Methodologies for Evaluating Congestion Mitigation and Air Quality Improvement Projects

Maricopa Association of Governments

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Table of Contents

Page

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

BICYCLE AND PEDESTRIAN FACILITIES 7
- Bicycle and Pedestrian Facilities Example 11

BUS AND LIGHT RAIL PROJECTS 12
- New Bus Service 12
- New Bus Service Example 15
- New Light Rail Service 16
- New Light Rail Service Example 18

DIESEL RETROFITS AND ANTI-IDLING PROGRAMS 19
- Diesel Retrofits 20
- Diesel Retrofits Example 22
- Diesel Anti-Idling Programs 22
- Truck Stop Electrification Example 24
- Auxiliary Power Units Example 24

INTERSECTION IMPROVEMENTS 25
- Additional Turning Lanes Example 26
- Roundabout Example 27

NATURAL GAS AND ELECTRIC VEHICLES 28
- Natural Gas Vehicles Example 30
- Electric Vehicles Example 30

PARK AND RIDE FACILITIES 31
- Park and Ride Lot Example 33

PAVING PROJECTS 33
- Paving Unpaved Roads Without Paved Shoulders Example 36
- Paving Unpaved Roads, Shoulders and Curb and Gutter Example 37

PM-10 CERTIFIED STREET SWEEPERS 38
- PM-10 Certified Street Sweepers Example 44

RIDESHARE PROGRAMS 45
- Regional Rideshare Program Example 47

TRAFFIC FLOW IMPROVEMENTS 48
Traffic Signal Coordination 53
Traffic Signal Coordination Example 54
Intelligent Transportation Systems 55
Intelligent Transportation Systems Example 56

TRIP REDUCTION PROGRAM 57
Trip Reduction Program Example 60

VANPOOL VEHICLES 61
Vanpool Vehicles Example 63

REFERENCES 64

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 emission 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 emission 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.

The CMAQ methodologies dated March 31, 2001 were revised in September 2011 to add a new methodology for calculating the emission benefits and cost-effectiveness of natural gas and electric vehicles purchased with CMAQ funds. The paved road particulate emission factors have also been updated utilizing the latest (July 1, 2011) vehicle registration data provided by the Arizona Department of Transportation and data from the new MAG truck model.

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 metropolitan planning organizations (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 were applied between August 2005 and April 2009 (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), the emission factors for the ozone precursors, total organic gases (TOG) and nitrogen oxides (NOx), and for particulate matter less than or equal to 10 microns (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 methodologies.

To implement Sierra's recommendation (3), MAG contracted with Lee Engineering and Texas Transportation Institute (TTI) in 2010 to update the methodology for evaluating intelligent transportation system (ITS) projects (Lee/TTI, 2010). The ITS project evaluation methodology recommended by Lee/TTI has been implemented in the 2011 CMAQ methodologies.

Lee/TTI also suggested that the cost-effectiveness scores were too high for studies that will not reduce transportation emissions until the project is fully implemented (e.g., ITS strategic plans). In the past, these studies received emission reduction credit as though the project were fully implemented. In the future, they will receive five percent of the emission reduction benefit of the fully implemented project. Examples include stand-alone planning, engineering and design projects that are CMAQ-eligible.

The 2011 MAG CMAQ methodologies utilize emission factors derived from the latest EPA onroad mobile source emissions model, MOVES2010a. The activity rates from the "Transportation Demand Management, Annual Report" (Valley Metro, 2010) and "Trip Reduction Program, Annual Report" (MCAQD, 2009), have also been updated, as recommended in (6).

MAG conducted a workshop on December 6, 2010 to discuss the proposed changes to the 2011 CMAQ methodologies. Input from the workshop has been incorporated into the methodologies, as discussed in the Overview of Key Assumptions. Since Sierra Research concluded that MAG continues to have the most sophisticated methods among the states and communities surveyed, no other major changes have been made to the 2011 methodologies.

The 2011 CMAQ methodologies continue to assume that the priority weight for carbon monoxide (CO) is zero. Participants attending the MAG CMAQ workshop in 2005 suggested that a weight of zero be assigned to CO 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 the Federal Highway Administration. If EPA lowers the National Ambient Air Quality Standard for CO in the future, the priority weight might may need to be changed. 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 2011 CMAQ methodologies, the priority weights for all other pollutants (i.e., TOG, NOx, and PM-10)[1] used in calculating cost-effectiveness are set to one[2]. Since the Maricopa County area is a nonattainment area for PM-10 and has not yet attained the more stringent eight-hour ozone standard of 0.075 ppm, it is appropriate to set equivalent priority weights for these three pollutants.

Seasonal adjustment factors are applied to the MOVES emission factors (i.e., TOG and NOx are

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[1]PM-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.

[2]Emission reductions from CMAQ-eligible sweeping and paving projects located within four miles of a PM-10 monitor are assigned a priority weight of two.

divided by two to reflect the six-month ozone season)[3]. The use of MOVES emission factors will result in cost-effectiveness scores that differ from those calculated using MOBILE6 in 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 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 (FHWA, 2008). Although MAG makes every effort to quantify the emission reduction impact of each project, FHWA guidance allows a qualitative evaluation to be made when a quantitative analysis is not possible. Qualitative evaluations 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 (e.g., 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 FHWA guidance 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 CO, TOG, NOx, and PM-10; and (2) the cost-

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

effectiveness of each project in dollars per metric ton of emissions reduced per year. Because the CMAQ methodologies use the new EPA onroad mobile source emissions model (MOVES) and the latest regional planning assumptions, the emission reductions may not be consistent with previous CMAQ analyses or air quality plans that used earlier models and assumptions. Most projects reduce CO, TOG, NOx and PM-10 emissions. In some cases (e.g., paving projects), 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 Emission Simulator (MOVES) model to estimate CO, TOG, NOx, and PM-10[4] emission factors for the implementation year of the project. The emission factors will be based on the latest vehicle registrations and market shares of fuel types specific to Maricopa County. The default speed of area-wide traffic is assumed to be 30 miles per hour, unless specified otherwise in the methodologies.

The PM-10 emission rates for unpaved roads and alleys are derived from the AP-42 equation for unpaved roads (EPA, 2006). The AP-42 emission factors are used in calculating the benefits of projects that pave unpaved roads and alleys.

EPA has recently updated the AP-42 equation used to calculate PM-10 emission factors for particulate matter re-entrained into the air by vehicles traveling on paved roads (EPA, 2011). The new AP-42 emission factors are used in calculating the benefits of street sweeping, shoulder paving, and other projects that reduce paved road emissions. The AP-42 emission factors in the September 2011 CMAQ methodologies utilize July 1, 2011 vehicle registrations and outputs of the new MAG truck model to estimate vehicle weights on freeways and arterials in the PM-10 nonattainment area.

At the December 6, 2010 MAG CMAQ Methodologies Workshop, it was suggested that priority consideration or weighting be given to projects that solely address PM-10 emissions, when those project locations are in close proximity to a historically-exceeding air quality monitor. To respond to this suggestion, CMAQ-eligible street sweeping or paving (i.e., unpaved road, alley or shoulder) projects located within four miles[5] of a PM-10 monitor will be assigned a priority weight of two, rather than one, when PM-10 emission reductions are calculated.

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 CO emission reductions are only calculated for the annual CMAQ report. No seasonal adjustment (i.e., division by four) is applied when estimating CO

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[4]MOVES estimates emissions from tailpipe exhaust, tire wear and brake wear for PM-10.

[5]The modeling domain to be used in demonstrating attainment of the PM-10 standard during high wind conditions in the 2012 MAG Five Percent Plan for PM-10 includes emission sources that are located within four miles upwind of PM-10 monitors.

emissions for the annual CMAQ report.

TOG and NOx 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 emission reductions and cost-effectiveness for projects requesting CMAQ funding, TOG and NOx reductions are divided by a seasonal factor of two to account for the six-month ozone season. No seasonal adjustment (i.e., division by two) is applied when estimating TOG and NOx emissions for the annual CMAQ report.

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, NOx and PM-10) for CMAQ projects do not represent an average day during the year.

In the CMAQ methodologies, the cost-effectiveness of a project is calculated by dividing the annualized CMAQ cost by the annual emission reduction. The annual emission reduction is obtained by converting the total weighted reduction in CO, TOG, NOx and PM-10 emissions in kilograms per day to metric tons per year. The CMAQ 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 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), Natural Gas and Electric Vehicles, Park and Ride Facilities, Paving Projects, PM-10 Efficient Street Sweepers, Rideshare Programs, Traffic Flow Improvements, Trip Reduction Program,[6] and Vanpool Vehicles.

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[6]In 2010, the Ozone Education and Telework Programs, which were previously evaluated as separate CMAQ projects, were merged with the Regional Rideshare Program.

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 of the project.

Application of Methodologies

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

BICYCLE AND PEDESTRIAN FACILITIES

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

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

The CO, TOG, NOx, and PM-10 emission factors are calculated for the implementation year of the project. The project life for bicycle 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 vehicles 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.[7] The weekday ADT will be converted to annual average daily traffic (***AADT***) by multiplying by 0.93. The vehicles reduced will be calculated

[7]Derived from CARB, 2005.

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.

Table 1. Adjustment Factors[8]

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

Table 2. Activity Center Credits[9]

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

[8]Adapted from CARB, 2005.

[9]Ibid.

The VMT reduced by bicycle/pedestrian facilities is estimated by multiplying the vehicles 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.

The MOVES model will be run to estimate CO, TOG, NOx, and PM-10 emission factors for light duty vehicles, assuming a speed of 30 miles per hour. The off-network (Road Type 1) emission factors in grams per vehicle per hour (OFF_{CO}, OFF_{TOG}, OFF_{NOx}, OFF_{PM}) will be multiplied by the number of vehicles reduced by bicycle/pedestrian trips.[10] The arterial (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 the 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 factor for all arterials, based on the new AP-42 equation, is 0.34 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.

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).
- If shoulder paving is part of the project, whether the project is located within four miles of a PM-10 monitor.

Formulas:

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

[10]It is assumed that each bicycle/pedestrian trip reduces off-network emissions (i.e., cold start, hot soak and evaporative emissions) for one vehicle hour between 6 a.m. and 6 p.m.

where: ***A*** = the adjustment factor from Table 1
C = the activity center credit from Table 2
AADT = the ***ADT*** on the adjacent or nearest parallel arterial (maximum = 30,000 ADT), multiplied by 0.93

$$\textit{VMT Reduced } (\textbf{VMTR}) = \textbf{VR} * \textbf{trip length}$$

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.

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

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

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 (0.35 g/mi)
w1-w4= weighting factors for CO, TOG, NOx, and PM-10, respectively

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

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

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

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

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. The shoulder paving project is not located within four miles of any PM-10 monitor.

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.
- The shoulder paving with curb and gutter is not located within four miles of a PM-10 monitor.

Calculations:

The primary Adjustment Factor (**A**) is derived from Table 1. Since the ***ADT*** is 18,000, the ***AADT*** is 16,740 (0.93 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 on one-side of the road is 0.27 grams per vehicle mile of travel (see the section on Paving Projects).

$$\textit{Vehicles Reduced } (\textbf{VR}) = 16{,}740 * (0.0020 + 0.0015) = 59 \ \frac{vehicles}{day}$$

$$\textit{VMT Reduced } (\textbf{VMTR}) = 59 * 4.0 = 236 \ \frac{vehicle-miles}{day}$$

$$\textit{Daily Emissions Reduction for Bike Lane} = [59 * (\frac{0.0*4.16}{4} + \frac{1.0*0.48}{2} + \frac{1.0*0.26}{2} + (1.0*0.004)] +$$

$$[236 * (\frac{0.0*2.04}{4} + \frac{1.0*0.13}{2} + \frac{1.0*0.42}{2} + (1.0*(0.04+0.35))] * \frac{1}{1000} = 0.18 \ \frac{kilograms}{day}$$

$$\textit{Daily Emissions Reduction for Paving Shoulder} = (1.0*0.27*16{,}740*1.5)*\frac{1}{1000} = 6.78\ \frac{\textit{kilograms}}{\textit{day}}$$

$$\textit{Total Daily Emissions Reduction} = 0.18 + 6.78 = 6.96\ \frac{\textit{kilograms}}{\textit{day}}$$

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

$$\textit{Cost-Effectiveness} = \frac{0.0672 * 585{,}000 * 1000}{6.96 * 365} = 15{,}475\ \frac{\textit{dollars}}{\textit{metric ton}}$$

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 number of vehicles and vehicle miles of travel (VMT) driven with a single occupant.

