DRAFT

Methodologies for Evaluating Congestion Mitigation and Air Quality Improvement Projects

Maricopa Association of Governments

March 15, 2009

Table of Contents

Page

INTRODUCTION 1
Reviews of the CMAQ Methodologies 1
CMAQ Project Review Process 4
Overview of Key Assumptions 5
Application of Methodologies 7

BICYCLE AND PEDESTRIAN FACILITIES 7
Bicycle and Pedestrian Facilities Example 10

BUS AND LIGHT RAIL PROJECTS 12
New Bus Service 12
New Bus Service Example 14
New Light Rail Service 15
New Light Rail Service Example 17

DIESEL RETROFITS AND ANTI-IDLING PROGRAMS 18
Diesel Retrofits 18
Diesel Retrofits Example 19
Diesel Anti-Idling Programs 20
Truck Stop Electrification Example 22
Auxiliary Power Units Example 22

INTERSECTION IMPROVEMENTS 23
Additional Turning Lanes Example 24
Roundabout Example 25

OZONE EDUCATION PROGRAM 26
Ozone Education Program Example 27

PARK AND RIDE FACILITIES 28
Park and Ride Lot Example 29

PAVING PROJECTS 30
Paving Unpaved Roads Without Paved Shoulders Example 33
Paving Unpaved Roads With Paved Shoulders and Curb and Gutter Example 34
Paving Unpaved Access Points Example 35

PM-10 CERTIFIED STREET SWEEPERS 35
PM-10 Certified Street Sweepers Example 42

RIDESHARE PROGRAMS 43
Regional Rideshare Program Example 44

TELEWORK PROGRAM 45
Telework Program Example 47

TRAFFIC FLOW IMPROVEMENTS 47
Traffic Signal Coordination 48
Traffic Signal Coordination Example 50
Intelligent Transportation Systems 50
Intelligent Transportation Systems Example 51
Freeway Management System 52
Freeway Management System Example 53

TRIP REDUCTION PROGRAM 54
Trip Reduction Program Example 55

VANPOOL VEHICLES 56
Vanpool Vehicles Example 58

REFERENCES 59

INTRODUCTION

The purpose of the Congestion Mitigation and Air Quality Improvement (CMAQ) Program is to provide federal funding for projects designed to assist nonattainment and maintenance areas in complying with the National Ambient Air Quality Standards. The most recent federal guidance for the CMAQ program, effective October 20, 2008, indicates that the emissions benefits and disbenefits for CMAQ project proposals should be quantified, if possible, for all pollutants for which the area is in nonattainment or maintenance status, including appropriate precursor emissions. The Maricopa Association of Governments (MAG) has developed methodologies for quantifying emissions benefits and disbenefits and calculating the cost-effectiveness of proposed CMAQ projects. MAG has updated the CMAQ methodologies periodically since 1999 to address changes in federal guidance, new project types, and improved technical methods and assumptions.

Reviews of the CMAQ Methodologies

In 2002, MAG contracted with Sierra Research to review CMAQ methodologies and identify the most promising project evaluation techniques used by MPOs in the western U.S. On April 29, 2002, MAG conducted a half-day workshop describing the CMAQ methodologies in use by the western MPOs and the findings and recommendations of the Sierra Research study. In general, Sierra concluded that "the methods established by MAG for computing the cost-effectiveness of proposed CMAQ projects are easily the most sophisticated encountered in the review of western communities." The Sierra Research recommendations and input from the 2002 workshop were incorporated into the 2004 MAG CMAQ methodologies (MAG, 2004b).

On June 28, 2005, MAG conducted a second workshop to discuss additional revisions to the CMAQ methodologies. The input from this workshop was incorporated into the MAG CMAQ methodologies that have been applied since August 2005 (MAG, 2005).

In 2008, MAG contracted with Sierra Research to review CMAQ approaches used elsewhere and recommend improvements to the 2005 MAG methodologies (MAG, 2008). The major findings of this study are summarized below.

(1) MAG's CMAQ methodologies adequately address the key issues in the latest federal transportation legislation (SAFETEA-LU, 2005). As recommended by SAFETEA-LU, MAG's CMAQ process includes an evaluation and prioritization of diesel retrofit projects, prioritizes projects based on cost-effectiveness, and allows funding of transportation systems management and operations projects that mitigate congestion and improve air quality.

(2) Like MAG, the California Air Resources Board (CARB) has eliminated carbon monoxide (CO) emissions from their calculations of cost-effectiveness for CMAQ projects.

(3) The level of detail used by the Texas Department of Transportation in evaluating CMAQ projects (TTI, 2007) is higher than currently required by the MAG methodologies. For

example, the TTI methodology for ITS projects quantifies the emission reductions attributable to alleviating peak and off-peak recurrent and non-recurrent congestion. The TTI methodologies require extensive data collection on the part of entities requesting CMAQ funds. Sierra points out that the TTI methods are also used to quantify control measures for Texas SIPs.[1]

(4) California communities can download automated database programs to quantify twelve types of CMAQ projects. Several other communities have established spreadsheets that automate the calculation of benefits and cost-effectiveness for project sponsors. Colorado has automated the procedures used to prepare the annual CMAQ reports. Sierra recommends that MAG consider automating its CMAQ methodologies.

(5) The MAG CMAQ methodologies should be updated to be consistent with assumptions in the Eight-Hour Ozone Plan (MAG, 2007a) and Five Percent Plan for PM-10 (MAG, 2007b).

(6) Sierra recommends that the local sources from which activity rates have been derived (e.g. On Board Bus and Household Travel Surveys, MAG Congestion Studies, Travel Demand Management Surveys, Maricopa County Trip Reduction Program Reports) be reviewed and updated where appropriate.[2]

(7) The 2008 Sierra Research report concludes that: "Overall, the methods established by MAG for computing the cost-effectiveness of proposed CMAQ projects are still the most sophisticated of the states and communities surveyed, particularly for fugitive dust emission calculations."

Since Sierra Research has concluded that MAG continues to have the most sophisticated methods, major changes to the methodologies are not required. However, the TOG, NOx and PM-10 emission factors have been updated in this document to be consistent with assumptions in the 2007 MAG Ozone and PM-10 Plans, as recommended by Sierra.

---

[1]It is important to note that it would be difficult for MAG member agencies to collect this type of detailed data, especially given the typically tight time constraints for submission and evaluation of CMAQ projects. Accurate emission reduction estimates are necessary for legally-binding control measures in a State Implementation Plan (SIP); in CMAQ evaluations, the emission reductions are quantified in order to compare the relative cost-effectiveness of potential CMAQ projects (for new TIP projects or year-end closeout) and estimate the benefits of completed projects (in the annual CMAQ report). Neither of these CMAQ purposes warrants the same level of precision in the estimation of emission reductions that would be required for a SIP.

[2]The 2004 MAG CMAQ methodologies updated the activity rates based on the latest local studies; however, it was found that these rates do not vary significantly over time.

On March 31, 2009, MAG will conduct a workshop to discuss the findings of the latest Sierra Research review and proposed changes to the CMAQ methodologies. Input from workshop participants will be incorporated into the final version of the 2009 CMAQ methodologies.

In this document, the priority weights in the example equations have also been revised for ozone precursor emissions. This change was precipitated by EPA's lowering of the eight-hour ozone standard (from 0.80 to 0.75 ppm) in March 2008. Based on 2006-2008 monitoring data, Maricopa County is likely to be designated a nonattainment area for the new eight-hour ozone standard. Because CMAQ projects that reduce total organic gases (TOG) and nitrogen oxides (NOx) will contribute to attainment of the new, more stringent ozone standard, the weights used in calculating cost-effectiveness have been increased for these ozone precursors. To calculate the new weights, the 2008 light duty vehicle emission rates for TOG and NOx have been set equal to the emission rate for PM-10, a pollutant for which the area is also in nonattainment.[3] The table below shows the new priority weights of 0.89 for TOG and 1.03 for NOx that result in the PM-10 emission rate of 0.68 grams per vehicle mile of travel (vmt).

Pollutant	2008 Light Duty Vehicle Emission Rates[4]	Priority Weight	Weighted Emission Rates
CO	8.47 grams/vmt	0.00	0.00 grams/vmt
TOG	0.76 grams/vmt	0.89	0.68 grams/vmt
NOx	0.66 grams/vmt	1.03	0.68 grams/vmt
PM-10	0.68 grams/vmt	1.00	0.68 grams/vmt

Participants in the 2005 MAG CMAQ workshop suggested that MAG assign a weight of zero to carbon monoxide (CO) emissions when calculating cost-effectiveness and this suggestion was implemented in the 2005 methodologies. As indicated in the 2008 Sierra Research study, CARB also assigns a weight of zero to CO emissions when evaluating CMAQ projects. Since the Maricopa County area has not violated the CO standard since 1996 and monitored CO concentrations continue to decline, zeroing out the CO emissions in the CMAQ cost-effectiveness calculation remains appropriate. However, CO emission reductions must still be calculated for funded projects in the annual CMAQ report required by FHWA. If EPA were to lower the CO standard in the future, the

---

[3]In the 2005 CMAQ methodologies, the priority weights were derived by setting the 2005 light duty vehicle emission rates for TOG and NOx equal to one-half of the PM-10 emission rate. The 2005 light duty vehicle emission rates were derived from MOBILE6.2 and PART5.

[4]The 2008 light duty vehicle exhaust emission rates for CO, TOG, and NOx were derived from MOBILE6.2. The 2008 PM-10 rate of 0.03 g/vmt for exhaust, tire wear and brake wear emissions was also derived from MOBILE6.2. The 2008 PM-10 emission rate of 0.65 g/vmt for reentrained dust created by vehicles traveling on paved roads was derived from EPA AP-42 equations and is consistent with assumptions in the Five Percent Plan for PM-10 (MAG, 2007b).

priority weight could change. For these reasons, CO emissions are included in the equations and examples shown in this document, even though the priority weight is zero. PM-2.5 emissions are not included in the MAG CMAQ methodologies, because the Phoenix-Mesa Metropolitan Statistical Area was designated an attainment area for PM-2.5 in September 2004.

The priority weights shown above will be used in calculating cost-effectiveness for projects requesting CMAQ funding. The weights are applied to the seasonally adjusted emission rates (i.e., TOG and NOx are divided by two to reflect the six-month ozone season)[5]. The cost-effectiveness calculations for the example projects in this document have been updated with the new priority weights for TOG and NOx. Their use will result in cost-effectiveness scores that differ from those calculated using previous versions of the MAG CMAQ methodologies.

CMAQ Project Review Process

Each year MAG programs available CMAQ funds. As part of the programming process, jurisdictions are requested through the MAG Management Committee, MAG Transportation Review Committee, and MAG modal committees, to submit requests for federally funded projects. After the receipt of project requests, MAG evaluates CMAQ projects for possible inclusion in the Transportation Improvement Program. The MAG modal committees are furnished with the CMAQ assessment, along with the Congestion Management System rating score, for project evaluation purposes. Recommendations from the MAG modal committees are forwarded to the Transportation Review Committee for programming consideration.

The CMAQ project assessment may be in the form of a quantitative analysis resulting from the methodologies or a qualitative evaluation. CMAQ guidance allows a qualitative evaluation to be made when a quantitative analysis is not possible, although every effort will be made to quantify the emissions reduction impact of each project. Qualitative assessments may be based on a reasonable review of how a project or program will decrease emissions. Committed transportation control measures identified in the air quality plans receive priority in CMAQ project programming.

The CMAQ methodologies provide options for local input, while striving to keep the overall data requirements from being overly complex and burdensome. In general, agencies submitting CMAQ projects may provide local data to replace default values in any of the methodologies, as long as there is supporting written documentation. The values to be substituted and the supporting documentation (i.e., traffic engineering modeling; city-specific survey data) must accompany the request for CMAQ funding.

The methodologies included in this report were developed in response to federal guidance (FHWA, 2008) requiring the quantification of emission reductions for proposed CMAQ projects, whenever possible. Other potential project benefits such as human health, safety, land use, and

[5]A seasonal adjustment factor is not applied to PM-10, because violations of the PM-10 standard could occur at any time of the year.

congestion mitigation impacts are not addressed. It is also important to note that emission reductions and cost-effectiveness are not the only factors considered in evaluating and selecting candidates for CMAQ funding.

Overview of Key Assumptions

The methodologies for quantifying the emission reductions and cost-effectiveness of typical CMAQ projects are described below. In general, the methodologies estimate (1) emission reductions in kilograms per day, which are the sum of reductions in TOG, NOx, and PM-10; and (2) the cost-effectiveness of each project in dollars per metric ton of emissions reduced per year. Because the CMAQ methodology uses the latest EPA emissions models and regional planning assumptions, the emission reductions may not be consistent with previous CMAQ analyses or air quality plans that used earlier EPA models and assumptions. Some projects do not reduce PM-10 emissions and only CO, TOG, and NOx benefits are calculated. In other cases, only PM-10 emissions are reduced. If a proposed project combines two project types (i.e., paving a dirt road and adding a bicycle lane), the combined impact of the two portions of the project is included in the total emission reduction.

The EPA MOBILE6 emissions model will be run to estimate CO, TOG, NOx, and PM-10 emission factors for the implementation year of the project, assuming that the project is implemented in the CMAQ funding year. The MOBILE6 emission factors will be based on the latest vehicle registrations and diesel split factors. The PM-10 emissions output by MOBILE6 include tailpipe exhaust, tire wear and brake wear emissions. The average speed of area-wide traffic is assumed to be 30 miles per hour, unless specified otherwise in the methodologies.

PM-10 emission rates for unpaved and paved roads used in this document are derived from the Five Percent Plan for PM-10 (MAG, 2007b). The unpaved road emission rate used in the methodology for paving unpaved roads is 666.62 grams per vehicle mile of travel (vmt).

The PM-10 emission rates for reentrainment by vehicles traveling on paved roads are: 0.18 grams per vmt on freeways; 1.70 grams per vmt on low traffic roads (carrying less than 10,000 vehicles per day); 0.92 grams per vmt for all non-freeways~~,~~ and 0.65 grams per vmt for all road types. In the Salt River Area, the paved road PM-10 emission rate is 3.44 grams per vmt for all non-freeways (MAG, 2008).[6]

Carbon monoxide emission reductions are calculated for the range of temperatures on the winter episode day in the EPA-approved carbon monoxide maintenance plan (MAG, 2003). As previously indicated, the priority weight for CO is zero and the CO emission reduction benefits are only calculated for the annual CMAQ report. No seasonal adjustment (i.e, division by four) is applied when estimating CO emissions for the annual CMAQ report.

[6]All of these paved road emissions rates assume paved shoulders and curb and gutter.

TOG and NOx emissions are calculated for the range of temperatures on the summer episode day in the Eight-Hour Ozone Plan (MAG, 2007a). In the calculation of total emissions and cost-effectiveness for projects requesting CMAQ funding, TOG and NOx reductions are divided by a seasonal factor of two to account for the six-month ozone season. No seasonal adjustment (i.e, division by two) is applied when estimating TOG and NOx emissions for the annual CMAQ report. Temperature is not used in estimating PM-10 emissions, and no seasonal factor is applied, because exceedances of the daily PM-10 standard can occur at any time of year. Because of the seasonal and priority weight assumptions discussed above, total emission reductions (i.e., sum of CO, TOG, NOx and PM-10) for CMAQ projects do not represent an average day during the year.

In the CMAQ methodologies, the cost-effectiveness of a project is calculated by dividing the annualized total project cost by the annual emission reduction. The annual emission reduction is obtained by converting the total weighted reduction in CO, TOG, NOx and PM-10 emissions in kilograms per day to metric tons per year. The total cost is amortized over the expected project life using a three percent discount rate, which represents the opportunity cost of using public dollars to fund a project, versus investing the same funds in a certificate of deposit earning three percent per year over the life of the project. The general approach for calculating cost-effectiveness and the discount rate are consistent with those used by the California Air Resources Board (CARB, 2005).

The remainder of this document describes the methodologies and assumptions used to estimate emission reductions and cost-effectiveness for typical CMAQ projects. The description of the methodology for each project type is divided into three sections. The first section describes the modeling methodology, assumptions, and defaults. The second lists the data that are requested from the entity proposing the project. If any of the required data are not provided, default assumptions are substituted. The third section provides the formulas used in the analyses. Data from the first and second sections are input to the formulas to estimate the emission reduction and cost-effectiveness of a proposed project. At least one example calculation is provided for each project type. The examples represent generic CMAQ projects, provided to demonstrate how the methodology will be applied. The emission reductions and cost-effectiveness calculated for actual CMAQ projects will be dependent upon local inputs and may vary substantially from the examples.

