

Draft
**Methodologies for Evaluating
Congestion Mitigation and Air Quality Improvement Projects**

Maricopa Association of Governments

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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.

- (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.
- (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.”

As recommended by Sierra Research in (5) above, the emission factors for total organic gases (TOG), nitrogen oxides (NO_x) and PM-10 were updated in the 2009 CMAQ methodologies to be consistent with assumptions in the 2007 MAG Ozone and PM-10 Plans. On March 31, 2009, MAG conducted a workshop to discuss the findings of the latest Sierra Research review and proposed changes to the CMAQ methodologies. Input from workshop participants was incorporated into the 2009 CMAQ methodologies.

To implement Sierra’s recommendation (3), MAG contracted with Lee Engineering and Texas Transportation Institute (TTI) in early 2010 to update the CMAQ methodology for intelligent transportation system (ITS) projects (Lee, 2010). The ITS project evaluation methodology recommended by Lee/TTI has been implemented in the 2010 CMAQ methodologies. In addition, the 2010 MAG CMAQ methodologies utilize emission rates from the latest EPA onroad mobile source emissions model, MOVES2010.

In the 2010 CMAQ methodologies, MAG has also updated the activity rates from the Transportation Demand Management, Annual Report (Valley Metro, 2010) and Trip Reduction Program, Annual Report (MCAQD, 2009), as recommended in (6). Since Sierra Research concluded in (7) that MAG continues to have the most sophisticated methods among the states and communities surveyed, no other major changes have been made to the 2010 methodologies.

MAG intends to conduct a workshop in the Fall of 2010 to discuss the proposed changes in the Draft 2010 CMAQ methodologies. Input from participants will be incorporated into the methodologies.

The 2010 CMAQ methodologies assume that the priority weight for carbon monoxide is zero. Participants attending the MAG CMAQ workshop in 2005 suggested that a weight of zero be assigned to carbon monoxide emissions when calculating cost-effectiveness and this 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 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.

In the 2010 CMAQ methodologies, the priority weights for all other pollutants (i.e., TOG, NO_x, and PM-10)¹ used in calculating cost-effectiveness are set to one. Seasonal adjustment factors are applied to the MOVES emission rates (i.e., TOG and NO_x are divided by two to reflect the six-month ozone season)². The use of MOVES emission rates 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 MAG makes every effort to quantify the

¹PM-2.5 emissions are not included in the MAG CMAQ methodologies, because EPA designated the Phoenix-Mesa Metropolitan Statistical Area as an attainment area for PM-2.5 in September 2004.

²A seasonal adjustment factor is not applied to PM-10, because violations of the PM-10 standard can occur during any season of the year.

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 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, NO_x, 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 NO_x benefits are calculated. In other cases, only PM-10 emissions are reduced. If a proposed project combines two project types (e.g., paving a dirt road and adding a bicycle lane), the combined impact of the two portions of the project is included in the total emissions reduction.

MAG will run the latest version of the EPA mobile source emissions model, MOVES, to estimate CO, TOG, NO_x, and PM-10 emission factors for the implementation year of the project. The MOVES factors will be based on the latest Maricopa County vehicle registration data and market shares of fuel types. The PM-10 emissions output by MOVES 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 AP-42 equations (EPA, 2006). The emission rate used in the methodology for paving unpaved roads is 660.16 grams per mile. This value is consistent with the 2008 Periodic Emissions Inventory for PM-10 (MCAQD, 2010).

The paved road PM-10 emission rates are also consistent with assumptions in the 2008 Periodic Emissions Inventory: 0.18 grams mile for freeways; 1.69 grams per mile for low traffic arterials (carrying less than 10,000 vehicles per day); 0.65 grams per mile for high traffic arterials ($\geq 10,000$ vehicles per day); 0.91 grams per mile for all arterials; and an average of 0.65 grams per mile for all road types (freeways plus arterials). In the Salt River Area, the paved road PM-10 emission rate is 3.44 grams per mile for all arterials (MAG, 2008).³

The Salt River Area is bounded by 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 regionwide vehicle weight of 3.18 tons.

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.

TOG and NO_x emissions are calculated for the range of temperatures on the June 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 NO_x 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 NO_x emissions for the annual CMAQ report.

The temperatures used in estimating PM-10 emissions with MOVES represent hourly average temperatures in the year 2008. 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., the sum of CO, TOG, NO_x 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, NO_x 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 is consistent with that 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

³All of these paved road emission rates assume paved shoulders with curb and gutter.

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, representing generic CMAQ projects, are 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), Park and Ride Facilities, Paving Projects, PM-10 Efficient Street Sweepers, Rideshare Programs, Telework Program, Traffic Flow Improvements, Trip Reduction Program, and Vanpool Vehicles.⁴

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 expected 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.

⁴In 2010, the Ozone Education Program was combined with the Regional Rideshare Program.

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, NO_x, 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, NO_x, and PM-10 emission factors are calculated for the implementation year of the project. The project life for bicycle lanes on roads or shoulders will be twenty years; for sidewalks, bicycle paths, and pedestrian paths, thirty years; and for overpasses and underpasses, fifty years.

The number of vehicle trips replaced by bicycle or pedestrian trips will be estimated based on the average weekday traffic (*ADT*) on the adjacent or nearest parallel arterial to the bicycle or pedestrian facility, where the ADT is provided by the entity requesting CMAQ funding for the project. The maximum allowable ADT will be 30,000 vehicle trips per weekday.⁵ The ADT will be converted to annual average daily traffic (*AADT*) by multiplying by 0.91. The vehicle trips reduced will be calculated by multiplying the AADT by the sum of the adjustment factor (*A*) and the activity center credit (*C*).

The adjustment factor (*A*) in Table 1 is 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.

The usefulness of a bicycle/pedestrian facility is also dependent upon its location. Usage estimates for bicycle/pedestrian facilities will take into consideration the number of activity centers near the proposed facility. The credit (*C*) for activity centers located along a bicycle/pedestrian facility is shown in Table 2.

The VMT reduced by bicycle/pedestrian facilities is estimated by multiplying the vehicle trips reduced by the average trip length. 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, 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 applied for multi-use paths.

⁵Derived from CARB, 2005.

The MOVES model will be run assuming a speed of 30 miles per hour to estimate CO, TOG, NO_x, and PM-10 emission factors for light duty vehicles. The off-network (MOVES Road Type 1) emission factors in grams per vehicle (OFF_{CO} , OFF_{TOG} , OFF_{NOx} , OFF_{PM}) will be multiplied by the vehicle trips replaced by bicycle/pedestrian trips. The arterial (MOVES Road Types 3 and 5) emission factors in grams per mile (ARF_{CO} , ARF_{TOG} , ARF_{NOx}) will be multiplied by the VMT reduced by bicycle/pedestrian trips.

For PM-10, the paved road emission factor for arterials (PEF) will be added to the arterial emission factor (ARF_{PM}) before being multiplied by the VMT reduced by bicycle/pedestrian facilities. The paved road emission factors for all arterials is 0.91 grams per mile.

If a bike lane project includes shoulder paving, additional credit for reducing PM-10 emissions will be assigned to the project. The emission factors and equations used in calculating PM-10 reductions due to shoulder paving are described in the section on Paving Projects.

Table 1. Adjustment Factors⁶

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

Table 2. Activity Center Credits⁷

Examples of Activity Centers: bank, church, hospital, health care facility, park and ride lot, office park, post office, public library, shopping area or grocery store, schools, university or junior college.		
Number of activity centers	ACTIVITY CENTER 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

⁶Adapted from CARB, 2005.

⁷Ibid.

The formulas below are used to calculate the emission reductions and cost-effectiveness for 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, health care facility, 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).
- Whether the project is located inside or outside the Salt River Area.

Formulas:

$$Vehicles\ Reduced\ (VR) = AADT * (A + C)$$

where: *A* = the adjustment factor from Table 1

C = the activity center credit from Table 2

AAADT = the average weekday traffic (*ADT*) on the adjacent or nearest parallel arterial (maximum = 30,000 ADT) multiplied by 0.91

$$VMT\ Reduced\ (VMTR) = VR * trip\ length$$

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.

$$Daily\ Emissions\ Reduction = [VR * (\frac{w1 * OFF_{CO}}{4} + \frac{w2 * OFF_{TOG}}{2} + \frac{w3 * OFF_{NOx}}{2} + w4 * OFF_{PM})] +$$

$$[VMTR * (\frac{w1 * ARF_{CO}}{4} + \frac{w2 * ARF_{TOG}}{2} + \frac{w3 * ARF_{NOx}}{2} + w4 * (ARF_{NM} + PEF))] * \frac{1}{1000} = \frac{kilograms}{day}$$

where: **OFF** = the off-network light duty vehicle emission factor for each pollutant
ARF = the arterial light duty vehicle emission factor for each pollutant
PEF = the paved road PM-10 emission factor for non-freeways (0.91 g/mi)
w1-w4 = weighting factors for CO, TOG, NOx, and PM-10, respectively

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

where: **i** = discount rate of 3 percent
life = effectiveness period of 20 years for bicycle lanes on a road or shoulder; 30 years for a sidewalk, bicycle path, or pedestrian path; and 50 years for an overpass or underpass.

