0.84	0.02	63	0.16	3.99	1.29	0.02
34	0.17	4.03	0.83	0.02	64	0.17	4.07	1.33	0.02
					<b>65</b>	<b>0.17</b>	<b>4.14</b>	<b>1.37</b>	<b>0.02</b>

Source: EMFAC2002 Version 2.2 (Apr03), annual average emissions, statewide vehicle fleet, 50% humidity, temperature 75 degrees F. ROG includes running exhaust and running evaporative emissions. PM10 Ex includes running exhaust emissions only.

**Table 5 On-Road Emission Factors  
for Heavy-Duty Cleaner Vehicle Projects (2004-2006)**

**BEFORE PROJECT Baseline Emission Factors  
New Diesel Vehicles**

Vehicle Type	Gross Vehicle Weight Rating (lbs)	Model Year	Emission Factors (g/mi)	
			NO <sub>x</sub>	PM
Urban transit buses	> 33,000	2004 - 2006	<b>8.3</b>	<b>0.1</b>
Transit buses, School buses, and trucks	14,001 – 33,000	2004 - 2006	<b>4.8</b>	<b>0.3</b>
Class 8 trucks	> 33,000	2004 - 2006	<b>5.8</b>	<b>0.3</b>

**Source:** EMFAC2002, version 2.2, zero-mile emission rates based on chassis tests including off-cycle emissions and The Carl Moyer Program Guidelines, September 2003, pp. 17-18, 29-31, and 142-145. All factors have been adjusted for California diesel fuel. Following the Moyer Guidelines, NO<sub>x</sub> rates were multiplied by 0.87, and PM rates were multiplied by 0.9. As diesel buses have not yet demonstrated achievement of the 2004 diesel NO<sub>x</sub> standard 0.5 g/bhp-hr, baseline buses are expected to be alternative fueled vehicles that achieve 2.4 g/bhp-hr NO<sub>x</sub> + NMHC (i.e., 1.9 g/bhp-hr NO<sub>x</sub> + 0.5 g/bhp-hr NMHC).

**AFTER PROJECT Emission Factors  
New Cleaner Vehicle Purchases or Re-powers (Typically Alternative-Fueled Vehicles)**

Vehicle Type	Gross Vehicle Weight Rating (lbs)	Engine Certification Emission Rates (g/bhp-hr)		Conversion Factors* (bhp-hr/mi)	Emission Factors (g/mi)	
		NO <sub>x</sub>	PM		NO <sub>x</sub>	PM
Urban transit buses	> 33,000	0.5		4.3	<b>2.2</b>	<b>0.025**</b>
		1.5		4.3	<b>6.4</b>	<b>0.025**</b>
Buses and trucks	14,001 – 33,000	1.5	0.023***	2.3	<b>3.4</b>	<b>0.053</b>
		2.0	“	2.3	<b>4.6</b>	“
Class 8 trucks	> 33,000	1.5	0.023****	2.6	<b>3.9</b>	<b>0.060</b>
		2.0	“	2.6	<b>5.2</b>	“

For emission certification to 1.8 NO<sub>x</sub> + NMHC, assume 80% is NO<sub>x</sub> for alternative fuel engines or 1.44 g/bhp-hr.

\* The Carl Moyer Program Guidelines, September 2003, page 30.

\*\* The Carl Moyer Program Guidelines, September 2003, page 142. Based on in-use data for natural gas urban buses.

\*\*\* PM emission rate is assumed to be the same as for Class 8 trucks because school buses and trucks with GVWR 14,001– 33,000 lbs are certified to the same PM standard (0.10 g/bhp-hr) as Class 8 trucks.

\*\*\*\* Based on ARB Memorandum from Ms. Cindy Sullivan to Air Pollution Control and Air Quality Management Districts, February 21, 2001.

**Cleaner vehicles** could be compressed natural gas (CNG), liquefied natural gas (LNG), or cleaner diesel with after-treatment technology to reduce NO<sub>x</sub> and PM. The “After Project” emission factors are based on typical CNG vehicles; however, after-treatment applied to CNG vehicles has been shown to reduce even more PM and also, formaldehyde.

If the project's NO<sub>x</sub> engine certification rate is not shown in the table, multiply the appropriate rate times the conversion factor corresponding to the vehicle class to get grams per mile. For refuse vehicles or retrofit projects, see Carl Moyer Program Guidelines for emission rates.

**Table 6 Off-Road Emission Factors  
for Cleaner Vehicle Projects (2004 – 2005)**

Find the horsepower (hp) and model year for the engine that best describes the engine being replaced to determine the “before project” baseline emission factors. Find the hp and model year for the newer engine. These factors represent the “after project” cleaner engine emission factors.