This document describes methodologies for the following project types, in alphabetical order: Bicycle and Pedestrian Facilities, Bus and Light Rail Projects, Diesel Retrofits and Anti-Idling Programs, Intersection Improvements (including Roundabouts), Ozone Education Program, Park and Ride Facilities, Paving Projects, PM-10 Efficient Street Sweepers, Rideshare Programs, Telework Program, Traffic Flow Improvements, Trip Reduction Program, and Vanpool Vehicles.[7]

---

[7]The methodology for High Occupancy Vehicle (HOV) Facilities included in the 2005 CMAQ methodologies has been eliminated from the 2009 CMAQ methodologies, because it is anticipated that future HOV projects will utilize funding sources other than CMAQ. The 2005 CMAQ methodology for Freight Projects focused on Truck Stop Electrification which is addressed as a Diesel Anti-Idling Program in the 2009 CMAQ methodologies.

These represent the most common CMAQ project types in the MAG region. CMAQ-eligible projects that do not fall into one of these categories will also be quantified, if feasible, on a case-by-case basis. If CMAQ funding for one phase (e.g., planning or design) of an eligible project is requested, the emission reduction benefit will be calculated for the first year that the project is to be completed. If additional CMAQ funds have been or will be requested to complete a project (e.g., a light rail segment), the requesting entity will be asked to estimate the total CMAQ funds to be used in calculating the cost-effectiveness for the project.

Application of Methodologies

The CMAQ methodologies calculate cost-effectiveness, a measure that is used in prioritizing projects that are candidates for future CMAQ funds. The methodologies are also used to quantify daily emission reductions for annual CMAQ reports submitted to FHWA. If emission reduction credit for a CMAQ-funded project in the Transportation Improvement Program has not been taken in a State Implementation Plan (SIP), the benefits of the project may also be used in transportation conformity. Since the annual CMAQ report and conformity analyses require emission reductions by individual pollutant, the priority weights (*w1, w2, w3, w4*) and seasonality factors (e.g., dividing VOC and NOx by two) are not used in these applications.

BICYCLE AND PEDESTRIAN FACILITIES

"Encouragement of Bicycle Travel" and "Development of Bicycle Travel Facilities" are committed control measures in the Serious Area CO Plan (MAG, 2001) and Serious Area PM-10 Plan (MAG, 2000a). Bicycle facilities have the potential to reduce commute and other non-recreational trips. Bicycle paths are facilities which are physically separated from motor vehicle traffic. Bicycle lanes are striped for preferential or exclusive use of bicycles. CO, TOG, NOx, and PM-10 emission reductions occur when bicycle trips replace single occupant vehicle trips.

"Encouragement of Pedestrian Travel" is also a committed control measure in the MAG Serious Area CO and PM-10 Plans. Pedestrian facilities provide or improve pedestrian access. Emissions are reduced when vehicle trips are replaced by walking.

The CO, TOG, NOx, and PM-10 emission factors are calculated for the implementation year of the project. The project life for bicycle and pedestrian paths and bicycle lanes on roads or shoulders is twenty years; fifty years, for overpasses and underpasses. The average weekday traffic (***ADT***) estimates for the adjacent or nearest parallel arterial must be provided by the entity requesting CMAQ funding for the project.

MOBILE6 will be run assuming a speed of 30 miles per hour to estimate CO, TOG, NOx, and PM-10 emission factors for light duty vehicles. Since it is assumed that bicycle/pedestrian trips replace vehicle trips that are four miles or less, the cold start emission factor will be used for all vehicle trips replaced by bicycle/pedestrian trips ($\boldsymbol{CEF_{CO}}$, $\boldsymbol{CEF_{TOG}}$, $\boldsymbol{CEF_{NOx}}$, $\boldsymbol{CEF_{PM}}$). Evaporative emissions from the hot engine at the end of each trip will also be estimated for TOG ($\boldsymbol{HEF_{TOG}}$).

The number of vehicle trips replaced by bicycle or pedestrian trips will be estimated based on the average weekday traffic on the adjacent or nearest parallel arterial to the bicycle/pedestrian path. The ADT on the road will be converted to annual average daily traffic (AADT) by multiplying by 0.91. The vehicle trips reduced will be estimated using the adjustment factors from Table 1. The adjustment factors are dependent upon the length of the bicycle/pedestrian project and the AADT on the road parallel to the bicycle/pedestrian project. Given the relative importance of bridges and underpasses that connect bicycle/pedestrian paths, the adjustment factor used for bridges and underpasses will be based on the sum of the lengths of the two paths connected.

Estimates of the VMT reduced are based on the average number of vehicle trips reduced, multiplied by average trip lengths. Consistent with assumptions in MAG transportation modeling concerning pedestrian trips to transit centers, a pedestrian trip length of one-half mile will be assumed. Based on data in Bicycle Demand and Benefit Model (Alta Transportation Consulting, April 2000) an average bicycle trip length of four miles will be assumed. For multi-use paths, it will be assumed that half of the trips are bicycle and half are pedestrian. Therefore, an average trip length of 2.25 miles will be assumed for multi-use paths.

The usefulness of a bicycle/pedestrian path is also dependent upon its location. Usage estimates for bicycle/pedestrian paths will take into consideration the number of activity centers near the proposed bicycle/pedestrian path. The credit for activity centers along a bicycle/pedestrian path is shown in Table 2.

Table 1. Adjustment Factors[8]

ANNUAL AVERAGE DAILY TRAFFIC (AADT)	LENGTH OF PROJECT (one direction)	**ADJUSTMENT FACTOR (*A*)**
AADT ≤ 12,000 vehicles per day	≤ 1 mile	0.0019
	> 1 mile and ≤ 2 miles	0.0029
	> 2 miles	0.0038
12,000 < AADT ≤ 24,000 vehicles per day	≤ 1 mile	0.0014
	> 1 mile and ≤ 2 miles	0.0020
	> 2 miles	0.0027
AADT > 24,000 vehicles per day	≤ 1 mile	0.0010
	> 1 mile and ≤ 2 miles	0.0014
	> 2 miles	0.0019

[8]Data adapted from the California Air Resources Board (CARB, 2005).

Table 2. Activity Center Credits[9]

Examples of Activity Centers: bank, church, hospital or HMO, park and ride, office park, post office, public library, shopping area or grocery store, schools, university or junior college.		
Number of activity centers	**Credit (C)**	
	Within ½ mile	Within ¼ mile
at least three	0.0005	0.001
more than three but less than seven	0.001	0.002
seven or more	0.0015	0.003

The formulas below are used to calculate the annual emission reductions and cost-effectiveness of bicycle and pedestrian facilities.

Inputs Required from Entity Requesting CMAQ Funds:

- ***CMAQ Cost***.
- Average weekday traffic (***ADT***) on the nearest parallel arterial.
- Number of activity centers (i.e. bank, church, hospital, HMO, light rail station, park and ride lot, office park, post office, public library, shopping area, grocery store, university or junior college) within ¼ mile and ½ mile of the bicycle/pedestrian project.
- Length of bicycle/pedestrian path (for a bridge/underpass; the combined length of the paths connected by the bridge/underpass).

Formulas:

$$\textit{Trips Reduced}\ (\boldsymbol{TR}) = \boldsymbol{ADT} * 0.91 * (\boldsymbol{A} + \boldsymbol{C})$$

where: ***A*** = the adjustment factor from Table 1
C = the activity center credit from Table 2
ADT = the average weekday traffic on the adjacent or nearest parallel arterial
0.91 = factor to convert average weekday traffic to annual average daily traffic
ADT * 0.91 = the annual average daily traffic (**AADT**) on the adjacent or nearest parallel arterial

$$\textit{VMT Reduced}\ (\boldsymbol{VR}) = \boldsymbol{ATR} * \textit{trip length}$$

[9]Ibid.

where: ***trip length*** = the length of a bicycle trip is assumed to be 4.0 miles and the length of a pedestrian trip is assumed to be 0.5 miles. For a multi-use path, it is assumed that the average trip length is 2.25 miles.

$$Daily\ Emissions\ Reduction = [(TR * \frac{w2 * HEF_{TOG}}{2}) +$$

$$(VR * (\frac{w1 * CEF_{CO}}{4} + \frac{w2 * CEF_{TOG}}{2} + \frac{w3 * CEF_{NOx}}{2} + (w4 * (CEF_{PM} + PEF))))] * \frac{1}{1000} = \frac{kilograms}{day}$$

where: $\boldsymbol{HEF_{TOG}}$ = the hot soak light duty vehicle trip end emission factor for TOG
CEF = the cold start light duty vehicle emission factor for each pollutant
PEF = the paved road PM-10 emission factor for arterials
w1-w4= weighting factors for CO, TOG, NOx, and PM-10, respectively

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

where: ***i*** = discount rate of 3 percent
life = effectiveness period of 20 years for bicycle and pedestrian paths; 20 years for a bicycle lane on a road or shoulder; and 50 years for an overpass or underpass.

$$Cost\text{-}Effectiveness = \frac{CRF * CMAQ\ Cost * 1000}{Daily\ Emissions\ Reduction * 365} = \frac{dollars}{metric\ ton}$$

where: ***CMAQ Cost*** = the CMAQ funding requested for the project.

Bicycle and Pedestrian Facilities **EXAMPLE**

A city proposes to pave an unpaved shoulder with curb and gutter and create a 1.5 mile long bike lane in 2015 at a total cost of $650,000, where $65,000 will be paid with local funds. The bike lane will be adjacent to an arterial with average weekday traffic (**ADT**) of 18,000 vehicles per day. The

bike lane will be outside the Salt River Area. There are three activity centers (a grocery store, a library, and a park and ride) less than one-quarter mile from the path. There are four additional activity centers (two office parks, a church, and a post-office) between one-quarter and one-half mile from the path for a total of seven activity centers within one-half mile.

Inputs Required from Entity Requesting CMAQ Funds:

- ***CMAQ Cost*** = $585,000.
- Project length (***miles***) = 1.5 miles.
- Average weekday traffic (***ADT***) on adjacent arterial = 18,000.
- Activity centers within ¼ mile = 3 OR activity centers within ½ mile = 7.

Calculations:

The primary Adjustment Factor (**A**) is calculated from Table 1. Since the **ADT** is 18,000, the annual average daily traffic (**AADT**) is 16,380 (0.91 x 18,000). From Table 1, the adjustment factor for a path adjacent to a roadway with between 12,000 and 24,000 AADT and between one and two miles in length is 0.0020. The Activity Center Credit (**C**) is calculated from Table 2. There are two choices of activity center credit for this project, since there are three activity centers within one-quarter mile (0.001) and seven centers within one-half mile (0.0015). The higher value, 0.0015, is chosen. Additional credit will also be given to the project for reducing PM-10 by paving an unpaved shoulder. The emission reduction credit for paving the unpaved shoulder with curb and gutter outside the Salt River Area is 0.75 grams per vehicle mile of travel (from the methodology for Paving Projects).

$$\textit{Trips Reduced } (\boldsymbol{TR}) = 18{,}000 * 0.91 * (0.0020 + 0.0015) = 57 \ \frac{trips}{day}$$

$$\textit{VMT Reduced } (\boldsymbol{VR}) = 57 * 4.0 = 228 \ \frac{vehicle\text{-}miles}{day}$$

$$\textit{Daily Emissions Reduction: for Bike Lane} = [57 * \frac{0.89*1.21}{2} +$$

$$[228 * (\frac{0.00*58.27}{4} + \frac{0.89*2.58}{2} + \frac{1.03*1.16}{2} + 1.0*(.02+0.92))] * \frac{1}{1000} = 0.64 \ \frac{kilograms}{day}$$

$$\textit{Daily Emissions Reduction for Paving Shoulder} = (1.0*0.75*18{,}000*0.91*1.5)*\frac{1}{1000} = 18.43 \ \frac{kilograms}{day}$$

$$\textit{Total Daily Emissions Reduction} = 0.64 + 18.43 = 19.07 \ \frac{kilograms}{day}$$

$$\textit{Capital Recovery Factor } (\boldsymbol{CRF}) = \frac{(1+0.03)^{20} * (0.03)}{(1+0.03)^{20} - 1} = 0.0672$$

$$\textit{Cost-Effectiveness} = \frac{0.0672 * 585{,}000 * 1000}{19.07 * 365} = 5{,}648 \ \frac{dollars}{metric\ ton}$$

BUS AND LIGHT RAIL PROJECTS

"Expansion of Public Transportation Programs" and "Mass Transit Alternatives" are committed control measures in the MAG Serious Area CO and PM-10 Plans. These measures reduce CO, TOG, NOx, and PM-10 emissions by reducing the vehicle miles of travel (VMT) driven in single occupant vehicles.

New Bus Service

Bus service on new routes and increased frequency on existing bus routes provide a new level of service and reduce VMT. The daily emissions reduction attributable to the new bus service will be estimated based on the difference between the emissions from the light duty vehicle trips replaced by the bus trips and the sum of the bus emissions from the new service and vehicle emissions from people driving to access the bus.

The vehicle miles of travel replaced ($\boldsymbol{VMT_{REP}}$) by the new bus service will be estimated based on the fraction of riders on the bus who drove to their destination prior to introduction of the new bus service ($\boldsymbol{F_1}$). This fraction will be multiplied by total bus riders and the average trip length replaced by the bus service (***trip length***$_1$). The VMT replaced by bus trips will be multiplied by light duty vehicle emission factors from MOBILE6 and fugitive dust emission factors from the Five Percent Plan for PM-10 (MAG, 2007b) for vehicles traveling on a paved road to estimate the emissions from trips replaced by transit.

The automobile VMT added ($\boldsymbol{VMT_{ADD}}$) by people driving to reach the new transit service will be estimated based on the fraction of riders on the bus who drive to transit ($\boldsymbol{F_2}$). This fraction will be multiplied by total bus riders and the average trip length to reach transit (***trip length***$_2$). The VMT added by automobile trips to reach transit will be multiplied by light duty vehicle emission factors from MOBILE6 and paved road emissions factors from the Five Percent Plan for PM-10 to estimate the automobile emissions added by trips to reach transit.

The emissions from the bus itself (***BUS***) are equal to the number of miles driven daily by the bus multiplied by the exhaust plus fugitive dust emission factors for the bus. Exhaust emission factors for buses are estimated using MOBILE6. In addition to the exhaust emission factors, a fugitive dust emission factor from the Five Percent Plan for PM-10 is included in the net emission factor. It will be assumed that a bus travels 100 miles per weekday ($\boldsymbol{VMT_{BUS}}$).

Inputs Required from Entity Requesting CMAQ Funds:

- ***CMAQ Funding***.
- Fraction of riders who previously drove to their destination ($\boldsymbol{F_1}$). For example, if 75 of 100 bus riders drove vehicles to their destination before introduction of the new bus, F_1 would equal 0.75. Default = 0.5 (CARB).

- Fraction of riders who drive to reach transit (***F_2***). For example, if 10 of 100 riders of the new bus drive to reach the bus, F_2 would equal 0.10. Default = 0.03 (Valley Metro, 2001 On Board Origin and Destination Survey).
- Average length of trip from home to destination (***trip length$_1$***). Default = 10.6 miles (from 2001 Maricopa Regional Household Travel Survey and 2002 transportation model validation, February 15, 2005).
- Total daily ridership of each new bus (***R***). For example, if the new bus is expected to carry 400 people per day, *R* would equal 400. Default = 307 (Valley Metro).
- Average length of trip driving from home to transit (***trip length$_2$***). Default = 5 miles (Valley Metro, 2001 On Board Origin and Destination Survey).