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

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

Bicycle and Pedestrian Facilities

EXAMPLE

A city proposes to build a 1.5 mile bike lane by paving an unpaved shoulder with curb and gutter 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 outside the Salt River Area with average weekday traffic of 18,000 vehicles per day. There are three activity centers (a grocery store, a library, and a park and ride lot) 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 proposed project 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.
- Shoulder paving with curb and gutter outside the Salt River Area = 0.75 g/mi.

Calculations:

The primary Adjustment Factor (**A**) is derived from Table 1. Since the **ADT** is 18,000, the annual average daily traffic 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 obtained 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 be given to the project for reducing PM-10 by paving an unpaved shoulder. The emission reduction credit for paving an unpaved shoulder with curb and gutter outside the Salt River Area is 0.75 grams per vehicle mile of travel (from the section on Shoulder Paving Projects).

$$\text{Vehicles Reduced (VR)} = 18,000 * 0.91 * (0.0020 + 0.0015) = 57 \frac{\text{vehicles}}{\text{day}}$$

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

$$\text{Daily Emissions Reduction for Bike Lane} = [57 * (\frac{0.0 * 2.85}{4} + \frac{1.0 * 0.34}{2} + \frac{1.0 * 0.17}{2} + (1.0 * 0.002))] +$$

$$[228 * (\frac{0.0 * 2.04}{4} + \frac{1.0 * 0.13}{2} + \frac{1.0 * 0.42}{2} + (1.0 * (0.04 + 0.91)))] * \frac{1}{1000} = 0.29 \frac{\text{kilograms}}{\text{day}}$$

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

$$\text{Total Daily Emissions Reduction} = 0.29 + 18.43 = 18.72 \frac{\text{kilograms}}{\text{day}}$$

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

$$\text{Cost-Effectiveness} = \frac{0.0672 * 585,000 * 1000}{18.72 * 365} = 5,753 \frac{\text{dollars}}{\text{metric ton}}$$

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 (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 (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 onroad (Road Types 3 and 5) light duty vehicle emission factors from MOVES and fugitive dust emission factors from the latest periodic emissions inventory (MCAQD, 2010) for vehicles traveling on a paved road to estimate the emissions from trips replaced by transit.

The VMT added (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 (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 vehicle trips to reach transit will be multiplied by light duty vehicle emission factors from MOVES and paved road emissions factors from AP-42 to estimate the automobile emissions added by trips to reach transit. The vehicles reduced (VR) by the new bus service will be estimated as the number of riders who previously drove to their destination minus the number of riders that drove to the bus.

The emissions produced by the bus (BUS) are equal to the off-network emissions for one vehicle and the number of miles driven daily by the bus multiplied by the on-road exhaust emission factor plus the paved road dust emission factor for the bus. The off-network and exhaust emission factors for buses are estimated using MOVES. A paved road dust emission factor for a bus has been calculated assuming an average weight of 18 tons (i.e., 11 g/mi). It will also be assumed that a typical bus travels 100 miles per annual average day (VMT_{BUS}).

Inputs Required from Entity Requesting CMAQ Funds:

- **CMAQ Funding.**
- Fraction of riders who previously drove to their destination in a single occupant vehicle (F_1). For example, if 75 of 100 bus riders would have driven an SOV to their destination, F_1 would equal 0.75. Default = 0.50 (CARB, 2005).
- Fraction of riders who drive to reach transit (F_2). For example, if 5 of 100 riders of the new bus drive to reach the bus, F_2 would equal 0.05. Default = 0.03 (RPTA, 2008).
- Average length of vehicle trips ($trip\ length_1$). Default = 10.6 miles (from 2001 Maricopa Regional Household Travel Survey and 2002 transportation model validation, Feb.15, 2005).
- Total daily ridership of each new bus (R). For example, if the new bus is expected to carry 400 passengers per day, R would equal 400. Default = 307 (RPTA, 2010).

- Average length of trip driving from home to transit (*trip length₂*). Default = 5 miles (Valley Metro, 2001).

Formulas:

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

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

$$Vehicles\ Reduced\ (VR) = R * (F_1 - F_2)$$

where: **R** = the average ridership on the bus per operating day

F₁ = the fraction of riders on the bus who previously drove a single occupant vehicle

trip length₁ = the average trip length replaced for each rider who previously drove

F₂ = the fraction of riders who drive to transit

trip length₂ = the average trip length driven to transit

$$Onroad\ Vehicle\ Emissions\ Reduced\ (VER_1) = (VMT_{REP} - VMT_{ADD}) * \left(\frac{w1 * ONF_{CO}}{4} + \frac{w2 * ONF_{TOG}}{2} + \frac{w3 * ONF_{NOx}}{2} + \right.$$

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

$$Off-network\ Vehicle\ Emissions\ Reduced\ (VER_2) = VR * \left(\frac{w1 * OFF_{CO}}{4} + \frac{w2 * OFF_{TOG}}{2} + \frac{w3 * OFF_{NOx}}{2} + \right.$$

$$\left. w4 * OFF_{PM} \right) * \frac{1}{1000} * 0.91 = \frac{kilograms}{day}$$

where: **VMT_{REP}** = the vehicle travel replaced by bus service

VMT_{ADD} = the VMT added as a result of trips driven to reach transit

ONF = the onroad light duty vehicle emission factor for each pollutant

OFF = the off-network light duty vehicle emission factor for each pollutant

PEF = the paved road PM-10 emission factor for all road types (0.65 g/mi)

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

Bus Emissions(BE) =

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

$$\text{Daily Emissions Reduction} = VER_1 + VER_2 - BE = \frac{\text{kilograms}}{\text{day}}$$

where: *BEF* = the onroad bus emission factor for each pollutant (includes tire and brake wear for PM-10)

PEF_{BUS} = the paved road emission factor for a bus (11.00 g/mi)

VMT_{BUS} = the daily bus VMT

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

where: *i* = discount rate of 3 percent

life = effectiveness period of 12 years (CARB, 2005)

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

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 would drive in a single occupant vehicle to their destination (*F₁*) = 0.5.
- Fraction of riders who drive in a single occupant vehicle to reach transit (*F₂*) = 0.03.
- Average length of vehicle trips (*trip length₁*) = 10.6 miles.
- Total daily ridership on the new bus (*R*) = 307.
- Average length of trip from home to transit (*trip length₂*) = 5 miles.

Calculations:

$$VMT_{REP} = 307 * 0.5 * 10.6 = 1,627$$

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

$$VR = 307 * (0.5 - 0.03) = 144$$

$$VER_1 = (1,627 - 46) * \left(\frac{0.0 * 2.04}{4} + \frac{1.0 * 0.13}{2} + \frac{1.0 * 0.42}{2} + (1.0 * (0.04 + 0.65)) \right) * \frac{1}{1000} * 0.91 = 1.39 \frac{\text{kilograms}}{\text{day}}$$

$$VER_2 = 144 * \left(\frac{0.0 * 2.85}{4} + \frac{1.0 * 0.34}{2} + \frac{1.0 * 0.17}{2} + (1.0 * 0.002) \right) * \frac{1}{1000} * 0.91 = 0.03 \frac{\text{kilograms}}{\text{day}}$$

$$BE = 100 * \left(\frac{0.0 * 1.32}{4} + \frac{1.0 * 0.34}{2} + \frac{1.0 * 4.25}{2} + (1.0 * (0.31 + 11.00)) \right) * \frac{1}{1000} * 0.91 = 1.24 \frac{\text{kilograms}}{\text{day}}$$

$$\text{Daily Emissions Reduction} = 1.39 + 0.03 - 1.24 = 0.18 \frac{\text{kilograms}}{\text{day}}$$

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

$$\text{Cost-Effectiveness} = \frac{0.1005 * 288,000 * 1000}{0.18 * 365} = 440,548 \frac{\text{dollars}}{\text{metric ton}}$$

New Light Rail Service

Light rail represents another alternative mode to single occupant vehicle travel. Light rail service decreases 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.

The MOVES model will be run for the CMAQ funding year to estimate the onroad light duty vehicle emission factors for CO, TOG, NOx, and PM-10 (ONF_{CO} , ONF_{TOG} , ONF_{NOx} , and ONF_{PM}). The paved road emission factor for all roads of 0.65 grams per mile will be added to ONF_{PM} . These

emission factors will be multiplied by the reduction in vehicle miles of travel. MOVES will also be run to estimate the off-network emission factors (OFF_{CO} , OFF_{TOG} , OFF_{NOx} , and OFF_{PM}), which will be multiplied by the reduction in vehicles. These emission reductions will be summed to estimate the total emissions benefit of the Light Rail project.

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 75 of 100 rail riders drove vehicles to their destination before introduction of the new rail service, F_1 would equal 0.75. Default = 0.50 (CARB, 2005).
- Fraction of riders who drive to reach rail (F_2). For example, if 5 of 100 riders drive to reach the rail line, F_2 would equal 0.05. Default = 0.03 (RPTA, 2008)
- Average length of vehicle trips (**trip length₁**). Default = 10.6 miles (from 2001 Maricopa Regional Household Travel Survey and 2002 transportation model validation, Feb.15, 2005)
- 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 length₂**). Default = 5 miles (Valley Metro, 2001).

