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DRCOG CMAQ Benefits Study Methodology
Guidelines for Data Parameters and Application to Projects

Prepared for

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Transportation Planning and Operations

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1. CMAQ Program Purpose

The primary focus of the Congestion Mitigation Air Quality (CMAQ) program is air quality improvement, reflecting the requirements placed on the transportation sector by the Clean Air Act Amendments of 1990 to help meet national air quality goals. The CMAQ program provides flexible federal funding from the Federal Highway Administration (FHWA) for States to use in nonattainment areas and maintenance areas to help them address air quality concerns from transportation sources. The Denver Regional Council of Governments (DRCOG) administers the CMAQ program in the Denver metro area (DRCOG Metropolitan Planning Area). CMAQ funding is allocated to **projects that contribute to a reduction in emissions** for the following greenhouse gases and pollutants in the DRCOG Metropolitan Planning Area:

- Nitrogen Oxides (NOX) and Volatile Organic Compounds (VOC), which is Ozone, due to non-attainment area status, and
- Carbon Monoxide (CO) and Particulate Matter (PM-10) due to maintenance area status.

In addition, DRCOG also measures Carbon Dioxide (CO2) to respond to the DRCOG Board commitment to reducing greenhouse gases.

Although the FHWA does not specify that States use a particular emissions reduction methodology, it does stipulate that States make sure determinations of air quality benefits are credible and based on a reproducible and logical analytical procedure, and that emissions to be reported in a consistent fashion across projects to allow accurate comparison during project selection and prioritization[1]. In addition, FHWA also requires that States use the latest Motor Vehicle Emissions Simulator (MOVES) emissions model developed by the Environmental Protection Agency to estimate fuel consumption and emissions of greenhouse gases and other pollutants.

2. Overview of CMAQ Benefits Study

In the early CMAQ years, traffic signal retiming projects were the prevalent type of projects and DRCOG (including local stakeholders) developed a standard methodology to identify project related emissions reductions. However, as Transportation Systems Management & Operations (TSM&O) projects, such as; travel time monitoring, C2C between two signal control systems, regional data warehouse, and other projects such as bicycle detection, transit and other "soft" projects (defined in Section 6) have become more prevalent and mainstream, project sponsors have struggled with how to identify and calculate emissions reductions for these types of projects. DRCOG noticed that there was no consistency how project sponsors reported project related air quality and emissions benefits, which was primarily due to not having clear and well defined guidance. Also, in many cases input data needed to calculate air quality and emissions benefits was not readily available and/or accessible to project sponsors. This resulted in frustration to project sponsors struggling to comply with this project requirement to calculate emissions benefits, and to DRCOG having to evaluate a wide range of project methodologies and then select and prioritize projects based on disparate project information. Therefore, DRCOG initiated the CMAQ Benefits Study Project to identify and/or develop a consistent process and methodology that project sponsors could easily apply to a broad range of operational projects to identify project related emission reductions.

The goal of the CMAQ Benefits Study was to **develop a simple, consistent and uniform approach** that can be used by project sponsors to determine projected project emissions/air quality benefits prior to project implementation and actual project emissions/air quality benefits after project implementation, and that

[1] The Colorado Department of Transportation Congestion Mitigation & Air Quality Program 2007-2008 Report.

can be applied equivalently to all types of present and future projects. The terms consistent, simple and uniform within the context of this CMAQ Benefits Study process were defined as follows:

- **Consistent** – Conforming regularly to the same pattern or principle.
    - Project sponsors know what is expected and that project requirements will be applied in a like manner.
- **Simple** – To make easier or less complex being not complicated.
    - The process is easily understood by project sponsors and input data are readily available and accessible.
- **Uniform** – Unchanging and regular application or process.
    - Project sponsors understand that the same requirements apply to all projects.

3. Literature Research Regarding Existing Emissions Tools

A literature search was conducted to identify what types of tools were available to calculate air quality and emissions benefits and to evaluate the practicality and usefulness of the tools in conjunction with the goal of the CMAQ Benefits Study. The literature search, which is attached as **Appendix A**, revealed there are a number of tools that, although primarily calculate project cost/benefit, can be used to calculate air quality emissions benefits. The tools are categorized into three groups that have the following characteristics:

- Sketch Planning Tools – typically use spreadsheets or simply structured databases, and are intended to provide relatively easy and fast analysis of the particular transportation systems management & operations (TSM&O) strategy and often require relatively limited input data.
- Post Processing Tools – more complex and generally include customized interfaces and analysis processes and are intended to link with travel demand models, simulation models or Highway Performance Monitoring System (HPMS) databases, and require more specific data and additional effort to configure and operate.
- Multiresolution/Multiscenario Tools – most complex and require integration of multiple analysis tools such as, combining the analysis capabilities of a travel demand model with a simulation model and requires much broader types of data that may not be readily available.

In conjunction with the CMAQ Benefits Study goals, the following criteria were developed to guide and determine the level of effort that would be applied for further consideration of the tool.

- The level of effort and expertise required by the agency to use the tool including if specialized training and/or software is needed and/or additional agency IT support.
- Data required by the tool and its accessibility and availability.
- Level of accuracy must be commensurate with project requirements and needs.

Based on the project goals and criteria, Post Processing and Multiresolution/Multiscenario tools were excluded from further and more in-depth review and consideration, and the literature search focused on the six Sketch Planning Tools that were identified. Upon further review of the tools, Tool for Operations Benefit/Cost (TOPS-BC) was selected to perform a proof of concept analysis because:

- It addressed most of the typically recognized TSM&O strategies, such as; traveler information, traffic incident management, ramp metering systems, CCTV, advanced traffic demand management, etc.
- It can be used to calculate emissions benefits.
- It was developed and is supported by FHWA.

- Other Sketch Planning Tools were either no longer supported, only applied to very limited strategies, such as; employer based TDM programs, freeway service patrol, converting freeway lanes to toll facilities or required user to input California area-specific data.

4. TOPS-BC Proof of Concept

TOPS-BC was developed to provide support and guidance to conduct benefit/cost analysis of a wide range of TSM&O strategies. It is structured in a modular format (tabs) that identifies certain TSM&O strategies to calculate cost and to calculate benefits. In performing the proof of concept the first step was to align the 13 projects that were selected as part of the DRCOG FY14-FY17 ITS Pool Program as closely as possible with the relevant TOPS-BC module cost and benefit tabs (see **Attachment A**). One project was not able to be aligned because there was no relevant TSM&O strategy and two projects were aligned with TSM&O strategies that were less than ideally relevant due to TSM&O strategy limitations. Following this an assessment of the required cost and benefit data inputs was performed to identify the number of data inputs, the potential source and owner of data, the accessibility of the data to project sponsors and the level of difficulty that project sponsors would likely encounter to access the data. There was nine cost data inputs and 76 benefit data inputs for a total of 85 cost/benefit data inputs. Although many of the benefit data inputs allowed for use of available default data, the default data was as of 2010. The level of difficulty that project sponsors would likely encounter in accessing the data inputs was determined based on the following:

- Easy – input is readily available in system or records
- Moderate – in a system, but no direct access
- Difficult – not in a system or unknown

Thirty eight data inputs were determined as Easy, 19 data inputs were determined as Moderate and 28 data inputs were determined as Difficult (see **Attachment B**, which can be accessed by "clicking" on the paperclip that is displayed on the upper left-side of this document). Also, it was determined there was potentially 18 different sources that might have to be used to get the data, for which a source could not be identified for 16 data inputs (see **Attachment C**) and at least eleven different owners of the data (see **Attachment D**).