Formulas:

$$\textit{VMT Replaced } (\boldsymbol{VMT_{REP}}) = R * F_1 * \textit{trip length}_1$$

$$\textit{VMT added } (\boldsymbol{VMT_{ADD}}) = R * F_2 * \textit{trip length}_2$$

where: ***R*** = the ridership on the bus per operating day
F_1 = the fraction of riders on the bus who previously drove
trip length$_1$ = the average trip length replaced for each rider who previously drove
F_2 = the fraction of riders who drive to transit
trip length$_2$ = the average trip length driven to transit

$$\textit{Vehicle Emissions Reduced } (\boldsymbol{VER}) = (\boldsymbol{VMT_{REP}} - \boldsymbol{VMT_{ADD}}) * \left(\frac{w1 * LEF_{CO}}{4} + \frac{w2 * LEF_{TOG}}{2} + \frac{w3 * LEF_{NOx}}{2} + (w4 * (LEF_{PM} + PEF)) * \frac{1}{1000} * 0.91 = \frac{\textit{kilograms}}{\textit{day}}\right.$$

where: ***VMT_{REP}*** = the vehicle travel replaced by bus service
VMT_{ADD} = the VMT added as a result of trips driven to reach transit
LEF = the light duty vehicle emission factor for each pollutant
PEF = the paved road PM-10 emission factor for all road types
0.91 = factor to convert from average weekday to annual average daily vehicle trips
w1-w4 = weighting factors for CO, TOG, NOx, and PM-10, respectively

$$\textit{Bus Emissions } (\boldsymbol{BUS}) = \left(\frac{w1 * BEF_{CO}}{4} + \frac{w2 * BEF_{TOG}}{2} + \frac{w3 * BEF_{NOx}}{2} + (w4 * (BEF_{PM} + PEF))\right) * VMT_{BUS} * \frac{1}{1000} * 0.91 = \frac{\textit{kilograms}}{\textit{day}}$$

where: ***BEF*** = the bus exhaust emission factor for each pollutant (includes tire wear and brake wear for PM-10)
VMT_{BUS} = the daily bus VMT

$$Daily\ Emissions\ Reduction = \boldsymbol{VER} - \boldsymbol{BUS} = \frac{kilograms}{day}$$

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

where: ***i*** = discount rate of 3 percent
life = effectiveness period of 12 years (CARB, 2005)

$$Cost\text{-}Effectiveness = \frac{\boldsymbol{CRF} * \boldsymbol{CMAQ\ Cost} * 1000}{Daily\ Emissions\ Reduction * 365} = \frac{dollars}{metric\ ton}$$

where: ***CMAQ Cost*** = the CMAQ funding requested for the project.

New Bus Service **EXAMPLE**

A city proposes to purchase a diesel bus to start a new bus route in 2015. The cost of the bus is $320,000. The city proposes to pay $32,000 and requests $288,000 of CMAQ funding.

Inputs Required from Entity Requesting CMAQ Funds:

- ***CMAQ Cost*** = $288,000.
- Fraction of riders who previously drove to their destination (F_1) = 0.5.
- Fraction of riders who drive to reach transit (F_2) = 0.03.
- Average length of trip from home to destination ($trip\ length_1$) = 10.6 miles.
- Total daily ridership on the new bus (***R***) = 307.
- Average length of trip from home to transit ($trip\ length_2$) = 5 miles.

Calculations:

$$VMT_{REP} = 307 * 0.50 * 10.6 = 1{,}627$$

$$VMT_{ADD} = 307 * 0.03 * 5 = 46$$

$$VER = (1{,}627-46)*\left(\frac{0.00*6.38}{4}+\frac{0.89*0.45}{2}+\frac{1.03*0.34}{2}+(1.0*(0.02+0.65))*\frac{1}{1000}*0.91\right) = 1.50\ \frac{kilograms}{day}$$

$$BUS = 100 * \left(\frac{0.00*0.46}{4}+\frac{0.89*0.30}{2}+\frac{1.03*1.75}{2}+(1.0*(0.09+0.65))*\frac{1}{1000}*0.91\right) = 0.16\ \frac{kilograms}{day}$$

$$Daily\ Emissions\ Reduction = 1.50 - 0.16 = 1.34\ \frac{kilograms}{day}$$

$$Capital\ Recovery\ Factor\ (CRF) = \frac{(1+0.03)^{12} * (0.03)}{(1+0.03)^{12} - 1} = 0.1005$$

$$Cost\text{-}Effectiveness = \frac{0.1005 * 288{,}000 * 1000}{1.34 * 365} = 59{,}178\ \frac{dollars}{metric\ ton}$$

New Light Rail Service

Light rail represents a new alternative mode to single occupant vehicle travel. Light rail service will decrease emissions by reducing vehicle miles of travel. The daily emissions reduction attributable to the provision of new rail service or the improvement of existing service will be based on the estimated number of light rail passengers who previously drove in single occupant vehicles. Emissions from light rail passengers driving to access the light rail stations will be deducted from the benefit.

Inputs Required from Entity Requesting CMAQ Funds:

- ***CMAQ Funding (total for the rail segment being funded)***.
- Fraction of riders who previously drove to their destination (F_1). For example, if 50 of 100 rail riders drove vehicles to their destination before introduction of the new rail service, F_1 would equal 0.5.
- Fraction of riders who drive to reach rail (F_2). For example, if 20 of 100 riders drive to reach the rail line, F_2 would equal 0.20.
- Average length of trip from home to destination (***trip length***$_1$).
- Total daily ridership on the rail line (***R***). For example, if the new line is expected to carry 30,000 passengers per day, *R* would equal 30,000.

- Average length of trip driving from home to rail (***trip length***$_2$).

Formulas:

$$VMT\ Replaced\ (\boldsymbol{VMT_{REP}}) = R*F_1*trip\ length_1$$

$$VMT\ added\ (\boldsymbol{VMT_{ADD}}) = R*F_2*trip\ length_2$$

where: ***R*** = the ridership on the rail segment per average weekday
F$_1$ = the fraction of rail riders who previously drove in a single occupant vehicle
trip length$_1$ = the average trip length replaced for each rider who previously drove
F$_2$ = the fraction of riders who drive to the rail station
trip length$_2$ = the average trip length driven to the rail station

$$Daily\ Emissions\ Reduction = (\boldsymbol{VMT_{REP}} - \boldsymbol{VMT_{ADD}})*(\frac{w1*LEF_{CO}}{4}+\frac{w2*LEF_{TOG}}{2}+\frac{w3*LEF_{NOx}}{2}+$$

$$(w4*(LEF_{PM}+PEF))*\frac{1}{1000}*0.91 = \frac{kilograms}{day}$$

where: ***VM***
T$_{REP}$ = the vehicle travel replaced by the rail service
VMT$_{ADD}$ = the VMT added as a result of trips driven to the rail station
LEF = the light duty vehicle emission factor for each pollutant
PEF = the paved road PM-10 emission factor for all road types
w1-w4 = weighting factors for CO, TOG, NOx, and PM-10, respectively
0.91 = factor to convert from average weekday to annual average daily vehicle trips

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

where: ***i*** = discount rate of 3 percent
life = effectiveness period of 20 years

$$Cost\text{-}Effectiveness = \frac{\boldsymbol{CRF}*\boldsymbol{CMAQ\ Cost}*1000}{Daily\ Emissions\ Reduction*365} = \frac{dollars}{metric\ ton}$$

where: ***CMAQ Cost*** = the CMAQ funding requested for the project.

In FY 2013, Valley Metro Rail (VMR) requests $4,000,000 in CMAQ funds to augment the cost of constructing an additional 20-mile segment of the light rail system. VMR estimates that a total of $20 million in supplemental CMAQ funds will be needed to complete the new light rail segment. Transit modeling indicates that 30,000 passengers will ride the new segment on an average weekday during the first full year of operation in 2015. VMR anticipates that 50 percent of the light rail passengers would have previously driven in single occupant vehicles, traveling an average of 10.6 miles from their origin to their destination. Twenty percent of the light rail riders are expected to drive to the light rail station and the average length of these trips is estimated to be 5 miles.

Inputs Required from Entity Requesting CMAQ Funds:

- ***Total CMAQ Cost for new segment*** = $20,000,000.
- Number of light rail passengers per average weekday ***(R)*** = 30,000.
- Fraction of riders who previously drove to their destination in an SOV (F_1) = 0.50.
- Average length of SOV trips diverted to rail (***trip length***$_1$) = 10.6 miles.
- Fraction of riders who drive to the rail station (F_2) = 0.20.
- Average length of trips driven to the rail station (***trip length***$_2$) = 5 miles.

Calculations:

$$\textit{VMT Replaced } (VMT_{REP}) = 30{,}000 * 0.5 * 10.6 = 159{,}000$$

$$\textit{VMT added } (VMT_{ADD}) = 30{,}000 * 0.2 * 5.0 = 30{,}000$$

$$\textit{Daily Emissions Reduction} = (159{,}000 - 30{,}000) * \left(\frac{0.00*6.38}{4} + \frac{0.89*0.45}{2} + \frac{1.03*0.34}{2} + (1.0*(0.02+0.65))\right) * \frac{1}{1000} * 0.91 = 122.71 \ \frac{kilograms}{day}$$

$$\textit{Capital Recovery Factor } (CRF) = \frac{(1+0.03)^{20} * (0.03)}{(1+0.03)^{20} - 1} = 0.0672$$

$$\textit{Cost-Effectiveness} = \frac{0.0672 * 20{,}000{,}000 * 1000}{122.71 * 365} = 30{,}007 \ \frac{dollars}{metric\ ton}$$

DIESEL RETROFITS AND ANTI-IDLING PROGRAMS

FHWA has indicated that retrofits for diesel engines and anti-idling programs for diesel trucks are eligible for CMAQ funding, if they reduce emissions primarily in a nonattainment or maintenance area (FHWA, 2008). Federal transportation legislation also authorizes use of CMAQ funds for these types of projects (SAFETEA-LU, 2005).

Diesel retrofit projects may include engine upgrades, repowers, or replacements; cleaner fuels; emission control technologies (e.g., diesel oxidation catalysts and catalyzed diesel particulate filters); or idle controls. CMAQ funds may be used to retrofit onroad and nonroad diesel engines. Projects that retrofit diesel engines can significantly reduce tailpipe emissions of NOx and PM-10.

CMAQ may also be used to fund the capital costs of anti-idling programs, including advanced truck stop electrification projects and installation of auxiliary power units (APUs) on heavy duty diesel trucks. Heavy duty diesel trucks typically idle 6-10 hours per day to power the sleeper cab air conditioning, heating, and appliances (FHWA, 2009). Projects that reduce idling of diesel vehicles can significantly reduce tailpipe emissions of NOx and PM-10.

Diesel Retrofits

The benefits of diesel retrofits can be quantified by comparing emissions before and after installation of the retrofit emission control technology. CMAQ projects would typically involve installing catalyst devices and particulate filters on diesel engines manufactured after 1990. If the retrofits are occurring to onroad vehicles, MOBILE6 will be run to estimate CO, TOG, NOx, and PM-10 emission rates at 30 mph for each model year heavy duty diesel vehicle that is being retrofitted. If the retrofits are occurring to nonroad engines, the latest version of the EPA NONROAD model will be run to determine the emission rates for each model year engine that is being retrofitted. The emission rates for the non-retrofitted vehicles/engines will be multiplied by the average annual vehicle miles traveled by all vehicles of that model year. The resultant emissions will be compared with the emissions generated by a heavy duty diesel vehicle (using MOBILE6) or engine (using the NONROAD model) manufactured in 2015. The difference will represent the emissions benefit of the diesel retrofit project. It is expected that the vehicles or engines that are retrofitted will be kept in service for at least five years.

Inputs Required from Entity Requesting CMAQ Funds:

- ***CMAQ Cost***.
- Model year(s) of the vehicles to be retrofitted.
- Average annual mileage traveled by the vehicles being retrofitted.

Formulas:

$$\textit{Emissions Before Retrofit } (EBR_i) = VMT_i * \left(\frac{w1 * BEF_{CO}}{4} + \frac{w2 * BEF_{TOG}}{2} + \frac{w3 * BEF_{NOx}}{2} + (w4 * BEF_{PM10})\right)$$

$$Emissions\ After\ Retrofit\ (EAR) = \sum VMT_i * \left(\frac{w1 * AEF_{CO}}{4} + \frac{w2 * AEF_{TOG}}{2} + \frac{w3 * AEF_{NOx}}{2} + (w4 * AEF_{PM10})\right)$$

___where: $\boldsymbol{VMT_i}$ = the annual miles driven by vehicles of model year *i*
BEF = the heavy duty diesel emission factor for each pollutant in model year *i*
AEF = the heavy duty diesel emission factor for each pollutant in model year 2015
w1-w4 = weighting factors for CO, TOG, NOx, and PM-10, respectively

$$Daily\ Emissions\ Reduction = (\sum \boldsymbol{EBR_i} - \boldsymbol{EAR}) * \frac{1}{1000} * \frac{1}{365} = \frac{kilograms}{day}$$

where: **1/365** = factor to convert annual emissions to daily emissions

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

where: *i* = discount rate of 3 percent
life = effectiveness period of 5 years

$$Cost\text{-}Effectiveness = \frac{\boldsymbol{CRF} * \boldsymbol{CMAQ}\ Cost * 1000}{Daily\ Emissions\ Reduction * 365} = \frac{dollars}{metric\ ton}$$

___where: ***CMAQ Cost*** = the CMAQ funding requested for the project.

Diesel Retrofits **EXAMPLE**

A city requests $350,000 in FY 2015 CMAQ funds to retrofit 40 heavy duty diesel vehicles in the municipal fleet with oxidation catalysts and particulate filters. The city will provide a $50,000 cash match for the project. The model years of the vehicles to be retrofitted range from 1995 to 1999. The average annual miles driven by each vehicle is 20,000. The city commits to use the retrofitted vehicles for at least five more years.

Inputs Required from Entity Requesting CMAQ Funds:

- ***CMAQ Cost*** = $350,000.
- Model year [# of vehicles] = 1996 [10], 1997 [7], 1998 [8], 1999 [15].
- Average annual miles driven per vehicle = 20,000.

Calculations:

$$EBR_{1996} = 200{,}000*(\frac{0.00*4.41}{4}+\frac{0.89*0.95}{2}+\frac{1.03*17.89}{2}+(1.00*0.81)) * \frac{1}{1000} = 2{,}089.2\ \frac{kilograms}{year}$$

$$EBR_{1997} = 140{,}000*(\frac{0.00*3.87}{4}+\frac{0.89*0.86}{2}+\frac{1.03*17.92}{2}+(1.00*0.71)) * \frac{1}{1000} = 1{,}445.0\ \frac{kilograms}{year}$$

$$EBR_{1998} = 160{,}000*(\frac{0.00*3.50}{4}+\frac{0.89*0.80}{2}+\frac{1.03*17.74}{2}+(1.00*0.62)) * \frac{1}{1000} = 1{,}617.9\ \frac{kilograms}{year}$$

$$EBR_{1999} = 300{,}000*(\frac{0.00*3.29}{4}+\frac{0.89*0.74}{2}+\frac{1.03*17.35}{2}+(1.00*0.54)) * \frac{1}{1000} = 2{,}941.4\ \frac{kilograms}{year}$$

$$EAR = 800{,}000*(\frac{0.00*0.46}{4}+\frac{0.89*0.30}{2}+\frac{1.03*1.75}{2}+(1.00*0.09)) * \frac{1}{1000} = 899.8\ \frac{kilograms}{year}$$

$$Daily\ Emissions\ Reduction = (8{,}093.5 - 899.8) * \frac{1}{365} = 19.71\ \frac{kilograms}{day}$$

$$Capital\ Recovery\ Factor\ (CRF) = \frac{(1+0.03)^5 * (0.03)}{(1+0.03)^5 - 1} = 0.2184$$

$$Cost\text{-}Effectiveness = \frac{0.2184 * 350{,}000 * 1000}{19.71 * 365} = 10{,}625\ \frac{dollars}{metric\ ton}$$

<u>Diesel Anti-Idling Programs</u>

Projects that reduce idling emissions from heavy duty diesel vehicles are eligible for CMAQ funding, if they reduce emissions in a nonattainment or maintenance area (FHWA, 2008). One example would be a public-private partnership to implement a truck stop electrification project within a nonattainment or maintenance area. Emissions will be reduced because trucks will turn off their

engines and receive compartment cooling/heating and other services (cable TV, high speed internet) from the electric stalls during rest stops.

Another example of an anti-idling program would be the installation of auxiliary power units (APUs) on a fleet of diesel trucks that operate primarily within a nonattainment or maintenance area. APUs are mobile idle reduction technology that provides air conditioning, heat, and power for sleeper cab appliances, as well as battery charging and start assist for the main engine. They can be diesel or battery powered or a combination of both (FHWA, 2009).