		(g/hp-hr)	(g/hp-hr)	(g/hp-hr)	(g/hp-hr)
<b>HP</b>	<b>Model Year</b>	<b>ROG</b>	<b>CO</b>	<b>NOx</b>	<b>PM</b>
51-120	1987 or older	1.44	4.80	13.00	0.84
51-120	1988 - 1997	0.99	3.49	8.75	0.69
51-120	1998 - 2003	0.99	3.49	6.90	0.69
51-120	2004	0.46	3.23	5.64	0.39
51-120	2005	0.28	3.14	5.22	0.29
121-175	1969 or older	1.32	4.40	14.00	0.77
121-175	1970 - 1971	1.10	4.40	13.00	0.66
121-175	1972 - 1979	1.00	4.40	12.00	0.55
121-175	1980 - 1984	0.94	4.30	11.00	0.55
121-175	1985 - 1987	0.88	4.20	11.00	0.55
121-175	1988 - 1996	0.68	2.70	8.17	0.38
121-175	1997 - 2002	0.68	2.70	6.90	0.38
121-175	2003	0.33	2.70	5.26	0.24
121-175	2004	0.22	2.70	4.72	0.19
121-175	2005	0.16	2.70	4.44	0.16
176-250	1969 or older	1.32	4.40	14.00	0.77
176-250	1970 - 1971	1.10	4.40	13.00	0.66
176-250	1972 - 1979	1.00	4.40	12.00	0.55
176-250	1980 - 1984	0.94	4.30	11.00	0.55
176-250	1985 - 1987	0.88	4.20	11.00	0.55
176-250	1988 - 1995	0.68	2.70	8.17	0.38
176-250	1996 - 2002	0.32	0.92	6.25	0.15
176-250	2003	0.19	0.92	5.00	0.12
176-250	2004	0.14	0.92	4.58	0.11
176-250	2005	0.12	0.92	4.38	0.11
251-500	1969 or older	1.26	4.20	14.00	0.74
251-500	1970 - 1971	1.05	4.20	13.00	0.63
251-500	1972 - 1979	0.95	4.20	12.00	0.53
251-500	1980 - 1984	0.90	4.20	11.00	0.53
251-500	1985 - 1987	0.84	4.10	11.00	0.53
251-500	1988 - 1995	0.68	2.70	8.17	0.38
251-500	1996 - 2000	0.32	0.92	6.25	0.15
251-500	2001	0.19	0.92	4.95	0.12
251-500	2002	0.14	0.92	4.51	0.11
251-500	2003 - 2004	0.12	0.92	4.29	0.11
251-500	2005	0.10	0.92	4.00	0.11

**Table 6 Off-Road Emission Factors  
for Cleaner Vehicle Projects (2004 – 2005)  
(continued)**

<b>HP</b>	<b>Model Year</b>	(g/hp-hr) <b>ROG</b>	(g/hp-hr) <b>CO</b>	(g/hp-hr) <b>NOx</b>	(g/hp-hr) <b>PM</b>
501-750	1969 or older	1.26	4.20	14.00	0.74
501-750	1970 - 1971	1.05	4.20	13.00	0.63
501-750	1972 - 1979	0.95	4.20	12.00	0.53
501-750	1980 - 1984	0.90	4.20	11.00	0.53
501-750	1985 - 1987	0.84	4.10	11.00	0.53
501-750	1988 - 1995	0.68	2.70	8.17	0.38
501-750	1996 - 2001	0.32	0.92	6.25	0.15
501-750	2002	0.19	0.92	4.95	0.12
501-750	2003	0.14	0.92	4.51	0.11
501-750	2004 - 2005	0.12	0.92	4.29	0.11
>750	1969 or older	1.26	4.20	14.00	0.74
>750	1970 - 1971	1.05	4.20	13.00	0.63
>750	1972 - 1979	0.95	4.20	12.00	0.53
>750	1980 - 1984	0.90	4.20	11.00	0.53
>750	1985 - 1987	0.84	4.10	11.00	0.53
>750	1988 - 1999	0.68	2.70	8.17	0.38
>750	2000 - 2005	0.32	0.92	6.25	0.15

**Source:** Air Resources Board Emission Inventory for Off-Road Large Compression-Ignited Engines Using the New Off-Road Emissions Model (Mail Out MSC #99-32)

**Other information needed** to estimate emissions are operating hours and load factor. Operating hours for construction equipment can range from 535 to 1641 hours per year and the load factor can vary between 0.43 and 0.78. Operating hours for agricultural equipment can range from 90 to 790 hours per year and the load factor can vary between 0.43 to 0.70.