TOPS-BC can be used to formulate a very comprehensive project cost analysis including, lifecycle capital and operations and maintenance costs, average annual cost, forecasted stream of cost and the net present value of the costs and project benefit analysis including, hours of travel saved, hours of non-recurring delay saved, fuel savings and number of crashes reduced and value of reduced crashes resulting in a project cost/benefit ratio. However, the project sponsor would still need to extract certain data inputs to calculate project related air quality and emissions benefits. Also, based on using TOPS-BC for this exercise, it was determined that TOPS-BC would require that project sponsors spend a significant amount of time reviewing and learning the TOPS-BC User's Manual, and working with the tool to understand it and become proficient in applying it to projects. In addition, the tool does not contain modules for "soft" projects, which is very concerning as these types of projects have increased, and are expected to continue to increase over the coming years.

Therefore, based on these findings it was decided that TOPS-BC did not meet the goal of the CMAQ Benefits Study and should not be used to calculate project related air quality and emissions benefits, but using TOPS-BC revealed that there was a small, yet essential, number of data input parameters that could be applied to any project to calculate air quality and emissions benefits.

5. Emissions Reduction Data Parameters

Emissions/air quality benefits and fuel consumption benefits only result due to an increase in average speed of traffic or conversely a reduction in stopped delay, which in both cases result in a reduction in link travel time. To assist project sponsors to identify and calculate projected emissions benefits for projects submitted as part of the DRCOG ITS Pool Program, the following data parameters, which are essential to calculate emissions benefits for any project, were identified:

- Segment(s) and/or Corridor(s) Length
- Impact Period for Project (daily and annual)
- Traffic Volumes
- Current Speed or Stopped Delay (existing condition)
- Estimated Increase in Average Speed or Reduction in Stopped Delay (projected for after condition)

6. Project Process to Determine Emissions Reduction and Related Data Parameters

As shown in Section 5, the emissions reduction data parameters are fundamental in order to determine emissions/air quality benefits. However, prior to calculating emissions/air quality benefits it is imperative to carefully articulate the purpose of the project so that it is clear what the project will accomplish, and to determine and define the project impact landscape, both in terms of scope (project benefits) and geographical area (extent of the project), as this is an essential first step to confirm that the project is viable and to identify the appropriate increase in speed or reduction of stopped delay value to estimate emissions/air quality benefits. **Figure 1** shows the described process with additional explanation below.

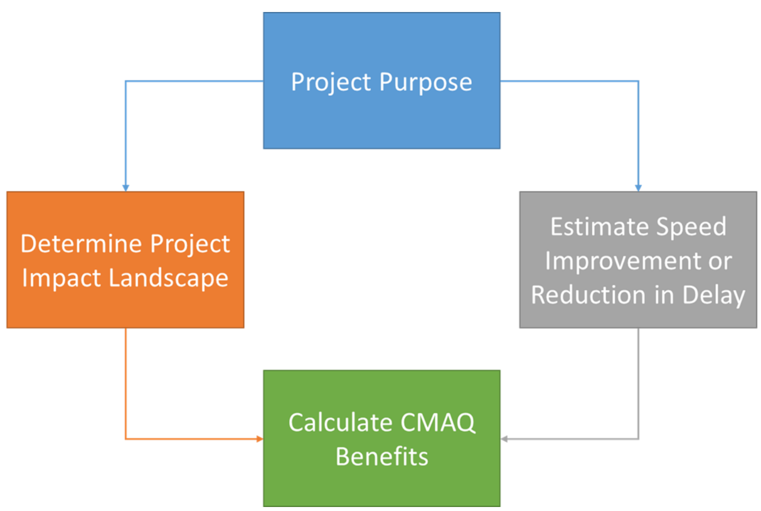

Figure 1: CMAQ Project Process

The project process as illustrated is a very high-level summary. It is not meant to imply that it covers the entire project process or all project related information required within the DRCOG project application, but rather to highlight several critical elements that are crucial within the project development process so that the project sponsor can accurately define the project and related benefits and DRCOG can critically assess the project.

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Certain projects lend themselves better than others with regard to data being applicable and readily available for each data parameter. There were two challenges that needed to be resolved:

- How to apply data parameters representatively to complex traditional traffic operations projects and “soft” projects, such as; studies, guidelines, software upgrades, etc., and
- How to apply data parameters to other future projects that were not submitted as part of the DRCOG ITS Pool Projects (FY14 – FY17), but that are expected to become more prevalent in future years, such as; transit, bike/pedestrian, intersection operations (new turn lanes), vehicle fleets, alternative fuels and Transportation Demand Management (TDM), and
- What is a reasonable estimated increase in speed or reduction in stopped delay that is projected to be realized once the project is implemented. More information regarding reasonable estimated increase in speed is provided in Section 7.

For purposes of this methodology all projects that were submitted as part of the DRCOG ITS Pool Projects (FY14 – FY17) were assessed to identify similarities with regard to data availability and applicability for each data parameter, including other future projects that were not submitted. Based on the similarities, the projects were categorized and defined as follows:

- **Traditional Traffic Operations Projects** – These projects are typically implemented at a site on a roadway or within a corridor segment, and are well defined in terms of location (segment or corridor) and impact period such that traffic volumes are easily applied. These projects require the least amount of work in applying the data parameters due to the limited and relatively confined nature of the project. Application of the data parameters is very straight forward once the data is collected and requires very minimal to no data manipulation prior to application. There are typically many documented benefit studies for these projects.
- **Complex Traditional Traffic Operations Projects** – These projects typically involve higher functionality and are typically implemented on one or more corridors. Due to the extensive nature of the project, application of the data parameters is not straight forward as more data is needed. There are few studies that document benefits for these projects.
- **Soft Projects** – These projects include training, studies, software upgrades and others that are not typically implemented directly on the roadway system. Due to the nature of the work being performed, application of the data parameters is very difficult. Also, there are no studies that document benefits for these projects.
- **Other Future Projects** – These projects are becoming more mainstream and are expected to be part of the projects that are submitted on a more frequent basis in the upcoming years. Due to the abstract nature of these projects many of the data parameters identified will not apply, and other data parameters will need to be supplemented. FHWA performed a study[2] to evaluate the cost-effectiveness of CMAQ eligible project types. The study reviewed more than 2,000 projects, which were categorized into 19 project types, several of which correlate to the Other Future Projects. It is recommended that at the time projects in this category are submitted, the project sponsor should consult the study to identify applicable data parameters to calculate project related air quality and emissions benefits. More information regarding the study is provided in Section 7.

[2] Congestion Mitigation and Air Quality (CMAQ) Improvement Program, Cost Effectiveness Tables Development and Methodology, December 3, 2015

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Table 1 shows all of the DRCOG ITS Pool Projects (FY14 – FY17), regardless if the project was selected, grouped by category as identified above, including Other Future Projects. This is to illustrate the range of projects that were submitted and how challenging it is to establish a consistent methodology.