To quantify the benefit of an anti-idling project, MOBILE6 will be run to estimate idling emission rates for NOx and PM-10 for heavy duty diesel vehicles in the year of project implementation. The MOBILE6 emission rates for heavy duty diesel vehicles operating at 2.5 miles per hour will be converted to grams per hour and multiplied by the estimated daily reduction in idling hours. The resultant emissions will represent the reduction benefit of a truck stop electrification project. For a CMAQ project involving auxiliary power units, the benefit will be calculated as the difference between the idling emissions for diesel trucks before and after installation of the APUs.

Inputs Required from Entity Requesting CMAQ Funds:

- ***CMAQ Cost***.
- Diesel vehicle idling hours reduced on an annual average day (***IR***).

Formulas:

$$\textit{Daily Emissions Reduction} = \boldsymbol{IR} * \left(\frac{w3 * DIEF_{NOx}}{2} + (w4 * DIEF_{PM10})\right) * \frac{1}{1000} = \frac{\textit{kilograms}}{\textit{day}}$$

where: ***IR*** = diesel vehicle idling hours reduced by the project on an annual average day
DIEF = the heavy duty diesel idling emission factor (in grams per mile at 2.5 mph) for NOx and PM-10 (multiplied by 2.5 mph to convert to grams per hour)

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

where: i = discount rate of 3 percent
life = effectiveness period of 5 years

$$\textit{Cost-Effectiveness} = \frac{\boldsymbol{CRF} * \boldsymbol{CMAQ}\ \textit{Cost} * 1000}{\textit{Daily Emissions Reduction} * 365} = \frac{\textit{dollars}}{\textit{metric ton}}$$

___where: ***CMAQ Cost*** = the CMAQ funding requested for the project.

Truck Stop Electrification **EXAMPLE**

A city located within the PM-10 nonattainment area would like to enter into a legal agreement with a private firm to build 50 electrified stalls at a truck stop along an Interstate facility in the city limits. The total cost of the project is estimated to be $1,000,000. The city will donate land appraised at $100,000 to accommodate the 50 electrified stalls. The city requests $500,000 in FY 2015 CMAQ funds. The private firm has committed to pay the remaining capital cost of the project. The city estimates that space utilization will be 90 percent and truck idling will be reduced by 8 hours per utilized space for a total of 360 hours reduced per annual average day.

Inputs Required from Entity Requesting CMAQ Funds:

- ***CMAQ Cost*** = $500,000.
- ***IR*** = 360 hours of diesel vehicle idling reduced per annual average day.

Calculations:

$$\textit{Daily Emissions Reduction} = 360 * \left(\frac{1.03*135}{2} + (1.00*0.89)\right) * \frac{1}{1000} = 25.35 \ \frac{\textit{kilograms}}{\textit{day}}$$

$$\textit{Capital Recovery Factor } (\textbf{CRF}) = \frac{(1+0.03)^5 * (0.03)}{(1+0.03)^5 - 1} = 0.2184$$

$$\textit{Cost-Effectiveness} = \frac{0.2184 * 500{,}000 * 1000}{25.35 * 365} = 11{,}802 \ \frac{\textit{dollars}}{\textit{metric ton}}$$

Auxiliary Power Units **EXAMPLE**

A city located within the eight-hour ozone nonattainment area would like to install APUs equipped with 2003 Kubota engines on its fleet of diesel municipal buses. The city has 100 diesel buses that are all model year 2006 or older. Emissions will be reduced because the bus drivers will turn off their engines and receive compartment cooling during rest stops. The total cost of the project is estimated to be $700,000. The city requests $500,000 in FY 2015 CMAQ funds and estimates that bus idling will be reduced by 2 hours per bus per day for a total of 200 hours per annual average day.

The idle emission factors for the diesel buses before installing the APUs are 135 grams per hour for NOx and 3.68 grams per hour for PM-10 (FHWA, 2009). The 2003 Kubota engine has EPA-certified emissions levels of 4.7 grams per brake horsepower hour for NOx and 0.24 grams per brake horsepower per hour for PM-10 (40 CFR Part 89). Multiplying by a horsepower load factor of 5 (FHWA, 2009) produces APU emission rates of 23.5 grams per hour for NOx and 1.2 grams per hour for PM-10. These emissions are subtracted from the idling emissions for the buses without the APUs to obtain the net benefit of the APUs.

Inputs Required from Entity Requesting CMAQ Funds:

- ***CMAQ Cost*** = $500,000.
- ***IR*** = 200 hours of diesel vehicle idling reduced per annual average day.

Calculations:

$$\textit{Daily Emissions Reduction} = 200 * \left(\left(\frac{1.03*135}{2} + (1.00*3.68)\right) - \left(\frac{1.03*23.5}{2} + (1.00*1.2)\right)\right) * \frac{1}{1000} = 11.98 \ \frac{\textit{kilograms}}{\textit{day}}$$

$$\textit{Capital Recovery Factor } (\boldsymbol{CRF}) = \frac{(1+0.03)^5 * (0.03)}{(1+0.03)^5 - 1} = 0.2184$$

$$\textit{Cost-Effectiveness} = \frac{0.2184 * 500{,}000 * 1000}{11.98 * 365} = 24{,}973 \ \frac{\textit{dollars}}{\textit{metric ton}}$$

INTERSECTION IMPROVEMENTS

Intersection improvements include projects which add left or right turn lanes or construct roundabouts to improve traffic flow. These improvements reduce vehicle delay and idling emissions. The entity requesting CMAQ funds will provide the total reduction in vehicle hours of delay per weekday, based on traffic operations modeling of the intersection improvement. Industry standard intersection analysis tools such as Highway Capacity Manual (HCM) software, NETSIM, SYNCHRO, and TRANSYT-7F should be used to simulate the delay before and after the changes to the intersection (FHWA, 2009). MAG will apply idling emission factors to the vehicle hours of delay reduced to determine the daily emissions reduction. This methodology assumes that reductions in delay are the principal source of emissions benefits attributable to an intersection improvement.

MOBILE6 will be run to estimate the idle emission factors for CO, TOG, NOx, and PM-10 for all vehicle classes in the year of project implementation ($\boldsymbol{IEF_{CO}}$, $\boldsymbol{IEF_{TOG}}$, $\boldsymbol{IEF_{NOx}}$, and $\boldsymbol{IEF_{PM}}$). As recommended in EPA's "Technical Guidance on the Use of MOBILE6 for Inventory Preparation,"

the idle emission factor will be estimated by running the model at 2.5 miles per hour and converting the resulting emission factor in grams per mile to grams per hour, using 2.5 miles per hour.

Inputs Required from Entity Requesting CMAQ Funds:

- ***CMAQ Cost***.
- The total weekday vehicle hours of delay reduced due to the intersection improvement (***DR***).

Formulas:

$$\textit{Daily Emissions Reduction} =$$

$$DR * \left[\frac{w1*IEF_{CO}}{4} + \frac{w2*IEF_{TOG}}{2} \frac{w3*IEF_{NOx}}{2} + w4*IEF_{PM}\right]*0.91*\frac{1}{1000} = \frac{kilograms}{day}$$

where: ***DR*** = Reduction in total weekday vehicle hours of delay due to the improvement
IEF = the idling emission factor for all vehicle classes for each pollutant (in grams/hr)
0.91 = factor to convert from average weekday traffic to annual average daily traffic
w1-w4 = weighting factors for CO, TOG, NOx, and PM-10, respectively

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

where: ***i*** = discount rate of 3 percent
life = effectiveness period of 20 years

$$\textit{Cost-Effectiveness} = \frac{CRF * CMAQ\ Cost * 1000}{\textit{Daily Emissions Reduction} * 365} = \frac{dollars}{metric\ ton}$$

where: ***CMAQ Cost*** = the CMAQ funding requested for the project.

Additional Turning Lanes **EXAMPLE**

A city proposes to add second left turn lanes westbound and northbound and a dedicated right turn lane eastbound at an intersection in 2015 at a cost of $2,000,000. The city proposes to pay $200,000 and requests $1,800,000 of CMAQ funding. A city consultant has simulated the traffic operations at the intersection before and after the capacity improvements using SYNCHRO and has determined that the total reduction in vehicle hours of delay will be 70 hours per average weekday in 2015.

Inputs Required from Entity Requesting CMAQ Funds:

- ***CMAQ Cost*** = $1,800,000.
- ***DR*** = 70 vehicle hours of delay reduced per weekday.

Calculations:

$$\textit{Daily Emissions Reduction} =$$

$$70*(\frac{0.00*38.54}{4}+\frac{0.89*7.13}{2}+\frac{1.03*2.53}{2}+(1.0*0.08))*0.91*\frac{1}{1000} = 0.29\ \frac{kilograms}{day}$$

$$\textit{Capital Recovery Factor } (\textbf{CRF}) = \frac{(1+0.03)^{20}\ *\ (0.03)}{(1+0.03)^{20}\ -1} = 0.0672$$

$$\textit{Cost-Effectiveness} = \frac{0.0672\ *\ 1{,}800{,}000\ *\ 1000}{0.29\ *\ 365} = 1{,}142{,}749\ \frac{dollars}{metric\ ton}$$

Roundabout **EXAMPLE**

ADOT proposes to build a roundabout in 2015 at a freeway interchange. Traffic operations modeling performed by an ADOT consultant indicates that the roundabout will reduce average vehicle delay by 120 hours per weekday. The cost of the project is $2,000,000. ADOT proposes to pay $200,000 and requests $1,800,000 of CMAQ funding.

Inputs Required from Entity Requesting CMAQ Funds:

- ***CMAQ Cost*** = $1,800,000.
- ***DR*** = 120 vehicle hours of delay reduced per weekday.

$$\textit{Daily Emissions Reduction} =$$

$$120*(\frac{0.00*38.54}{4}+\frac{0.89*7.13}{2}+\frac{1.03*2.53}{2}+(1.0*0.08))*0.91*\frac{1}{1000} = 0.50\ \frac{kilograms}{day}$$

$$\textit{Capital Recovery Factor } (\textbf{CRF}) = \frac{(1+0.03)^{20}\ *\ (0.03)}{(1+0.03)^{20}\ -1} = 0.0672$$

$$\textit{Cost-Effectiveness} = \frac{0.0672\ *\ 1{,}800{,}000\ *\ 1000}{0.50\ *\ 365} = 662{,}795\ \frac{dollars}{metric\ ton}$$

OZONE EDUCATION PROGRAM

"Areawide Public Awareness Programs" is a committed control measure in the MAG 1999 Serious Area CO and PM-10 Plans. Past Air Quality Education Programs have been conducted during the winter months for CO and PM-10 and the summer months for ozone. These educational and outreach efforts focus on encouraging the public to reduce single occupant vehicle (SOV) travel, especially during periods of high measured concentrations, called pollution "alerts." Air Quality Educational Program messages are communicated through the news media, television and radio spots, posters, and the Internet. During pollution alerts, residents are encouraged to take alternate modes, such as carpools, vanpools, buses, bicycles, or walking. Telecommuting and compressed work schedules are also encouraged. These programs reduce emissions primarily by decreasing the total vehicle miles of travel (VMT) for commute trips.

Based on TDM surveys conducted in 1999-2003 for RPTA, an average of 26 percent of commute trips by persons not employed at home were taken by an alternate mode, including telecommuting and compressed work schedules (RPTA, 2003). The average trip length of commute trips by all modes for 1999-2001 was 12.6 miles (RPTA, 2001).[10]

The MOBILE6 model will be run for the CMAQ funding year to estimate the average light duty vehicle emissions of TOG, NOx, and PM-10 ($\boldsymbol{LEF_{TOG}}$, $\boldsymbol{LEF_{NOx}}$, and $\boldsymbol{LEF_{PM}}$) in grams per mile. The emission factors are multiplied by the reduction in vehicle miles of travel (***VR***) to estimate the daily emissions reduction benefit of the Ozone Education Program. The CO emission factor is not included because this program is not in operation during the winter CO season. The PM-10 factor is divided by two to reflect the six month duration of the ozone education program.

Inputs Required from Entity Requesting CMAQ Funds:

- ***CMAQ Cost***.
- Percent of alternate mode use attributable to the Ozone Education Program ***(P)***.

Formulas:

$$\textit{VMT Reduced } (\boldsymbol{VR}) = \frac{.26 * W * P}{1.2} * 12.6$$

where: ***.26*** = 1999-2003 average percent of trips by employees using alternate modes including telecommuting and compressed work schedules (Table 16a, RPTA, 2003)
W = daily home-based work person trips = 1.6 * total employment in Maricopa County for CMAQ funding request year (MAG trip attraction equation)
P = percent of alternate mode use attributable to the Ozone Education Program

[10]Data on commute trip lengths are not available in TDM surveys conducted by RPTA after 2001.

1.2 = average vehicle occupancy (derived from Table 15, RPTA, 2001)
12.6 = 1999-2001 average commute trip length by all modes (Table 52, RPTA, 2001)

$$Daily\ Emissions\ Reduction = VR * \left(\frac{w2 * LEF_{TOG}}{2} + \frac{w3 * LEF_{NOx}}{2} + \frac{w4 * (LEF_{PM} + PEF}{2}\right) * \frac{1}{1000} * \frac{250}{365} = \frac{kilograms}{day}$$

where: ***LEF*** = the light duty vehicle emission factor for each pollutant
PEF = the paved road PM-10 emission factor for all road types
w2-w4 = weighting factors for TOG, NOx, and PM-10, respectively
250/365 = factor to convert from an average weekday to an annual average day

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

where: ***i*** = discount rate of 3 percent
life = program period of 1 year

$$Cost\text{-}Effectiveness = \frac{CRF * CMAQ\ Cost * 1000}{Daily\ Emissions\ Reduction * 365} = \frac{dollars}{metric\ ton}$$

where: ***CMAQ Cost*** = the CMAQ funding requested for the project

Ozone Education Program **EXAMPLE**

RPTA requests $300,000 in FY 2015 CMAQ funds for the Ozone Education Program and estimates that the share of the annual alternative mode use attributable to the Ozone Education Program is five percent. Based on interpolations of 2010 and 2020 projections adopted by the MAG Regional Council in May 2007, the total employment for Maricopa County in 2015 is expected to be 2,473,000.

Inputs Required from Entity Requesting CMAQ Funds:

- ***CMAQ Cost*** = $300,000.
- ***P*** = 5 %.[11]

[11]In the 2005 CMAQ methodologies, the value of "P" for this example was 10%. This value has been cut in half to represent the six-month Ozone Education Program season.

Calculations:

$$VMT\ Reduced\ (\boldsymbol{VR}) = \frac{.26 * (1.6 * 2{,}473{,}000) * .05}{1.2} * 12.6 = 540{,}103$$

$$Daily\ Emissions\ Reduction = 540{,}103 * \left(\frac{0.89*0.45}{2} + \frac{1.03*0.34}{2} + \frac{1.0*(0.02+0.65)}{2}\right) * \frac{1}{1000} * \frac{250}{365} = 262.78\ \frac{kilograms}{day}$$

$$Capital\ Recovery\ Factor\ (\boldsymbol{CRF}) = \frac{(1+0.03)^1 * (0.03)}{(1+0.03)^1 - 1} = 1.03$$

$$Cost\text{-}Effectiveness = \frac{1.03 * 300{,}000 * 1000}{262.78 * 365} = 3{,}222\ \frac{dollars}{metric\ ton}$$

PARK AND RIDE FACILITIES

"Park and Ride Lots" is a committed control measure in the MAG 1999 Serious Area CO and PM-10 Plans. Park and ride facilities reduce vehicle trips and emissions by encouraging carpooling, vanpooling, and transit ridership. These projects reduce light duty vehicle exhaust emissions of CO, TOG, and NOx, and exhaust plus reentrained emissions of PM-10.

The methodology is based on the number of park and ride spaces to be built and the projected utilization rate in ten years when the facility is scheduled to open. It is assumed that each vehicle parked in the facility (spaces times the utilization rate) represents two commute trips. An average trip length is derived from regional commuting data collected by the Regional Public Transportation Authority and applied to the total commute trips. The average trip length driven to park and ride lots (from a MAG park-and-ride lot survey) is subtracted from the average commute trip length. The net trip length is applied to the total commute trips reduced to obtain the average weekday reduction in vehicle miles of travel (VMT).

The MOBILE6 model will be run for the year that the project is implemented to estimate the average light duty vehicle emission factors for CO, TOG, NOx, and PM-10 ($\boldsymbol{LEF_{CO}}$, $\boldsymbol{LEF_{TOG}}$, $\boldsymbol{LEF_{NOx}}$, and $\boldsymbol{LEF_{PM}}$).