New Bus Service

Bus service on new routes and increased frequency on existing bus routes provide a new level of service and reduce vehicles and 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 vehicles replaced by the bus and the sum of the bus emissions from the new service and vehicle emissions from people driving to access the bus.

The vehicle miles of travel replaced ($\boldsymbol{VMT_{REP}}$) by the new bus service will be estimated based on the fraction of riders on the bus who drove to their destination prior to introduction of the new bus service ($\boldsymbol{F_1}$). This fraction will be multiplied by total bus riders and the average trip length replaced by the bus service (***trip length***$_1$). The VMT replaced by bus trips will be multiplied by onroad (Road Types 2-5) light duty vehicle emission factors from MOVES and paved road PM-10 emission factors from AP-42 to estimate the emissions from VMT replaced by 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 vehicles reduced will be multiplied by the off-network (Road Type 1) light duty vehicle emission factors in grams per vehicle per hour from MOVES.[11]

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[11]It is assumed that each bus passenger that previously drove to their destination reduces off-network emissions (i.e., cold start, hot soak and evaporative emissions) by one vehicle hour between 6 a.m. and 6 p.m.

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 PM-10 emission factors from AP-42 to estimate the light duty emissions added by vehicle trips to reach transit.

The emissions produced by the bus (***BE***) are equal to the number of miles driven daily by the bus multiplied by the on-road exhaust emission factor plus the off-network emissions for the bus plus the paved road PM-10 emission factor for the bus. The paved road dust emission factor for a bus (1.74 grams per mile) has been calculated, assuming an average vehicle weight of 18 tons. The off-network and exhaust emission factors for buses are estimated using MOVES. Based on 2011 RPTA data, a typical bus travels 121 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 = 284 (Based on 2011 RPTA data).
- Average length of trip driving from home to transit (***trip length***$_2$). Default = 5 miles (Valley Metro, 2001).

Formulas:

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

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

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

where: $\boldsymbol{R}$ = the average ridership on the bus per operating day
$\boldsymbol{F_1}$ = the fraction of riders on the bus who previously drove a single occupant vehicle
$\boldsymbol{trip\ length_1}$ = the average trip length replaced for each rider who previously drove
$\boldsymbol{F_2}$ = the fraction of riders who drive to transit
$\boldsymbol{trip\ length_2}$ = the average trip length driven to transit

$$Onroad\ Vehicle\ Emissions\ Reduced\ (\boldsymbol{VER_1}) = (\boldsymbol{VMT_{REP}} - \boldsymbol{VMT_{ADD}}) * (\frac{w1 * ONF_{CO}}{4} + \frac{w2 * ONF_{TOG}}{2} + \frac{w3 * ONF_{NOx}}{2} + (w4 * (ONF_{PM} + PEF)) * \frac{1}{1000} = \frac{kilograms}{day}$$

$$Off\text{-}network\ Vehicle\ Emissions\ Reduced\ (\boldsymbol{VER_2}) = \boldsymbol{VR} * (\frac{w1 * OFF_{CO}}{4} + \frac{w2 * OFF_{TOG}}{2} + \frac{w3 * OFF_{NOx}}{2} + w4 * OFF_{PM}) * \frac{1}{1000} = \frac{kilograms}{day}$$

where: $\boldsymbol{VMT_{REP}}$ = the vehicle travel replaced by bus service
$\boldsymbol{VMT_{ADD}}$ = the VMT added as a result of trips driven to reach transit
$\boldsymbol{ONF}$ = the onroad light duty vehicle emission factor for each pollutant
$\boldsymbol{OFF}$ = the off-network light duty vehicle emission factor for each pollutant
PEF = the paved road PM-10 emission factor for all road types (0.26 g/mi)
$\boldsymbol{w1\text{-}w4}$ = weighting factors for CO, TOG, NOx, and PM-10, respectively

$$Bus\ Emissions(\boldsymbol{BE}) =$$

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

where: $\boldsymbol{BEF}$ = the onroad bus emission factor for each pollutant (includes tire and brake wear for PM-10)
$\boldsymbol{PEF_{BUS}}$ = the paved road emission factor for a bus (1.74 g/mi)
$\boldsymbol{VMT_{BUS}}$ = the annual average daily bus VMT (121)

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

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

where: $\boldsymbol{i}$ = discount rate of 3 percent
$\boldsymbol{life}$ = effectiveness period of 12 years (CARB, 2005)

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

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

New Bus Service **EXAMPLE**

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

Inputs Required from Entity Requesting CMAQ Funds:

- ***CMAQ Cost*** = $288,000.
- Fraction of riders who would drive in a single occupant vehicle to their destination ($\boldsymbol{F_1}$) = 0.50.
- Fraction of riders who drive in a single occupant vehicle to reach transit ($\boldsymbol{F_2}$) = 0.03.
- Average length of vehicle trips (***trip length***$_1$) = 10.6 miles.
- Total daily ridership on the new bus ($\boldsymbol{R}$) = 284.
- Average length of trip from home to transit (***trip length***$_2$) = 5 miles.

Calculations:

$$\boldsymbol{VMT_{REP}} = 284 * 0.5 * 10.6 = 1{,}505$$

$$\boldsymbol{VMT_{ADD}} = 284 * 0.03 * 5 = 43$$

$$\boldsymbol{VR} = 284 * (0.5 - 0.03) = 133$$

$$\boldsymbol{VER_1} = (1{,}505 - 43) * \left(\frac{0.0*2.00}{4} + \frac{1.0*0.12}{2} + \frac{1.0*0.41}{2} + (1.0*(0.04+0.26)) * \frac{1}{1000} = 0.83\ \frac{kilograms}{day}\right.$$

$$VER_2 = 133 * \left(\frac{0.0*4.16}{4} + \frac{1.0*0.48}{2} + \frac{1.0*0.26}{2} + (1.0*0.004)\right) * \frac{1}{1000} = 0.05 \ \frac{kilograms}{day}$$

$$BE = 121 * \left(\frac{0.0*1.71}{4} + \frac{1.0*0.40}{2} + \frac{1.0*5.42}{2} + (1.0*(0.40+1.74)) * \frac{1}{1000} = 0.61 \ \frac{kilograms}{day}$$

$$Daily\ Emissions\ Reduction = 0.83 + 0.05 - 0.61 = 0.27 \ \frac{kilograms}{day}$$

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

$$Cost\text{-}Effectiveness = \frac{0.1005 * 288{,}000 * 1000}{0.27 * 365} = 293{,}699 \ \frac{dollars}{metric\ ton}$$

New Light Rail Service

Light rail represents another alternative mode to single occupant vehicle travel. Light rail service decreases emissions by reducing vehicles and 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 (Road Types 2-5) for CO, TOG, NOx, and PM-10 (ONF_{CO}, ONF_{TOG}, ONF_{NOx}, *and* ONF_{PM}). The paved road emission factor for all roads (0.26 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.[12] These emission reductions will be summed to estimate the total emissions benefit of the Light Rail project.

[12]It is assumed that each light rail passenger that previously drove to their destination reduces off-network emissions (i.e., cold start, hot soak and evaporative emissions) by one vehicle hour between 6 a.m. and 6 p.m.

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 ($\boldsymbol{F_1}$). 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 ($\boldsymbol{F_2}$). 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 length***$_1$). Default = 10.6 miles (from 2001 Maricopa Regional Household Travel Survey and 2002 transportation model validation, Feb.15, 2005)
- Total annual average daily ridership on the rail line (***R***). For example, if the new line is expected to carry 30,000 passengers per annual average day, *R* would equal 30,000.
- Average length of trip driving from home to rail (***trip length***$_2$). Default = 5 miles (Valley Metro, 2001).

Formulas:

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

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

$$\textit{Vehicles Reduced } (\boldsymbol{VR}) = R * (F_1 - F_2)$$

where: ***R*** = the ridership on the rail segment per annual average day
$\boldsymbol{F_1}$ = the fraction of rail riders who previously drove in a single occupant vehicle
trip length$_1$ = the average trip length replaced for each rider who previously drove
$\boldsymbol{F_2}$ = the fraction of riders who drive to the rail station
trip length$_2$ = the average trip length driven to the rail station

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

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

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

$$w4 * OFF_{PM}) * \frac{1}{1000} = \frac{\textit{kilograms}}{\textit{day}}$$

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

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 (0.26 g/mi)
w1-w4 = weighting factors for CO, TOG, NOx, and PM-10, respectively

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

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

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

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

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 annual average day 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 (F_1) = 0.50.
- Average length of vehicle trips diverted to rail (***trip length***$_1$) = 10.6 miles.
- Fraction of riders who drive to the rail station (F_2) = 0.03.
- Average length of trips driven to the rail station (***trip length***$_2$) = 5 miles.

Calculations:

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

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

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

$$VER_1 = (159{,}000 - 4{,}500) * \left(\frac{0.0*2.00}{4} + \frac{1.0*0.12}{2} + \frac{1.0*0.41}{2} + (1.0*(0.04+0.26))\right) * \frac{1}{1000} = 87.29 \ \frac{kg}{day}$$

$$VER_2 = 14{,}100 * \left(\frac{0.0*4.16}{4} + \frac{1.0*0.48}{2} + \frac{1.0*0.26}{2} + (1.0*0.004)\right) * \frac{1}{1000} = 5.27 \ \frac{kg}{day}$$

$$\textit{Daily Emissions Reduction} = 87.29 + 5.27 = 92.56 \ \frac{kilograms}{day}$$

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

$$\textit{Cost-Effectiveness} = \frac{0.0672 * 20{,}000{,}000 * 1000}{92.46 * 365} = 39{,}825 \ \frac{dollars}{metric\ ton}$$

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 15 ppm.[13] 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.

[13]EPA ultralow sulfur fuel standards became effective for nonroad engines in June 2010.

Inputs Required from Entity Requesting CMAQ Funds:

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

Formulas:

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

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

where: $\boldsymbol{VMT_i}$ = the annual miles driven by vehicles of model year *i*
BEF = the heavy duty diesel emission factor for each pollutant in model year *i,* 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

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

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

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

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

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

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

Diesel Retrofits **EXAMPLE**

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. MOVES estimates that the PM-10 exhaust emissions for a 2005 heavy duty vehicle running on ultra-low sulfur diesel fuel is 1.11 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:

$$\textit{Daily Emissions Reduction} = 20{,}000 * 40 * (1.00 * 1.11) * 0.90 * \frac{1}{1000} * \frac{1}{365} = 2.19\ \frac{\textit{kilograms}}{\textit{day}}$$

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

$$\textit{Cost-Effectiveness} = \frac{0.2184 * 160{,}000 * 1000}{2.19 * 365} = 43{,}716\ \frac{\textit{dollars}}{\textit{metric ton}}$$

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 extended idling emission factors for NOx and PM-10 for heavy duty diesel vehicles in the year of project implementation. The MOVES emission rates in grams per vehicle per hour will be multiplied by the estimated daily reduction in idling hours. The resultant emissions will represent the reduction benefit of a truck stop electrification project. For a CMAQ project involving auxiliary power units, the benefit will be calculated as the difference between the idling emissions for diesel trucks before and after installation of the APUs.

Inputs Required from Entity Requesting CMAQ Funds:

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

Formulas:

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

where: ***DIR*** = diesel vehicle idling hours reduced by the project on an annual average day
DIEF = the heavy duty diesel extended idling emission factor (in grams per vehicle per hour) for NOx and PM-10

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

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

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

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

Truck Stop Electrification **EXAMPLE**

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

Inputs Required from Entity Requesting CMAQ Funds:

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

Calculations:

$$\textit{Daily Emissions Reduction} = 360 * (1.0 * \frac{9.17}{2} + (1.0 * .037)) * \frac{1}{1000} = 1.66 \frac{\textit{kilograms}}{\textit{day}}$$

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

$$\textit{Cost-Effectiveness} = \frac{0.2184 * 500{,}000 * 1000}{1.66 * 365} = 180{,}228 \frac{\textit{dollars}}{\textit{metric ton}}$$

Auxiliary Power Units **EXAMPLE**

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

The idle emission factors for the diesel buses before installing the APUs are 135 grams per hour for NOx and 3.68 grams per hour for PM-10 (FHWA, 2009). The 2003 Kubota engine has EPA-certified emissions levels of 4.7 grams per brake horsepower hour for NOx and 0.24 grams per brake horsepower per hour for PM-10 (40 CFR Part 89). Multiplying by a horsepower load factor of 5 (FHWA, 2009) produces APU emission rates of 23.5 grams per hour for NOx and 1.2 grams per

hour for PM-10. These emissions are subtracted from the idling emissions for the buses without the APUs to obtain the net benefit of the APUs.