Table 1: DRCOG ITS Pool Projects (FY14 – FY17) and Other Future Projects by Project Category

Project Category	Project	Application of Data Parameters
Traditional Traffic Operations Projects	• Traffic signal system replacement/upgrade • Traffic Responsive Control • Traffic Adaptive Control • Extend reach of signal system control • Install UPS at intersection • Flashing Yellow Arrow implementations • Bicycle detection • Fiber Interconnect (traffic signals on corridor) • Ramp Metering (advanced functionality) • Replace/upgrade ramp metering system	• Easy and generally straight forward • Many previous studies with documented benefits
Complex Traditional Traffic Operations Projects	• ATM elements • System Monitoring – CCTV/system detectors • Travel time monitoring system • Driver feedback signs • Upgrading communications from serial to Ethernet • Upgrade SONET field communications system	• Harder and not as straight forward • Few previous studies with documented benefits
Soft Projects	• Public Safety CADD Interface • Incident Management Training • C2C Feasibility Study (fiber interconnect between two signal systems • CTMS software revision for travel time monitoring • Regional Data Warehouse/Cognos Licensing • Performance Monitoring System • Purdue Coordination Diagrams	• Very difficult and not straight forward • No previous studies with documented benefits
Other Future Projects	• Transit • Bike/pedestrian • Intersection operations (new turn lanes) • Vehicle fleets • Alternative fuels • Transportation Demand Management (TDM)	• Conventional data parameters do not apply • Consult FHWA study identified above

In looking at Table 1, the following items are very obvious.

- Although data may be available for projects within each project category, application of the data may be incrementally more difficult for Complex Traditional Traffic Operations Projects and Soft Projects.
- An estimated increase in speed is necessary to calculate an emissions/air quality benefit for all projects; except projects specifically designed to reduce stopped delay, such as; Flashing Yellow Arrow implementations and others (possibly Incident Management projects) that will not apply an estimated increase in speed, but will apply estimated reduction in stopped delay to calculate emissions/air quality benefit.
- Other Future Projects, due to the nature of the projects, require some different and/or additional data parameters to calculate emissions/air quality benefits.

7. FHWA Study to Evaluate CMAQ Projects Cost-Effectiveness in Reducing Pollutants

Moving Ahead for Progress in the 21st Century Act (MAP-21) required FHWA to perform a study to evaluate the cost-effectiveness of CMAQ eligible project types by criteria pollutant and develop a table showing such information[3]. To fulfil that requirement, Volpe National Transportation Systems Center prepared *Congestion Mitigation and Air Quality (CMAQ) Improvement Program, Cost-Effectiveness Tables Development and Methodology*, dated December 3, 2015. **MAP-21 also requires that MPOs consider the table(s) when selecting projects or developing performance plans** [bold added].

As mentioned above, the study reviewed more than 2,000 projects that were categorized into 19 project types. The study showed cost-effectiveness estimates, represented in terms of dollar per ton of pollutant reduced, across a range of five criteria pollutants for each project type by median-cost effectiveness and the lowest project cost. The study developed a methodology and identified relevant data parameters for each project type to perform the analysis.

In conjunction with this DRCOG CMAQ Benefits Study, a Summary and Comparison with DRCOG CMAQ Prototype Projects (seven prototype projects were selected to apply CMAQ Benefits methodology and data parameters) and the FHWA CMAQ Projects Cost-Effectiveness Study was conducted to determine the soundness, reasonableness and credibility of the CMAQ Benefits methodology and process. The Summary and Comparison with DRCOG CMAQ Prototype Projects is attached as **Appendix B**, which also provides further detail regarding the FHWA CMAQ Projects Cost-Effectiveness Study.

Of particular interest was that the FHWA CMAQ Projects Cost-Effectiveness Study regarding projects in the project type identified as Intelligent Transportation Systems/Intersection Improvements, which is the category that most of the DRCOG CMAQ Program projects fit into, found that:

> *"Distinct to other project types, each of the intersection improvement scenarios involved a specific improvement in travel speeds (or a reduction in delay, in the case of left-turn lanes), **generally around five miles per hour** [bold added] (from bases ranging from 15 to 40 miles per hour). In all, 20 scenarios were included in the analysis."*[4]

[3] 23 U.S.C. Sec. 149, (i)
[4] The FHWA CMAQ Projects Cost-Effectiveness Study - Page 67

This appeared to validate the 5 miles per hour (MPH) increase in speed, which was applied to the DRCOG CMAQ prototype projects to calculate air quality and emissions benefits. Subsequent to this, DRCOG performed an analysis of traffic signal timing benefits for all projects from 2010 to 2015 for all periods, and concluded that there was an average speed increase of about 3.5 MPH fairly consistent from period to period, year after year with a fairly consistent mean and fairly consistent standard deviation. Because the transportation system is mature and improvements are being made to fairly well-maintained corridors, 3.5 MPH seems to be a reasonable estimated increase in speed and is therefore recommended as the default value in Section 8.6.

Finally, the Summary and Comparison with DRCOG CMAQ Prototype Projects concluded that:

> *. . . . the DRCOG CMAQ Prototype Project methodology and data parameters is a sound process that provides reasonably quantifiable emissions/air quality benefits and project cost-effectiveness with respect to reducing subject pollutants. The DRCOG CMAQ Prototype Projects methodology and data parameters seem to be very consistent with the Study methodology and data parameters, which provides a creditable validation and a very high-level of confidence with the DRCOG CMAQ Prototype Projects methodology and data parameters and the process.*

8. Recommended Guidelines for Data Parameters and Applying Data Parameters to Projects

As mentioned earlier, for a project to be eligible for CMAQ funding it must demonstrate an emissions/air quality benefit, which will only result from an increase in speed or a reduction in stopped delay for most projects. Other Future Projects will need to identify other applicable data parameters associated specifically with the project.

Although the same data parameters will be used for every project; except for Other Future Projects, they will be applied based on the project type in conjunction with the project category. Project sponsors will be responsible to obtain the data for each data parameter, and will have to exercise judgment in determining how each data parameter best applies to the specific project.

The Guidelines are meant to assist project sponsors by providing a standard framework, data parameters and process that can be applied to projects in a consistent manner to calculate air quality and emissions benefits. To that extent the Guidelines meet the FHWA requirements that:

> *States make sure that determinations of air quality benefits are credible and based on a reproducible and logical analytical procedure, and that emissions to be reported in a consistent fashion across projects to allow accurate comparison during project selection and prioritization.*

Project sponsors always have the flexibility to use additional or other data parameters and related data from case studies or other substantiated sources that may be more relevant to the specific project based on project sponsors judgment. It is the responsibility of project sponsors to determine the most appropriate data parameters that should be applied to a specific project, and it is also the responsibility of project sponsors to ensure and justify that the data is both relevant and credible.

To assist project sponsors the following outlines a step-by-step process, which coincides with the attached **CMAQ Benefits Methodology Emissions Spreadsheet** that is explained in Section 9, regarding how the data parameters will be applied to projects within each project category, and identifies recommended guidelines pertaining to the data parameters and the data source(s) that can be used to obtain data for each data parameter. Other Future Projects are not included within this step-by-step process.

8.1 Step One: Project Sponsor Must Identify the Project Corridor(s) and Segment(s)

For both Traditional Traffic Operations Projects and Complex Traffic Operations Projects it should be relatively easy to identify the project corridor(s) and segment(s) as these projects are usually implemented on the roadway system. It is more difficult for Soft Projects because it requires that the project be associated to the applicable roadway system. This requires judgment on the part of the project sponsor and may require use of a surrogate, but related, project application in order to make a reasonable roadway association to the project.

As an example, a project such as the Regional Data Warehouse/Cognos Licensing that developed a regional data warehouse and issued Cognos licenses to users to access the data warehouse and generate reports was associated to the roadway system based on the corridors identified in Cognos, within the DRCOG MPO, due to the fact that these corridors are being reported on the Cognos system.

Soft Projects require more work than Complex Traditional Traffic Operations Projects due to the need to first identify a reasonably related project application that can be used to associate the project to the applicable roadway system.