Inputs Required from Entity Requesting CMAQ Funds:

- ***CMAQ Cost***.
- Number of spaces ***(S)***.
- Projected utilization rate ***(U)*** in ten years (the midpoint of the project life).

Formulas:

$$VMT\ Reduced\ (VR) = S * U * 2 * (12.6 - 3.5)$$

where: ***S*** = number of parking spaces provided in the park and ride facility
U = average weekday utilization rate in ten years
2 = number of vehicle commute trips per average weekday
12.6=1999-2001 average commute trip length by all modes (Table 52, RPTA, 2001)
3.5 =average miles driven to park and ride lots (from MAG park-and-ride lot survey)

$$Daily\ Emission\ Reduction = VR * \left(\frac{w1 * LEF_{CO}}{4} + \frac{w2 * LEF_{TOG}}{2} + \frac{w3 * LEF_{NOx}}{2} + w4 * (LEF_{PM} + PEF)\right) * \frac{1}{1000} * \frac{250}{365} = \frac{kilograms}{day}$$

where: ***LEF*** = the light duty vehicle emission factor for each pollutant
PEF = the paved road PM-10 emission factor for all road types
250/365 = factor to convert from a weekday to an annual average day
w1-w4 = weighting factors for CO, TOG, NOx, and PM-10, respectively

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

where: ***i*** = discount rate of 3 percent
life = effectiveness period of 20 years

$$Cost\text{-}Effectiveness = \frac{CRF * CMAQ\ Cost * 1000}{Daily\ Emissions\ Reduction * 365} = \frac{dollars}{metric\ ton}$$

where: ***CMAQ Cost*** = the CMAQ funding requested for the project.

Park and Ride Lot **EXAMPLE**

A city requests $200,000 in FY 2015 CMAQ funds to construct a park and ride lot with 300 spaces. The city will use an additional $50,000 in local funds. The city estimates that 90 percent of these spaces will be utilized on a typical weekday in 2025.

Inputs Required from Entity Requesting CMAQ Funds:

•***CMAQ Cost*** = $200,000.
•**S** = 300 spaces.
•**U** = 90% utilization in 2025.

$$\textit{VMT Reduced } (\textbf{VR}) = 300 * 0.90 * 2 * 9.1 = 4{,}914$$

$$\textit{Emissions Reduction} = 4{,}914*\left(\frac{0.00*6.38}{4}+\frac{0.89*0.45}{2}+\frac{1.03*0.34}{2}+(1.0*(0.02+0.65))\right)*\frac{1}{1000}*\frac{250}{365}=3.52\ \frac{\textit{kilograms}}{\textit{day}}$$

$$\textit{Capital Recovery Factor } (\textbf{CRF}) = \frac{(1+0.03)^{20} * (0.03)}{(1+0.03)^{20} - 1} = 0.0672$$

$$\textit{Cost-Effectiveness} = \frac{0.0672 * 200{,}000 * 1000}{3.52 * 365} = 10{,}461\ \frac{\textit{dollars}}{\textit{metric ton}}$$

PAVING PROJECTS

"Pave or Stabilize Unpaved Shoulders" and "Pave or Stabilize Existing Public Dirt Roads and Alleys" are committed measures in the MAG Five Percent Plan for PM-10 (MAG 2007b). Paving projects are effective in reducing PM-10 and therefore, represent potential candidates for CMAQ funds. Typical projects requesting CMAQ funds are for paving unpaved shoulders, curbs and gutters, unpaved roads, and unpaved access points. These projects reduce PM-10, but not CO, TOG, or NOx.

The Five Percent Plan for PM-10 assumes an unpaved road emission rate of 666.62 grams per vehicle mile of travel (g/vmt) (**BEF**) and an average paved road emission rate of 3.51 g/vmt (**AEF**) on low volume roads (i.e., those carrying less than 10,000 vehicles per day) with unpaved shoulders. The difference between these paved and unpaved emission rates, 663.11 g/vmt, represents the reduction in PM-10 emissions due to paving of dirt roads outside the Salt River Area. In the Salt River Area, the average emission rate is 6.88 g/vmt for paved roads without shoulders and the emission reduction due to paving a dirt road in the Salt River Area is 659.74 g/vmt.

The benefits of paving unpaved shoulders and/or installing curbs and gutters (C&G) are also derived from the MAG Five Percent Plan. Outside the Salt River Area, the reduction factor (**RF**) for paving shoulders with C&G on both sides of the road is 1.81 g/vmt for roads with less than 10,000 vehicles per day and 1.49 g/vmt for roads with 10,000 or more vehicles per day. In the Salt River Area, the

RF for paving shoulders with C&G on both sides of a road is 3.44g/vmt.[12] As shown in the formulas below, the **RF**s vary based on the extent of shoulder and/or C&G paving.

To be consistent with the Five Percent Plan, paving unpaved access points will be assumed to reduce emissions by 343 grams per access point per day. If the number of access points to be paved is not supplied, it will be assumed that eight access points were paved per project mile.

Inputs Required from Entity Requesting CMAQ Funds:

- ***CMAQ Cost***.
- Project length (***centerline miles***).
- Average weekday traffic (***ADT)*** for paving unpaved roads or shoulders.
- The number of access points to be paved (***access points***) - if paving unpaved access points.
- Whether the project includes paving the shoulder and/or providing curb and gutter on one or both sides of the road.

Formulas:

<u>For Paving Unpaved Shoulders and/or Providing Curb and Gutter (C&G)</u>:

$$\textit{Daily Emissions Reduction} = w4 * RF * \textbf{miles} * \textbf{ADT} * 0.91 * \frac{1}{1000} = \frac{\textit{kilograms}}{\textit{day}}$$

where: ***RF*** = Reduction factor for:

Low volume roads (<10,000 ADT) outside the Salt River Area =

1.81 g/vmt, if paving shoulders and providing C&G on both sides of the road;
1.36 g/mvt, if paving shoulders on both sides of the road without C&G;
0.91 g/vmt, if paving shoulder and providing C&G on one side of the road;
0.68 g/vmt, if paving shoulder on one side of the road without C&G;
0.45 g/vmt, if providing C&G on both sides of a road with paved shoulders; or
0.23 g/vmt, if providing C&G on one side of a road with a paved shoulder.

High volume roads (≥ 10,000 ADT) outside the Salt River Area =

1.49 g/vmt, if paving shoulders and providing C&G on both sides of the road;
1.12 g/mvt, if paving shoulders on both sides of the road without C&G;
0.75 g/vmt, if paving shoulder and providing C&G on one side of the road;
0.56 g/vmt, if paving shoulder on one side of the road without C&G;
0.37 g/vmt, if providing C&G on both sides of a road with paved shoulders; or
0.19 g/vmt, if providing C&G on one side of a road with a paved shoulder.

---

[12]Paving unpaved shoulders with C&G in the Salt River Area reduces paved road emissions by 50 percent; therefore, **RF** due to paving shoulders with C&G in the Salt River Area is 6.88 g/vmt x 0.50 = 3.44 g/vmt. (MAG, 2008).

All roads inside the Salt River Area =

3.44 g/vmt, if paving shoulders and providing C&G on both sides of the road;
2.58 g/mvt, if paving shoulders on both sides of the road without C&G;
1.72 g/vmt, if paving shoulder and providing C&G on one side of the road;
1.29 g/vmt, if paving shoulder on one side of the road without C&G;
0.86 g/vmt, if providing C&G on both sides of a road with paved shoulders; or
0.43 g/vmt, if providing C&G on one side of a road with a paved shoulder.

miles = the length of the project (in centerline miles)
ADT = the average weekday traffic on the road adjacent to the unpaved shoulders
0.91 = the factor to convert from weekday to annual average daily traffic
w4 = the PM-10 weighting factor

For Paving Unpaved Roads:

$$\textit{Daily Emissions Reduction} = \boldsymbol{w4} * (\boldsymbol{BEF} - \boldsymbol{AEF}) * \boldsymbol{miles} * \boldsymbol{ADT} * 0.91 * \frac{1}{1000} = \frac{\textit{kilograms}}{\textit{day}}$$

where: ***BEF*** = the PM-10 emission factor for vehicles traveling on unpaved roads = 666.62 g/vmt
AEF = the PM-10 emission factor for vehicles traveling on paved roads outside the Salt River Area = 3.51 g/vmt or inside the Salt River Area = 6.88 g/vmt
miles = the length of the project (in centerline miles)
ADT = the average weekday traffic on the road adjacent to the unpaved shoulders
0.91 = the factor to convert from weekday to annual average daily traffic
w4 = the PM-10 weighting factor

For Paving Unpaved Access Points:

$$\textit{Daily Emissions Reduction} = \boldsymbol{w4} * \frac{343\ \textit{grams}}{\textit{access point-day}} * \boldsymbol{access\ points} * \frac{1}{1000} = \frac{\textit{kilograms}}{\textit{day}}$$

where: ***access points*** = the number of access points to be paved
w4 = the PM-10 weighting factor

For All Paving Projects:

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

where: ***i*** = discount rate of 3 percent
life = effectiveness period of 20 years

$$Cost\text{-}Effectiveness = \frac{\boldsymbol{CRF} * \boldsymbol{CMAQ\ Cost} * 1000}{Daily\ Emissions\ Reduction * 365} = \frac{dollars}{metric\ ton}$$

where: ***CMAQ Cost*** = the CMAQ funding requested for the project.

Paving Unpaved Roads Without Paved Shoulders **EXAMPLE**

A jurisdiction proposes to pave a 1.5 mile section of unpaved road in FY 2015 which has an average weekday traffic volume of 120 vehicles per day. No paved shoulders or curb and gutter will be provided. The project is located outside of the Salt River Area. The total cost of the project is $675,000. The jurisdiction proposes to pay $75,000 and requests $600,000 in CMAQ funds.

Inputs Required from Entity Requesting CMAQ Funds:

- ***CMAQ Cost*** = $600,000.
- Project length (***miles***) = 1.5 miles.
- Average weekday traffic (***ADT***) on the unpaved road = 120.

Calculations:

$$Daily\ Emissions\ Reduction = 1.0 * (666.62 - 3.51) * 1.5 * 120 * 0.91 * \frac{1}{1000} = 108.62\ \frac{kilograms}{day}$$

$$Capital\ Recovery\ Factor\ (\boldsymbol{CRF}) = \frac{(1+0.03)^{20} * (0.03)}{(1+0.03)^{20} - 1} = 0.0672$$

$$Cost\text{-}Effectiveness = \frac{0.0672 * 600{,}000 * 1000}{108.62 * 365} = 1{,}017\ \frac{dollars}{metric\ ton}$$

Paving Unpaved Roads With Paved Shoulders and Curb and Gutter EXAMPLE

A city proposes to pave one mile of an unpaved road in FY 2015 which has a traffic volume of 120 vehicles per average weekday. The project will pave the shoulders and provide curb and gutter on both sides of the road. The paving project is located outside of the Salt River Area. The total cost of the project is $675,000. The city proposes to pay $75,000 and requests $600,000 of CMAQ funding.

Inputs Required from Entity Requesting CMAQ Funds:

- ***CMAQ Cost*** = $600,000.
- Project length (***miles***) = 1 mile.
- Average weekday traffic (***ADT***) on unpaved road = 120.

Calculations:

Calculate the daily emissions reduction from paving the unpaved road:

$$\textit{Daily Emissions Reduction} = 1.0 * (666.62 - 3.51) * 1.0 * 120 * 0.91 * \frac{1}{1000} = 72.41 \ \frac{kilograms}{day}$$

Calculate the daily emissions reduction from paving the shoulder and providing curb and gutter on both sides of the road:

$$\textit{Daily Emissions Reduction} = 1.0 * 1.81 * 1.0 * 120 * 0.91 * \frac{1}{1000} = 0.20 \ \frac{kilograms}{day}$$

The total daily emissions reduction from paving the unpaved road with a shoulder and curb and gutter is:

$$\textit{Total Daily Emissions Reduction} = 72.41 + 0.20 = 72.61 \ \frac{kilograms}{day}$$

$$\textit{Capital Recovery Factor } (\boldsymbol{CRF}) = \frac{(1+0.03)^{20} * (0.03)}{(1+0.03)^{20} - 1} = 0.0672$$

$$\textit{Cost-Effectiveness} = \frac{0.0672 * 600{,}000 * 1000}{72.61 * 365} = 1{,}521 \ \frac{dollars}{metric\ ton}$$

Paving Unpaved Access Points **EXAMPLE**

A city proposes to pave unpaved access points on two miles of paved road in FY 2015. The city proposes to pay $50,000 and requests $250,000 of CMAQ funding. The city indicates that there are sixteen access points that will be paved along the two miles of road.

Inputs Required from Entity Requesting CMAQ Funds:

- ***CMAQ Cost*** = $250,000.
- Project length (***miles***) = 2 miles.
- Access points to be paved (***access points***) =16.

Calculations:

$$\textit{Daily Emissions Reduction} = 1.0 * \left(\frac{343\ \textit{grams}}{\textit{access point-day}}\right) * 16 * \frac{1}{1000} = 5.49\ \frac{\textit{kilograms}}{\textit{day}}$$

$$\textit{Capital Recovery Factor (CRF)} = \frac{(1+0.03)^{20}\ (0.03)}{(1+0.03)^{20}\ -1} = 0.0672$$

$$\textit{Cost-Effectiveness} = \frac{0.0672 * 250{,}000 * 1000}{5.49 * 365} = 8{,}384\ \frac{\textit{dollars}}{\textit{metric ton}}$$

PM-10 CERTIFIED STREET SWEEPERS

"PM-10 Efficient Street Sweepers" is a committed measure in the Five Percent Plan for PM-10 (MAG, 2007b). Street sweepers certified in accordance with South Coast Air Quality Management District Rule 1186 reduce PM-10 on paved roads, which reduces reentrainment of PM-10 by vehicles traveling on the road. Therefore, the purchase of PM-10 certified street sweepers is eligible for CMAQ funds. Emission reductions for this type of project will be calculated for PM-10 only.

The emission reductions are addressed as two separate components: the reduction in reentrained dust from vehicles traveling on the roadways cleaned by the sweeper and the reduction in dust from the actual sweeping process. These components will be combined to determine the total emissions reduction associated with a PM-10 certified street sweeper. Each component is described in a separate section below.

Reduced Reentrained Dust from Vehicles Traveling on Roadways. If the sweeper is being purchased to replace an existing conventional sweeper, the emission reduction will be based on a comparison of the emissions from the base silt loading on a paved road after using a conventional sweeper

versus emissions from the reduced silt loading attributable to a PM-10 certified sweeper. The reduced silt loading results in lower emissions of reentrained dust from vehicles traveling on the road. If the sweeper is being purchased to replace an older PM-10 certified sweeper, the emission reduction will be based on a comparison of the utilization rates of the new PM-10 certified sweeper versus the older certified sweeper.

If the street sweeper is being purchased to increase the frequency of sweeping, the emission reduction will be based on a comparison of emissions using a PM-10 certified sweeper with the new cycle length **(*daysnew*)** versus the same sweeper with the existing cycle length **(*days*)**. If the street sweeper is being purchased to expand coverage, the emission reduction will be based on the difference between the emissions from an unswept road (using the initial emission factors in Tables 4 and 5) and the emissions after sweeping with a PM-10 certified unit for the expanded area **(*milesnew*)**.

The emission factor for reentrained dust varies depending upon how often a street is swept. It will be assumed that requested PM-10 certified street sweepers use the same sweeping schedule as the conventional street sweepers they replace. To be consistent with the Five Percent Plan for PM-10, it will be assumed that the silt loading on a street returns to its initial level nine days after the street is swept by a PM-10 certified sweeper and six days after being swept by a conventional sweeper. The initial unswept emission factors derived from the Five Percent Plan are 0.18 grams per vehicle mile of travel for freeways and 0.92 grams per vehicle mile of travel for arterials. The latter represents a VMT-weighted average of the low ADT (1.70 g/vmt) and high ADT (0.65 g/vmt) emission factors for arterials outside the Salt River Area.

In the Salt River Area, Sierra Research recommends that a paved road PM-10 emission factor of 3.44 g/vmt for all arterials (MAG 2008). As defined in the Five Percent Plan, the Salt River Area has boundaries of: Van Buren Street on the north, 7th Street on the east, Baseline Road on the south, and 59th Avenue on the west. The higher paved road emission rate in the Salt River Area is due to the heavier weight (i.e., 4.1 tons) of vehicles traveling on paved roads in this industrial area, compared with the average vehicle weight of 3.18 tons in the rest of the region. Emission reduction credit for PM-10 street sweepers to be purchased with CMAQ funds for use in the Salt River Area will be calculated using this higher paved road emission rate.