Inputs Required from Entity Requesting CMAQ Funds:

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

Calculations:

$$\textit{Daily Emissions Reduction} = 200 * (1.0 * \frac{(135-23.5)}{2} + (1.0 * (3.68-1.2)) * \frac{1}{1000} = 11.65\ kg/day$$

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

$$\textit{Cost-Effectiveness} = \frac{0.2184 * 500{,}000 * 1000}{11.65 * 365} = 25{,}681 \frac{dollars}{metric\ ton}$$

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, NOx, and PM-10 for all vehicle classes in the year of project implementation ($\boldsymbol{IEF_{CO}}$, $\boldsymbol{IEF_{TOG}}$, $\boldsymbol{IEF_{NOx}}$, and $\boldsymbol{IEF_{PM}}$). 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:

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

where: ***DR*** = Reduction in total weekday vehicle hours of delay due to the improvement
IEF = the idling emission factor for all vehicle classes for each pollutant (in grams/hr)
CF = factor to convert from average weekday traffic (ADT) to annual average daily traffic (AADT); for freeways, multiply ADT by 0.92; for arterials, multiply ADT by 0.93.
w1-w4 = weighting factors for CO, TOG, NOx, and PM-10, respectively

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

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

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

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

Additional Turning Lanes **EXAMPLE**

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

Inputs Required from Entity Requesting CMAQ Funds:

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

Calculations:

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

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

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

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

Roundabout **EXAMPLE**

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

Inputs Required from Entity Requesting CMAQ Funds:

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

Calculations:

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

$$120 * \left(\frac{0.0*19.44}{4}+\frac{1.0*2.77}{2}+\frac{1.0*6.26}{2}+(1.0*0.93)\right)*0.92*\frac{1}{1000} = 0.60\ \frac{kilograms}{day}$$

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

$$\textit{Cost-Effectiveness} = \frac{0.0672 * 1{,}800{,}000 * 1000}{0.60 * 365} = 552{,}329\ \frac{dollars}{metric\ ton}$$

NATURAL GAS AND ELECTRIC VEHICLES

The incremental cost of purchasing an alternative fuel vehicle versus a comparable gasoline fuel vehicle is eligible to be funded with CMAQ (FHWA, 2011). Natural gas vehicles produce lower exhaust emissions than gasoline-fueled vehicles, while electric vehicles produce zero exhaust emissions. The CMAQ methodology for quantifying the emission reductions and cost-effectiveness of natural gas vehicles, as a potential candidate for CMAQ funding, relies on a comparison of natural gas and gasoline exhaust emission factors for the same vehicle type (e.g., light duty auto). Electric vehicles are assumed to eliminate the exhaust emissions for the type and model year of gasoline vehicles being replaced. MOVES2010a emission factors will be used to evaluate the emission reductions and cost-effectiveness of electric vehicles. Since MOVES2010a does not currently provide emission factors for natural gas vehicles, MOBILE6.2 emission factors will be used to compare the emissions produced by natural gas and gasoline vehicles. If a future version of MOVES provides emission factors for natural gas and other alternative fuel vehicles, MOVES will be used to evaluate these proposed CMAQ projects.

For electric vehicles, the MOVES model will be run for the model year of the gasoline vehicle to be replaced to estimate the onroad exhaust emission factors for CO, TOG, NOx, and PM-10. These emission factors will be multiplied by the daily vehicle miles of travel to determine the emissions reduced in grams per day for each electric vehicle that is purchased.

For natural gas vehicles, the MOBILE6.2 model will be run to estimate the onroad exhaust emission factors for CO, VOC, NOx, and PM-10 for the natural gas vehicle in the model year to be purchased and the gasoline vehicle in the model year to be replaced. For natural gas vehicles, the exhaust emission factors for volatile organic compounds (VOC) will be substituted for total organic gases (TOG) in the equations below, because the VOC component of TOG emissions is the major contributor to the formation of ground-level ozone and more accurately represents the ozone reduction benefits of natural gas vehicles. The exhaust emission factor for the natural gas vehicle will be subtracted from the emission factor for the gasoline vehicle to be replaced. The difference will be multiplied by the daily vehicle miles of travel to determine the emissions reduced in grams per day for each natural gas vehicle that is purchased.

Inputs Required from Entity Requesting CMAQ Funds:

- ***CMAQ Cost*** (difference between cost of alternative vehicle and comparable gasoline vehicle)**.**
- Number of vehicles by fuel type (e.g., electric or natural gas) and vehicle type (e.g., car) (***N***).
- Average number of miles traveled per weekday by vehicle being replaced ***(VMT)***.
- Model year and type of gasoline vehicle(s) being replaced.

Formulas:

$$GVE = [\frac{w1*ONF_{CO}}{4} + \frac{w2*ONF_{TOG}}{2} + \frac{w3*ONF_{NOx}}{2} + w4*ONF_{PM}]*\frac{250}{365} = \frac{grams}{day}$$

$$AVE = [\frac{w1*ONF_{CO}}{4} + \frac{w2*ONF_{TOG}}{2} + \frac{w3*ONF_{NOx}}{2} + w4*ONF_{PM}]*\frac{250}{365} = \frac{grams}{day}$$

where: ***GVE*** **=** Emissions for the type and model year of gasoline vehicle being replaced
AVE **=** Emissions for the alternative vehicle (for electric vehicles, ***AVE*** = zero)
ONF = the vehicle exhaust emission factor for each pollutant
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

$$Daily\ Emissions\ Reduction = N * (GVE - AVE) * VMT * \frac{1}{1000} = \frac{kilograms}{day}$$

where: ***N*** **=** Number of gasoline vehicles being replaced
VMT **=** Average weekday miles to be traveled by each new vehicle
ONF = the onroad light duty vehicle emission factor for each pollutant

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

where: ***i*** = discount rate of 3 percent
life = vehicle life, based on the difference between the model year of vehicle being purchased and the model year being replaced

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

where: ***CMAQ Cost*** = the difference between the cost of the alternative vehicle and a comparable gasoline vehicle

Natural Gas Vehicles **EXAMPLE**

A city requests FY 2015 CMAQ funds to replace a 2007 eight-passenger gasoline-fueled van with a 2015 eight-passenger natural gas-fueled van. The city provides documentation that a comparable 2015 model year gasoline van would cost $5,000 less than the natural gas van. The city will provide an additional $30,000 in local funds to pay for the new natural gas van. The city estimates that the gasoline van being replaced travels 50 miles on a typical weekday. Since a natural gas vehicle is being requested, MOBILE6.2 will be utilized to estimate the exhaust emission factors. The estimated life of the van is 8 years (2015 model year minus 2007 model year).

Inputs Required from Entity Requesting CMAQ Funds:

- ***CMAQ Cost*** = $5,000.
- ***N*** = 1 natural gas van.
- ***VMT*** = 50 miles per weekday.
- ***life*** = 8 years.

Calculations:

$$GVE = [\frac{0.0*3.6367}{4}+\frac{1.0*0.0915}{2}+\frac{1.0*0.2658}{2}+1.0*0.0042]*\frac{250}{365} = 0.1252\ \frac{grams}{day}$$

$$AVE = [\frac{0.0*0.4800}{4}+\frac{1.0*0.0030}{2}+\frac{1.0*0.3283}{2}+1.0*0.0042]*\frac{250}{365} = 0.1163\ \frac{grams}{day}$$

$$Daily\ Emissions\ Reduction = 1 * (0.1252 - 0.1163) * 50 * \frac{1}{1000} = 0.0004\ kg/day$$

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

$$Cost\text{-}Effectiveness = \frac{0.1425 * 5{,}000 * 1{,}000}{0.0004 * 365} = 4{,}880{,}137\ \frac{dollars}{metric\ ton}$$

Electric Vehicles **EXAMPLE**

A city requests FY 2015 CMAQ funds to purchase a 2015 electric vehicle to replace a 2010 gasoline-fueled car used by city staff. The city provides documentation that a comparable 2015 gasoline car would cost $10,000 less than the electric car. The city will provide an additional $20,000 in local funds to purchase the electric vehicle. The city estimates that the gasoline car being replaced travels 50 miles on a typical weekday. Since an electric vehicle is being requested, MOVES2010a will be

utilized to estimate the exhaust emission factors for the 2010 model year car, while the electric vehicle will be assumed to generate zero emissions. The estimated life of the vehicle is 5 years (2015 model year minus 2010 model year).

Inputs Required from Entity Requesting CMAQ Funds:

- ***CMAQ Cost*** = $10,000.
- ***N*** = 1 electric vehicle.
- ***VMT*** = 50 miles.
- ***life*** = 5 years.

Calculations:

$$GVE = [\frac{0.0*1.1273}{4}+\frac{1.0*0.0152}{2}+\frac{1.0*0.0719}{2}+1.0*0.0030]*\frac{250}{365} = 0.0319\ \frac{grams}{day}$$

$$AVE = 0.0000\ \frac{grams}{day}$$

$$Daily\ Emissions\ Reduction = 1 * (0.0319 - 0.0000) * 50 * \frac{1}{1000} = 0.0016\ kg/day$$

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

$$Cost\text{-}Effectiveness = \frac{0.2184 * 10{,}000 * 1{,}000}{0.0016 * 365} = 3{,}739{,}726\ \frac{dollars}{metric\ ton}$$

PARK AND RIDE FACILITIES

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

The methodology is based on the number of park and ride spaces to be built and the projected utilization rate 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. The average trip length for commute trips is derived from regional commuting data collected by the Maricopa County Trip Reduction Program. The average trip length driven to park and ride lots (derived 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 (Road Types 2-5) for CO, TOG, NOx, and PM-10 (ONF_{CO}, ONF_{TOG}, ONF_{NOx}, *and* ONF_{PM}). The paved road emission factor for all roads (0.26 grams per mile) will be added to ONF_{PM}. These emission factors will be multiplied by the reduction in vehicle miles of travel.

Inputs Required from Entity Requesting CMAQ Funds:

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

Formulas:

$$\textit{VMT Reduced}\ (\boldsymbol{VMTR}) = \boldsymbol{S} * \boldsymbol{U} * \mathbf{2} * (\mathbf{15.4} - \mathbf{3.5})$$

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

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

where: ***ONF*** = the onroad light duty vehicle emission factor for each pollutant
PEF = the paved road PM-10 emission factor for all road types (0.26 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

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

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

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

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

Park and Ride Lot **EXAMPLE**

A city requests $200,000 in 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.

Calculations:

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

$$VER = 6{,}426 * \left(\frac{0.0*2.00}{4} + \frac{1.0*0.12}{2} + \frac{1.0*0.41}{2} + (1.0*(0.04+0.26))\right) * \frac{1}{1000} * \frac{250}{365} = 2.49\ \frac{kilograms}{day}$$

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

$$Cost\text{-}Effectiveness = \frac{0.0672 * 200{,}000 * 1000}{2.49 * 365} = 14{,}788\ \frac{dollars}{metric\ ton}$$

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 factor (*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 factor (*AEF*) on low volume arterials (<10,000 vehicles per day) with unpaved shoulders is 1.47 grams per mile. The difference between the unpaved and paved emission rate (658.69 g/mi) represents the reduction in PM-10 emissions due to paving dirt roads in the PM-10 nonattainment area.

The unpaved alley emission rate is 417.45 grams per mile (MCAQD, 2010). The difference between the unpaved and paved (i.e., 1.47) emission rates, 415.98 grams per mile, represents the emission reduction for paving dirt alleys 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) and the new AP-42 paved road PM-10 equation (EPA, 2011). As shown below, the reduction factors (RFs) for paving shoulders vary based on the extent of shoulder and/or C&G paving. Shoulder paving projects within the Salt River Area receive higher reduction benefits. 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.