Formulas:

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

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

$$Vehicles\ Reduced\ (VR) = R * (F_1 - F_2)$$

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 length₁ = the average trip length replaced for each rider who previously drove

F_2 = the fraction of riders who drive to the rail station

trip length₂ = the average trip length driven to the rail station

$$Onroad\ Vehicle\ Emissions\ Reduced\ (VER_1) = (VMT_{REP} - VMT_{ADD}) * \left(\frac{w1 * ONF_{CO}}{4} + \frac{w2 * ONF_{TOG}}{2} + \frac{w3 * ONF_{NOx}}{2} + \right.$$

$$\left. \frac{w4 * (ONF_{PM} + PEF)}{1000} \right) * 0.91 = \frac{kilograms}{day}$$

$$\text{Off-network Vehicle Emissions Reduced (VER}_2\text{)} = \text{VR} * \left(\frac{w1 * \text{OFF}_{\text{CO}}}{4} + \frac{w2 * \text{OFF}_{\text{TOG}}}{2} + \frac{w3 * \text{OFF}_{\text{NOx}}}{2} + \right.$$

$$\left. w4 * \text{OFF}_{\text{PM}} \right) * \frac{1}{1000} * 0.91 = \frac{\text{kilograms}}{\text{day}}$$

$$\text{Daily Emissions Reduction} = \text{VER}_1 + \text{VER}_2 = \frac{\text{kilograms}}{\text{day}}$$

where: VMT_{REP} = the vehicle travel replaced by the rail service

VMT_{ADD} = the VMT added as a result of trips driven to the rail station

ONF = the onroad light duty vehicle emission factor for each pollutant

OFF = the off-network vehicle emission factor for each pollutant

PEF = the paved road PM-10 emission factor for all road types (0.65 g/mi)

$w1-w4$ = weighting factors for CO, TOG, NOx, and PM-10, respectively

0.91 = factor to convert from average weekday to annual average daily vehicle trips

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

where: i = discount rate of 3 percent

life = effectiveness period of 20 years

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

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

New Light Rail Service

EXAMPLE

In 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.

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 (*F₁*) = 0.50.
- Average length of vehicle trips diverted to rail (*trip length₁*) = 10.6 miles.
- Fraction of riders who drive to the rail station (*F₂*) = 0.03.
- Average length of trips driven to the rail station (*trip length₂*) = 5 miles.

Calculations:

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

$$VMT \text{ added } (VMT_{ADD}) = 30,000 * 0.03 * 5.0 = 4,500$$

$$Vehicles \text{ Replaced } (VR) = 30,000 * (0.5 - 0.03) = 14,100$$

$$VER_1 = (159,000 - 4,500) * \left(\frac{0.0 * 2.00}{4} + \frac{1.0 * 0.12}{2} + \frac{1.0 * 0.41}{2} + (1.0 * (0.04 + 0.65)) \right) * \frac{1}{1000} * 0.91 = 134.27 \frac{kg}{day}$$

$$VER_2 = 14,100 * \left(\frac{0.0 * 2.85}{4} + \frac{1.0 * 0.34}{2} + \frac{1.0 * 0.17}{2} + (1.0 * 0.002) \right) * \frac{1}{1000} * 0.91 = 3.30 \frac{kg}{day}$$

$$Daily \text{ Emissions Reduction} = 134.27 + 3.30 = 130.97 \frac{kilograms}{day}$$

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

$$Cost\text{-Effectiveness} = \frac{0.0672 * 20,000,000 * 1000}{130.97 * 365} = 28,115 \frac{dollars}{metric ton}$$

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).

The term diesel retrofit includes any technology or system that achieves emission reductions beyond that required by the EPA regulations at the time of new engine certification (EPA, 2007). Diesel retrofit projects may include replacement of high-emitting vehicles/equipment with cleaner vehicles/equipment (including hybrid or alternative fuel models); repowering or engine replacement; rebuilding the engine to a cleaner standard; purchase and installation of advanced emissions control technologies (such as particulate matter traps or oxidation catalysts); or the use of a cleaner fuel. CMAQ funds may be used to retrofit onroad diesel vehicles or nonroad diesel vehicles/engines used in construction. Projects that retrofit diesel engines can significantly reduce tailpipe emissions; the pollutants reduced will vary depending upon the technology or system that is installed. For example, installation of catalyzed diesel particulate filters or diesel oxidation catalysts will reduce particulate matter (PM-10 and PM-2.5), while replacing an older engine with newer technology will reduce CO, TOG, NOx, and PM-10 emissions.

In addition, CMAQ may 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

CMAQ projects would typically involve retrofitting diesel engines manufactured between 1990 and 2007. If the retrofits are for onroad vehicles, MOVES will be run to estimate exhaust emission rates at 30 mph for each model year heavy duty diesel vehicle that is being retrofitted. Since ultra low sulfur fuel has been required for onroad diesel vehicles nationwide since October 2006, the sulfur level in the diesel fuel will be set at 15 ppm in MOVES. 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 and the diesel sulfur level will be set to 500 ppm. 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.

For vehicles/engines being retrofitted with diesel oxidation catalysts, the PM-10 exhaust emissions will be reduced by 30 percent. If the vehicles/engines are being retrofitted with catalyzed diesel particulate filters, the PM-10 exhaust emissions will be reduced by 90 percent (EPA, 2007).

If the engines are being replaced or rebuilt, the emissions of CO, TOG, NOx and PM-10 from the older model year vehicle/engine will be compared with the emissions generated by a heavy duty diesel onroad vehicle (using MOVES) or a nonroad engine (using NONROAD) manufactured in 2015. The difference between the emissions for the older model year and 2015 will represent the 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:

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

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

— where: 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 , assuming ultra-low sulfur fuel (15 ppm) for onroad vehicles or low sulfur fuel (500 ppm) for nonroad vehicles/engines
 AEF = the onroad heavy duty diesel factor for each pollutant in model year 2015
 $w1-w4$ = weighting factors for CO, TOG, NOx, and PM-10, respectively

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

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

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

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

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

where: $CMAQ\ Cost$ = the CMAQ funding requested for the project.

A city requests \$160,000 in FY 2015 CMAQ funds to retrofit 40 heavy duty diesel vehicles in the onroad municipal fleet with catalyzed diesel particulate filters. The city will provide a \$10,000 cash match for the project. The average model year of the vehicles to be retrofitted is 2005. 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. MOVES2010 estimates that the PM-10 exhaust emissions for a 2005 heavy duty vehicle running on ultra-low sulfur diesel fuel is 0.81 grams per mile. Because particulate filters are being installed, the PM-10 exhaust emissions from the vehicle fleet will be reduced by 90 percent.

Inputs Required from Entity Requesting CMAQ Funds:

- *CMAQ Cost* = \$160,000.
- Average model year = 2005.
- Average annual miles driven per vehicle = 20,000.

Calculations:

$$Daily\ Emissions\ Reduction = 20,000 * 40 * (1.00 * 0.81) * 0.90 * \frac{1}{1000} * \frac{1}{365} = 1.60 \frac{kilograms}{day}$$

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

$$Cost-Effectiveness = \frac{0.2184 * 160,000 * 1000}{1.60 * 365} = 59,836 \frac{dollars}{metric\ ton}$$

Diesel Anti-Idling Programs

Projects that reduce idling emissions from heavy duty diesel vehicles in a nonattainment or maintenance area are eligible for CMAQ funding (FHWA, 2008). One example would be a public-private partnership to implement a truck stop electrification project. 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, MOVES 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 MOVES 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:

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

where: *DIR* = 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)

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

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

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

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.
- **DIR** = 360 hours of diesel vehicle idling reduced per annual average day.

Calculations:

$$\text{Daily Emissions Reduction} = 360 * \left(\frac{0.0 * 15.73}{4} + \frac{1.0 * 6.37}{2} + \frac{1.0 * 48.93}{2} + (1.0 * 7.29) \right) * \frac{1}{1000} = 12.58 \frac{\text{kilograms}}{\text{day}}$$

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

$$\text{Cost-Effectiveness} = \frac{0.2184 * 500,000 * 1000}{12.58 * 365} = 23,782 \frac{\text{dollars}}{\text{metric ton}}$$

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.
- *DIR* = 200 hours of diesel vehicle idling reduced per annual average day.

Calculations:

$$\text{Daily Emissions Reduction} = 200 * \left(\left(\frac{0.0 * 15.73}{4} + \frac{1.0 * 6.37}{2} + \frac{1.0 * 25.43}{2} + 1.00 * 6.09 \right) \right) * \frac{1}{1000} = 4.40 \text{ kg/day}$$

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

$$\text{Cost-Effectiveness} = \frac{0.2184 * 500,000 * 1000}{4.40 * 365} = 67,995 \frac{\text{dollars}}{\text{metric ton}}$$

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.

MOVES will be run to estimate the idle emission factors for CO, TOG, NO_x, and PM-10 for all vehicle classes in the year of project implementation (*IEF_{CO}*, *IEF_{TOG}*, *IEF_{NO_x}*, and *IEF_{PM}*). 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:

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

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

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

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

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

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:

Daily Emissions Reduction =

$$70 * \left(\frac{0.0 * 19.44}{4} + \frac{1.0 * 2.77}{2} + \frac{1.0 * 6.26}{2} + (1.0 * 0.93) \right) * 0.91 * \frac{1}{1000} = 0.35 \frac{\text{kilograms}}{\text{day}}$$

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

$$\text{Cost-Effectiveness} = \frac{0.0672 * 1,800,000 * 1000}{0.35 * 365} = 946,849 \frac{\text{dollars}}{\text{metric ton}}$$

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.