The Five Percent Plan also indicates that the PM-10 certified sweepers reduce the initial silt loading by 86 percent (i.e. the silt loading is reduced to 14 percent of the initial level), while conventional sweepers reduce the initial silt loading by 55 percent. The schedule in the Five Percent Plan for percent of initial silt loading on days after PM-10 certified street sweeping is as follows: day of sweeping - 14 percent, 1 day after - 24 percent, 2 days after - 34 percent, 3 days after - 44 percent, 4 days after - 54 percent, 5 days after - 64 percent, 6 days after - 74 percent, 7 days after - 84 percent, 8 days after - 94 percent, and nine days or more after - 100 percent of initial silt loading. Similarly, the silt loading at varying days after sweeping with a conventional sweeper is as follows: day of sweeping - 45 percent, 1 day after - 55 percent, 2 days after - 65 percent, 3 days after - 75 percent, 4 days after - 85 percent, 5 days after - 95 percent, and 6 days or more after - 100 percent of initial silt loading.

The paved road emission factor for reentrained dust is exponentially related to the silt loading[13]. Therefore, the change in emission factors over time after sweeping does not follow the same linear relationship as percent reductions in silt loadings. The PM-10 emission factors for sweeping freeways and non-freeways with a PM-10 certified unit are listed in Table 4 for various days following street sweeping. Similar factors for a conventional sweeper are provided in Table 5. In Tables 4 and 5, the emission factors for sweeping non-freeways in the Salt River Area are based on a higher initial unswept emission rate from the Five Percent Plan, as recommended by Sierra Research (MAG, 2008).

Based on sweeping frequency, the emission factors in Tables 4 and 5 will be combined to create a weighted average emission factor as shown in the formulas below. Separate weighted emission factors will be estimated to reflect the impact of sweeping with PM-10 certified sweepers and conventional sweepers. The difference between these two emission factors is the incremental reduction in emissions achieved by replacing a conventional street sweeper with a PM-10 certified unit.

Table 4. PM-10 Emission Factors as a Function of Days After Sweeping with a PM-10 Certified Sweeper

	Freeway	Non-freeway	Salt River Area Non-freeway
day of sweeping (k=1)	0.05 g/vmt	0.26 g/vmt	0.96 g/vmt
1 day after sweeping (k=2)	0.07 g/vmt	0.36 g/vmt	1.36 g/vmt
2 days after sweeping (k=3)	0.09 g/vmt	0.46 g/vmt	1.71 g/vmt
3 days after sweeping (k=4)	0.11 g/vmt	0.54 g/vmt	2.02 g/vmt
4 days after sweeping (k=5)	0.12 g/vmt	0.62 g/vmt	2.30 g/vmt
5 days after sweeping (k=6)	0.13 g/vmt	0.69 g/vmt	2.57 g/vmt
6 days after sweeping (k=7)	0.15 g/vmt	0.76 g/vmt	2.83 g/vmt
7 days after sweeping (k=8)	0.16 g/vmt	0.82 g/vmt	3.07 g/vmt
8 days after sweeping (k=9)	0.17 g/vmt	0.88 g/vmt	3.30 g/vmt
9 days after sweeping (k>9)	0.18 g/vmt	0.92 g/vmt	3.44 g/vmt

[13]The AP-42 equation for paved road PM-10 emission factors is calculated by raising the silt loading to the power of 0.65.

Table 5. PM-10 Emission Factors as a Function of Days After Sweeping with a Conventional Sweeper

	Freeway	Non-freeway	Salt River Area Non-freeway
day of sweeping (k=1)	0.11 g/vmt	0.55 g/vmt	2.05 g/vmt
1 day after sweeping (k=2)	0.12 g/vmt	0.62 g/vmt	2.33 g/vmt
2 days after sweeping (k=3)	0.14 g/vmt	0.69 g/vmt	2.60 g/vmt
3 days after sweeping (k=4)	0.15 g/vmt	0.76 g/vmt	2.85 g/vmt
4 days after sweeping (k=5)	0.16 g/vmt	0.83 g/vmt	3.10 g/vmt
5 days after sweeping (k=6)	0.17 g/vmt	0.89 g/vmt	3.33 g/vmt
6 days after sweeping (k>6)	0.18 g/vmt	0.92 g/vmt	3.44 g/vmt

The difference between the initial unswept emission factor and the PM-10 certified sweeper emission factor when applied to the new area being swept (***milesnew***) represents the reduction in emissions achieved by expanding the area of sweeping. The difference between the PM-10 certified emission factors for the old (***days***) and new (***daysnew***) cycle lengths represents the reduction achieved by increasing the frequency of sweeping.

To calculate the benefits of a new PM-10 certified sweeper that will replace an older certified unit, the utilization rate of the new and older sweepers will be compared. The requestor will provide the percent of time that the older unit was not utilized during the previous year due to maintenance and repair downtime. The average daily benefit of the new sweeper based on the emission factors in Table 4 will be reduced by the difference between 95 percent (the assumed utilization rate for a new sweeper) and the utilization rate (1.0 - percent downtime) for the older sweeper.

Reduced Emissions During the Sweeping Process. The reduction in PM-10 from the actual sweeping process will be based upon the California Air Resources Board estimate that a PM-10 certified street sweeper entrains 0.05 pounds per mile less PM-10 than a conventional sweeper during the sweeping process (CARB, 2005). For this analysis, the emissions reduction is converted to kilograms per vehicle mile, resulting in an emission reduction factor of 0.023 kilograms per vehicle mile traveled by the PM-10 certified sweeper. This estimate will be combined with the estimate of miles traveled per day by the PM-10 certified sweeper to produce a total reduction in emissions in kilograms for an average day. This reduction will only be applied when a PM-10 certified sweeper will replace a conventional sweeper.

Inputs Required from Entity Requesting CMAQ Funds:

PM-10 certified street sweepers are eligible for purchase with CMAQ funds if they replace an existing unit that has not been certified by South Coast Rule 1186, replace a Rule 1186 certified unit that is at least eight years old, increase the frequency of sweeping, expand the area that is swept, or a combination of these functions. Input requirements for each of these functions are described below. If the requested unit will perform more than one function, the requestor will need to provide all of the inputs described under each function. Note that the sweeping cycle (***days* or *daysnew***) referred to below represents the number of calendar days that elapse before the same lane of road is re-swept by the same sweeper.

For all sweeper requests:

- ***CMAQ Cost***.
- Average weekday traffic (***ADT***) per lane on streets to be swept by the PM-10 certified sweeper.
- Whether the requested unit will sweep freeways or non-freeways.

If the new sweeper will replace a non-certified sweeper:

- Current number of days per sweeping cycle (***days***) for the unit being replaced.
- Lane miles (***miles***) swept per cycle by the unit being replaced.

If the new sweeper will replace an older PM-10 certified sweeper:

- Percent of time the older certified sweeper was not utilized during the previous year as a result of maintenance and repair downtime.
- Current number of days per sweeping cycle (***days***) for the unit being replaced.
- Lane miles (***miles***) swept per cycle by the unit being replaced.

If the new sweeper will be used to increase the frequency of sweeping:

- Planned number of days per sweeping cycle (***daysnew***) for the lanes to be swept.
- Current number of days per sweeping cycle (***days***) for the lanes to be swept.
- Lane miles (***miles***) of roads to be swept per cycle.

If the new sweeper will be used to expand the area to be swept:

- Planned number of days per cycle (***daysnew***) on roads in the expanded area.
- Lane miles (***milesnew***) of roads to be swept per cycle in the expanded area.

Formulas:

Reduced Reentrained Dust from Vehicles Traveling on Roadways:

Emission factor for roads swept with PM-10 certified street sweepers:

$$PM\text{-}10\ Certified\ Sweeper\ Emission\ Factor\ (\boldsymbol{PEF}) = \frac{\sum_{k=1}^{days} (PM\text{-}10\ certified\ emission\ factor)_k}{days}$$

Emission factor for roads swept with conventional street sweepers:

$$Conventional\ Sweeper\ Emission\ Factor\ (\boldsymbol{CEF}) = \frac{\sum_{k=1}^{days} (conventional\ emission\ factor)_k}{days}$$

where: $(\boldsymbol{PM\text{-}10\ certified\ emission\ factor})_k$ = the emission factor on day k from Table 4
$(\boldsymbol{conventional\ emission\ factor})_k$ = the emission factor on day k from Table 5
days = current number of days per sweeping cycle

Replacing a Conventional Sweeper:

$$Daily\ Emissions\ Reduction = w4 * \boldsymbol{miles} * \boldsymbol{ADT} * 0.91 * (\boldsymbol{CEF} - \boldsymbol{PEF}) * \frac{1}{1000} = \frac{kilograms}{day}$$

Replacing an Older PM-10 Certified Sweeper:

$$Daily\ Emissions\ Reduction = w4 * \boldsymbol{miles} * \boldsymbol{ADT} * 0.91 * \boldsymbol{PEF} * (0.95 - URATE_{old}) * \frac{1}{1000} = \frac{kilograms}{day}$$

Increasing the Frequency of Sweeping:

$$Daily\ Emissions\ Reduction = w4 * \boldsymbol{miles} * \boldsymbol{ADT} * 0.91 * (\boldsymbol{PEF} - \boldsymbol{PEF}_{new}) * \frac{1}{1000} = \frac{kilograms}{day}$$

Expanding the Coverage of Sweeping:

$$Daily\ Emissions\ Reduction = w4 * \mathbf{milesnew} * \mathbf{ADT} * 0.91 * (\mathbf{IEF} - \mathbf{PEF}_{new}) * \frac{1}{1000} = \frac{kilograms}{day}$$

where: ***w4*** = the PM-10 weighting factor
miles = lane miles of street to be swept per cycle
ADT = average weekday traffic per through lane to be swept by the requested sweeper
0.91 = factor to convert from weekday traffic to annual average daily traffic
$\mathbf{URATE}_{old}$ = percent utilization of the older PM-10 certified sweeper during the past year
$\mathbf{PEF}_{new}$ = PM-10 certified sweeper emission factor calculated with ***days*** = ***daysnew***
IEF = the initial silt loading emission factor in Table 4 (i.e., 9 days after sweeping) or Table 5 (i.e., 6 days after sweeping)
milesnew = lane miles of streets be swept per cycle in the expanded area

<u>Reduced Emissions During the Sweeping Process</u> (This reduction is only applied if the requested sweeper replaces a non-certified unit):

$$Daily\ Emissions\ Reduction\ for\ the\ Sweeping\ Process = w4 * (\frac{\mathbf{miles}}{\mathbf{days}}) * 0.023 = \frac{kilograms}{day}$$

where: **0.023** = kilograms per vehicle mile reduction in reentrained dust from the sweeping process itself.
w4 = the PM-10 weighting factor

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

where: ***i*** = discount rate of 3 percent
life = effectiveness period of 8 years (MAG, 1998)

$$Cost\text{-}Effectiveness = \frac{\mathbf{CRF} * \mathbf{CMAQ\ Cost} * 1000}{Daily\ Emissions\ Reduction * 365} = \frac{dollars}{metric\ ton}$$

where: ***CMAQ Cost*** = the CMAQ funding requested for the project.

A city proposes to purchase a PM-10 certified street sweeper in FY 2010 to replace a non-certified sweeper. The replacement unit will not be used to increase the frequency of sweeping or the area swept. The cost of CMAQ-eligible equipment on the sweeper is $150,000. The city proposes to pay $15,000 and requests $135,000 of CMAQ funding. The certified sweeper will be used on streets (non-freeways) outside the Salt River Area with average weekday traffic per through lane of 5,000 vehicles. Each lane mile of street is currently swept once every 14 days. During this 14-day cycle, 200 lane miles are swept using the non-certified sweeper being replaced.

Inputs Required from Entity Requesting CMAQ Funds:

- ***CMAQ Cost*** = $135,000.
- Average weekday traffic per through lane swept with the conventional sweeper to be replaced (***ADT***)= 5,000 vehicles/day.
- Current number of days in the sweeping cycle using the conventional sweeper to be replaced (***days***) = 14 days.
- Lane miles of streets swept per sweeping cycle with the conventional sweeper to be replaced (***miles***) = 200 lane miles.

Calculations:

$$CEF = \frac{0.55 + 0.62 + 0.69 + 0.76 + 0.83 + 0.89 + (8 * 0.92)}{14} = 0.836$$

$$PEF = \frac{0.26 + 0.36 + 0.46 + 0.54 + 0.62 + 0.69 + 0.76 + 0.82 + 0.88 + (5 * 0.92)}{14} = 0.714$$

$$\textit{Daily Emissions Reduction for Reentrainment} = 1.0*200*5000*0.91*(0.836 - 0.714)*\frac{1}{1000} = 111.02\ \frac{kilograms}{day}$$

$$\textit{Daily Emissions Reduction for the Sweeping Process} = 1.0 * \frac{200}{14} * 0.023 = 0.33\ \frac{kilograms}{day}$$

$$CRF = \frac{(1+0.03)^8 * (0.03)}{(1+0.03)^8 - 1} = 0.1425$$

$$\textit{Cost-Effectiveness} = \frac{0.1425 * 135{,}000 * 1000}{111.35 * 365} = 473\ \frac{dollars}{metric\ ton}$$

RIDESHARE PROGRAMS

"Employer Rideshare Program Incentives" and "Preferential Parking for Carpools and Vanpools" are committed control measures in the MAG 1999 Serious Area CO and PM-10 Plans. Ridesharing in carpools and vanpools reduces emissions by decreasing the total vehicle miles of travel (VMT) for commute trips. MAG programs CMAQ funding for the Regional Rideshare Program operated by RPTA and partial funding for the Capitol Rideshare Program conducted by the Arizona Department of Administration.

Based on TDM surveys conducted in 1999-2003 for RPTA, an average of 14 percent of all work trips are made by carpools and vanpools (RPTA, 2003). The average trip length of commute trips by all modes during the period 1999-2001 was 12.6 miles and the average vehicle occupancy was 1.2 (RPTA, 2001).[14]

The MOBILE6 model will be run for the CMAQ funding year to estimate the average light duty vehicle emissions of CO, TOG, NOx, and PM-10 (**LEF_{CO}, LEF_{TOG}, LEF_{NOx}, and LEF_{PM}**) in grams per mile. The emission factors will be multiplied by the reduction in vehicle miles of travel (**VR**) to estimate the emissions benefit of ridesharing.

Inputs Required from Entity Requesting CMAQ Funds:

- ***CMAQ Cost.***
- Percent of carpooling participation attributable to the Regional Rideshare Program (**P**).

Formulas:

$$\textit{VMT Reduced } (\boldsymbol{VR}) = \frac{.14 * W * P}{1.2} * 12.6$$

where: **.14** = 1999-2003 average percent of total commute trips by carpooling (Table 16a, RPTA, 2003)
W = daily home-based work person trips = 1.6 * total employment in Maricopa County for CMAQ funding request year (MAG trip attraction equation)
P = percent of carpooling attributable to the Regional Rideshare Program
1.2 = average vehicle occupancy for all modes (derived from Table 15, RPTA, 2001)
12.6 = 1999-2001 average commute trip length by all modes (Table 52, RPTA, 2001)

[14]Data on commute trip lengths and vehicle occupancy are not available in TDM surveys conducted by RPTA after 2001.

$$Daily\ Emissions\ Reduction = VR * [\frac{w1 * LEF_{CO}}{4} + \frac{w2 * LEF_{TOG}}{2} + \frac{w3 * LEF_{NOx}}{2} + w4 * (LEF_{PM} + PEF)] * \frac{1}{1000} * \frac{250}{365} = \frac{kilograms}{day}$$

where: ***LEF*** = the light duty vehicle emission factor for each pollutant
PEF = the paved road PM-10 emission factor for all road types
w1-w4 = weighting factors for CO, TOG, NOx, and PM-10, respectively
250/365 = factor to convert from an average weekday to an annual average day

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

where: ***i*** = discount rate of 3 percent
life = program period of 1 year

$$Cost\text{-}Effectiveness = \frac{CRF * CMAQ\ Cost * 1000}{Daily\ Emissions\ Reduction * 365} = \frac{dollars}{metric\ ton}$$

where: ***CMAQ Cost*** = the CMAQ funding requested for the project.