8.2 Step Two: Project Sponsor Must Determine the Project Corridor(s) and Segment(s) Length

Once the project corridor(s) and segment(s) have been identified the lengths can be determined for each corridor(s) and segment(s). Corridor improvement projects that apply to more than one corridor should use the segment length for each of the corridors.

Guidelines:
Depending on the project, the segment length could include the following:

- Limits of the corridor
- Signal spacing for arterials
- Left turn bay length for Flashing Yellow Arrow implementations
- Ramp spacing for freeways

Data Source:
For state highways CDOT Online Transportation Information System (OTIS) provides highway and traffic data. For non-state highway local roadways the respective jurisdiction should have the segment length data. Alternatively, local project sponsor data sources or Google could provide this information.

8.3 Step Three: Project Sponsor Must Identify Impact Period for Project

For most projects the impact period is obvious, as the project is designed to provide an operational improvement for a specific problem. For other projects that the impact period is not as clear, the project sponsor will have to use judgment to determine the most appropriate impact period for the project including by direction, if applicable. If projects make improvements during periods other than in the peak period(s) they can use the specific time period when the project would demonstrate improvements. This is very important as the traffic volume(s) will be used for the impact period identified including by direction, if applicable. For example, a ramp metering project impact period would be peak period for the direction of travel onto the roadway.

Guidelines:
The time period for which the project is specifically implemented or expected to show improvement. The impact period consists of three components:

- Daily Impact Period,
- Direction and
- Annual Impact Period

The following identifies several options that should be considered regarding each impact period component:

Daily Impact Period – the time during the day that the project is specifically designed to improve operations.

- All day, i.e., 24 hours
- Peak period(s)- AM (6-9) or PM (3-6)
- Off-peak period(s)- (9AM-3PM) or (6PM-10PM)
- During the day- 6AM to 6PM
- Specific corridor peak period – (For example I-70 west peak period is westbound Saturday morning and eastbound Sunday afternoon)

Because CMAQ benefits are only realized during periods when speeds are 50 MPH or less for CO and 49 MPH or less for VOC, respectively (55 MPH or less for CO2 and 37 MPH or less for NOX, respectively)[5], it is recommended that projects focus on improvements during peak periods, i.e., both AM (6-9) and PM (3-6) for weekdays, regardless if the project provides improvements during other periods that may have higher speeds.

Direction – the direction, if applicable, during the daily impact period that the project is most likely to improve operations.

- Northbound
- Southbound
- Eastbound
- Westbound

Annual Impact Period – the annual time period that the project is specifically designed to improve operations.

- Weekday only, i.e., annualized with 250 days
- Weekend only, i.e., annualized with 104 days
- Every day, i.e., annualized with 365 days

Data Source:
Project sponsor will determine the impact period for the project in accordance with the purpose and intent of the project.

[5] MOVES2014a using the 2015 MOVES2014a modeling assumptions.

8.4 Step Four: Project Sponsor Must Obtain Traffic Volume(s) for the Project Corridor(s) and Segment(s) during Daily Impact Period

Traffic volume(s) will need to be obtained for the corridor(s) and segment(s) during the Daily Impact Time-Period of the project including by direction, if applicable.

Guidelines:
Traffic volume at the project implementation site or traffic volume(s) on a corridor or corridors, as applicable, regarding the project. Depending on the length of the corridor it may be necessary to average segment traffic volumes.

Data Source:
For state highways CDOT Online Transportation Information System (OTIS) provides highway and traffic data. For non-state highway local roadways the respective jurisdiction should have traffic volume data.

8.5 Step Five: Project Must Obtain Speed (actual) or Stopped Delay for the Corridor(s) and Segment(s) during Daily Impact Period

Speed or reduction in stopped delay will need to be obtained for the corridor(s) and segment(s) during the Daily Impact Period of the project including by direction, if applicable. This will provide the project actual baseline speed or reduction in stopped delay to which the estimated increase in speed or the projected reduction in stopped delay will be used to calculate the projected emissions/air quality benefit.

Guidelines:
Speed data will be for the corridor or segment length during the Daily Impact Period including by Direction, if applicable, for the project. Reduction in stopped delay will be provided by the project sponsor based on travel runs or other verifiable data modeling or analytical related projects.

Data Source:
For all roadways INRIX provides speed data based on user selected parameters including; segment limits, time of day, roadway direction and others. It should be for applicable weekday or weekend time period. If weekday is applicable, speed should be calculated based on monthly average from Tuesday to Thursday. If weekend is applicable, speed should be calculated based on monthly average for Saturday and Sunday.

Flashing Yellow Arrow implementation projects primary purpose is not to increase speed but to reduce stopped delay (Stop Delay Concept). Therefore, rather than speed project sponsors will need to consider/collect the following information to calculate emissions/air quality benefits for Flashing Yellow Arrow projects:

- If a vehicle is stopped, it means the speed is 0 MPH
- The amount of time a vehicle is stopped is stopped delay
- The project would need to collect before condition stopped delay in the field
- The project would need to reasonably predict reduction in stopped delay using published technical studies or other verifiable case studies
- Segment length is not applicable for Flashing Yellow Arrow implementations

8.6 Step Six: Apply Estimated Increase in Speed (projected)

The challenges with determining the estimated increase in speed have been discussed above in the assessment.

Guidelines:
To proceed with a simple, uniform and consistent process, all projects should assume an estimated increase in speed of 3.5 MPH, which is reasonable as a starting place; except projects that are specifically designed to reduce stopped delay such as; Flashing Yellow Arrow projects that should use the Stop Delay Concept identified above in Step Five. Other incident management related projects may also choose to use stopped delay, and in which case should consult page 100 of the FHWA *Congestion Mitigation and Air Quality (CMAQ) Improvement Program, Cost-Effectiveness Tables Development and Methodology*, dated December 3, 2015.

Data Source:
Project sponsor will use 3.5 MPH for all projects.

8.7 Step Seven: Project Must Identify Project Cost and Project Life Cycle

Project cost is necessary to calculate dollars per ton for each criteria pollutant reduced on an annual basis. Project cost should include CMAQ funds and, if applicable, required matching local funds. Project life cycle is needed to calculate the total benefit of tons for criteria pollutant reduced over the project life cycle including dollars per ton for each criteria pollutant reduced over the project life cycle. Examples of project life cycles can be found on page 40 of the FHWA *Congestion Mitigation and Air Quality (CMAQ) Improvement Program, Cost-Effectiveness Tables Development and Methodology*, dated December 3, 2015.

8.8 Step Eight: Calculating Project Emissions/Air Quality Benefits

By following the steps above, the project sponsor has the following data

- Corridor (s)
- Segment(s) and/or Corridor(s) Length
- Impact Period for Project (daily and annual)
- Traffic Volumes by direction and by impact period
- Current Speed or stopped delay (before condition) by direction and by impact period
- Estimated Increase in Speed or stopped delay (projected for after condition) by direction and by impact period
- Project Cost
- Project Life Cycle

9. Inputting Project Data Parameters in CMAQ Benefits Methodology Emissions Spreadsheet

The CMAQ Benefits Methodology Emissions Spreadsheet contains two project samples: Travel Time Monitoring based on an increase in speed and Flashing Yellow Arrow based on a reduction in stopped delay. The project sponsor can use the appropriate project sample as a template for their project. The Spreadsheet can be accessed by “clicking” on the paperclip that is displayed on the upper left-side of this document. The Spreadsheet also contains the Emission Curves[6] table, which is used to determine the output rates for each criteria pollutant. The following provides a summary overview regarding how to use the Spreadsheet (it is assumed that the user has proficient working knowledge and ability with Excel) to input project related data obtained as identified in Section 8.