Calculations:

Daily Emissions Reduction =

$$120 * \left(\frac{0.0 * 19.44}{4} + \frac{1.0 * 2.77}{2} + \frac{1.0 * 6.26}{2} + (1.0 * 0.93) \right) * 0.91 * \frac{1}{1000} = 0.59 \frac{\text{kilograms}}{\text{day}}$$

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

$$\text{Cost-Effectiveness} = \frac{0.0672 * 1,800,000 * 1000}{0.59 * 365} = 561,690 \frac{\text{dollars}}{\text{metric ton}}$$

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 MOVES model will be run for the project implementation year to estimate the onroad light duty vehicle emission factors for CO, TOG, NOx, and PM-10 (ONF_{CO} , ONF_{TOG} , ONF_{NOx} , and ONF_{PM}). The paved road emission factor for all roads of 0.65 grams per mile will be added to ONF_{PM} . These emission factors will be multiplied by the reduction in vehicle miles of travel. MOVES will also be run to estimate the off-network emission factors (OFF_{CO} , OFF_{TOG} , OFF_{NOx} , and OFF_{PM}), which will be multiplied by the reduction in the number of vehicles. These emission reductions will be summed to estimate the total emissions benefit of the Park and Ride project.

Inputs Required from Entity Requesting CMAQ Funds:

- **CMAQ Cost.**
- Number of spaces (S).
- Estimated utilization rate (U).

Formulas:

$$VMT\ Reduced\ (VMTR) = S * U * 2 * (15.4 - 3.5)$$

$$Vehicles\ Reduced\ (VR) = S * U$$

where: S = number of parking spaces provided in the park and ride facility
 U = average weekday utilization rate
 2 = number of vehicle commute trips per average weekday
 15.4 = average commute trip length by all modes (MCAQD, 2009)
 3.5 = average miles driven to park and ride lots (from MAG park-and-ride lot survey)

$$VER_1 = VMTR * \left(\frac{w1 * ONF_{CO}}{4} + \frac{w2 * ONF_{TOG}}{2} + \frac{w3 * ONF_{NOx}}{2} + w4 * (ONF_{PM} + PEF) \right) * \frac{1}{1000} * \frac{250}{365} = \frac{\text{kilograms}}{\text{day}}$$

$$VER_2 = VR * \left(\frac{w1 * OFF_{CO}}{4} + \frac{w2 * OFF_{TOG}}{2} + \frac{w3 * OFF_{NOx}}{2} + (w4 * OFF_{PM}) \right) * \frac{1}{1000} * \frac{250}{365} = \frac{\text{kilograms}}{\text{day}}$$

$$\text{Daily Emissions Reduction} = VER_1 + VER_2 = \frac{\text{kilograms}}{\text{day}}$$

where: *ONF* = the onroad light duty vehicle emission factor for each pollutant
OFF = the off-network vehicle emission factor for each pollutant
PEF = the paved road PM-10 emission factor for all road types (0.65 g/mi)
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

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

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

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

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

Park and Ride Lot

EXAMPLE

A city requests \$200,000 in CMAQ funds to construct a park and ride lot with 300 spaces in 2015. 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.

Inputs Required from Entity Requesting CMAQ Funds:

- *CMAQ Cost* = \$200,000.
- *S* = 300 spaces.
- *U* = 90% utilization.

$$VMT\ Reduced\ (VMTR) = 300 * 0.90 * 2 * 11.9 = 6,426$$

$$Vehicles\ Reduced\ (VR) = 300 * 0.90 = 270$$

$$VER_1 = 6,426 * \left(\frac{0.0 * 2.00}{4} + \frac{1.0 * 0.12}{2} + \frac{1.0 * 0.41}{2} + (1.0 * (0.04 + 0.65)) \right) * \frac{1}{1000} * \frac{250}{365} = 4.20 \frac{\text{kilograms}}{\text{day}}$$

$$VER_2 = 270 * \left(\frac{0.0 * 2.85}{4} + \frac{1.0 * 0.34}{2} + \frac{1.0 * 0.17}{2} + (1.0 * 0.02) \right) * \frac{1}{1000} * \frac{250}{365} = 0.05 \frac{\text{kilograms}}{\text{day}}$$

$$Daily\ Emissions\ Reduction = 4.20 + 0.05 = 4.25 \frac{\text{kilograms}}{\text{day}}$$

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

$$Cost\text{-}Effectiveness = \frac{0.0672 * 200,000 * 1000}{4.25 * 365} = 8,664 \frac{\text{dollars}}{\text{metric ton}}$$

PAVING PROJECTS

“Reduce Particulate Emissions from Unpaved Roads and Alleys,” “Curbing, Paving or Stabilizing Shoulders on Paved Roads,” and “Paving, Vegetating and Chemically Stabilizing Unpaved Access Points Onto Paved Roads” are committed measures in the MAG Serious Area PM-10 Plan (MAG, 2000a). 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, unpaved alleys, and unpaved access points. These projects reduce PM-10, but not CO, TOG, or NOx.

The emission rate (*BEF*) for unpaved roads based on the Maricopa County 2008 Periodic Emissions Inventory is 660.16 grams per mile (MCAQD, 2010). The paved road emission rate (*AEF*) on low volume arterials (<10,000 vehicles per day) with unpaved shoulders outside the Salt River Area is 3.51 grams per mile (MAG, 2007c). The difference between the paved and unpaved emission rate (656.65 g/mi) represents the reduction in PM-10 emissions due to paving dirt roads outside the Salt River Area. Inside the Salt River Area, the emission rate for vehicles traveling on paved roads without shoulders is 6.88 grams per mile and the emission reduction due to paving dirt roads is 653.28 grams per mile.

For unpaved alleys, the unpaved road emission rate is 417.46 grams per mile (MCAQD, 2010). The difference between the paved and unpaved (3.51 g/mi) emission rate, 413.95 grams per mile, represents the emission reduction for paving dirt alleys anywhere in the PM-10 nonattainment area.

The benefits of paving unpaved shoulders and/or installing curbs and gutters (C&G) are derived from the MAG Silt Loading Study (MAG, 2007c). 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 3.44 g/vmt.⁸ As shown in the formulas below, the RFs vary based on the extent of shoulder and/or C&G paving.

To be consistent with the Serious Area PM-10 Plan (MAG, 2000a), paving unpaved access points are assumed to reduce emissions by 343 grams per access point per day. No credit for access points will be assigned if there are no access points identified on the CMAQ project application.

Inputs Required from Entity Requesting CMAQ Funds:

- *CMAQ Cost.*
- Project length (*in centerline miles*).
- Average weekday traffic (*ADT*) for paving unpaved roads, alleys 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.
- For road and shoulder paving projects, whether the project is located inside or outside the Salt River Area.

Formulas:

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

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

where: **RF** = Reduction factor for:
 Low volume roads (<10,000 ADT) outside the Salt River Area =
 1.81 g/mi, if paving shoulders and providing C&G on both sides of the road;
 1.36 g/mi, if paving shoulders on both sides of the road without C&G;
 0.91 g/mi, if paving shoulder and providing C&G on one side of the road;

⁸Paving 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).

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

High volume roads ($\geq 10,000$ 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/vmt, 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.

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/vmt, 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 or Alleys:

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

where: **BEF** = the PM-10 emission factor for vehicles traveling on unpaved roads or alleys

AEF = the PM-10 emission factor for vehicles traveling on paved roads or alleys

miles = the length of the project (in centerline miles)

ADT = the average weekday traffic on the unpaved road or alley

0.91 = the factor to convert from weekday to annual average daily traffic

w4 = the PM-10 weighting factor

For Paving Unpaved Access Points:

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

where: **access points** = the number of access points to be paved

w4 = the PM-10 weighting factor

For All Paving Projects:

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

where: i = discount rate of 3 percent

life = effectiveness period of 20 years

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

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 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 application does not specify how many access points will be paved. 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.
- No access points are being paved.
- The project is located outside of the Salt River Area.

Calculations:

$$\text{Daily Emissions Reduction} = 1.0 * 656.65 * 1.5 * 120 * 0.91 * \frac{1}{1000} = 107.56 \frac{\text{kilograms}}{\text{day}}$$

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

$$\text{Cost-Effectiveness} = \frac{0.0672 * 600,000 * 1000}{107.56 * 365} = 1,027 \frac{\text{dollars}}{\text{metric ton}}$$

Paving Unpaved Roads, Shoulders and Curb and Gutter

EXAMPLE

A city proposes to pave one mile of an unpaved road in 2015 which has a traffic volume of 120 vehicles per average weekday. The project will also 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 project application indicates that four access points will be paved. 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.
- Access points being paved = 4.
- The project is located outside of the Salt River Area.

Calculations:

Calculate the daily emissions reduction from paving the unpaved road:

$$\text{Daily Emissions Reduction} = 1.0 * 656.65 * 1.0 * 120 * 0.91 * \frac{1}{1000} = 71.71 \frac{\text{kilograms}}{\text{day}}$$

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

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

Calculate the daily emissions reduction from paving four unpaved access points:

$$\text{Daily Emissions Reduction} = 1.0 * 343 * 4 * \frac{1}{1000} = 1.37 \frac{\text{kilograms}}{\text{day}}$$

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

gutter and paving four unpaved access points:

$$\text{Total Daily Emissions Reduction} = 71.71 + 0.20 + 1.37 = 73.28 \frac{\text{kilograms}}{\text{day}}$$

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

$$\text{Cost-Effectiveness} = \frac{0.0672 * 600,000 * 1000}{73.28 * 365} = 1,507 \frac{\text{dollars}}{\text{metric ton}}$$

PM-10 CERTIFIED STREET SWEEPERS

“PM-10 Efficient Street Sweepers” is a committed measure in the Serious Area PM-10 Plan (MAG, 2000a). 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 used in the 2008 PM₁₀ Periodic Emissions Inventory (MCAQD, 2010) are 0.18 grams per mile for freeways and 0.91 grams per mile for arterials. The latter represents a 2008 VMT-weighted average of the low ADT (1.69 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 a paved road PM-10 emission factor of 3.44 grams per mile for all arterials (MAG, 2008). 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 3.0 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 PM-10 certified sweepers are assumed to 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 for the 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 loading⁹. 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 3 for various days following street sweeping. Similar factors for a conventional sweeper are provided in Table 4. In Tables 3 and 4, the emission factors for sweeping non-freeways in the Salt River Area are based on a higher initial unswept emission rate recommended by Sierra Research (MAG, 2008).