Regional Rideshare Program **EXAMPLE**

RPTA requests $594,000 in FY 2015 CMAQ funds for the Regional Rideshare Program and indicates that the Regional Rideshare Program is responsible for ten percent of employee participation in carpooling. Based on interpolation of 2010 and 2020 projections adopted by the MAG Regional Council in May 2007, the total employment for Maricopa County in 2015 is expected to be 2,473,000.

Inputs Required from Entity Requesting CMAQ Funds:

- ***CMAQ Cost*** = $594,000.
- ***P*** = 10%.

Calculations:

$$VMT\ Reduced\ (VR) = \frac{0.14 * (1.6 * 2{,}473{,}000) * 0.10}{1.2} * 12.6 = 581{,}650$$

$$\textit{Daily Emissions Reduction} =$$

$$581{,}650*\left(\frac{0.00*6.38}{4}+\frac{0.89*0.45}{2}+\frac{1.03*0.34}{2}+(1.0*(0.02+0.65))\right)*\frac{1}{1000}*\frac{250}{365} = 416.46\ \frac{\textit{kilograms}}{\textit{day}}$$

$$\textit{Capital Recovery Factor } (\textbf{CRF}) = \frac{(1+0.03)^1 * (0.03)}{(1+0.03)^1 - 1} = 1.03$$

$$\textit{Cost-Effectiveness} = \frac{1.03 * 594{,}000 * 1000}{416.46 * 365} = 4{,}025\ \frac{\textit{dollars}}{\textit{metric ton}}$$

TELEWORK PROGRAM

"Encouragement of Telecommuting, Teleworking and Teleconferencing" is a committed control measure in the MAG 1999 Serious Area CO and PM-10 Plans. The program encourages employers to set up and institutionalize telecommuting options for employees. The program provides consulting services to implement or expand corporate telecommuting programs, including advice on information technology and telecommunications connectivity. The current outreach effort targets CEOs of companies to obtain top-level commitment. The program also aims to increase general public awareness of telecommuting via TV programs, press releases, and advertisements in corporate publications. The Telework Program reduces emissions by decreasing the total vehicle miles of travel (VMT) for commute trips.

Based on averages for 1999-2003 from TDM surveys conducted by RPTA, 3.5 percent of daily commute trips are replaced by telecommuting (RPTA, 2003). The average trip length of commute trips by telecommuters is 19.0 miles (RPTA, 2000a). The MOBILE6 model will be run for the CMAQ funding year to estimate average light duty vehicle emissions of CO, TOG, NOx, and PM-10 ($\mathbf{LEF_{CO}}$, $\mathbf{LEF_{TOG}}$, $\mathbf{LEF_{NOx}}$, and $\mathbf{LEF_{PM}}$) in grams per mile. The emission factors will be multiplied by the reduction in vehicle miles of travel (**VR**) to estimate the emissions benefit of the Telework Program.

Inputs Required from Entity Requesting CMAQ Funds:

- ***CMAQ Cost***.
- Percent of telecommuting attributable to the Telework Program (***P***).

Formulas:

$$\textit{Commute Trips Avoided } (\textbf{CTA}) = \frac{.035 * W}{1.2}$$

$$VMT\ Reduced\ (VR) = CTA * P * 19.0$$

where: **.035** = 1999-2003 average percent of commute trips replaced by telecommuting on an average weekday (Table 16a, RPTA, 2003)
W= daily home-based work person trips = 1.6 * total employment in Maricopa County in the CMAQ funding request year (from MAG trip generation equation)
1.2 = average vehicle occupancy (derived from Table 15, RPTA, 2001)
P = percent of telecommuting attributable to the Telework Program
19.0 = average one-way commute trip length in miles for telecommuters (Table 4, RPTA, 2000a)

$$Daily\ Emissions\ Reduction = VR * \left[\frac{w1 * LEF_{CO}}{4} + \frac{w2 * LEF_{TOG}}{2} + \frac{w3 * LEF_{NOx}}{2} + w4 * (LEF_{PM} + PEF)\right] * \frac{1}{1000} * \frac{250}{365} = \frac{kilograms}{day}$$

where: ***LEF*** = the light duty vehicle emission factor for each pollutant
PEF = the paved road PM-10 emission factor for all road types
w1-w4 = weighting factors for CO, TOG, NOx, and PM-10, respectively
250/365 = factor to convert from an average weekday to an annual average day

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

where: ***i*** = discount rate of 3 percent
life = program period of 1 year

$$Cost\text{-}Effectiveness = \frac{CRF * CMAQ\ Cost * 1000}{Daily\ Emissions\ Reduction * 365} = \frac{dollars}{metric\ ton}$$

where: ***CMAQ Cost*** = the CMAQ funding requested for the project.

Telework Program **EXAMPLE**

RPTA requests $300,000 in FY 2015 CMAQ funds for the Telework Program. RPTA indicates that the share of telecommuting attributable to the Telework Program is 20 percent. Based on interpolation of 2010 and 2020 projections adopted by the MAG Regional Council in May 2007, the total employment for Maricopa County in 2015 is expected to be 2,473,000.

Inputs Required from Entity Requesting CMAQ Funds:

- ***CMAQ Cost*** = $300,000.
- ***P*** = 20%.

Calculations:

$$\textit{Commute Trips Avoided } (\textbf{CTA}) = \frac{.035 * (1.6 * 2{,}473{,}000)}{1.2} = 115{,}407$$

$$\textit{VMT Reduced } (\textbf{VR}) = 115{,}407 * .20 * 19.0 = 438{,}547$$

$$\textit{Daily Emissions Reduction} =$$

$$438{,}547 * \left(\frac{0.00*6.38}{4} + \frac{0.89*0.45}{2} + \frac{1.03*0.34}{2} + (1.0*(0.02+0.65)) * \frac{1}{1000} * \frac{250}{365} = 314.00 \ \frac{\textit{kilograms}}{\textit{day}}\right.$$

$$\textit{Capital Recovery Factor } (\textbf{CRF}) = \frac{(1+0.03)^1 * (0.03)}{(1+0.03)^1 - 1} = 1.03$$

$$\textit{Cost-Effectiveness} = \frac{1.03 * 300{,}000 * 1000}{314.00 * 365} = 2{,}696 \ \frac{\textit{dollars}}{\textit{metric ton}}$$

TRAFFIC FLOW IMPROVEMENTS

"Coordinate Traffic Signal Systems," "Develop Intelligent Transportation Systems," and "Reduce Traffic Congestion at Major Intersections" are committed control measures in the MAG 1999 Serious Area CO and PM-10 Plans. These measures reduce emissions by increasing vehicle speeds or reducing vehicle idling.

The 2005 CMAQ methodologies (MAG, 2005) state that MAG will run FHWA's ITS Deployment Analysis System (IDAS) software to estimate the CO, TOG, and NOx emission reductions for Traffic Signal Coordination, Freeway Management System (FMS), and other Intelligent Transportation System (ITS) projects that are proposed for CMAQ funding. Unfortunately, application of IDAS did not provide the level of sensitivity needed to evaluate the emissions benefits of the types of traffic flow improvement projects typically proposed for MAG CMAQ funding. As a result, MAG is proposing to substitute the following methodologies for future CMAQ evaluations of traffic flow improvement projects.

Traffic Signal Coordination

The following methodology will be used to calculate the daily CO, TOG and NOx emission reductions attributable to traffic signal coordination projects. PM-10 emission reductions are not estimated, because changes in speed do not impact PM-10 emissions. The formulas and data in Table 6 were obtained from the California Air Resources Board (CARB, 2005). The length of the project, the ADT, and the category in Table 6 that best represents the proposed project will be provided by the agency requesting CMAQ funding.

Inputs Required from Entity Requesting CMAQ Funds:

- ***CMAQ Cost***.
- Length of project (***miles***).
- Current average weekday traffic (***ADT***).
- The category into which the proposed project should be classified (see Table 6)

Formulas:

$$\textit{Daily Emissions Reduction} = \textbf{\textit{miles}} * \textbf{\textit{ADT}} * \mathbf{0.91} *$$

$$[(\frac{w1*BEF_{CO}}{4} + \frac{w2*BEF_{TOG}}{2} + \frac{w3*BEF_{NOx}}{2}) - (\frac{w1*AEF_{CO}}{4} + \frac{w2*AEF_{TOG}}{2} + \frac{w3*AEF_{NOx}}{2})]*\frac{1}{1000} = \frac{kilograms}{day}$$

where: ***miles*** = the length of the project
ADT = the average weekday traffic
0.91 = the factor for converting ADT to annual average daily traffic (AADT)
BEF = the emission factor for all vehicle classes at the pre-project speed
AEF = the emission factor at the post-project speed (from Table 6)
w1-w3 = weighting factors for CO, TOG, and NOx, respectively

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

where: ***i*** = discount rate of 3 percent
life = effectiveness period of 5 years (CARB, 2005)

$$Cost\text{-}Effectiveness = \frac{CRF * CMAQ\ Cost * 1000}{Daily\ Emissions\ Reduction * 365} = \frac{dollars}{metric\ ton}$$

where: ***CMAQ Cost*** = the CMAQ funding requested for the project.

Table 6. Traffic Signal Coordination - Post-Project Speeds

Category	Before Condition	After Condition	Increase in Speed
one	Non-interconnected, pre-timed signals with old timing plan	Advanced computer-based control	25 percent
two	Interconnected, pre-timed signals with old timing plan	Advanced computer-based control	17.5 percent
three	Non-interconnected signals with traffic-actuated controllers	Advanced computer-based control	____16 percent
four	Interconnected, pre-timed signals with actively managed timing	Advanced computer-based control	_____8 percent
five	Interconnected, pre-timed signals with various forms of master control and various qualities of timing plans	Optimization of signal timing plans. No change in hardware	____12 percent
six	Non-interconnected, pre-timed signals with old timing plan	Optimization of signal timing plan	____7.5 percent

Traffic Signal Coordination **EXAMPLE**

A city proposes to install a system in FY 2015 that synchronizes the traffic lights on three miles of street. The city will be replacing interconnected, pre-timed signals with actively managed timing with an advanced computer-based control system. The cost of the system is $150,000. The city proposes to pay $15,000 and requests $135,000 of CMAQ funding. The average speed on the three miles of street is estimated to be 25 mph. Since the project falls within category four of Table 6, the post-improvement speed will be eight percent higher than 25 mph or 27 mph. The weekday traffic on the road is estimated to be 10,000 vehicles per day.

Inputs Required from Entity Requesting CMAQ Funds:

- ***CMAQ Cost*** = $135,000.
- Length of project (***miles***) = 3.
- Average weekday traffic (***ADT***) = 10,000.
- The pre-project speed = 25 mph.
- The category into which the proposed project is classified (from Table 6) = four

Calculations:

$$\textit{Daily Emissions Reduction} = 3 * 10{,}000 * 0.91 *$$

$$\left[\left(\frac{0.00*5.65}{4} + \frac{0.89*0.47}{2} + \frac{1.03*0.53}{2}\right) - \left(\frac{0.00*5.59}{4} + \frac{0.89*0.46}{2} + \frac{1.03*0.52}{2}\right)\right] * \frac{1}{1000} = 0.26\ \frac{\textit{kilograms}}{\textit{day}}$$

$$\textit{Capital Recovery Factor } (\textbf{CRF}) = \frac{(1+0.03)^5 * (0.03)}{(1+0.03)^5 - 1} = 0.2184$$

$$\textit{Cost-Effectiveness} = \frac{0.2184 * 135{,}000 * 1000}{0.26 * 365} = 310{,}685\ \frac{\textit{dollars}}{\textit{metric ton}}$$

Intelligent Transportation Systems

The installation of Intelligent Transportation Systems (ITS) alerts drivers concerning congestion incidents. ITS permits more efficient re-routing of traffic and reduces vehicle idling which, in turn, reduces emissions. The requestor will provide the total hours of vehicle delay to be reduced by the project on a typical weekday. The vehicle delay reduction (in hours per weekday) will be multiplied by the CO, TOG, NOx and PM-10 idling emission factors (in grams per hour) to estimate kilograms reduced per weekday.

Inputs Required from Entity Requesting CMAQ Funds:

- ***CMAQ Cost***.
- The vehicle hours of delay reduced by the project on an average weekday ***(DR)***

Formulas:

$$Daily\ Emissions\ Reduction = DR * [\frac{w1*IEF_{CO}}{4} + \frac{w2*IEF_{TOG}}{2} \frac{w3*IEF_{NOx}}{2} + w4*IEF_{PM}]*0.91*\frac{1}{1000} = \frac{kilograms}{day}$$

where: ***DR*** = the vehicle hours of delay reduced on an average weekday due to the project
IEF= the idling emission factor in grams/hour for each pollutant
0.91 = factor to convert from an average weekday to an annual average day
w1-w4 = weighting factors for CO, TOG, NOx, and PM-10, respectively

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

where: ***i*** = discount rate of 3 percent
life = effectiveness period of 10 years (CARB, 2005)

$$Cost\text{-}Effectiveness = \frac{CRF * CMAQ\ Cost * 1000}{Daily\ Emissions\ Reduction * 365} = \frac{dollars}{metric\ ton}$$

where: ***CMAQ Cost*** = the CMAQ funding requested for the project.

Intelligent Transportation Systems **EXAMPLE**

A city proposes to install ITS technology on several major arterials in FY 2015. The city engineer estimates that the project will reduce vehicle delay by 25 hours on an average weekday. The cost of the project is $150,000. The city proposes to pay $15,000 and is requesting $135,000 in CMAQ funding.

Inputs Required from Entity Requesting CMAQ Funds:

- ***CMAQ Funding*** = $135,000.
- ***DR*** = 25 vehicle hours of delay reduced per average weekday.

Calculations:

$$Daily\ Emissions\ Reduction = 25*(\frac{0.00*38.54}{4}+\frac{0.89*7.13}{2}+\frac{1.03*2.53}{2}+(1.0*0.08))*0.91*\frac{1}{1000} = 0.10\ \frac{kilograms}{day}$$

$$Capital\ Recovery\ Factor\ (\boldsymbol{CRF}) = \frac{(1+0.03)^{10}\ *\ (0.03)}{(1+0.03)^{10}\ -1} = 0.1172$$

$$Cost\text{-}Effectiveness = \frac{0.1172\ *\ 135{,}000\ *\ 1000}{0.10\ *\ 365} = 433{,}479\ \frac{dollars}{metric\ ton}$$

<u>Freeway Management System</u>

The Freeway Management System (FMS) reduces emissions by decreasing vehicle idling due to accidents or other incidents that create traffic congestion on freeways. ADOT will provide the total hours of vehicle delay to be reduced by the FMS project on a typical weekday. The vehicle delay reduction (in hours per weekday) will be multiplied by the CO, TOG, NOx, and PM-10 idling emission factors (in grams per hour) to estimate kilograms reduced per weekday.

***Inputs Required from Entity Requesting CMAQ Funds*:**

- ***CMAQ Cost***.
- The vehicle hours of delay reduced by the project on an average weekday ***(DR)***

Formulas:

$$Daily\ Emissions\ Reduction = \boldsymbol{DR}\ *\ [\frac{w1*IEF_{CO}}{4}+\frac{w2*IEF_{TOG}}{2}\frac{w3*IEF_{NOx}}{2}+w4*IEF_{PM}]*0.91*\frac{1}{1000} = \frac{kilograms}{day}$$

where: ***DR*** = vehicle hours of delay reduced on an average weekday due to the project
IEF= the idling emission factor in grams/hour for each pollutant
0.91 = factor to convert from an average weekday to an annual average day
w1-w4 = weighting factors for CO, TOG, NOx, and PM-10, respectively

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

where: ***i*** = discount rate of 3 percent
life = effectiveness period of 10 years

$$Cost\text{-}Effectiveness = \frac{\boldsymbol{CRF} * \boldsymbol{CMAQ}\ Cost * 1000}{Daily\ Emissions\ Reduction * 365} = \frac{dollars}{metric\ ton}$$

where: ***CMAQ Cost*** = the CMAQ funding requested for the project.

Freeway Management System **EXAMPLE**

ADOT proposes to add six variable message signs to the freeway system in FY 2015. The cost of the project is $500,000. ADOT proposes to pay $50,000 and requests $450,000 in CMAQ funding. An ADOT traffic engineer estimates that the FMS project will reduce vehicle delay on the freeways by 250 hours on a average weekday.