To be consistent with the Serious Area PM-10 Plan (MAG, 2000a), paving of unpaved access points is 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.
- If the project is located within four miles of a PM-10 monitor, specify which monitor.

Formulas:

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

$$\textit{Daily Emissions Reduction} = w4 * RF * \textbf{miles} * \textbf{ADT} * 0.93 * \frac{1}{1000} = \frac{\textit{kilograms}}{\textit{day}}$$

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

For low volume roads (<10,000 ADT) =

0.76 g/mi, if paving shoulders and providing C&G on both sides of the road;
0.57 g/mi, if paving shoulders on both sides of the road without C&G;
0.38 g/mi, if paving shoulder and providing C&G on one side of the road;
0.29 g/mi, if paving shoulder on one side of the road without C&G;
0.19 g/mi, if providing C&G on both sides of a road with paved shoulders; or
0.10 g/mi, if providing C&G on one side of a road with a paved shoulder.

For high volume roads (≥ 10,000 ADT) =

0.53 g/vmt, if paving shoulders and providing C&G on both sides of the road;
0.40 g/mvt, if paving shoulders on both sides of the road without C&G;
0.27 g/vmt, if paving shoulder and providing C&G on one side of the road;
0.20 g/vmt, if paving shoulder on one side of the road without C&G;
0.14 g/vmt, if providing C&G on both sides of a road with paved shoulders; or
0.07 g/vmt, if providing C&G on one side of a road with a paved shoulder.

For all roads inside the Salt River Area =

1.31 g/vmt, if paving shoulders and providing C&G on both sides of the road;
0.98 g/mvt, if paving shoulders on both sides of the road without C&G;
0.66 g/vmt, if paving shoulder and providing C&G on one side of the road;
0.49 g/vmt, if paving shoulder on one side of the road without C&G;
0.32 g/vmt, if providing C&G on both sides of a road with paved shoulders; or
0.16 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
0.93 = the factor to convert from weekday to annual average daily traffic on arterials.
w4 = the PM-10 weighting factor (***w4*** = 2, if the project is within 4 miles of a PM-10 monitor; otherwise, ***w4*** = 1)

For Paving Unpaved Roads or Alleys:

$$\textit{Daily Emissions Reduction} = w4 * (BEF - AEF) * miles * ADT * 0.93 * \frac{1}{1000} = \frac{kilograms}{day}$$

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 with unpaved shoulders (1.47 g/mi)
miles = the length of the project (in centerline miles)
ADT = the average weekday traffic on the unpaved road or alley
0.93 = the factor to convert from weekday to annual average daily traffic on arterials.
w4 = the PM-10 weighting factor (***w4*** = 2, if the project is within 4 miles of a PM-10 monitors; otherwise, ***w4*** = 1)

For Paving Unpaved Access Points:

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

where: ***access points*** = the number of access points to be paved
w4 = the PM-10 weighting factor (***w4*** = 2, if the project is within 4 miles of a PM-10 monitor; otherwise, ***w4*** = 1)

For All Paving Projects:

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

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

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

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

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 within four miles of a PM-10 monitor. 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 within four miles of a PM-10 monitor.

Calculations:

$$Daily\ Emissions\ Reduction = 2.0 * 658.69 * 1.5 * 120 * 0.93 * \frac{1}{1000} = 220.53\ \frac{kilograms}{day}$$

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

$$Cost\text{-}Effectiveness = \frac{0.0672 * 600{,}000 * 1000}{220.53 * 365} = 501\ \frac{dollars}{metric\ ton}$$

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 not located within four miles of a PM-10 monitor. 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 not located within four miles of any PM-10 monitor.

Calculations:

Calculate the daily emissions reduction from paving the unpaved road:

$$Daily\ Emissions\ Reduction = 1.0 * 658.69 * 1.0 * 120 * 0.93 * \frac{1}{1000} = 73.51\ \frac{kilograms}{day}$$

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

$$Daily\ Emissions\ Reduction = 1.0 * 0.76 * 1.0 * 120 * 0.93 * \frac{1}{1000} = 0.08\ \frac{kilograms}{day}$$

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

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

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

$$\textit{Total Daily Emissions Reduction} = 73.51 + 0.08 + 1.37 = 74.96 \frac{\textit{kilograms}}{\textit{day}}$$

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

$$\textit{Cost-Effectiveness} = \frac{0.0672 * 600{,}000 * 1000}{74.96 * 365} = 1{,}474 \frac{\textit{dollars}}{\textit{metric ton}}$$

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. It will also 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 unswept emission factors based on the new AP-42 equation for paved roads are 0.11 grams per mile for freeways and 0.35 grams per mile for arterials outside the Salt River Area. The latter represents a 2011 VMT-weighted average of the low and high ADT emission factors for all arterials in the PM-10 nonattainment 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 is defined as the area 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 3.44 g/mi emission factor has been reduced by 62 percent to represent the percent reduction in the arterial emission factor using the 2011 AP-42 equation (i.e., 0.35 grams per mile) versus the 2006 AP-42 equation (i.e., 0.92 grams per mile). The resulting paved road emission rate of 1.31 grams per mile is higher in the Salt River Area 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 2.72 tons for vehicles traveling on arterials in the nonattainment area. Emission reduction credit for PM-10 certified street sweepers to be used in the Salt River Area will be calculated using this higher paved road emission factor.

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 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 factor of 3.44 grams per mile recommended by Sierra Research (MAG, 2008). For the 2011 CMAQ methodologies, this emission factor has been reduced by 62 percent, which is the change in the average arterial paved road emission rate (from 0.92 g/mi to 0.35 g/mi) due to the new AP-42 equation (EPA, 2011).

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.

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.

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)	0.03 g/vmt	0.10 g/vmt	0.36 g/vmt
1 day after sweeping (k=2)	0.04 g/vmt	0.14 g/vmt	0.52 g/vmt
2 days after sweeping (k=3)	0.05 g/vmt	0.17 g/vmt	0.65 g/vmt
3 days after sweeping (k=4)	0.06 g/vmt	0.21 g/vmt	0.77 g/vmt
4 days after sweeping (k=5)	0.07 g/vmt	0.23 g/vmt	0.88 g/vmt
5 days after sweeping (k=6)	0.08 g/vmt	0.26 g/vmt	0.98 g/vmt
6 days after sweeping (k=7)	0.09 g/vmt	0.29 g/vmt	1.07 g/vmt
7 days after sweeping (k=8)	0.10 g/vmt	0.31 g/vmt	1.17 g/vmt
8 days after sweeping (k=9)	0.11 g/vmt	0.34 g/vmt	1.26 g/vmt
9 days after sweeping (k>9)	0.11 g/vmt	0.35 g/vmt	1.31 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)	0.07 g/vmt	0.21 g/vmt	0.78 g/vmt
1 day after sweeping (k=2)	0.07 g/vmt	0.24 g/vmt	0.89 g/vmt
2 days after sweeping (k=3)	0.08 g/vmt	0.26 g/vmt	0.99 g/vmt
3 days after sweeping (k=4)	0.09 g/vmt	0.29 g/vmt	1.08 g/vmt
4 days after sweeping (k=5)	0.10 g/vmt	0.31 g/vmt	1.18 g/vmt
5 days after sweeping (k=6)	0.11 g/vmt	0.34 g/vmt	1.26 g/vmt
6 days after sweeping (k>6)	0.11 g/vmt	0.35 g/vmt	1.31 g/vmt

Inputs Required from Entity Requesting CMAQ Funds:

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.
- Whether the sweeper will be used in the Salt River Area.
- If the sweeping will occur within 4 miles of a PM-10 monitor, specify which monitor.

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

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

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

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

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

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

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

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

Formulas:

Reduced Reentrained Dust from Vehicles Traveling on Roadways:

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

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

Emission factor for roads swept with conventional street sweepers:

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

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

Replacing a Conventional Sweeper:

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

Replacing an Older PM-10 Certified Sweeper:

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

Increasing the Frequency of Sweeping:

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

Expanding the Coverage of Sweeping:

$$\textit{Daily Emissions Reduction} = w4 * \boldsymbol{milesnew} * \boldsymbol{AADT} * (\boldsymbol{IEF} - \boldsymbol{PEF}_{new}) * \frac{1}{1000} = \frac{\textit{kilograms}}{\textit{day}}$$

where: ***w4*** = the PM-10 weighting factor (***w4*** = 2, if the sweeping will occur within 4 miles of a PM-10 monitor; otherwise, ***w4*** = 1)
miles = lane miles of street to be swept per cycle
AADT = annual average daily traffic per through lane to be swept by the requested sweeper (for freeways, multiply 0.92 by the average weekday traffic (ADT); for arterials, multiply 0.93 by the ADT).

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*** = ***daysnew***
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)
milesnew = lane miles of streets to 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):

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

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

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

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

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

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. The sweeping with the PM-10 certified unit will occur within four miles of a PM-10 monitor.

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.
- The sweeping will occur outside the Salt River Area, but within 4 miles of a PM-10 monitor.

Calculations:

$$CEF = \frac{0.21 + 0.24 + 0.26 + 0.29 + 0.31 + 0.34 + (8 * 0.35)}{14} = 0.318$$

$$PEF = \frac{0.10 + 0.14 + 0.17 + 0.21 + 0.23 + 0.26 + 0.29 + 0.31 + 0.34 + (5 * 0.35)}{14} = 0.271$$

$$\textit{Daily Emissions Reduction for Reentrainment} = 2 * 200 * (5{,}000 * 0.93) * (0.318 - 0.271) * \frac{1}{1000} = 87.42 \ \frac{kilograms}{day}$$

$$\textit{Daily Emissions Reduction for the Sweeping Process} = 2 * \frac{200}{14} * 0.023 = 0.66 \ \frac{kilograms}{day}$$

$$\textit{Total Daily Emissions Reduction} = 87.42 + 0.66 = 88.08 \ \frac{kilograms}{day}$$

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

$$\textit{Cost-Effectiveness} = \frac{0.1425 * 135{,}000 * 1000}{88.08 * 365} = 598 \ \frac{dollars}{metric\ ton}$$

RIDESHARE PROGRAMS

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

Department of Administration. The Ozone Education Program and the Telework Program, both of which were previously evaluated as separate CMAQ-funded projects, have 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 0.26 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})[14]. 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:

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

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

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)

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[14]It is assumed that each carpool passenger reduces off-network emissions (i.e., cold start, hot soak and evaporative emissions) by one vehicle hour between 6 a.m. and 6 p.m.

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

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

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 (0.26 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

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

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

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

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

Regional Rideshare Program **EXAMPLE**

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

Inputs Required from Entity Requesting CMAQ Funds:

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

Calculations:

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

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

$$\boldsymbol{VER_1} = 523{,}658*(\frac{0.0*2.00}{4}+\frac{1.0*0.12}{2}+\frac{1.0*0.41}{2}+(1.0*(0.04+0.26)))*\frac{1}{1000}*\frac{250}{365} = 202.65\ \frac{kilograms}{day}$$

$$\boldsymbol{VER_2} = 21{,}252*(\frac{0.0*4.16}{4}+\frac{1.0*0.48}{2}+\frac{1.0*0.26}{2}+(1.0*(0.004)))*\frac{1}{1000}*\frac{250}{365} = 5.44\ \frac{kilograms}{day}$$

$$Daily\ Emissions\ Reduction = 202.65 + 5.44 = 208.09\ \frac{kilograms}{day}$$

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

$$Cost\text{-}Effectiveness = \frac{1.03 * 594{,}000 * 1000}{208.09 * 365} = 8{,}055\ \frac{dollars}{metric\ ton}$$

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 in a common geographic area, 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 emissions benefit 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 staff 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 MAG 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:[15]

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

where: $\boldsymbol{ADT_i}$ = Average weekday traffic for each affected link
$\boldsymbol{ADT_T}$ = Total average weekday traffic for affected system (vehicles/day)
$\boldsymbol{E_{REG}}$ = Regional freeway emissions (grams)
$\boldsymbol{F_{Eff}}$ = Project effectiveness factor for each affected freeway[16]
$\mathbf{F_{NR}}$ = Nonrecurring emissions (decimal)[17]

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[15]Equation in Section 7.3 of the MOSERS report.