⁹The AP-42 equation for paved road PM-10 emission factors is calculated by raising the silt loading to the power of 0.65.

Based on sweeping frequency, the emission factors in Tables 3 and 4 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.

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 PM-10 certified unit, the utilization rate of the new and older sweepers will be compared. The project applicant 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 3 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.

Table 3. 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	0.25 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	0.45 g/vmt	1.71 g/vmt
3 days after sweeping (k=4)	0.11 g/vmt	0.53 g/vmt	2.02 g/vmt

4 days after sweeping (k=5)	0.12 g/vmt	0.61 g/vmt	2.30 g/vmt
5 days after sweeping (k=6)	0.13 g/vmt	0.68 g/vmt	2.57 g/vmt
6 days after sweeping (k=7)	0.15 g/vmt	0.75 g/vmt	2.83 g/vmt
7 days after sweeping (k=8)	0.16 g/vmt	0.81 g/vmt	3.07 g/vmt
8 days after sweeping (k=9)	0.17 g/vmt	0.87 g/vmt	3.30 g/vmt
9 days after sweeping (k>9)	0.18 g/vmt	0.91 g/vmt	3.44 g/vmt

Table 4. 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	0.54 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	0.75 g/vmt	2.85 g/vmt
4 days after sweeping (k=5)	0.16 g/vmt	0.82 g/vmt	3.10 g/vmt
5 days after sweeping (k=6)	0.17 g/vmt	0.88 g/vmt	3.33 g/vmt
6 days after sweeping (k>6)	0.18 g/vmt	0.91 g/vmt	3.44 g/vmt

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:

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

Emission factor for roads swept with conventional street sweepers:

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

where: $(PM-10 \text{ certified emission factor})_k$ = the emission factor on day k from Table 3
 $(conventional \text{ emission factor})_k$ = the emission factor on day k from Table 4
 $days$ = current number of days per sweeping cycle

Replacing a Conventional Sweeper:

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

Replacing an Older PM-10 Certified Sweeper:

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

Increasing the Frequency of Sweeping:

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

Expanding the Coverage of Sweeping:

$$Daily \text{ Emissions Reduction} = w4 * miles_{new} * ADT * 0.91 * (IEF - PEF_{new}) * \frac{1}{1000} = \frac{kilograms}{day}$$

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

$URATE_{old}$ = percent utilization of the older PM-10 certified sweeper during the past year

PEF_{new} = PM-10 certified sweeper emission factor calculated with $days = days_{new}$

IEF = the initial silt loading emission factor in Table 3 (i.e., 9 days after sweeping) or Table 4 (i.e., 6 days after sweeping)

$miles_{new}$ = lane miles of streets be swept per cycle in the expanded area

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

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

where: **0.023** = kilograms per vehicle mile reduction in reentrained dust from the sweeping process itself.

w4 = the PM-10 weighting factor

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

where: **i** = discount rate of 3 percent

life = effectiveness period of 8 years (MAG, 1998)

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

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

PM-10 Certified Street Sweepers

EXAMPLE

A city proposes to purchase a PM-10 certified street sweeper in 2015 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:

$$CEF = \frac{0.54 + 0.62 + 0.69 + 0.75 + 0.82 + 0.88 + (8 * 0.91)}{14} = 0.827$$

$$PEF = \frac{0.25 + 0.36 + 0.45 + 0.53 + 0.61 + 0.68 + 0.75 + 0.81 + 0.87 + (5 * 0.91)}{14} = 0.704$$

$$\text{Daily Emissions Reduction for Reentrainment} = 1.0 * 200 * 5000 * 0.91 * (0.827 - 0.704) * \frac{1}{1000} = 111.93 \frac{\text{kilograms}}{\text{day}}$$

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

$$\text{Total Daily Emissions Reduction} = 111.93 + 0.33 = 112.26 \frac{\text{kilograms}}{\text{day}}$$

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

$$\text{Cost-Effectiveness} = \frac{0.1425 * 135,000 * 1000}{112.26 * 365} = 469 \frac{\text{dollars}}{\text{metric ton}}$$

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. The Ozone Education Program which was previously evaluated as a separate CMAQ-funded project has been integrated into the Regional Rideshare Program.

Based on the TDM survey conducted in 2009 (Valley Metro, 2010), an average of 11 percent of all work trips are made by carpools and vanpools. The average trip length of commute trips by all modes in 2009 was 15.4 miles (MCAQD, 2009) and the average vehicle occupancy was 1.28 (Cummings, 2010).

The MOVES model will be run for the CMAQ funding year to estimate the onroad (Road Types 2-5) light duty vehicle emission factors for CO, TOG, NOx, and PM-10 (ONF_{CO} , ONF_{TOG} , ONF_{NOx} , and ONF_{PM}). The paved road emission factor for all roads of 0.65 grams per mile will be added to

ONF_{PM} . MOVES will also be run to generate off-network (Road Type 1) light duty vehicle emission factors for each pollutant (OFF_{CO} , OFF_{TOG} , OFF_{NOx} , and OFF_{PM}). The onroad emission factors will be multiplied by vehicle miles of travel, while the off-network emission factors will be multiplied by the vehicles reduced. These emission reductions will be summed to estimate the total benefit of the Rideshare Program.

Inputs Required from Entity Requesting CMAQ Funds:

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

Formulas:

$$VMT\ Reduced\ (VMTR) = \frac{0.11 * W * P}{1.28} * 15.4$$

$$Vehicles\ Reduced\ (VR) = \frac{VMTR}{15.4 * 1.6}$$

where: **0.11** = percent of total commute trips by carpooling and vanpooling (Valley Metro, 2010)
 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
1.28 = average vehicle occupancy for all modes (Cummings, 2010)
15.4 = Average commute trip length by all modes (MCAQD, 2009)

$$VER_1 = VMTR * \left[\frac{w1 * ONF_{CO}}{4} + \frac{w2 * ONF_{TOG}}{2} + \frac{w3 * ONF_{NOx}}{2} + w4 * (ONF_{PM} + PEF) \right] * \frac{1}{1000} * \frac{250}{365} = \frac{\text{kilograms}}{\text{day}}$$

$$VER_2 = VR * \left[\frac{w1 * OFF_{CO}}{4} + \frac{w2 * OFF_{TOG}}{2} + \frac{w3 * OFF_{NOx}}{2} + w4 * OFF_{PM} \right] * \frac{1}{1000} * \frac{250}{365} = \frac{\text{kilograms}}{\text{day}}$$

where: **ONF** = the onroad light duty vehicle emission factor for each pollutant
 OFF = the off-network vehicle emission factor for each pollutant
 PEF = the paved road PM-10 emission factor for all road types (0.65 g/mi)
 $w1-w4$ = weighting factors for CO, TOG, NOx, and PM-10, respectively
250/365 = factor to convert from an average weekday to an annual average day

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

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

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

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:

$$\text{VMTR} = \frac{0.11 * (1.6 * 2,473,000) * 0.10}{1.28} * 15.4 = 523,658$$

$$\text{VR} = \frac{523,658}{15.4 * 1.6} = 21,252$$

$$VER_1 = 523,658 * \left(\frac{0.0 * 2.00}{4} + \frac{1.0 * 0.12}{2} + \frac{1.0 * 0.41}{2} + (1.0 * (0.04 + 0.65)) \right) * \frac{1}{1000} * \frac{250}{365} = 342.53 \frac{\text{kilograms}}{\text{day}}$$

$$VER_2 = 21,252 * \left(\frac{0.0 * 2.85}{4} + \frac{1.0 * 0.34}{2} + \frac{1.0 * 0.17}{2} + (1.0 * (0.02)) \right) * \frac{1}{1000} * \frac{250}{365} = 4.00 \frac{\text{kilograms}}{\text{day}}$$

$$\text{Daily Emissions Reduction} = 342.53 + 4.00 = 346.53 \frac{\text{kilograms}}{\text{day}}$$

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

$$\text{Cost-Effectiveness} = \frac{1.03 * 594,000 * 1000}{346.53 * 365} = 4,837 \frac{\text{dollars}}{\text{metric ton}}$$

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 data collected in 2009, 11 percent of daily commute trips are replaced by telecommuting or compressed work schedules (Valley Metro, 2010) and the average trip length avoided by telecommuting and compressed work schedules is 19.1 miles (derived from Valley Metro, 2010 and MCAQD, 2009).