[6] MOVES2014a using the 2015 MOVES2014a modeling assumptions.

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- Review the project samples to determine which sample best reflects how project related emissions benefits will be calculated, i.e., an increase in speed or a reduction in stopped delay for the project.
- Create a project sheet for the project and copy the desired project sample into the project sheet (rename created project sheet tab with name of project).
- Do not change the name of Emission Curves tab as it is used as a “look up” table for the project sheet(s).
- Insert project related data obtained in Section 8 only in the appropriate areas (columns and rows)/cells (highlighted in yellow) on the project sheet. Additional corridor and segment data may be added above the line identified on the project sheet.
- If additional corridor and segment data is added, copy formulas from row above for each criteria pollutant (columns K through AK) for increase in speed projects including after speed (column I), and (columns K through AG) for reduction in stopped delay projects. Only delete rows of data that will not be used in the project.
- Default values highlighted in green should not be changed unless substantiated by project sponsor.
- On the Emissions Benefits Summary Table in the project sheet, ensure that formula includes all rows for each criteria pollutant Benefit on the project sheet.
- Once data has been inputted into the project spreadsheet and all corresponding formulas have been copied, and the formula has been updated in the Emissions Benefits Summary Table to include all rows for each criteria pollutant Benefit on the project sheet, the air quality and emissions benefits including cost-effectiveness over the project life cycle will be calculated in the Emissions Benefits Summary Table.

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ITS Pool Prioritization (1)	Project Purpose Category	2014 - 2017 Projects (2)	Agency	TOPS BC Module (3)
Prepare and implement regional traffic incident management system improvements *(Priority Level 1)*	Traffic Incident Management Improvements	Incident Management Systems	CDOT Real-Time Traffic Management Branch	Traffic Incident Management – FSP
		Public Safety CADD Interface	CDOT ITS Branch	Traffic Incident Management – FSP
Extend and expand traffic monitoring infrastructure and capability *(Priority Level 2)*	System Monitoring Improvements	Implement System Monitoring: CCTV, system detectors		Supporting Strategies - CCTV
		Travel Time Monitoring System	• Arapahoe County • Centennial • Denver • Greenwood Village • Lakewood	Advanced Traffic Demand Management
		CTMS software revision for Travel Time Monitoring	CDOT ITS Branch	Traveler Information
		ATM elements		Advanced Traffic Demand Management
Prepare and implement projects that facilitate coordinated operations across multiple jurisdictions *(Priority Level 3)*	Data Integration & Performance Management Improvements	Regional Data Warehouse	CDOT ITS Branch	N/A
		Performance Monitoring System		N/A
Prepare and implement projects that facilitate coordinated operations across multiple jurisdictions *(Priority Level 3)*	Communication System Improvements	Upgrading communications from serial to Ethernet		N/A
		Upgrade SONET field communications system		N/A
Prepare and implement project that improve work	Work Zone Management Improvements			

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ITS Pool Prioritization (1)	Project Purpose Category	2014 - 2017 Projects (2)	Agency	TOPS BC Module (3)
zone/special event management *(Priority Level 4)*				
Prepare and implement project that expand operational capabilities *(Priority Level 5)*	Traffic Signal & Ramp Metering System(s) Operational Improvements	Traffic signal system replacement/upgrade	Thornton	Traffic Signal Coordination – Central Control
		Purdue Coordination Diagrams		Traffic Signal Coordination – Traffic Actuated
		Extend reach of the system control		Traffic Signal Coordination – Central Control
		Install UPS at intersection		Traffic Signal Coordination Systems – Preset Timing
		Flashing yellow arrow implementations		Traffic Signal Coordination – Actuated
		Traffic Responsive Control Implementation		Traffic Signal Coordination – Actuated
		Traffic Adaptive Control implementation		Traffic Signal Coordination – Actuated
		Ramp Metering (advanced functionality)	CDOT Region 1	Ramp Metering Systems – Traffic Actuated
		Bicycle Detection		Supporting Strategies – Loop Detection
		Implement C2C between two signal control systems	Denver	Traffic Signal Coordination – Central Control
		Replace/upgrade ramp metering system	CDOT Region 1	Ramp Metering Systems – Central Control
		Driver Feedback Signs		Traveler Information - DMS

1. DRCOG Regional Intelligent Transportation Systems Deployment Program, Adopted June 2014, Appendix A (Priority Table).
2. List of Projects Submitted to DRCOG for 2014 through 2017 ITS Pool. Projects highlighted in yellow were selected (Table 5 – DRCOG RITS Deployment Program).
3. TOPS B/C is a sketch-planning level decision support developed by FHWA Office of Operations. It can be used to conduct benefit/cost analysis on TSM&O strategies including, travel time and speed, throughput, safety, emissions, energy, costs, efficiency and other.

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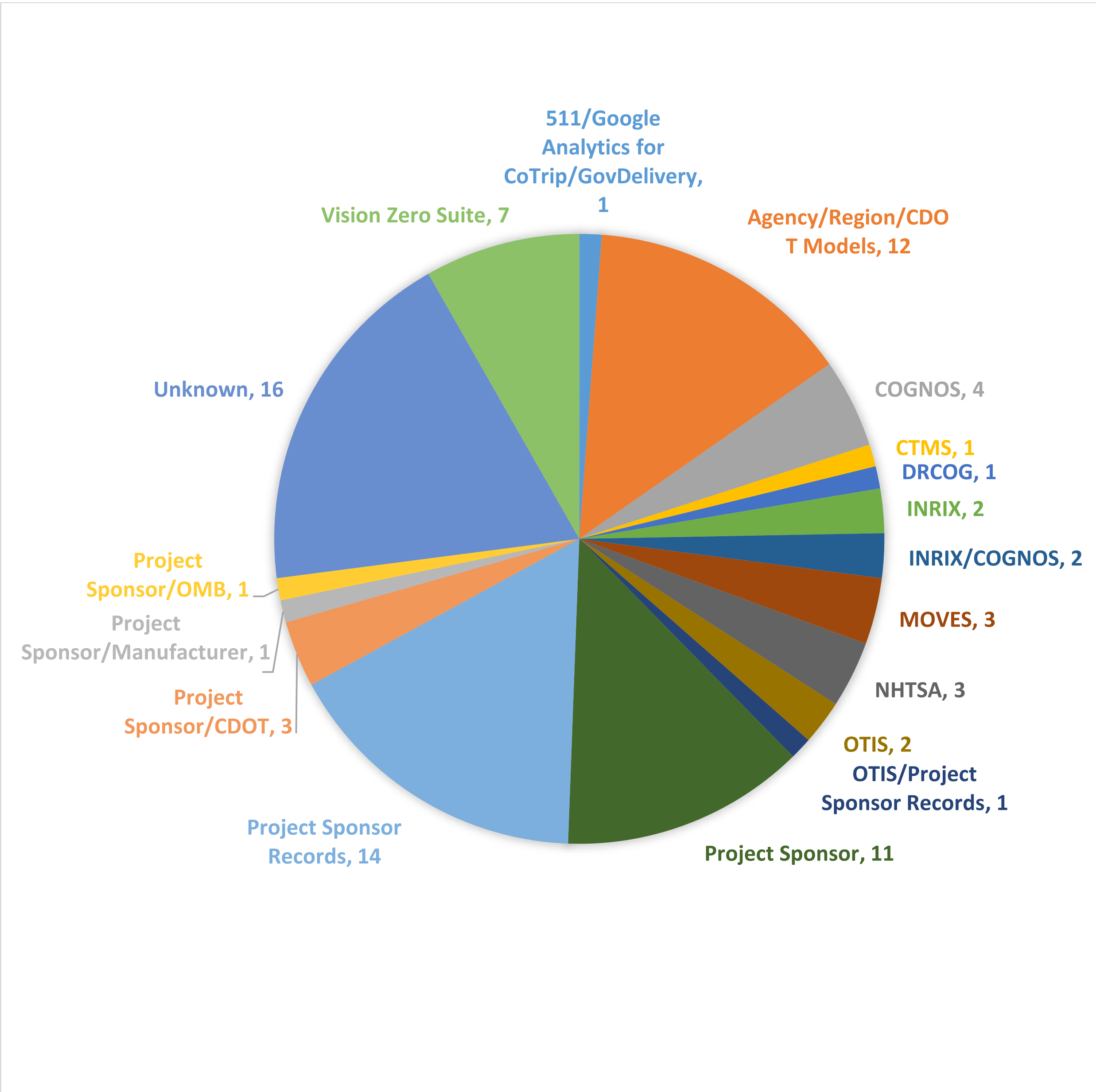