[16]From 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."

[17]From 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."

For Regional/Systemwide Projects (e.g., Freeway Management System):[18]

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

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

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

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:

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

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

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

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

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

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[18]Equation 2 in Section 7.4 of the MOSERS report.

$F_{ER,P}$ = 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:[19]

$$\textit{Daily Emission Reduction (grams/day)} = \sum_{1}^{n} [L_i * AADT_i * (EF_B - EF_A)_i] \quad (MOSERS\ 3)$$

where: $AADT_i$ = Annual average daily traffic for each affected roadway (for freeways, multiply average weekday traffic (ADT) by 0.92; for arterials multiply ADT by 0.93)
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 or arterial affected by ITS (miles)
N = Number of affected corridors

Lee/TTI recommended that the MOSERS 3 equation be used for all ITS projects until results of the ongoing MAG study on nonrecurring congestion become available. 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. MAG Environmental Division staff will calculate the emission reductions 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. Lee/TTI indicated 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, MAG Environmental Division staff will assign five percent of the maximum benefit of the Project to ITS planning and study elements.

[19]Equation 1 in Section 7.4 of MOSERS report.

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:

$$\textit{Daily Emissions Reduction} = \textbf{miles} * \textbf{ADT} * \textbf{0.93} *$$

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

where: ***miles*** = the length of the project
ADT = the average weekday traffic
0.93 = the factor for converting ADT to annual average daily traffic on arterials
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

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

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

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

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:

$$\textit{Daily Emissions Reduction} = 3*(10{,}000*0.93)*[(\frac{0.0*4.94}{4}+\frac{1.0*0.17}{2}+\frac{1.0*0.65}{2}+1.0*0.06) - \frac{0.00*4.74}{4} + \frac{1.0*0.16}{2} + \frac{1.0*0.61}{2} + 1.0*0.05)] * \frac{1}{1000} = 0.98 \ \frac{\textit{kilograms}}{\textit{day}}$$

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

$$\textit{Cost-Effectiveness} = \frac{0.2184 * 135{,}000 * 1000}{0.98 * 365} = 82{,}427 \ \frac{\textit{dollars}}{\textit{metric ton}}$$

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:

$$\textit{Daily Emissions Reduction} = \textbf{miles} * \textbf{AADT} *$$

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

where: ***miles*** = the length of the project
AADT = the annual average daily traffic (for freeways, multiply average weekday traffic (ADT) by 0.92; for arterials, multiply ADT by 0.93*)*
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

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

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

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

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:

$$\textit{Daily Emissions Reduction} = 30*(10{,}000*0.93)*[(\frac{0.0*4.94}{4}+\frac{1.0*0.17}{2}+\frac{1.0*0.65}{2}+1.0*0.06) -$$

$$\frac{0.00*4.74}{4} + \frac{1.0*0.16}{2} + \frac{1.0*0.61}{2} + 1.0*0.05)] * \frac{1}{1000} * 0.5 = 4.88 \frac{\textit{kilograms}}{\textit{day}}$$

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

$$\textit{Cost-Effectiveness} = \frac{0.2184 * 135{,}000 * 1000}{4.88 * 365} = 16{,}553 \frac{\textit{dollars}}{\textit{metric ton}}$$

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, NOx, and PM-10 (ONF_{CO}, ONF_{TOG}, ONF_{NOx}, and ONF_{PM}). The paved road emission factor for all roads of 0.26 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}).[20] 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:

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

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

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 (1/6 of the work trip rate of 1.6)

[20]It is assumed that each trip reduced by the Trip Reduction Program reduces off-network emissions (i.e., cold start, hot soak and evaporative emissions) by one vehicle hour between 6 a.m. and 6 p.m.

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)

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

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

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

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 (0.26 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

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

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

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

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

Trip Reduction Program **EXAMPLE**

Maricopa County requests $910,000 in FY 2015 CMAQ funds for the Trip Reduction Program. The Arizona Department of Environmental Quality contributes $948,000 to the program. The County 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:

$$\textit{VMT Reduced } (\boldsymbol{VMTR}) = \frac{((0.24*(1.6*2{,}473{,}000)*0.32) + (0.52*(.27*100{,}000))*0.25}{1.28} * 14.7 = 912{,}784$$

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

$$\boldsymbol{VER_1} = 912{,}784*(\frac{0.0*2.00}{4}+\frac{1.0*0.12}{2}+\frac{1.0*0.41}{2}+(1.0*(0.04+0.26)))*\frac{1}{1000}*\frac{250}{365} = 353.23 \ \frac{\textit{kilograms}}{\textit{day}}$$

$$\boldsymbol{VER_2} = 38{,}809*(\frac{0.0*4.16}{4}+\frac{1.0*0.48}{2}+\frac{1.0*0.26}{2}+(1.0*0.004))*\frac{1}{1000}*\frac{250}{365} = 9.94 \ \frac{\textit{kilograms}}{\textit{day}}$$

$$\textit{Daily Emissions Reduction} = 353.23 + 9.94 = 363.17 \ \frac{\textit{kilograms}}{\textit{day}}$$

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

$$\textit{Cost-Effectiveness} = \frac{1.03 * 910{,}000 * 1000}{363.17 * 365} = 7{,}071 \ \frac{\textit{dollars}}{\textit{metric ton}}$$

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 x255) - 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, NOx, and PM-10 (ONF_{CO}, ONF_{TOG}, ONF_{NOx}, and ONF_{PM}) and the off-network vehicle emission factors (MOVES Road Type 1) for each pollutant (OFF_{CO}, OFF_{TOG}, OFF_{NOx}, and OFF_{PM}).[21] Emission factors for onroad vans ($VONF_{CO}$, $VONF_{TOG}$, $VONF_{NOx}$, and $VONF_{PM}$) and off-network vans ($VOFF_{CO}$, $VOFF_{TOG}$, $VOFF_{NOx}$, and $VOFF_{PM}$) will also be estimated using MOVES. The paved road emission factor (*PEF*) for all roads of 0.26 grams per mile will be added to $ONF_{PM.}$ and $VONF_{PM.}$ 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:

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

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

[21]It is assumed that each vanpool passenger reduces off-network emissions (i.e., cold start, hot soak and evaporative emissions) by one vehicle hour between 6 a.m. and 6 p.m.

where: ***VMT*** = the vehicle miles of travel replaced by the vanpool each year (93,789)
vehicles = the number of 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 (0.26 g/mi)

$$Vanpool\ Emissions\ (VE) = [(miles_{vanpool} * (\frac{w1*VONF_{CO}}{4} + \frac{w2*VONF_{TOG}}{2} + \frac{w3*VONF_{NOx}}{2} + w4*(VONF_{PM} + PEF))) +$$

$$(days_{vanpool} * (\frac{w1*VOFF_{CO}}{4} + \frac{w2*VOFF_{TOG}}{2} + \frac{w3*VOFF_{NOx}}{2} + w4*VOFF_{PM}))] * \frac{1}{1000}$$

where: $\boldsymbol{miles}_{\mathbf{vanpool}}$ = the miles driven annually by a van used as a vanpool (16,830)
ONF = the onroad emission factors for a van for each pollutant
$\boldsymbol{days}_{\mathbf{vanpool}}$ = the days driven annually by a van used as a vanpool (255)
OFF = the off-network emission factors for a van for each pollutant

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

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

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

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

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

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

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:

$$\textit{VMT Emissions Reduced } (\textbf{VMTR}) = 93{,}789 * \left(\frac{0.0*2.00}{4}+\frac{1.0*0.12}{2}+\frac{1.0*0.41}{2}+(1.0*(0.04+0.26))*\frac{1}{1000}\right. = 52.99\ \frac{kg}{yr}$$

$$\textit{Vehicle Emissions Reduced } (\textbf{VR}) = 2{,}040 * \left(\frac{0.0*4.16}{4}+\frac{1.0*0.48}{2}+\frac{1.0*0.26}{2}+(1.0*0.004)*\frac{1}{1000}\right. = 0.76\ \frac{kg}{yr}$$

$$\textit{Vanpool Emissions } (\textbf{VE}) = (16{,}830 * \left(\frac{0.0*2.74}{4}+\frac{1.0*0.19}{2}+\frac{1.0*0.67}{2}+(1.0*(0.05+0.26))\right) +$$

$$255 * \left(\frac{0.0*6.18}{4}+\frac{1.0*0.67}{2}+\frac{1.0*0.39}{2}+(1.0*0.005)\right))*\frac{1}{1000} = 12.59\ \frac{kg}{yr}$$

$$\textit{Daily Emissions Reduction} = 1 * (52.99 + 0.76 - 12.59) * \frac{1}{365} = 0.11\ \frac{kg}{day}$$

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

$$\textit{Cost-Effectiveness} = \frac{0.269 * 25{,}000 * 1000}{0.11 * 365} = 167{,}497\ \frac{dollars}{metric\ ton}$$

REFERENCES

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

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

Cummings, 2010. E-mail correspondence from Phil Cummings, MCAQD, to Cathy Arthur, MAG. *Revised Equation for Vehicle Trips Reduced by TRP*. January 27, 2010.

EPA, 2006. *AP 42, Fifth Edition, Compilation of Air Pollutant Emission Factors, Volume 1: Stationary Point and Area Sources. Section 13.2.1: Paved Roads and Section 13.2.2: Unpaved Roads.* Published by EPA in November 2006.

EPA, 2007. *The Cost-Effectiveness of Heavy-Duty Diesel Retrofits and Other Mobile Source Emission Reduction Projects and Programs.* May 2007.

EPA, 2011. *AP 42, Fifth Edition, Compilation of Air Pollutant Emission Factors, Volume I: Chapter 13.2.1. Paved Roads, Final Section. Published by EPA in January 2011.*

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

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

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

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

Lee/TTI, 2010. *Update the CMAQ Methodology for Evaluating Proposed ITS Projects.* Prepared by Lee Engineering and Texas Transportation Institute for the Maricopa Association of Governments. July 2010.

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

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

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

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

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

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

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

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

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

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

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

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

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

MAG, 2007c. *Maricopa Association of Governments Silt Loading Study.* Prepared by the College of Engineering, Center for Environmental Research and Technology, University of California, Riverside. March 30, 2007.

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

MCAQD, 2009. *Trip Reduction Program, Annual Report, July 1, 2008-June 30, 2009.* Prepared by the Maricopa County Trip Reduction Program Staff.

MCAQD, 2010. *2008 PM_{10} Periodic Emissions Inventory for the Maricopa County, Arizona, Nonattainment Area.* Prepared by the Maricopa County Air Quality Department. June 2010.

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

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

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

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

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

RPTA, 2008. *2007 Origin and Destination Survey*. Prepared by NuStats for the Valley Metro Regional Public Transportation Authority. December 2008.

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

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

Valley Metro, 2001. *On-Board Origin and Destination Survey*. Prepared by Valley Metro/Regional Public Transportation Authority. 2001.

Valley Metro, 2010. *Transportation Demand Management Annual Report, Fiscal Year 2009.* Prepared by Valley Metro/Regional Public Transportation Authority. April 2010.