The MOVES model will be run for the CMAQ funding year to estimate the onroad (Road Types 2-5) light duty vehicle emission factors for CO, TOG, NOx, and PM-10 (ONF_{CO} , ONF_{TOG} , ONF_{NOx} , and ONF_{PM}). The paved road emission factor for all roads of 0.65 grams per mile will be added to ONF_{PM} . MOVES will also be run to generate off-network (Road Type 1) light duty vehicle emission

factors for each pollutant (OFF_{CO} , OFF_{TOG} , OFF_{NOx} and OFF_{PM}). The onroad emission factors will be multiplied by vehicle miles of travel, while the off-network emission factors will be multiplied by the vehicles reduced. These emission reductions will be summed to estimate the total benefit of the Telework Program.

Inputs Required from Entity Requesting CMAQ Funds:

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

Formulas:

$$\text{Commute Trips Avoided (CTA)} = \frac{0.11 * W}{1.28}$$

$$\text{VMT Reduced (VMTR)} = \text{CTA} * P * 19.1$$

$$\text{Vehicles Reduced (VR)} = \frac{\text{CTA}}{1.6} * P$$

where: **0.11** = share of commute trips replaced by telecommuting and compressed work schedules on an average weekday (Valley Metro, 2010)

W = daily home-based work person trips = 1.6 * total employment in Maricopa County in the CMAQ funding request year (from MAG trip attraction equation)

1.28 = average vehicle occupancy for all modes (Cummings, 2010)

P = percent of suppressed telecommuting/compressed work schedule trips attributable to the Telework Program

19.1 = average commute trip length in miles for telecommuters and employees with compressed work schedules (derived from Valley Metro, 2010 and MCAQD, 2009)

1.6 = factor to convert trips avoided (*CTA*) to vehicles reduced (*VR*)

$$VER_1 = VMTR * \left[\frac{w1 * ONF_{CO}}{4} + \frac{w2 * ONF_{TOG}}{2} + \frac{w3 * ONF_{NOx}}{2} + w4 * (ONF_{PM} + PEF) \right] * \frac{1}{1000} * \frac{250}{365} = \frac{\text{kilograms}}{\text{day}}$$

$$VER_2 = VR * \left[\frac{w1 * OFF_{CO}}{4} + \frac{w2 * OFF_{TOG}}{2} + \frac{w3 * OFF_{NOx}}{2} + w4 * OFF_{PM} \right] * \frac{1}{1000} * \frac{250}{365} = \frac{\text{kilograms}}{\text{day}}$$

$$\text{Daily Emissions Reduction} = VER_1 + VER_2 = \frac{\text{kilograms}}{\text{day}}$$

where: **ONF** = the onroad light duty vehicle emission factor for each pollutant
OFF = the off-network vehicle emission factor for each pollutant
PEF = the paved road PM-10 emission factor for all road types (0.65 g/mi)
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

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

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

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

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

Telework Program

EXAMPLE

The Regional Public Transportation Authority (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:

$$\text{CTA} = \frac{0.11 * (1.6 * 2,473,000)}{1.28} = 340,038$$

$$\text{VMTR} = 340,038 * 0.20 * 19.1 = 1,298,945$$

$$\text{VR} = \frac{340,038}{1.6} * 0.20 = 42,505$$

$$VER_1 = 1,298,945 * \left(\frac{0.0*2.00}{4} + \frac{1.0*0.12}{2} + \frac{1.0*0.41}{2} + (1.0*(0.04+0.65)) \right) * \frac{1}{1000} * \frac{250}{365} = 849.65 \frac{\text{kilograms}}{\text{day}}$$

$$VER_2 = 42,505 * \left(\frac{0.0*2.85}{4} + \frac{1.0*0.34}{2} + \frac{1.0*0.17}{2} + 1.0*0.02 \right) * \frac{1}{1000} * \frac{250}{365} = 8.01 \frac{\text{kilograms}}{\text{day}}$$

$$\text{Daily Emissions Reduction} = 849.65 + 8.01 = 857.66 \frac{\text{kilograms}}{\text{day}}$$

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

$$\text{Cost-Effectiveness} = \frac{1.03 * 300,000 * 1000}{857.66 * 365} = 987 \frac{\text{dollars}}{\text{metric ton}}$$

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) stated that MAG would run the FHWA 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.

In 2008, Sierra Research indicated that 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 Texas Transportation Institute (TTI) methodology for ITS projects quantifies the emission reductions attributable to alleviating peak and off-peak recurrent and non-recurrent congestion.

To improve the methodologies used to evaluate traffic flow improvement projects proposed for CMAQ funding, MAG contracted with Lee Engineering and Texas Transportation Institute in early 2010. The new CMAQ methodologies recommended by Lee/TTI are described below (Lee/TTI, 2010). The recommended methodologies include four steps.

Step 1. Group individual project elements by Project.

Elements are individual projects in the MAG Transportation Improvement Program (TIP) that, when combined, lead to implementation of a Project that reduces emissions. An example of three elements that lead to implementation of a Project is shown in Table 5.

Table 5 - Example of Three Elements Grouped into a Single Project

TIP Project	Description	FY
FED-08	Purchase and Install Malfunction Management Units in all Traffic Control Cabinets	2008
FED-09	Install Video Detection System	2009
FED-10	Design and Construct Fiber Optic Cable Installations	2010

Elements can also include planning and design projects. Note that elements are typically implemented over a number of years in the TIP. Rather than estimating benefits for each element, in the example above the three elements would be analyzed as one Project with benefits assigned to a geographic area (i.e., city, town, Indian community, or regionwide). It is possible to have elements that support multiple Projects (e.g., fiber optics). If elements do not belong to a single project group, they will be grouped by jurisdiction and the element with the highest emission benefits will be used.

Lee/TTI recommended that MAG use an element grouping scheme that first grouped the elements by jurisdiction, then by level of improvement, then by market package, as identified in the Regional ITS Architecture. Lee/TTI identified four levels of improvement: 1 = Citywide, 2 = Arterial, 3 = Intersection, and 4 = Central. Level 4 improvements represent elements that could have regional implications such as the connection to a regional Traffic Management Center. Lee/TTI also used the MAG Regional ITS Architecture to sub-group elements by market package. The final grouping, shown in Appendix A, will be updated to include new ITS projects, when they are submitted for CMAQ funding.

The MAG ITS Program will be responsible for assigning a proposed CMAQ project (element) to the appropriate Project Group. The MAG Environmental Division will calculate the emission benefits of the proposed ITS project, according to the Lee/TTI recommended approaches described below.

Step 2. Calculate the emissions benefit for each Project in the build year (i.e, the final year of grouped elements).

In calculating the emission benefits for traffic signal coordination projects, Lee/TTI recommends that MAG continue to use the speed-based approach used in previous CMAQ methodologies. For other types of traffic flow improvements, Lee/TTI recommends use of the following new equations, derived from *The Texas Guide to Accepted Mobile Source Emission Reduction Strategies*, also called the MOSERS report (TTI, 2007).

For Incident Management Programs on Freeways:¹⁰

$$\text{Daily Emission Reduction (grams/day)} = E_{REG} * F_{NR} * \sum_1^n F_{EFF_i} * \frac{ADT_i}{ADT_T} \quad (\text{MOSERS 1})$$

where: ADT_i = Average daily traffic for each affected link
 ADT_T = Total average daily traffic for affected system (vehicles/day)
 E_{REG} = Regional freeway emissions (grams)
 F_{EFF} = Project effectiveness factor for each affected freeway¹¹
 F_{NR} = Nonrecurring emissions (decimal)¹²

For Regional/Systemwide Projects (e.g., Freeway Management System):¹³

$$\text{Daily Emission Reduction (grams/day)} = A + B + C + D \quad (\text{MOSERS 2})$$

A = Change in emissions from alleviating peak hour nonrecurrent congestion

$$A = E_P * F_{NR,P} * F_{ITS} * F_{EN,P}$$

B = Change in emissions from alleviating off-peak hour nonrecurrent congestion

$$B = E_{OP} * F_{OPH} * F_{NR,OP} * F_{ITS} * F_{EN,OP}$$

¹⁰Equation in Section 7.3 of the MOSERS report.

¹¹From Section 7.3 of the MOSERS report: “The FHWA Southern Resource Center, August 1999, reports a 50% effectiveness rate for detection and response; 25% for motor assistance patrol; 15% for surveillance.”

¹²From Section 7.3 of the MOSERS report: “According to the FHWA Southern Resource Center, August 1999 report, 4.9 percent of freeway emissions are caused by nonrecurring congestion.”

¹³Equation 2 in Section 7.4 of the MOSERS report.