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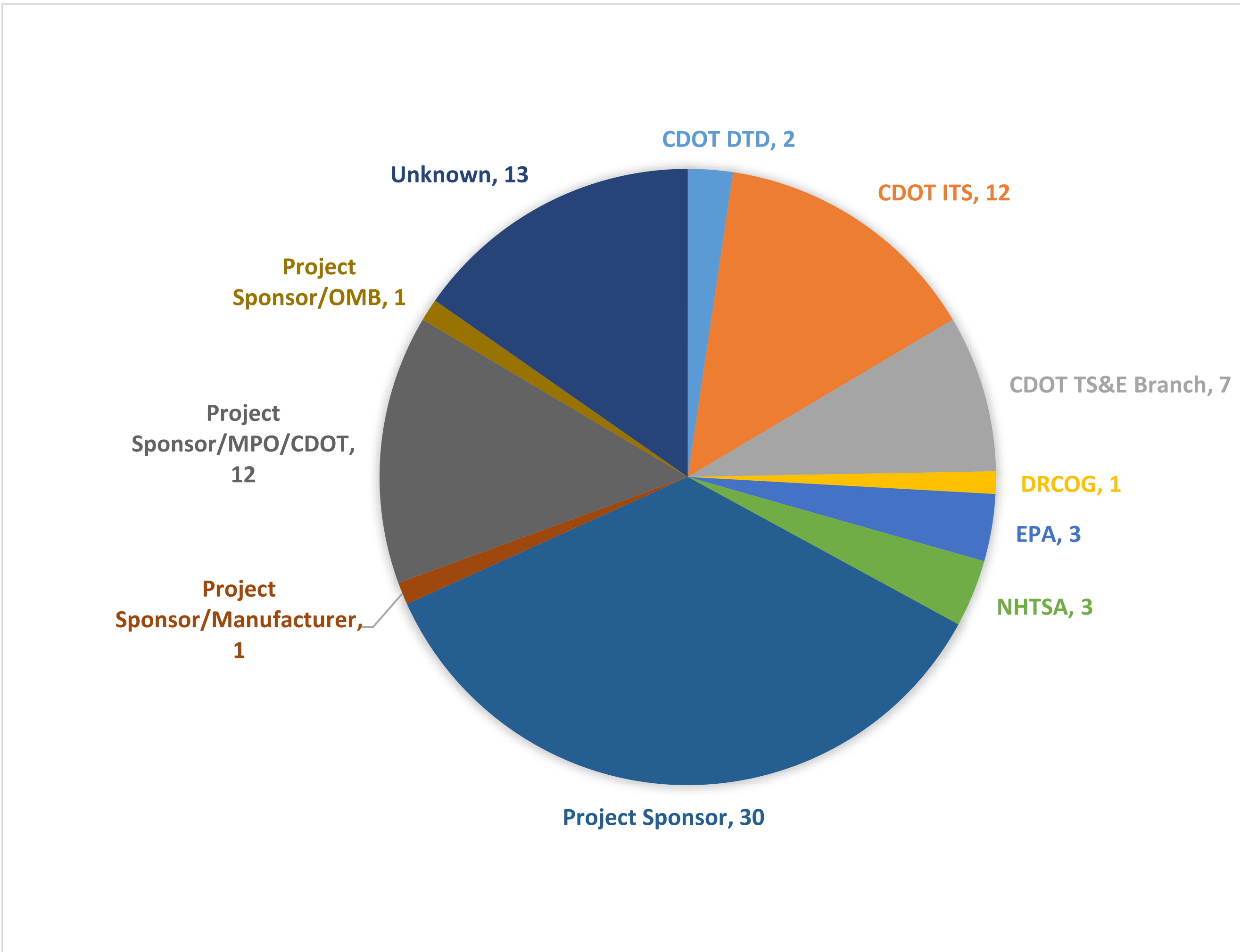

ATTACHMENT 2

CMAQ Benefits Study
Literature Research Findings

1. Overview of the CMAQ Program

Congress established the Congestion Mitigation Air Quality (CMAQ) program in the early 1990s under the Intermodal Surface Transportation Efficiency Act (ISTEA), and expanded and continued it to the present under subsequent Transportation Authorization Bills. The primary focus of the CMAQ program has been on air quality improvement, reflecting the requirements placed on the transportation sector by the Clean Air Act Amendments of 1990 to help meet national air quality goals. The CMAQ program provides flexible funding for States to use in nonattainment areas and maintenance areas to help them address air quality concerns from transportation sources.

Federal CMAQ funds, as part of the Federal Transportation Authorization Bill, are appropriated to CDOT to carry out and discharge CMAQ program responsibilities. The Transportation Commission, by adoption of resolutions, has delegated program administration to three eligible metropolitan planning organizations (MPO) and five rural PM-10 areas, including their funding allocations and other program recipient requirements.

2. DRCOG CMAQ Program

The Denver Regional Council of Governments (DRCOG) MPO administers the CMAQ program in the Denver metro area (DRCOG Metropolitan Planning Area). The primary requirement for CMAQ funded projects or programs is that they must identify emissions reductions. In the early CMAQ years, traffic signal retiming projects were the prevalent type of projects and DRCOG (including local stakeholders) developed a standard methodology to identify project related emissions reductions. However, as Transportation System Management & Operations (TSM&O) projects, such as; travel time monitoring, C2C between two signal control systems, regional data warehouse, bicycle detection and others have become more prevalent and mainstream, Project Sponsors have struggled with how to identify and calculate emissions reductions for these types of projects. Therefore, DRCOG initiated the CMAQ Benefits Study Project to identify and/or develop a consistent process and methodology that Project Sponsors could easily apply to a broad range of operational projects to identify project related emission reductions.

3. Purpose of the CMAQ Benefits Study Project

The purpose of the CMAQ Benefits Study Project is:

> *To develop a simple, consistent and uniform approach so Project Sponsors can identify and calculate emissions benefits, project cost/benefits and other related performance measure benefits, both before and after project implementation.*

The Federal Highway Administration (FHWA) does not specify that States use a particular emissions reduction methodology, FHWA stipulates that States make sure determinations of air quality benefits are credible and based on a reproducible and logical analytical procedure. FHWA requires emissions to be reported in a consistent fashion across projects to allow accurate comparison during project selection and prioritization[1]. In addition, FHWA also requires that States use the latest Motor Vehicle Emissions Simulator (MOVES) emissions model developed by the Environmental Protection Agency to estimate fuel consumption and emissions of greenhouse gases and other pollutants.