**Table 7 Medium-Duty Vehicle Emission Factors  
For Vanpool and Shuttle Evaluations  
(Model Years 1995 - 2003)**

Low-emission medium-duty vehicle (LEV) emission factors in grams per mile					
Weight (lbs.)*	ROG	NOx	PM10		CO
			Exhaust	Total**	
5751-8500	0.24	0.77	0.12	0.33	6.34
8501-10,000	0.29	0.88	0.12	0.33	7.02
10,001-14,000	0.38	1.29	0.12	0.33	8.93

Ultra low-emission medium-duty vehicle (ULEV) emission factors in grams per mile					
Weight (lbs.)*	ROG	NOx	PM10		CO
			Exhaust	Total**	
5751-8500	0.15	0.77	0.06	0.27	6.34
8501-10,000	0.17	0.88	0.06	0.27	7.02
10,001-14,000	0.23	1.29	0.06	0.27	8.93

Super ultra low-emission medium-duty vehicle (SULEV) emission factors in grams per mile					
Weight (lbs.)*	ROG	NOx	PM10		CO
			Exhaust	Total**	
5751-8500	0.07	0.39	0.06	0.27	3.20
8501-10,000	0.09	0.44	0.06	0.27	3.56
10,001-14,000	0.11	0.62	0.06	0.27	4.49

Zero-emission medium-duty vehicle (ZEV) emission factors in grams per mile					
Weight (lbs.)*	ROG	NOx	PM10		CO
			Exhaust	Total**	
All weights	0	0	0	0.21	0

If vanpool/shuttle project is using 2004+ model year vehicles, refer to Table 2.

**Source:** Based on California Vehicle Exhaust Standards ("LEV I"), January 1999. (LEV II went into effect in 2004.) Factors represent a weighted average of emission standards over a 120,000-mile life; the first 50,000 miles are assessed at the 50,000-mile standard, and the remaining 70,000 miles are assessed at the 120,000-mile standard.

\*Gross vehicle weights can be associated with passenger capacity as follows: 5751-8500, roughly 8 passengers; 8501-10,000, roughly 10-15 passengers; 10,001-14,000, roughly 20 passengers or more.

\*\* Total PM10 factors include motor vehicle exhaust, tire wear (0.008 g/m for all), brake wear (0.013 g/m for all), and entrained road dust (0.184 g/m for all). The PM10 exhaust factors are based on engine standards; tire wear and brake wear factors are based on EMFAC2002, version 2.2. The road dust portion of the PM10 factor is based on U.S. EPA's Compilation of Air Pollutant Emission Factors (AP-42, January 1995). Silt loading and vehicle weight data used as inputs to EPA's equation are from Improvement of Specific Emission Factors (BACM Project No. 1), Final Report, Midwest Research Institute, March 1996. Vehicle trip reductions may have little, if any, effect on road dust emissions from high volume facilities thought to be in equilibrium, i.e., the dust is fully entrained due to the heavy traffic. The road dust PM10 factor, however, may be multiplied times total VMT reductions as it has been scaled down to reflect emissions from lower-volume local and collector roads only.

## Table 8 Capital Recovery Factors

The following table gives capital recovery factors that may be used to annualize funding dollars according to project life. Below are the capital recovery factors calculated to two decimal places for a discount rate of 3 percent.

Project Life	Capital Recovery Factor for discount rate of 3%
1 year	1.03
3 years	0.35
5 years	0.22
7 years	0.16
10 years	0.12
12 years	0.10
15 years	0.08
20 years	0.07

The formula for the capital recovery factor is:

$$\text{Capital Recovery Factor (CRF)} = \frac{(1+i)^n(i)}{(1+i)^n - 1} \quad \text{where: } i = \text{discount rate} \\ n = \text{project life}$$

For example, if the project life is 1 year and the discount rate is 3%, then the capital recovery factor equals 1.03.

$$= \frac{(1+i)^n(i)}{(1+i)^n - 1} = \frac{(1+0.03)^1(0.03)}{(1+0.03)^1 - 1} = \frac{0.0309}{0.0300} = 1.03$$

To determine cost-effectiveness, funding dollars are amortized over the expected project life using a discount rate. The amortization formula yields a capital recovery factor, which, when multiplied by the funding, gives the annualized funding for the project over its expected lifetime. The discount rate reflects the opportunity cost of public funds for the clean air programs. This is the level of earnings that could be reasonably expected by investing public funds in various financial instruments, such as U.S. Treasury securities. Cost-effectiveness is determined by dividing annualized funds by annual emission reductions (ROG + NO<sub>x</sub> + PM<sub>10</sub>).