Inputs Required from Entity Requesting CMAQ Funds:

- ***CMAQ Cost*** = $450,000.
- ***DR*** = 250 vehicle hours of delay reduced per average weekday.

Calculations:

$$Daily\ Emissions\ Reduction = 250 * (\frac{0.00 * 38.54}{4} + \frac{0.89 * 7.13}{2} + \frac{1.03 * 2.53}{2} + (1.0 * 0.08)) * 0.91 * \frac{1}{1000} = 1.04\ \frac{kilograms}{day}$$

$$Capital\ Recovery\ Factor\ (\boldsymbol{CRF}) = \frac{(1+0.03)^{10}\ *\ (0.03)}{(1+0.03)^{10}\ -1} = 0.1172$$

$$Cost\text{-}Effectiveness = \frac{0.1172\ *\ 450{,}000\ *\ 1000}{1.04\ *\ 365} = 138{,}936\ \frac{dollars}{metric\ ton}$$

TRIP REDUCTION PROGRAM

"Trip Reduction Program" is a committed control measure in the MAG 1999 Serious Area CO and PM-10 Plans. The Trip Reduction Program requires employers with 50 or more employees at a work site in Area A to achieve target reductions in single occupant vehicle (SOV) trips through use of alternate transportation modes. Alternate transportation modes include carpooling, vanpooling, taking the bus, bicycling, and walking. Reductions in SOV trips due to telecommuting or compressed work schedules also qualify for credit in the trip reduction program. The program reduces emissions by decreasing the total vehicle miles of travel (VMT) for commute trips.

The Maricopa County Trip Reduction Program (TRP) maintains detailed information on participating organizations and their employees. For the period 1998-2002, the TRP indicates that 33 percent of employees work for TRP organizations and 26 percent of the commute trips taken by these employees are by alternate modes (or the commute trip is eliminated, in the case of telecommuting and compressed work weeks). In addition, the average one-way commute trip length for TRP employees is 11.4 miles and the average vehicle occupancy for TRP commute trips is 1.16.

The MOBILE6 model will be run for the CMAQ funding year to estimate the average light duty vehicle emissions of CO, TOG, NOx, and PM-10 (LEF_{CO}, LEF_{TOG}, LEF_{NOx}, *and* LEF_{PM}) in grams per mile. The emission factors will be multiplied by the reduction in vehicle miles of travel (*VR*) to estimate the emissions benefit of the Trip Reduction Program.

Inputs Required from Entity Requesting CMAQ Funds:

- ***CMAQ Cost***.
- Percent of alternate mode use attributable to the Trip Reduction Program (***P***).

Formulas:

$$\textit{VMT Reduced } (\boldsymbol{VR}) = \frac{\mathbf{.26} * \boldsymbol{W} * \mathbf{.33} * \boldsymbol{P}}{\mathbf{1.16}} * \mathbf{11.4}$$

where: **.26** = the percent of work trips in TRP organizations using alternate modes, including telecommuting and compressed work schedules (from 1998-2002 TRP data)
W = daily home-based work person trips = 1.6 * total employment in Area A in the CMAQ funding request year (from MAG trip generation equation)
.33 = percent of employees working for a TRP organization with at least 50 employees (from 1998-2002 TRP data)
P = percent of alternate mode use attributable to the Trip Reduction Program
1.16 = average vehicle occupancy (from 1998-2002 TRP data)
11.4 = average one-way commute trip length (from 1998-2002 TRP data)

$$Daily\ Emissions\ Reduction\ =$$

$$VR * [\frac{w1*LEF_{CO}}{4} + \frac{w2*LEF_{TOG}}{2} + \frac{w3*LEF_{NOx}}{2} + w4*(LEF_{PM}+PEF)] * \frac{1}{1000} * \frac{250}{365} = \frac{kilograms}{day}$$

where: ***LEF*** = the light duty vehicle emission factor for each pollutant
PEF = the paved road PM-10 emission factor for all road types
w1-w4 = weighting factors for CO, TOG, NOx, and PM-10, respectively
250/365 = factor to convert from an average weekday to an annual average day

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

where: ***i*** = discount rate of 3 percent
life = program period of 1 year

$$Cost\text{-}Effectiveness = \frac{CRF * CMAQ\ Cost * 1000}{Daily\ Emissions\ Reduction * 365} = \frac{dollars}{metric\ ton}$$

where: ***CMAQ Cost*** = the CMAQ funding requested for the project.

Trip Reduction Program **EXAMPLE**

Maricopa County requests $910,000 in FY 2015 CMAQ funds for the Trip Reduction Program. The Arizona Department of Environmental Quality contributes $948,000 to the program. The County indicates that the share of alternative mode use attributable to the Trip Reduction Program is 25 percent. Based on interpolation of 2010 and 2020 projections adopted by the MAG Regional Council in May 2007, the total employment for Maricopa County in 2015 is expected to be 2,473,000. Area A includes the most populous areas of Maricopa County, as well as the Apache Junction and Queen Creek areas of Pinal County. By 2015, it is estimated that there will be approximately 2.6 million people working in Area A.

Inputs Required from Entity Requesting CMAQ Funds:

- ***CMAQ Cost*** = $910,000.
- ***P*** = 25%.

Calculations:

$$VMT\ Reduced\ (VR) = \frac{.26 * (1.6 * 2{,}600{,}000) * .33 * .25}{1.16} * 11.4 = 876{,}935$$

$$Daily\ Emissions\ Reduction =$$

$$876{,}935 * \left(\frac{0.00*6.38}{4} + \frac{0.89*0.45}{2} + \frac{1.03*0.34}{2} + (1.0*(0.02+0.65))\right) * \frac{1}{1000} * \frac{250}{365} = 627.88\ \frac{kilograms}{day}$$

$$Capital\ Recovery\ Factor\ (CRF) = \frac{(1+0.03)^1 * (0.03)}{(1+0.03)^1 - 1} = 1.03$$

$$Cost\text{-}Effectiveness = \frac{1.03 * 910{,}000 * 1000}{627.88 * 365} = 4{,}090\ \frac{dollars}{metric\ ton}$$

VANPOOL VEHICLES

"Encouragement of Vanpooling" is a committed control measure in the MAG 1999 Serious Area CO and PM-10 Plans. Vanpools reduce emissions by decreasing the total vehicle miles of travel for commute trips.

Valley Metro indicates that a vanpool vehicle travels 66 miles (on average - round trip) per day on 255 commute days per year. This is equal to 16,830 commute miles annually per van. Valley Metro estimates that the average vanpool carries nine people, including the driver. It will be assumed that each vanpool passenger drives an average of three miles round trip to access the vanpool, which reduces the daily commute miles saved to 63 per passenger. This reduction accounts for vanpool passengers driving (park-and-ride) or being dropped off (kiss-and-ride) or the vanpool driver picking up and dropping off passengers. It will also be assumed that the average vehicle occupancy for commute trips by all modes is 1.2 (RPTA, 2001). Based on these assumptions, 16,830 miles per van

(vanpool miles) will replace 121,125 commute miles per year. Therefore, each vanpool reduces automobile VMT by 104,295 miles annually and each vanpool mile replaces approximately 7.2 commute miles.

The MOBILE6 model will be run for the year that the CMAQ funds are requested to estimate the average light duty vehicle emissions of CO, TOG, NOx, and PM-10 ($\boldsymbol{LEF_{CO}}$, $\boldsymbol{LEF_{TOG}}$, $\boldsymbol{LEF_{NOx}}$, and $\boldsymbol{LEF_{PM}}$) in grams per mile. The equivalent emission factors for light-duty gas trucks, LDGT3 and LDGT4, ($\boldsymbol{VEF_{CO}}$, $\boldsymbol{VEF_{TOG}}$, $\boldsymbol{VEF_{NOx}}$, and $\boldsymbol{VEF_{PM}}$), which includes full size vans, will also be estimated using MOBILE6. The emission factors will be multiplied by the appropriate vehicle miles of travel to estimate commute and vanpool emissions. The difference between the commute and vanpool emissions represents the net emission reduction benefit of vanpools.

Inputs Required from Entity Requesting CMAQ Funds:

- ***CMAQ Cost***.

Formulas:

$$\textit{Emissions Reduced } (\boldsymbol{ER}) = \boldsymbol{miles_{commute}} * \left(\frac{w1*LEF_{CO}}{4} + \frac{w2*LEF_{TOG}}{2} + \frac{w3*LEF_{NOx}}{2} + w4*(LEF_{PM}+PEF)\right) * \frac{1}{1000}$$

where: $\boldsymbol{miles_{commute}}$ = the commute miles replaced by the vanpool each year
$\boldsymbol{LEF}$ = the light duty vehicle emission factor for each pollutant
$\boldsymbol{PEF}$ = the paved road PM-10 emission factor for all road types

$$\textit{Vanpool Emissions } (\boldsymbol{VE}) = \boldsymbol{miles_{vanpool}} * \left(\frac{w1*VEF_{CO}}{4} + \frac{w2*VEF_{TOG}}{2} + \frac{w3*VEF_{NOx}}{2} + w4*VEF_{PM}\right) * \frac{1}{1000}$$

where: $\boldsymbol{miles_{vanpool}}$ = the miles driven annually by a van used for a vanpool
$\boldsymbol{VEF}$ = the emission factors for a van (LDGT3 and LDGT4) for each pollutant

$$\textit{Daily Emissions Reduction} = (\boldsymbol{ER} - \boldsymbol{VE}) * \frac{1}{365} = \frac{kilograms}{day}$$

where: **1/365** = factor to convert annual emissions to daily emissions

$$\textit{Capital Recovery Factor } (\boldsymbol{CRF}) = \frac{(1+i)^{life}\,(i)}{(1+i)^{life} - 1}$$

where: ***i*** = discount rate of 3 percent
life = effectiveness period of 4 years

$$Cost\text{-}Effectiveness = \frac{\boldsymbol{CRF} * \boldsymbol{CMAQ}\ Cost * 1000}{Daily\ Emissions\ Reduction * 365} = \frac{dollars}{metric\ ton}$$

where: ***CMAQ Cost*** = the CMAQ funding requested for the project.

Vanpool Vehicles **EXAMPLE**

RPTA proposes to purchase a fifteen-passenger van to be used in a vanpool. The cost of the van is $25,000. RPTA requests $25,000 of FY 2015 CMAQ funding.

Inputs Required from Entity Requesting CMAQ Funds:

- ***CMAQ Cost*** = $25,000.

Calculations:

$$Emissions\ Reduced\ (\boldsymbol{ER}) = 121{,}125 * \left(\frac{0.00*6.38}{4} + \frac{0.89*0.45}{2} + \frac{1.03*0.34}{2} + (1.0*(0.02+0.65))\right) * \frac{1}{1000} = 126.62\ \frac{kilograms}{year}$$

$$Vanpool\ Emissions\ (\boldsymbol{VE}) = 16{,}830 * \left(\frac{0.00*6.31}{4} + \frac{0.89*0.47}{2} + \frac{1.03*0.43}{2} + (1.0*(0.02+0.65))\right) * \frac{1}{1000} = 18.52\ \frac{kilograms}{year}$$

$$Daily\ Emissions\ Reduction = (126.62 - 18.52) * \frac{1}{365} = 0.30\ \frac{kilograms}{day}$$

$$Capital\ Recovery\ Factor\ (\boldsymbol{CRF}) = \frac{(1+0.03)^4 * (0.03)}{(1+0.03)^4 - 1} = 0.2690$$

$$Cost\text{-}Effectiveness = \frac{0.269 * 25{,}000 * 1000}{0.30 * 365} = 61{,}416\ \frac{dollars}{metric\ ton}$$

REFERENCES

Alta Transportation Consulting, 2000. *Bicycle Demand and Benefit Model*. Prepared by Alta Transportation Consulting. April 2000.

CARB, 2005. *Methods to Find the Cost-Effectiveness of Funding Air Quality Projects.* Prepared by the California Air Resources Board. May 2005.

FHWA, 2003. *Eligibility of Freight Projects and Diesel Retrofit Programs*. Memorandum from James M. Shrouds to FHWA Division Administrators. January 29, 2003.

FHWA, 2008. *Publication of Final Guidance on the Congestion Mitigation and Air Quality Improvement (CMAQ) Program*. Federal Highway Administration. Federal Register, October 20, 2008, Vol. 73, No. 203, p. 62362.

FHWA, 2009. Materials provided for a Webinare on CMAQ Methodologies conducted by Michael Roberts and John Byun of the Federal Highway Administration. March 11, 2009.

Kuzmyak, 2001. Appendix E: *Cost Effectiveness of Congestion Mitigation and Air Quality (CMAQ) Strategies.* Prepared for the CMAQ Evaluation Committee, Transportation Research Board by J. Richard Kuzmyak. December 2001.

MAG, 1993. *Feasibility and Cost-Effectiveness Study of New Air Pollution Control Measures*. Prepared by Sierra Research for the Maricopa Association of Governments. September 1993.

MAG, 1997. *Particulate Control Measure Feasibility Study*. Prepared by Sierra Research for the Maricopa Association of Governments. January 24, 1997.

MAG, 1998. *Most Stringent PM-10 Control Measure Analysis*. Prepared by Sierra Research for the Maricopa Association of Governments. May 13, 1998.

MAG, 2000a. *Revised MAG 1999 Serious Area Particulate Plan for PM-10 for the Maricopa County Nonattainment Area*. Prepared by the Maricopa Association of Governments. February 2000.

MAG, 2000b. *1998 MAG Regional Congestion Study*. Prepared by Traffic Research & Analysis, Inc., et. al., for the Maricopa Association of Governments. September 29, 2000.

MAG, 2001. *Revised MAG 1999 Serious Area Carbon Monoxide Plan for the Maricopa County Nonattainment Area*. Prepared by the Maricopa Association of Governments. March 2001.

MAG, 2002. *Review of Methodologies for Evaluating CMAQ Projects*. Prepared by Sierra Research for the Maricopa Association of Governments. May 30, 2002.

MAG, 2003. *Carbon Monoxide Redesignation Request and Maintenance Plan for the Maricopa County Nonattainment Area*. Prepared by the Maricopa Association of Governments. May 2003.

MAG, 2004a. *One-Hour Ozone Redesignation Request and Maintenance Plan for the Maricopa County Nonattainment Area*. Prepared by the Maricopa Association of Governments. March 2004.

MAG, 2004b. *Methodologies for Evaluating Congestion Mitigation and Air Quality Improvement Projects*. Prepared by the Maricopa Association of Governments. April 16, 2004.

MAG, 2005. *Methodologies for Evaluating Congestion Mitigation and Air Quality Improvement Projects*. Prepared by the Maricopa Association of Governments. August 15, 2005.

MAG, 2007a. *MAG 2007 Eight-Hour Ozone Plan for the Maricopa Nonattainment Area*. Prepared by the Maricopa Association of Governments. June 2007.

MAG, 2007b. *MAG 2007 Five Percent Plan for PM-10 for the Maricopa County Nonattainment Area*. Prepared by the Maricopa Association of Governments. December 2007.

MAG, 2008. *Draft Review of Methodologies for Evaluating CMAQ Projects*. Prepared by Sierra Research for the Maricopa Association of Governments. June 30, 2008.

RPTA, 1995. *1995 On-Board Origin and Destination Study*. Prepared by WestGroup Research for the Phoenix Regional Public Transportation Authority.

RPTA, 2000a. *Transportation Demand Management Survey*. Prepared by WestGroup Research for the Phoenix Regional Public Transportation Authority.

RPTA, 2000b. *Employee Telecommuting Study*. November 2000. Prepared by the Phoenix Regional Transportation Authority.

RPTA, 2001. *TDM Annual Survey, 2001.* Prepared by WestGroup Research for the Phoenix Regional Public Transportation Authority.

RPTA, 2003. *TDM Annual Survey, 2003.* Prepared by WestGroup Research for the Phoenix Regional Public Transportation Authority.

SAFETEA-LU, 2005. Safe Accountable Flexible Efficient Transportation Equity Act - A Legacy for Users. Signed into federal law by President George W. Bush on August 10, 2005. http://www.fhwa.dot.gov/safetealu/legis.htm.

TTI, 2007. *The Texas Guide to Accepted Mobile Source Emission Reduction Strategies*. Prepared by the Texas Transportation Institute for the Texas Department of Transportation, August 2007.