[1] The Colorado Department of Transportation Congestion Mitigation & Air Quality Program 2007-2008 Report.

4. Literature Research of Existing Tools and Applications

Literature research has revealed there is numerous analyses tools and methodologies that have been designed for conducting benefit/cost (B/C) analysis of one of more TSM&O strategies and projects (some TSM&O strategies are shown in Section 5.3). These include tools developed by regional, state, and Federal agencies, as well as proprietary tools developed by many private-sector enterprises; and range from simple methods intended for one-time analysis to more complex tools that are continually maintained and updated that form a continuing standardized framework for conducting B/C analysis for various agencies[2]. Benefit/cost analysis is an extremely important and valuable component within project development; however, pursuant to 23 USC 149 CMAQ funded projects or programs must reduce Carbon Monoxide (CO) and Particulate Matter (PM-10), and Nitrogen Oxides (NOx) and Volatile Organic Compounds (VOC), which are precursors to ozone, emissions from transportation related projects or programs. This fundamental requirement narrowed the analyses tools to several of the most widely distributed tools that either calculate emissions benefits or allow the user to calculate emissions benefits from other benefit data that is calculated by the tool, which is then used to calculate emission benefits. As mentioned, the tools range from simple to very complex, but can generally be segmented into the following three broad categories: Sketch Planning, Post Processing and Multiresolution/Multiscenario. **Table 1** shows the tool category, description and some advantages and concerns related to each tool category.

Table 1: Benefits/Cost Analysis Tools Category and Description

Tool Category	Description	Advantages	Concerns
Sketch Planning	Typically use spreadsheets or simply structured databases, and are intended to provide relatively easy and fast analysis of the particular TSM&O strategy and often require relatively limited input data, e.g., basic aggregated volume and speed.	• Simple, quick and low cost estimation of TSM&O strategy • Rely on generally available input data • Static default relationships between strategies and their impact on limited number of MOEs • Ability to customize and make adjustment to default parameters	• Lack rigor of more advanced analysis methods • Limited set of MOEs, reducing comprehensive B/C analysis • Assumes static, linear reactions of travelers in deployed strategies; does not account for route change, mode shift or changes in travel demand
Post Processing	More complex and generally include customized interfaces and analysis processes and are intended to link with travel demand models, simulation models or HPMS databases, and require	• Directly link B/C analysis with travel demand • Directly accept model data as inputs to analysis • Customized applications,	• Requires linkage of regional model or customized model routines • Significant effort required to develop, apply, test and validate methods

[2] FHWA Operations Benefit/Cost Analysis Desk Reference, Chapter 4.

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Tool Category	Description	Advantages	Concerns
	more specific data and additional effort to configure and operate.	algorithms and routines to apply to region's modeling framework to produce required MOEs	• Compatibility between tool and modeling platform
Multiresolution -Multiscenario	Most complex and require the integration of multiple analysis tools such as, combining the analysis capabilities of a travel demand model with a simulation model and requires much broader types of data that may not be readily available.	• High level of confidence in the accuracy of results • Full range of impacts of TSM&O strategy • Assess performance during varying conditions – incident vs no-incident, good weather vs weather conditions, etc.	• Significant effort to develop the analysis process & linking model platform • Compatibility of tools/methods – many are not easily combined • Complexity to develop model processes limits the scope of analysis

Table 2 shows tools within each tool category, primary purpose of the tool and the agency that developed the tool.

Table 2: Benefits/Cost Analysis Tools, Primary Purpose and Agency Developed

Tool Category	Tool	Version/Date	Primary Purpose	Agency Developed
Sketch Planning	Cal-BC	5.0 - February 2012	Conduct B/C analysis of traditional highway improvements	Caltrans
	Computer Model	Unable to locate	Estimate emissions benefits of employer-based travel demand management strategies	EPA
	SCRITS[3]	January 1999	Estimate user benefits of ITS and is a subset of the capabilities on TOPS-BC	SAIC[4] for FHWA
	TOPS-BC	1.0 – June 2013	Provides expected range of TSM&O strategy impacts, identifies B/C based on input needs, estimates life-cycle costs and project benefits	FHWA
	TIM-BC	1.0.0 – July 2015	Focuses on providing cost/benefits for service patrol programs	FHWA

[3] No longer supported by FHWA.
[4] Science Applications International Corporation.

	TRUCE	2.0 June 2007 (date estimated)	Estimates costs and benefits of converting all freeway lanes during peak periods into toll facilities including providing adequate transit for commuters not willing or unable to pay toll rates	FHWA
Post Processing	IDAS	Developed in 2001 and has undergone updates	Estimates changes in modal, route and temporal decisions of travelers resulting from ITS technologies	FHWA
	FITSEval	Unable to locate	Travel demand model post-processor to estimate B/C of ITS form FDOT standardized model	FDOT (under development)
	HERS-ST	5.0 – November 2013	Assesses impacts of traditional capacity improvements by modifying HPMS data characteristics	FHWA
	STEAM	2.02 - 2000	Computes net value of mobility and safety benefits for regionally important projects using travel demand modeling process	FHWA
	IMPACTS	Unable to locate	Spreadsheets related to the STEAM model evaluates highway expansion, bus system expansion light-rail investment, HOV lane and employer based TDM using travel demand model inputs	FHWA
	TRIMMS	2.0 – April 2009	Quantifies net social benefits for travel demand management initiatives	CUTR[5] (at the University of South Florida)
Multiresolution -Multiscenario	ICM Initiative	April 2011	Uses travel demand model to show long-term impacts of strategies and refined simulation model to identify operational performance impacts	FHWA

5. Selecting the Appropriate Tool to Calculate CMAQ Project Emissions Benefits

5.1. *Measures of Effectiveness*

As can be seen, most of the tools provide varying capabilities of analyzing the impact of TSM&O strategies on different Measures of Effectiveness (MOEs). Few existing tools are fully capable of estimating the impacts to the comprehensive range of measures that may be impacted by TSM&O strategies. Only multiresolution/multiscenario methods come closest to this comprehensive capability, and the ability of these methods to produce the full range of benefits is not intrinsic to the method itself, but is instead a

[5] Center for Urban Transportation Research.

product of the flexibility of the approach[6]. However, this must be taken into consideration with other factors, such as;

- Level of effort and expertise required by the agency to use the tool including if specialized training and/or software is needed and/or additional agency IT support.
- Data required by the tool and its accessibility and availability.
- Level of accuracy must be commensurate with project requirements and needs.

The tool must be capable of evaluating the TSM&O strategies and MOEs of interest to the agency, which as it pertains to these CMAQ projects is to identify emissions benefits, and it must also be appropriate to the scope of the analysis and be able to use with the nominal agency resources available. **Table 3**[7] shows the tools and the MOEs that the tool is capable of calculating.

Table 3: Benefits/Cost Analysis Tools and Measures of Effectiveness

Tool Category and Tool	Measures of Effectiveness						
	Mobility (Travel Time Savings)	**Reliability (Total Delay)**	**Safety (Number and Severity of Accidents)**	**Environment (Emissions Reduction)**	**Energy (Fuel Use)**	**Productivity (Agency Costs-Efficiency**	**Vehicle Operating Cost Savings**
Sketch Planning[8]							
Cal-BC	X		X	X			X
SCRITS			X	X	X		X
TOPS-BC	X	X	X	Y[9]	X	X	X
TIM-BC[10]		X		X	X		
Post Process							
IDAS	X	X	X	X	X	X	X
FITSEval	X		X	X	X		X
HERS-ST	X		X	X		X	X
STEAM	X		X	X	X		X
IMPACTS	X			X	X		X
TRIMMS	X			X	X		
Multi Res –Multi Scenario							

[6] FHWA Operations Benefit/Cost Analysis Desk Reference, Chapter 4.
[7] FHWA Operations Benefit/Cost Analysis Desk Reference, Chapter 4.
[8] Computer Model not included because it only applies to employer based TDM programs. TRUCE not included because it only applies to converting freeway lanes during peak periods to toll facilities.
[9] Emissions benefits are not directly calculated; however, the benefit information calculated within each MOE can be used, in conjunction with the MOVES Table, to calculate emissions/air quality benefits.
[10] TIM-BC only applies to Freeway Service Patrol (Courtesy Patrol) applications.