Appendix A

Project#	Jurisdiction	FY	LOC	Work Type	Group	Local Element	Market Package	MAG CMAQ Category	Project Type	Cost	Affected Roadway/Corridor						
											Length**	ADT	AADT	VMT	$Speed_{BEFORE}$	$Speed_{AFTER}$ Category	$Speed_{AFTER}$
AVN13-901	**Avondale**	2013	McDowell Rd form 99th Ave to Avondale Blvd (2 miles) plus 1/8 mile on 99th Ave from McDowell Rd north to the first signalized shopping center location	Proposed project is to furnish and install 2 1/8 miles of fiber optic cable, conduit, interdict, assocated equipment at 9 traffic signals and one CCTV camera	1	AV-1-E	ATMS01-04	Infrastructure	1	$1,011,794	2.125	29,000	26,390	56,079	30.7	2	36.1
AVNFED-02	**Avondale**	2008	Avondale City Hall	Develop strategic plan for the Avondale Traffic Management System and Design Operation Center	1	AV-1-P	ALL	Planning	1	$350,000	57	13,579	12,357	704,343	35		35.4
BCKFED-01	**Buckeye**	2009	Town of Buckeye-Miller Road (N-S) from I-10 (north limit) to Hazen Road (south limit).	Implement ITS Project	2	BU-2-I	ATMS03-13	Infrastructure	1	$210,000	7	3,694	3,362	23,531	30	1	37.5
CHNFED07-04	**Chandler_CH-2**	2011	Chandler Blvd - McQueen Rd to Gilbert Rd	Install fiber optic traffic signal interconnect	3	CH-2-E	ATMS03	Infrastructure	1	$152,600	2	31,200	28,392	56,784	23.3	4	25.2
CHN09-802	**Chandler**	2009CO	Chandler Blvd: Delaware St to Gilbert Rd	Install fiber-optic cable traffic signal interconnection	3	CH-2-E	ATMS03		1	$450,000	2.8	13,579	12,357	34,599	30	4	32.4
CHNFED-02	**Chandler**	2008	Chandler Boulevard, Delaware Street to Gilbert Road	Install fiber optic cable traffic signal interconnection	3	CH-2-E	ATMS03-04	Infrastructure	1	$315,000	2.8	24,800	22,568	63,190	35	4	37.8
CHANDLER2014	**Chandler**	2014	Ray, Elliot, Dobson, connecting at Arizona back to TMC	Provide fiber communications to Traffic Signals in the project back to the TMC.	3	CH-2-E	ATMS03	Infrastructure	1	$801,500	9	42,000	38,220	343,980	28		30.0
CHNFED07-03	**Chandler_CH-1**	2011	Arizona Ave - Pecos to Ocotillo Rd; Chandler Heights Rd to Riggs Rd	Install fiber optic traffic signal interconnect	3	CH-2-E	ATMS03-04	Infrastructure	1	$344,050	4	25,700	23,387	93,548	23.3	4	25.2
CHNFED07-05	**Chandler_CH-3**	2011	Ray Rd - 54th St to L101	Install fiber optic traffic signal interconnect	3	CH-2-E	ATMS03	Infrastructure	1	$297,640	4.5	31,700	28,847	129,812	23.3	4	25.2
CHNFED07-06	**Chandler_CH-4**	2011	Transit Signal Priority Pilot Study	Pilot study to investigate and operate a transit signal priority system along Arizona Ave	4	CH-2-P	ALL	Planning	1	$758,170	5	35,600	32,396	161,980	23.3	4	25.2
CHNFED07-07	**Chandler_CH-5**	2011	CCTV Camera Installation	Install Closed-Circuit TV camera at L202 (Santan Fwy) interchange locations	5	CH-3-E	ATMS01	Equipment	1	$92,800	4.5	16,700	15,197	68,387	23.3	4	25.2
Chandler	**NEW**	2008CO	Various Locations	Purchase of Autoscope video detection cameras to be placed in various signalized intersections around the City.	5	CH-3-E	ATMS01	Equipment	1	$518,650	102	27,765	25,266	2,577,147	35	4	37.8
CHN10-613	**Chandler**	2009CO	Buffalo Street to Colorado Street	Upgrade, retrofit and integrate TMC equipment	6	CH-4-E	ATMS01-05	Equipment	1	$1,000,000	114	16,251	14,788	1,685,879	23		25.0
EI Mirage2014	**EI Mirage**	2014	Within City Limits	Various arterial traffic signal enhancements to improve existing signalized intersections for computerized signal control, closed circuit video, improved pedestrian control, improved signage and signal preemption.	7	EM-3-E	ATMS01, ATMS03	Equipment	1	$415,660	16	30,981	28,193	451,085	25		27.0
Fountain Hills2014	**Fountain Hills**	2014	Shea Blvd. and Downtown Area	Provide an Initial Deployment ITS system for the traffic signals on Shea Blvd. and in the Downtown Area; with monitoring/control sites at Town Hall and the Street Yard.	8	FH-1-E	ATMS03	Equipment	1	$1,000,000	7	14,508	13,202	92,416	30	4	32.4
GLB13-905	**Gilbert**	2009	Guadalupe Rd, Higley Rd, and Williams Field Rd	Gilbert ATMS Fiber East Ring Project - Phase I (Design/Build), Design for a Fiber ring to connect to existing fiber to link out-lying traffic signals to the Gilbert Traffic Operations Center via fiber connection	9	GI-1-I	ALL	Infrastructure	1	$147,000	6.5	21,396	19,470	126,557	22.1	3	25.6
GLB13-906	**Gilbert**	2009	Higley Rd, Recker Rd, Guadalupe Rd, Elliot Rd, Warner Rd, Ray Rd, Williams Field Rd	Gilbert ATMS Fiber East Ring project - Phase II (Design/Build), Design for Fiber branch connections to link traffic signals to the future East Fiber Ring (Phase 1)	9	GI-1-I	ALL	Infrastructure	1	$147,000	9.5	12,770	11,621	110,397	22.1	3	25.6
Gilbert2014	**Gilbert**	2014	Seven intersections near Baseline Road & Val Vista Drive	The project enables the traffic control center to respond to traffic congestion at 7 intersections remotely and make real-time improvements.	10	GI-3-E	ATMS03	Equipment	1	$317,122	3	36,009	32,768	98,305	30	4	32.4
GLB13-904	**Gilbert**	2013	Pecos Rd.-Greenfield to Power Rd, Power Rd-Pecos to Queen Creek Rd, Germann Rd-Power to Sossaman Rd	The proposed project will install approximately five miles of fiber optic cable and associated communications hardware to complete a high-bandwidth, non-leased interconnection between the Traffic Operations Centers in the Towns of Gilbert and Queen Creek.	11	GI-4-E	ATMS07-1	Infrastructure	1	$137,690	7	28,000	25,480	178,360	30.7	3	35.6
GLN13-901	**Glendale**	2013	59th Ave between Northern and Bethany Home: Glendale Ave. between 51st Ave. and 67th Ave; Peoria Ave. between 47th Ave. and 67th Ave.	Variable message signs; ITS Conduit and Fiber	12	GL-2-E	ATMS06-08	Infrastructure	1	$998,857	7	35,500	32,305	226,135	30.7	3	35.6
Glendale2014	**Glendale**	2014	67th Avenue between Glendale Ave and Cholla Street, near the intersection of 83rd Ave/Maryland	Expand the city's remote traffic monitoring and management capabilities along with providing redundancies to the communications system.	13	GL-2-E	ATMS01, ATMS03	Equipment	1	$987,000	3.5	27,000	24,570	85,995	30		35.0
GLN13-903	**Glendale**	2009	Olive Avenue, 67th Ave to 59th Ave	ITS Fiber and 1 CCTV camera	13	GL-2-E	ATMS01, ATMS03	Equipment	1	$372,149	1	34,125	31,054	31,054	22.1	3	25.6
GLNFED07-02	**Glendale_GL-1**	2011	Glendale Sports Facilities	Purchase and install dynamic message signs	13	GL-2-E	ATMS01-08	Equipment	1	$1,233,511	3	32,000	29,120	87,360	15		16.8
GLNFED-03	**Glendale**	2012	Various Locations	Establish Fiber Optic Link With Nearby Arterial Streets in the Vicinity of US 60	14	GL-3-E	ATMS01, ATMS03	Infrastructure	1	$774,594	2	46,600	42,406	84,812	36	3	41.8
GLNFED-02	**Glendale**	2008	Various Locations	Install CCTV Cameras	14	GL-3-E	ATMS01-07	Equipment	1	$224,592	3	37,800	34,398	103,194	35		35.4
GLENDALE2009-1	**Glendale**	2009CO	Glendale TMC	Develop an ITS Strategic Plan document in line with regional ITS planning efforts	15	GL-4-P	ALL	Planning	1	$300,000	47	29,389	26,744	1,256,983	32.4	4	35.0
GLENDALE2009-2	**Glendale**	2009CO	Glendale TMC	Purchase a replacement traffic signal system to allow for remote control of the City's signalized intersections	15	GL-4-E	ATMS03		1	$96,000	37	29,587	26,924	996,195	30	4	32.4
GLENDALE2009-3	**Glendale**	2009COITS	Glendale TMC	Purchase replacement video wall and control equipment	15	GL-4-E	ATMS01, ATMS03, ATMS06, ATMS07, ATMS08	Equipment	1	$500,000			0	0			XXXXX
GDYFED07-03	**Goodyear_GO-1**	2011	Citywide	Implement traffic signal system, install miscellaneous ITS equipment (e.g., CCTV cameras, DMS, etc.	16	GY-1-E	ATMS03-07	Equipment	1	$2,140,000	141	5,200	4,732	667,212	23.3	1	29.1
GDY13-902	**Goodyear**	2009	Various Locations	Purchase Dynamic Message Signs	17	GY-1-E	ATMS06	Equipment	1	$200,000	4.75	31,000	28,210	133,998	22.1	4	23.9
GDYFED-01	**Goodyear**	2012	McDowell Road, Sarival Road to Litchfield Road	Design and Construct Fiber Optic Interconnection for Traffic Signals and Video	18	GY-1-I	ATMS01-08	Infrastructure	1	$591,045	3	35,000	31,850	95,550	40	1	50.0
GDY13-901	**Goodyear**	2013	Citywide	Design and construction of fiber optic interconnect in existing conduit for traffic management through video surveillance and data collection	18	GY-1-I	ATMS01-08	Infrastructure	1	$891,256	15	31,000	28,210	423,150	30.7	6	33.0