C = Change in emissions from alleviating peak hour recurrent congestion

$$C = E_p * F_{ITS} * (1 - F_{NR,p}) * F_{ER,p}$$

D = Change in emissions from alleviating off-peak hour recurrent congestion

$$D = E_{OP} * F_{OPH} * F_{ITS} * (1 - F_{NR,OP}) * F_{ER,OP}$$

where:

E_{OP} = Emissions generated by congestion on affected roadway system during the off-peak period for each pollutant (CO, TOG, NOx, PM-10) in grams

E_p = Emissions generated by congestion on affected roadway system during the peak period for each pollutant (CO, TOG, NOx, PM-10) in grams

$F_{EN,OP}$ = Percent of nonrecurrent congestion eliminated on roadways with ITS deployment, off-peak period (decimal)

$F_{EN,p}$ = Percent of nonrecurrent congestion eliminated on roadways with ITS deployment, peak period (decimal)

$F_{ER,OP}$ = Percent of recurrent congestion eliminated on roadways with ITS deployment, off-peak period (decimal)

$F_{ER,p}$ = Percent of recurrent congestion eliminated on roadways with ITS deployment, peak period (decimal)

F_{ITS} = Percent of roadway system coverage with ITS deployment (decimal)

$F_{NR,OP}$ = Percent of roadway system emissions caused by nonrecurring congestion in the off-peak period (decimal)

$F_{NR,p}$ = Percent of roadway system emissions caused by nonrecurring congestion in the peak period (decimal)

F_{OPH} = Percent of off-peak hour emissions affected by ITS deployment (decimal)

*For All Other Traffic Flow Improvement Projects:*¹⁴

$$\text{Daily Emission Reduction (grams/day)} = \sum_1^n [L_i * ADT_i * (EF_B - EF_A)] \text{ (MOSERS 3)}$$

¹⁴Equation 1 in Section 7.4 of MOSERS report.

where:

ADT_i = Average daily traffic for each affected roadway

EF_A = Speed-based running exhaust emission factor after implementation (CO, TOG, NOx, or PM-10) in grams per mile

EF_B = Speed-based running exhaust emission factor before implementation (CO, TOG, NOx, or PM-10) in grams per mile

L_i = Length of each freeway affected by ITS (miles)

N = Number of affected corridors

Lee/TTI recommended that MOSERS 3 equation be used for all ITS projects until the MAG study on nonrecurring congestion is completed (in late summer 2011). The MAG study will provide local values for many of the variables in MOSERS equations 1 and 2 (e.g., F_{NR} , the percent of roadway system emissions caused by nonrecurring congestion). Until these local data become available, MAG will apply the MOSERS 3 equation to evaluate all ITS projects that are proposed for CMAQ funding. The MAG Environmental Division will calculate the emissions reduction benefit for each element of the Project Group in order to identify the element with the maximum benefit.

Step 3. Allocate the maximum emissions benefit of the Project to elements in the same group based on the vehicle miles of travel (VMT) calculated for each element.

The emission reductions will be allocated to each element in proportion to the VMT calculated for that element. It is important to note that this approach allocates unrealistically high emission benefits to plans and studies because they typically cover large geographic areas and have high VMT levels. To offset this effect, five percent of the maximum benefit of the Project will be allocated to planning and study elements.

Step 4. Apply the current MAG pollutant weighting and develop cost effectiveness ranking.

Lee/TTI recommended that cost effectiveness be calculated in the same way as in the 2009 MAG CMAQ methodologies (MAG, 2009). The Lee/TTI recommendations are described for each type of traffic flow improvement project in the sections below.

Traffic Signal Coordination

MOVES will be run to calculate the daily CO, TOG, NOx, and PM-10 emission reductions attributable to traffic signal coordination projects. The information in Table 6 was obtained from the California Air Resources Board (CARB, 2005). The length of the project, the ADT, the pre-project speed, 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*).
- Pre-project speed.
- The category into which the proposed project should be classified (see Table 6).

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%
two	Interconnected, pre-timed signals with old timing plan	Advanced computer-based control	17.5%
three	Non-interconnected signals with traffic-actuated controllers	Advanced computer-based control	16%
four	Interconnected, pre-timed signals with actively managed timing	Advanced computer-based control	8%
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%
six	Non-interconnected, pre-timed signals with old timing plan	Optimization of signal timing plan	7.5%

Formulas:

$$\text{Daily Emissions Reduction} = \text{miles} * \text{ADT} * 0.91 *$$

$$\left[\left(\frac{w1 * BEF_{CO}}{4} + \frac{w2 * BEF_{TOG}}{2} + \frac{w3 * BEF_{NOx}}{2} + w4 * BEF_{PM10} \right) - \left(\frac{w1 * AEF_{CO}}{4} + \frac{w2 * AEF_{TOG}}{2} + \frac{w3 * AEF_{NOx}}{2} + w4 * BEF_{PM10} \right) \right] * \frac{1}{1000} = \frac{kg}{day}$$

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-w4 = weighting factors for CO, TOG, NOx, and PM-10, respectively

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

where: i = discount rate of 3 percent

life = effectiveness period of 5 years (CARB, 2005)

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

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

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 in 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:

$$\text{Daily Emissions Reduction} = 3 * 10,000 * 0.91 * \left[\left(\frac{0.0 * 4.94}{4} + \frac{1.0 * 0.17}{2} + \frac{1.0 * 0.65}{2} + 1.0 * 0.06 \right) - \right.$$

$$\left. \left(\frac{0.00 * 4.74}{4} + \frac{1.0 * 0.16}{2} + \frac{1.0 * 0.61}{2} + 1.0 * 0.05 \right) \right] * \frac{1}{1000} = 0.96 \frac{\text{kilograms}}{\text{day}}$$

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

$$\text{Cost-Effectiveness} = \frac{0.2184 * 135,000 * 1000}{0.96 * 365} = 84,144 \frac{\text{dollars}}{\text{metric ton}}$$

Intelligent Transportation Systems

The installation of Intelligent Transportation Systems (ITS) alerts drivers concerning congestion incidents. Incident management projects permit more efficient re-routing of traffic and reduce vehicle idling which, in turn, reduces emissions. Freeway Management System projects improve the traffic flow on the regional system of freeways. Other ITS projects improve the traffic flow on arterials. Until local values for the MOSERS 1 and 2 equations are obtained, Lee/TTI recommends that MOSERS 3 be applied to calculate the emission reduction benefits of all proposed ITS projects.

The MAG ITS Program will assign the proposed ITS project (element) to the appropriate Project Group. The MAG Environmental Division will calculate the emission benefits of each element in the Project Group in order to identify the maximum benefit among the elements. The maximum benefit will be apportioned based on the share of VMT associated with the proposed project element relative to the total VMT of all elements in the Group. If there are multiple corridors involved in an ITS project, then the formula would be applied to each corridor and the emissions benefits would be summed.

Inputs Required from Entity Requesting CMAQ Funds:

- **CMAQ Cost.**
- Length of project (*miles*).
- Average weekday traffic (*ADT*).
- The pre-project speed.
- The post-project speed.

Formulas:

$$\text{Daily Emissions Reduction} = \text{miles} * \text{ADT} * 0.91 *$$

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

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 for all vehicle classes at the post-project speed
w1-w4 = weighting factors for CO, TOG, NOx, and PM-10, respectively

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

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

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

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

Intelligent Transportation Systems

EXAMPLE

A city proposes to design and construct fiber optic cable installations in FY 2015. The MAG ITS Program determines that the project is an element of a larger Project Group for the same city that includes ITS projects that have already been approved for CMAQ funding in FY 2013 and FY 2014. The city estimates that the implementation of all elements in the Project Group will increase weekday vehicle speeds from 25 to 27 mph on 30 miles of arterials. The affected arterials carry an average of 10,000 vehicles per 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.

The MAG Environmental Division determines that this project element represents half of the total VMT for all elements in the Project Group. Therefore, the emission reduction benefits of this proposed project are reduced by 50 percent in the calculations below.

Inputs Required from Entity Requesting CMAQ Funds:

- *CMAQ Cost* = \$135,000.
- Length of project (*miles*) = 30.
- Average weekday traffic (*ADT*) = 10,000.
- The pre-project speed = 25 mph.
- The post-project speed = 27 mph.

Calculations:

$$\text{Daily Emissions Reduction} = 30 * 10,000 * 0.91 * \left[\left(\frac{0.00*4.94}{4} + \frac{1.0*0.17}{2} + \frac{1.0*0.65}{2} + 1.0*0.06 \right) - \left(\frac{0.00*4.74}{4} + \frac{1.0*0.16}{2} + \frac{1.0*0.61}{2} + 1.0*0.05 \right) \right] * \frac{1}{1000} * 0.5 = 4.78 \frac{\text{kilograms}}{\text{day}}$$

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

$$\text{Cost-Effectiveness} = \frac{0.2184 * 135,000 * 1000}{4.78 * 365} = 16,899 \frac{\text{dollars}}{\text{metric ton}}$$

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 and students. In 2009, TRP data (MCAQD, 2009) indicates that 32 percent of employees work for TRP organizations and 24 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 89,000 Maricopa County students participating in the TRP in 2009 made 54 percent of their trips by alternate modes. The 2009 TRP data also indicates that the average one-way trip length for TRP participants (both employees and students) is 14.7 miles. The average vehicle occupancy for all modes in 2009 was 1.28 (Cummings, 2010).

The MOVES model will be run for the CMAQ funding year to estimate the onroad (Road Types 2-5) light duty vehicle emission factors for CO, TOG, NO_x, and PM-10 (ONF_{CO} , ONF_{TOG} , ONF_{NO_x} and ONF_{PM}). The paved road emission factor for all roads of 0.65 grams per mile will be added to ONF_{PM} . MOVES will also be run to generate off-network (Road Type 1) light duty vehicle emission factors for each pollutant (OFF_{CO} , OFF_{TOG} , OFF_{NO_x} and OFF_{PM}). The onroad emission factors will be multiplied by vehicle miles of travel, while the off-network emission factors will be multiplied by the vehicles reduced. These emission reductions will be summed to estimate the total 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*).
- Total employment in Maricopa County in the CMAQ funding year (*TE*).
- Students participating in the TRP program in the CMAQ funding year (*ST*).