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Goodyear2014	**Goodyear**	2014	Van Buren Street - Estrella Parkway to Cotton Lane	This project will provide traffic signal connectivity to three existing and one future traffic signal. In addition, CCTV cameras will be provided at key intersections.	19	GY-2-E	ATMS01, ATMS03	Equipment	1	$812,000	2	13,600	12,376	24,752	30		37.2
MARICOPA COUNTY2009-4	**Maricopa County**	2009	Southwest Valley, 99th Ave to Citrus, Indian School Rd south to MC85	Implement an Arterial Motorist Assistance service as a pilot program for three years. This arterial program would be similar to the Freeway Service Patrol, and provide assistance such as fixing flat tires, moving disabled vehicles out of travel lanes, requesting tow services, or supporting police or REACT with arterial incident management. This pilot program would initially be focused on the Southwest Valley area, in the vicinity of the I-10 reconstruction, and would cover key east-west arterials (Indian School, Thomas, McDowell, Van Buren, Buckeye and MC 85), as well as north/south arterials, particularly near freeway interchanges. This pilot program is envisioned to be a roving patrol during peak travel, but also be dispatched as needed to support public safety or REACT. Costs shown are to cover a three-year pilot project.	20	MC-1-E	EM01-7		1	$245,000	10	19,000	17,290	172,900	22.1	5	24.8
MMAFED-03	**Maricopa County**	2009	Glendale, Peoria and Scottsdale City Limits	Establish REACT Arterial Incident Response Teams in Glendale and Peoria	20	MC-1-E	EM01-7	Other	3	$867,200	321	20,497	18,652	5,987,379	35		35.4
MMAFED-06	**Maricopa County**	2010	99th Avenue, Olive Avenue to Bell Road	Install Conduit and Fiber Optic Cable to Connect Existing and Planned ITS Field Devices	21	MC-2-E	ATMS01-02	Infrastructure	1	$805,000	5.2	12,500	11,375	59,150	50	2	58.8
MMAFED-02	**Maricopa County**	2012	Olive Avenue, Litchfield Road to the Agua Fria Freeway (101L)	Construct and Install New Conduit and New Fiber Optic Cable to Connect Existing Various Locations	21	MC-2-E	ATMS01-02, ATMS03-01, ATMS06-02	Infrastructure	1	$885,500	5.9	20,000	18,200	107,380	50	5	56.0
Maricopa County2014-2	**Maricopa County**	2014	Various locations along MC85 from Agua Fria Bridge West Terminal to 75th Ave	To extend traffic management capabilities along MC 85, thus improving traffic flow and overall roadway capacity, and reducing reliance on private sector leased lines for required communication links.	21	MC-2-E	ATMS01, ATMS03	Equipment	1	$847,000	5.5	25,700	23,387	128,629	30	4	32.4
MMA13-903	**Maricopa County**	2013	Sun Valley Parkway, I-10 to Bell Rd Connection	Implement a wireless communications system and CCTV on Sun Valley Parkway. Traffic signals will already be in place, and the wireless communications will provide interconnect and coordination capability.	21	MC-2-E	ATMS01-02	Equipment	1	$490,000	20	3,000	2,730	54,600	30.7	6	33.0
MMAFED-05	**Maricopa County**	2008	Sun City West	Construct and Install New Pull Boxes, Branch Conduits, New Backbone and Branch	21	MC-2-E	ATMS01, ATMS03, ATMS06	Infrastructure	1	$355,600	4.5	16,000	14,560	65,520	35	5	39.2
MMA13-904	**Maricopa County**	2013	DMS installations in the EB and WB direction at each of the following intersections: McDowell Rd and Avondale Blvd, McDowell Rd and Estrella Pkwy, MC85 and Avondale Blvd, MC85 and Estrella Pkwy	Install arterial DMS and associated conduit, pull boxes, fiber optic cable, communication equipment and electrical service equipment	22	MC-3-E	ATMS01, ATMS03, ATMS06	Infrastructure	1	$700,000	12	63,000	57,330	687,960	30.7	3	35.6
MMAFED07-02	**MaricopaCounty_M**	2011	Bell Rd, L303 to 75th Ave	Construction of dynamic message sign structures, fiber, and conduit	22	MC-3-E	ATMS06-02	Infrastructure	1	$546,000	11.5	72,340	65,829	757,038	10		10.1
MARICOPA COUNTY2009-1	**Maricopa County**	2009COITS	CCTV Camera Deployment - 11 Locations	Installation of 11 CCTV cameras at existing MCDOT signals to increase traffic surveillance coverage of key MCDOT arterial corridors	23	MC-3-E	ATMS01, ATMS03		1	$225,000			0	0			XXXXX
MMAFED07-03	**MaricopaCounty_M**	2011	Various locations	Signal modernization and installation of CCTV at five signalized intersections	23	MC-3-E	ATMS01-02	Equipment	1	$350,000	3.5	13,000	11,830	41,405	23.3	4	25.2
MMAFED-04	**Maricopa County**	2012	Valley Wide	Upgrade Regional Archived Server (RADS) Equipment to Facilitate Arterial Data Integration and Dissemination.	24	MC-4-E	AD1-2, AD2-1, ATMS07-1, ATMS07-2	Other	2	$68,250	2532	20,148	18,335	46,423,410	35		35.4
MMA13-902	**Maricopa County**	2013	Regionwide this project will enhance traveler information on key arterials throughout the region	Develop and implement arterial ATIS Enhancements, building on the previous Phase I efforts 511 enhancements, and other key projects.	24	MC-4-E	AD1-2	Other	2	$350,000	20	38,000	34,580	691,600	30.7	3	35.6
MMAFED-01	**Maricopa County**	2008	Valley Wide	System Enhancements to Expand Arterial Traveler Information Systems, Including 511 and az511.com	24	MC-4-E	AD2	Other	2	$385,000	2024	20,148	18,335	37,109,392	35		35.4
Maricopa County2014-1	**Maricopa County**	2014	Associated with AZTech Center-to-Center traffic management system located primarily at ADOT and MCDOT	Upgrade the Regional Archive Data Center Equipment and Systems to enhance archiving capacity and the utility of real time traffic data.	25	MC-4-E	ATIS01-1, ATIS01-4	Equipment	2	$136,500	700	15,000	13,650	9,555,000	30		35.0
MARICOPA COUNTY2009-3	**Maricopa County**	2009	Regionwide	Procure technical support services that will be integrally involved in integrating, expanding, and maintaining regional connectivity throughout the metropolitan region. Specifically, this contracted support would focus on near-term Regional Community Network implementation and expansion, and is also envisioned to support center-to-center connectivity among transportation and public safety agencies. This contracted technical support would work closely with state, county, transit operations and local traffic management agencies, as well as state and local public safety dispatch centers. Key functions will benefit from this technical support, including traffic management, signal operations, traveler information, incident management, and inter-agency coordination for work zones and planned special events. This contracted support would be based out of the MCDOT ITS Group and report to the MCDOT ITS Supervisor.	26	MC-4-I	ALL		2	$210,000	20	25,000	22,750	455,000	22.1	3	25.6
MMA13-901	**Maricopa County**	2013	Southwest Valley, 99th Ave to Cotton Ln to include McDowell Rd, Van Buren St, MC85/Buckeye	Develop a multi-agency Operations Plan that will support coordinated arterial operations, freeway/arterial coordination, incident management and traveler information. This Operations Plan will include agency roles and responsibility, equipment operation	27	MC-4-P	ALL	Planning	2	$35,000	10	24,000	21,840	218,400	30.7	5	34.4
MARICOPA COUNTY2009-2	**Maricopa County**	2009COITS	MCDOT Traffic Management Center Video Wall Replacement	Replacement of the MCDOT TMC video wall including design, equipment, installation, support structure, and support costs	27	MC-4-I	ATMS01, ATMS03, ATMS06, ATMS07, ATMS08	Equipment	1	$220,000			0	0			XXXXX
Mesa	**MES08-807**	2008CO	TS Signal Conversions - Phase 3 (Mesa Dr. and Main Street)	Expand fiber-optic network and link 11 traffic signals to the Mesa TMC	28	ME-2-E	ATMS03	Infrastructure	1	$2,555,000	3.5	35,800	32,578	114,023	30	2	35.3
MES08-807	**Mesa**	2009CO	ITS Signal Conversions - Phase 3 (Mesa Dr & Main St)	Expand fiber-optic network and link 11 traffic signals to the Mesa TMC	28	ME-2-E	ATMS03	Infrastructure	1	$2,220,000	3.5	35,800	32,578	114,023	30	2	35.3
MESFED-05	**Mesa**	2008	Mesa Drive and Main Street	Expand Fiber Optic Network and Link 11 Traffic Signals to the Mesa TMC	28	ME-2-E	ATMS03-08	Infrastructure	1	$1,000,000	3.5	35,800	32,578	114,023	30	2	35.3

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MESFED-01	**Mesa**	2009	Along Baseline Road, Southern Avenue, Dobson Road and Alma School Road	Establish Fiber Optic Link with Nearby Arterial Streets in Vicinity of US 60	28	ME-2-E	ATMS03-08	Infrastructure	1	$1,000,000	12.5	43,000	39,130	489,125	30	5	33.6
MESFED-06	**Mesa**	2009	Along Sections of Broadway Road, Dobson Road, Alma School Road and Baseline Road	Establish Fiber Optic Link on Broadway Road and Connection to West ITS Loop.	28	ME-2-E	ATMS03-08	Infrastructure	1	$1,000,000	4	38,000	34,580	138,320	30	5	33.6
MESFED-04	**Mesa**	2010	University Drive, Dobson Road to Country Club Drive; University Drive, Mesa Drive to Higley Road	Improvements to Existing Fiber Optic Communications Systems and Install Communications Network and ITS Devices	28	ME-2-E	ATMS01, ATMS03, ATMS06	Infrastructure	1	$1,000,000	7	38,000	34,580	242,060	35	5	39.2
MESFED-03	**Mesa**	2012	Guadalupe Rd, 101L to Extension; Dobson Rd, Lindner to Pampa; Alma School Rd, Median to Guadalupe	Improvements to Existing Fiber Optic Communications Systems and Install Communications Network and ITS Devices	28	ME-2-E	ATMS01, ATMS03, ATMS06	Infrastructure	1	$1,000,000	4.5	30,000	27,300	122,850	38	5	42.6
MESFED07-03	**Mesa_ME-1**	2011	Country Club Dr - McKellips Rd to Baseline Rd; Brown Rd - Country Club Dr to Date; 8th Street - Country Club Dr to Alma School Rd; University Dr - Country Club Dr to Center St	Install fiber optic communications and provide traffic signal controller upgrades	28	ME-2-E	ATMS03-08?	Infrastructure	1	$1,500,000	6.5	39,340	35,799	232,696	23.3	4	25.2
MES04-125C	**Mesa**	2009CO	Country Club Dr: 8th Ave to Baseline Rd (Including US-60 TI)	Install real-time adaptive signal system	28	ME-2-E	ATMS03-08	Equipment	1	$1,370,000	1.5	50,433	45,894	68,841	30	2	35.3
MES13-906	**Mesa**	2013	Ten intersections with highest crash rates within City of Mesa. This project has city-wide potential.	This project will implement video and acoustic sensors in the field to automatically detect and alert traffic operations staff of suspected crash or traffic impeding events. The communications will be facilitated using existing traffic controller cabinets	29	ME-3-E	ATMS01-09	Equipment	1	$420,000	40	56,000	50,960	2,038,400	30.7	5	34.4
MES09-607	**Mesa**	2009CO	Various Locations	Upgrade TMC equipment and purchase central components, field cameras and VMS	30	ME-3-E	AD1-4	Equipment	1	$566,550	171	20,154	18,340	3,136,164	23	2	27.0
MES13-902	**Mesa**	2013	West side mid-city (initial deployment), West city limits to Country Club, University to Broadway-but project has city-wide potential	Upgrade central traffic control system software to accommodate a lite version of adaptive control	31	ME-4-E	AD1-4	Equipment	1	$350,000	12	30,000	27,300	327,600	30.7	5	34.4
MAG-08	**MAG**	2008		Traffic Signal Optimization Program	32	MG-1-P	ALL		1	$300,000	30	20,000	18,200	546,000	35	4	37.8
MAG-09	**MAG**	2009		Traffic Signal Optimization Program	33	MG-1-P	ALL		1	$500,000	50	20,000	18,200	910,000	35	4	37.8
Peoria2014	**Peoria**	2014	Four Corridors: Peoria Ave, Northern Ave, Olive Ave and 75th Ave, located in the southern most area of City of Peoria	To upgrade the existing cabinets, traffic controllers and also upgrade the existing loop detection to video detection on selected corridors to improve the overall communication within the City's Network and also upgrade the hardware and software with the changing technologies in ITS.	34	PE-1-E	ATMS01, ATMS03	Equipment	1	$700,000	15	30,000	27,300	409,500	23		31.0
PEOFED07-02	**Peoria_PE-1**	2011	Various corridors	Install fiber optic cable, conduit, and CCTV cameras	34	PE-1-E	ATMS01, ATMS03	Equipment	1	$1,000,000	5.5	22,975	20,907	114,990	23.3	4	25.2
PEO13-904	**Peoria**	2009	Within City of Peoria, connecting existing traffic signals to central system	Exisiting traffic signals within the city of Peoria will be connected to the fiber backbone, and back to central with either fiber or wireless. This connection will allow the city to manage the signals in a manner to reduce congestion, delay, and improve	34	PE-1-E	ATMS01, ATMS03	Infrastructure	1	$525,000	17	20,750	18,883	321,003	22.1	4	23.9
PEO13-903	**Peoria**	2013	Beardsley Rd between 83rd Ave and Existing Fiber at 95th Ave and Lake Pleasant Parkway	Installation of Conduit, pull boxes, fiber, and CCTV cameras to connect signals to Central, and monitor traffic and provide real time traffic management on this segment of Beardsley Rd	35	PE-2-E	ATMS01, ATMS03	Infrastructure	1	$700,000	1.6	16,600	15,106	24,170	30.7	6	33.0
PEO13-901	**Peoria**	2013	83rd Ave beginning at Lone Cactus Dr and continuing north to Jomax Rd	Installation of Conduit, pull boxes, fiber, and CCTV cameras to connect signals to Central, and monitor traffic and provide real time traffic management on this segment of 83rd Ave	35	PE-2-E	ATMS01-10	Infrastructure	1	$700,000	3.7	15,500	14,105	52,189	30.7	6	33.0
Phoenix 2014-2	**Phoenix**	2014	Within Phoenix	To extend Phase B Fiber Optic Backbone.8	36	PX-1-E	ATMS03-02	Infrastructure	1	$818,000	770	28,000	25,480	19,619,600	30		35.0
PHXFED07-03	**Phoenix_PH-1**	2011	Citywide following the route of the Phoenix Regional ITS Fiber Optic Backbone	Construct Phoenix Regional ITS Telecommunications Expansion	36	PX-1-I	ATMS03-02	Infrastructure	1	$7,854,600	55	30,000	27,300	1,501,500	23.3	3	27.0
Phoenix 2014-1	**Phoenix**	2014	Within Phoenix	Develop the City of Phoenix ITS Strategic Plan.	36	PX-1-P	ALL	Planning	1	$182,000	770	28,000	25,480	19,619,600	30		35.0
QNCFED-02	**Queen Creek**	2012	Ellsworth Road, 2.5 miles South of Ellsworth Loop to Empire Blvd/Hunt Hwy	Construct Traffic Signal/CCTV System	37	QC-2-E	ATMS01-14, ATMS03-13	Equipment	1	$255,200	2.5	14,000	12,740	31,850	40	3	46.4
QNCFED-01	**Queen Creek**	2009	Rittenhouse Road, 1.5 miles East of Sossaman Rd to 1/2 mile West of Ellsworth Rd	Construct Traffic Signal/CCTV System	37	QC-2-E	ATMS01-14, ATMS03-13	Equipment	1	$172,700	1.6	8,400	7,644	12,230	40	3	46.4
QNC13-902	**Queen Creek**	2013	Various Locations Town-wide	Ten wireless traffic signal connections	38	QC-3-E	ATMS03-13	Infrastructure	1	$105,000	10	31,000	28,210	282,100	30.7	3	35.6
QNCFED07-01	**Queen Creek_QC-1**	2011	Town limits	Implementation of ITS software, hardware and 2 traffic signals	38	QC-3-E	ATMS01-14, ATMS03-13	Infrastructure	1	$386,200	2	20,000	18,200	36,400	23.3	1	29.1
QNCFED07-02	**Queen Creek_QC-2**	2011	Town limits	Purchase and installation of 1 mile of conduit and fiber optic cable and 2.25 traffic signals	38	QC-3-E	ATMS01-14, ATMS03-13	Infrastructure	1	$361,900	2.5	20,000	18,200	45,500	23.3	1	29.1
QNCFED07-03	**Queen Creek_QC-3**	2011	Town limits	Purchase and installation of 1 mile of conduit and fiber optic cable and 2.25 traffic signals	38	QC-3-E	ATMS01-14, ATMS03-13	Infrastructure	1	$361,900	2.5	20,000	18,200	45,500	23.3	1	29.1
QNCFED-03	**Queen Creek**	2008	Queen Creek Town Center	Construct ITS Infrastructure and Traffic Management System	39	QC-4-I	ATMS01-14, ATMS03-13	Infrastructure	1	$563,600	2.7	14,000	12,740	34,398	40	3	46.4
QNC08-803	**Queen Creek**	2009CO	Queen Creek Town Center	Construct ITS Infrastructure and Traffic Management System	39	QC-4-I	ATMS01-14, ATMS03-13	Infrastructure	1	$750,221	2.7	14,000	12,740	34,398	30.7	3	35.6
SCT13-902	**Scottsdale**	2013	Various locations	Last mile connections from City Fiber Network.	40	SC-1-E	ATMS03-10	Infrastructure	1	$350,000	30	50,000	45,500	1,365,000	30.7	3	35.6
SCTFED-06	**Scottsdale**	2012	Shea Blvd to Carefree Highway, 56th Street to 136th Street	Install Dynamic Message Signs	41	SC-2-E	ATMS06-12	Equipment	1	$250,000	16	59,300	53,963	863,408	35	4	37.8

Appendix A

Project#	Jurisdiction	FY	LOC	Work Type	Group	Local Element	Market Package	MAG CMAQ Category	Project Type	Cost	Affected Roadway/Corridor						
											Length**	ADT	AADT	VMT	$Speed_{BEFORE}$	$Speed_{AFTER}$ Category	$Speed_{AFTER}$
SCTFED07-06	**Scottsdale_SC-1**	2011	Shea Blvd to Carefree Hwy and 56th St to 136th St	Install traffic cameras	42	SC-2-E	ATMS01	Equipment	1	$338,000	33.9	34,300	31,213	1,058,121	23.3	5	26.1
SCTFED07-05	**Scottsdale_SC-2**	2011	Scottsdale Rd to Hayden Rd and Shea Blvd to McDowell Rd	Install software, detection equipment, and variable message signs	42	SC-2-E	ATMS01-11, ATMS03-10	Equipment	1	$177,500	14.8	32,300	29,393	435,016	23.3	2	27.4
SCTFED-04	**Scottsdale**	2008	South Scottsdale	Replace Controllers and Cabinets	43	SC-3-E	ATMS03-10	Equipment	1	$750,000	82	19,520	17,763	1,456,582	35	4	37.8
SCT13-903	**Scottsdale**	2009	South Scottsdale	Controller and cabinet replacement	43	SC-3-E	ATMS03-10	Equipment	1	$525,000	82	19,250	17,518	1,436,435	22.1	4	23.9
SCTFED-05	**Scottsdale**	2009	South Scottsdale	Replace Controllers and Cabinets	43	SC-3-E	ATMS03-10	Equipment	1	$750,000	82	19,520	17,763	1,456,582	35	4	37.8
SCTFED-07	**Scottsdale**	2010	South Scottsdale	Replace Controllers and Cabinets	43	SC-3-E	ATMS03-10	Equipment	1	$750,000	82	19,520	17,763	1,456,582	35	4	37.8
SCT12-813	**Scottsdale**	2009CO	Citywide	Acquisition of ITS signal controllers and cabinets	43	SC-3-E	ATMS03	Equipment	1	$467,452	30	35,612	32,407	972,208	30.7	3	35.6
Scottsdale2014	**Scottsdale**	2014	Loop 101 at three intersections, Hayden Road, the 101 Freeway interchange at Pima Rd and 90th Street	1. To identify traffic adaptive signal systems that have been deployed and returned successful outcomes in reducing traffic delay on stated corridors across the country. 2. Deploy the selected system on FLW and complete before and after delay studies. 3. Evaluate if the Adaptive System can minimize delay as well, or better than real-time control of the area signals through the Traffic Management Center and human intervention.	43	SC-3-P	ALL	Planning	1	$39,375	1	41,000	37,310	37,310	18		25.0
SUR13-902	**Surprise**	2013	Various Locations	Installation and integration of ITS Count Stations and DMS's on existing ITS corridors or bridged to adjacent existing corridors	44	SU-1-E	ATMS01, ATMS06, AD1	Equipment	1	$500,000	10	60,000	54,600	546,000	30.7	2	36.1
SURFED-02	**Surprise**	2012	Bell Road, Loop 303 to Jack Rabbit Trail (195th Avenue)	Design and Connect Traffic Signals, CCTV Cameras and Changeable Message Signs	45	SU-2-E	ATMS01-12	Equipment	1	$1,200,000	4	30,000	27,300	109,200	35	1	43.8
SUR13-901	**Surprise**	2013	Cotton Lane from Peoria Ave to Bell Rd	Optical Fiber interconnect of signals, TV cameras, dynamic message signs, and connection to ITS Fibert Backbone	45	SU-2-E	ATMS01-12	Infrastructure	1	$1,000,000	4	14,000	12,740	50,960	30.7	3	35.6
SUR13-903	**Surprise**	2013	Cotton Lane from Peoria Ave to Bell Rd	Optical Fiber interconnect of signals, TV cameras, dynamic message signs, and connection to ITS Fiber Backbone	45	SU-2-E	ATMS01-12	Infrastructure	1	$1,000,000	4	14,000	12,740	50,960	30.7	3	35.6
SUR10-614	**Surprise**	2009CO	Greenway Rd: US 60 (Grand Ave) to Cotton Lane	Construct fiber optic interconnection of traffic	45	SU-2-E	ATMS01-12, ATMS03-11, ATMS06-13	Infrastructure	1	$1,000,000	6	20,000	18,200	109,200	23		29.0
SURFED07-01	**Surprise_SU-1**	2011	Peoria Ave - Litchfield Rd to Jackrabbit Rd	Install fiber optic interconnect to include signals, TV cameras, dynamic message signs, and link to TMC	45	SU-2-I	ATMS01-12	Infrastructure	1	$1,000,000	7	44,000	40,040	280,280	23.3	3	27.0
SURFED-03	**Surprise**	2008	Coyote Lakes & Bell; Dysart & Bell; 134th Avenue & Bell (Bell Road Phase 1 Fiber addition)	Equipment (CCTV cameras) and installation	46	SU-3-E	ATMS01-12	Equipment	1	$20,000	2.5	65,000	59,150	147,875	45	2	52.9
Surprise	**SUR08-806**	2008CO	Bell Road and Coyote Lake, Dysart and 134th Ave	Provide and install CCTV Cameras on existing traffic signals	46	SU-3-E	ATMS01-12	Equipment	1	$28,000	2.5	65,000	59,150	147,875	45	2	52.9
TMPFED-02	**Tempe**	2009	Citywide	Install Video Detection System	47	TE-1-E	ATMS01-13	Equipment	1	$758,330	90	30,000	27,300	2,457,000	35	4	37.8
TMPFED07-04	**Tempe_TE-4**	2011	Citywide	Install wireless communications and CCTV monitoring at 26 intersections	47	TE-1-E	ATMS01-13	Equipment	1	$579,420	88	27,000	24,570	2,162,160	23.3	4	25.2
Tempe	**TMP11-703**	2008CO	Various Locations	Install wireless communications and CCTV monitoring at 26 intersections	47	TE-1-E	ATMS01-13	Equipment	1	$218,400	88	27,000	24,570	2,162,160	23.3	4	25.2
TMP12-804	**Tempe**	2009CO	Citywide	Design and Construct fiber-optic cable installations	47	TE-1-I	ATMS01-12	Infrastructure	1	$361,171	90	30,000	27,300	2,457,000	30	4	32.4
TMPFED-04	**Tempe**	2008	Citywide	Purchase and Install Malfunction Management Units In All Traffic Control Cabinets	48	TE-1-E	ATMS03-12	Equipment	1	$758,330	90	30,000	27,300	2,457,000	35	4	37.8
TMP13-902	**Tempe**	2013	City Wide	Procure and install traffic control cabinets and hardware-Phase 1 of 3	48	TE-1-E	ATMS03-12	Equipment	1	$539,000	25	35,000	31,850	796,250	30.7	4	33.2
Tempe	**TMP09-802**	2008CO	Citywide	Purchase and Install Malfunction Management Units In All Traffic Control Cabinets	48	TE-1-E	ATMS03-12	Equipment	1	$135,950	90	30,000	27,300	2,457,000	35	4	37.8
TMPFED-01	**Tempe**	2010	Citywide	Design and Construct Fiber Optic Cable Installations	48	TE-1-I	ATMS03-12	Infrastructure	1	$758,330	90	30,000	27,300	2,457,000	35	4	37.8
TMP13-903	**Temp**	2009	Citywide	Develop ITS and Communications Strategic Plan	48	TE-1-P	ALL	Planning	1	$115,500	75	35,000	31,850	2,388,750	22.1	4	23.9
TMPFED07-01	**Tempe_TE-1**	2011	Citywide	Install fiber optic connection between ADOT FMS backbone and traffic signal control cabinet at 22 local freeway traffic interchanges	48	TE-1-I	ATMS03-12	Infrastructure	1	$579,420	88	27,000	24,570	2,162,160	23.3	4	25.2
TMPFED-05	**Tempe**	2012	Along Light Rail Transit Corridor in Tempe	Install CCTV Monitoring Stations at Various Locations	49	TE-2-E	ATMS01-13	Equipment	1	$325,832	6	48,000	43,680	262,080	35	4	37.8
TMP12-806	**Tempe**	2009CO	Light Rail Transit Corridor in Tempe	Install CCTV monitoring stations	49	TE-2-E	ATMS01-13	Equipment	1	$425,099	6	48,000	43,680	262,080	32.4	4	35.0
Tempe2014	**Tempe**	2014	Corridors of Elliot/Guadalupe/Warner	This project proposes to use an existing conduit along Elliot for fiber optic communication to the signals. Wireless radios will be used to provide communication to signals along Guadalupe & Warner. CCTVs will be placed at the major intersections for traffic monitoring.	49	TE-2-E	ATMS01, ATMS03	Infrastructure	1	$415,485	13	31,275	28,460	369,983	30		33.0

Notes:

1. Under **FY**, CO = Closeout
2. Under **$Speed_{after}$ Category**, category numbers are derived from Table 6 of the 2010 CMAQ Methodologies