Formulas:

$$VMT\ Reduced\ (VMTR) = \frac{((0.24 * (1.6 * TE) * 0.32) + (0.52 * (0.27 * ST))) * P}{1.28} * 14.7$$

$$Vehicles\ Reduced\ (VR) = \frac{VMTR}{1.6 * 14.7}$$

where: **0.24** = percent of TRP employee commute trips using alternate modes, including telecommuting and compressed work schedules (Cummings, 2010)

1.6 = factor to convert employment to weekday work trips (from MAG trip attraction equation)

TE = Total Maricopa County employment in funding year (from MAG projections)

0.32 = percent of employees participating in the TRP (Cummings, 2010)

0.52 = percent of TRP student trips using alternative modes (Cummings, 2010)

0.27 = factor to convert students into weekday trips (one-sixth of work trip rate of 1.6)

ST = students in Maricopa County participating in the TRP in the funding year (default = 89,000 in 2009)

P = percent of alternate mode use attributable to the TRP

1.28 = average vehicle occupancy (Cummings, 2010)

14.7 = average one-way trip length to work or school (MCAQD, 2009)

$$VER_1 = VMTR * \left[\frac{w1 * ONF_{CO}}{4} + \frac{w2 * ONF_{TOG}}{2} + \frac{w3 * ONF_{NOx}}{2} + w4 * (ONF_{PM} + PEF) \right] * \frac{1}{1000} * \frac{250}{365} = \frac{\text{kilograms}}{\text{day}}$$

$$VER_2 = VR * \left[\frac{w1 * OFF_{CO}}{4} + \frac{w2 * OFF_{TOG}}{2} + \frac{w3 * OFF_{NOx}}{2} + (w4 * OFF_{PM}) \right] * \frac{1}{1000} * \frac{250}{365} = \frac{\text{kilograms}}{\text{day}}$$

$$Daily\ Emissions\ Reduction = VER_1 + VER_2 = \frac{\text{kilograms}}{\text{day}}$$

where: **ONF** = the onroad light duty vehicle emission factor for each pollutant
OFF = the off-network vehicle emission factor for each pollutant
PEF = the paved road PM-10 emission factor for all road types (0.65 g/mi)
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

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

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

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

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 estimates that the share of alternative mode use attributable to the Trip Reduction Program is 25 percent. The County also indicates that the number of students expected to participate in the TRP in 2015 is 100,000. 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** = \$910,000.
- **P** = 25%.
- **TE** = 2,473,000.
- **ST** = 100,000.

Calculations:

$$\text{VMT Reduced (VMTR)} = \frac{((.24 * (1.6 * 2,473,000)) * .32) + (.52 * (.27 * 100,000)) * .25}{1.28} * 14.7 = 912,784$$

$$\text{Vehicles Reduced (VR)} = \frac{912,784}{1.6 * 14.7} = 38,809$$

$$\text{VER}_1 = 912,784 * \left(\frac{0.0 * 2.00}{4} + \frac{1.0 * 0.12}{2} + \frac{1.0 * 0.41}{2} + (1.0 * (0.04 + 0.65)) \right) * \frac{1}{1000} * \frac{250}{365} = 597.06 \frac{\text{kilograms}}{\text{day}}$$

$$\text{VER}_2 = 38,809 * \left(\frac{0.0 * 2.85}{4} + \frac{1.0 * 0.34}{2} + \frac{1.0 * 0.17}{2} + (1.0 * 0.002) \right) * \frac{1}{1000} * \frac{250}{365} = 6.83 \frac{\text{kilograms}}{\text{day}}$$

$$\text{Daily Emissions Reduction} = 597.06 + 6.83 = 603.89 \frac{\text{kilograms}}{\text{day}}$$

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

$$\text{Cost-Effectiveness} = \frac{1.03 * 910,000 * 1000}{603.89 * 365} = 4,252 \frac{\text{dollars}}{\text{metric ton}}$$

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 estimates that the average vanpool vehicle travels 66 miles (on average - round trip) per day on 255 commute days per year. This is equivalent to 16,830 commute miles annually per van. Valley Metro also estimates that the average vanpool carries nine people, including the driver. The average commute trip length per vanpool rider is 24.1 miles one-way (MCAQD, 2009). Therefore, the daily commute miles (round trip) saved per vanpool occupant is 48.2. Assuming that all nine of the vanpool occupants would have driven in single-occupant vehicles (SOV), the vehicle miles of travel replaced by a vanpool is 93,789 ((9 x 48.2 x 255) - 16,830). The comparable number of vehicles reduced by each vanpool annually is 2,040 (8 passengers times 255 commute days).

The MOVES model will be run for the year that the CMAQ funds are requested to estimate the onroad (MOVES Road Types 2-5) light duty vehicle emission factors for CO, TOG, NO_x, and PM-10 (ONF_{CO} , ONF_{TOG} , ONF_{NO_x} , and ONF_{PM}) and the off-network vehicle emission factors (MOVES Road Type 1) for each pollutant (OFF_{CO} , OFF_{TOG} , OFF_{NO_x} , and OFF_{PM}). The paved road emission factor (PEF) for all roads of 0.65 grams per mile will be added to ONF_{PM} . Emission factors for onroad vans ($VONF_{CO}$, $VONF_{TOG}$, $VONF_{NO_x}$, and $VONF_{PM}$) and off-network vans ($VOFF_{CO}$,

$VOFF_{TOG}$, $VOFF_{NOx}$, and $VOFF_{PM}$) will also be estimated using MOVES. The ONF and VONF emission factors will be multiplied by the appropriate vehicle miles of travel. The OFF and VOFF emission factors will be multiplied by the number of vehicles reduced. The difference between the commute emissions reduced and the vanpool emissions will represent the net benefit of vanpools.

Inputs Required from Entity Requesting CMAQ Funds:

- *CMAQ Cost.*

Formulas:

$$VMT \text{ Emissions Reduced (VMTR)} = VMT * \left(\frac{w1 * ONF_{CO}}{4} + \frac{w2 * ONF_{TOG}}{2} + \frac{w3 * ONF_{NOx}}{2} + w4 * (ONF_{PM} + PEF) \right) * \frac{1}{1000}$$

$$Vehicle \text{ Emissions Reduced (VR)} = vehicles * \left(\frac{w1 * OFF_{CO}}{4} + \frac{w2 * OFF_{TOG}}{2} + \frac{w3 * OFF_{NOx}}{2} + (w4 * OFF_{PM}) \right) * \frac{1}{1000}$$

where: VMT = the vehicle miles of travel replaced by the vanpool each year (93,789)
 $vehicles$ = the light duty vehicles replaced by the vanpool each year (2,040)
 ONF = the onroad light duty vehicle emission factor for each pollutant
 OFF = the off-network light duty vehicle emission factor for each pollutant
 PEF = the paved road PM-10 emission factor for all road types (0.65 g/mi)

$$Vanpool \text{ Emissions (VE)} = [(miles_{vanpool} * \left(\frac{w1 * VONF_{CO}}{4} + \frac{w2 * VONF_{TOG}}{2} + \frac{w3 * VONF_{NOx}}{2} + w4 * VONF_{PM} \right)) + (days_{vanpool} * \left(\frac{w1 * VOFF_{CO}}{4} + \frac{w2 * VOFF_{TOG}}{2} + \frac{w3 * VOFF_{NOx}}{2} + w4 * VOFF_{PM} \right))] * \frac{1}{1000}$$

where: $miles_{vanpool}$ = the miles driven annually by a van used as a vanpool (16,830)
 $VONF$ = the onroad emission factors for a van for each pollutant
 $days_{vanpool}$ = the days driven annually by a van used as a vanpool (255)
 $VOFF$ = the off-network emission factors for a van for each pollutant

$$Daily \text{ Emissions Reduction} = N * (VMTR + VR - VE) * \frac{1}{365} = \frac{kilograms}{day}$$

where: N = the number of vans being purchased
 $1/365$ = factor to convert annual emissions to daily emissions

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

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

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

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:

$$\text{VMT Emissions Reduced (VMTR)} = 93,789 * \left(\frac{0.0*2.00}{4} + \frac{1.0*0.12}{2} + \frac{1.0*0.41}{2} + (1.0*(0.04+0.65)) \right) * \frac{1}{1000} = 89.57 \frac{\text{kilograms}}{\text{year}}$$

$$\text{Vehicle Emissions Reduced (VR)} = 2,040 * \left(\frac{0.0*2.85}{4} + \frac{1.0*0.34}{2} + \frac{1.0*0.17}{2} + (1.0*0.002) \right) * \frac{1}{1000} = 0.52 \frac{\text{kilograms}}{\text{year}}$$

$$\text{Vanpool Emissions (VE)} = 16,830 * \left(\frac{0.0*2.74}{4} + \frac{1.0*0.19}{2} + \frac{1.0*0.67}{2} + (1.0*(0.05+0.65)) \right) +$$

$$255 * \left(\frac{0.0*4.07}{4} + \frac{1.0*0.45}{2} + \frac{1.0*0.25}{2} + (1.0*(0.002)) \right) * \frac{1}{1000} = 19.11 \frac{\text{kilograms}}{\text{year}}$$

$$\text{Daily Emissions Reduction} = 1 * (89.57 + 0.52 - 19.11) * \frac{1}{365} = 0.35 \frac{\text{kilograms}}{\text{day}}$$

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

$$\text{Cost-Effectiveness} = \frac{0.269 * 25,000 * 1000}{0.35 * 365} = 52,642 \frac{\text{dollars}}{\text{metric ton}}$$

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