ICM Initiative	X	X	X	X	X	X	X

X = Primary analysis capability Y = Secondary analysis capability

5.2. *TSM&O Strategies*

Many of the tools identified were designed to analyze one or more of the typically recognized TSM&O strategies including:

- Travel Demand Management
- Public Transit Systems
- Arterial Traffic Management
- Commercial Vehicle Operations (CVO)
- HOT Lanes
- Freeway Management Systems
- Incident Management Systems
- Regional Multimodal Traveler Information
- Work Zone Management

Only multiresolution/multiscenario tools have the flexibility and capability to currently analyze all of the generally recognized TSM&O strategies identified above. Although some of the tools address multiple TSM&O strategies, only TOPS-BC and IDAS address all of the TSM&O strategies. TOPS-BC addresses most elements of the TSM&O strategies identified, expect for travel demand management, public transit systems and CVO for which it addresses some elements. IDAS addresses most elements of the TSM&O strategies identified, except for public transit systems for which it addresses some elements.

There are; however, other TSM&O strategies, such as; implementing a regional data warehouse, performing a software revision to improve travel time monitoring, implementing a performance measure system, upgrading communications from serial to Ethernet, conducting bicycle detection, etc., that do not necessarily fit within a typical recognized TSM&O strategy and will require some level of customization in order to identify and calculate benefits.

5.3. *Sketch Planning Tool Summary Analysis*

Sketch Planning tools provide a relatively easy and fast analysis of the TSM&O strategy while requiring relatively limited input data from the user, which for the most part is typical data that is readily available. Sketch Planning tools are considerably less complex than both Post Processing and Multiresolution/multiscenario tools and do not require any specialized training, or other “front end” applications such as travel demand models and/or traffic simulation models to perform the analysis or additional and continual ITS support.

As it pertains to Sketch Planning Tools, several tools were eliminated from further consideration due to the following:

- Computer Model – only applies to employer based TDM programs.
- SCRITS – no longer supported by FHWA.
- TIM-BC – only applies to Freeway Service Patrol (Courtesy Patrol) applications.
- TRUCE – only applies to converting freeway lanes during peak periods to toll facilities.

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CAL-BC calculates emissions benefits. However, further evaluation of the tool determined that it is not practical or feasible because it requires the user to input California area data (based on designated areas in the State) in order to calculate project life-cycle benefits, benefit/cost ratio and emissions benefits. Also, the tool uses accident data and fuel savings/emissions benefits based on the designated California area, which appears to be very difficult or not possible to modify these data. The tool requires the user to aggregate all cost data into one line item, which makes it impossible to account for different life cycles for multiple types of equipment implemented as part of the same project. Finally, the tool doesn't seem to provide the user with the capability to modify the spreadsheet for the respective application or customize for an application not included within the tool.

TOPS-BC may be a tool worth considering further because it provides capability to directly address all of the MOEs identified in Table 3, as well as the ability to calculate emissions/air quality benefits, which is the primary MOE for CMAQ funded projects, from the MOE benefits. Also, TOPS-BC addresses all of the typically recognized TSM&O strategies identified in Section 5.2, and provides the ability for the user to modify an existing application or to customize for other atypical TSM&O strategies/applications (also identified in Section 5.2) and to input user specific data in place of default data if so desired.

ATTACHMENT 2

FHWA CMAQ Project Cost-Effectiveness Study
Summary and Comparison with DRCOG CMAQ Prototype Projects

1. Overview

Moving Ahead for Progress in the 21st Century Act (MAP-21) required FHWA to perform a study to evaluate the cost-effectiveness of CMAQ eligible project types by criteria pollutant and develop a table showing such information[1]. To fulfil that requirement, Volpe National Transportation Systems Center prepared *Congestion Mitigation and Air Quality (CMAQ) Improvement Program, Cost-Effectiveness Tables Development and Methodology*, dated December 3, 2015 ("the Study"). MAP-21 also requires that MPOs consider the table(s) when selecting projects or developing performance plans.

The Study reviewed more than 2,000 projects that were identified in the CMAQ Public Access System for 2013 (the most recent fiscal year for which data was available at the time of the analysis) across the 17 CMAQ eligible project types as identified in the CMAQ Interim Program Guidance, dated November 2013 including some additional project types based on consultation with stakeholders and a review of relevant content in MAP-21. The Study states that:

> "The fullest representations of project-level data were found in data from the CMAQ project database, including the two most recent CMAQ assessment studies (2008 Assessment Study, 2014 Assessment Study), and in additional project summaries from States and localities containing data consistent with CMAQ project summaries . Additional key information was found in existing reviews of mobile emission mitigation projects, in particular *Multi-Pollutant Emissions Benefits of Transportation Strategies* (FHWA, 2006)."[2]

Not surprisingly, the majority of CMAQ funding falls into two project types; traffic flow improvements and transit projects accounting for nearly 67 percent of the projects.

Traffic flow improvements consist of projects such as:

- Roundabouts, left-turn or managed lanes, HOV lanes, traveler information systems, traffic signal synchronization, incident management systems, traffic management projects and value/congestion pricing projects.

Transit projects consists of projects such as:

- Projects that result in an increase in transit ridership and reduction in congestion including, facilities, vehicles and equipment, fuel, operating assistance and transit fare schedules.

The remaining CMAQ funding was spread among the following project types: about four percent for traffic control measures and travel demand management, about five percent for shared ride projects and about seven percent for pedestrian and bicycle projects with the rest allocated to diesel retrofit, idle technologies, freight, cold start and alternative fuels.

There is not a one-to-one relationship between projects identified within the 17 CMAQ eligible project types and the projects that the Study evaluated. For example, traveler information systems was not

[1] 23 U.S.C. Sec. 149, (i)
[2] The Study – Page 34

identified as a project within Congestion Reduction & Traffic Flow Improvements project type and no specific information is provided. However, the Study states that:

> "Difficulties in identifying representative project examples for some project types limited the range of potential projects included in the analysis, and the range of project types was further constrained through the relative maturity of some project types (i.e., some projects types that have been included in previous analyses are no longer funded commonly within CMAQ)."[3]

Based on this, it can be assumed that either there were not any traveler information projects or there were not enough projects to provide a representative sample. In any case, within that project type (Congestion Reduction & Traffic Flow Improvements) incident management, roundabouts and intersection improvements projects were identified in the Study.

2. Calculating Cost-Effectiveness

Cost effectiveness was calculated in terms of dollars per ton of pollutant reduced for five pollutants including, Fine particulate matter (PM2.5), Nitrogen oxides (NOx), Volatile organic compounds (VOC), Carbon monoxide (CO) and Particulate matter (PM10). The Study used the Environmental Protection Agency's (EPA) mobile source emissions model MOVES2010b to quantify emissions impacts for each of the five pollutants by identifying estimates of project-level impacts (e.g., VMT, travel speeds) combined with unit (e.g., per-mile, per-hour) emission rates from MOVES2010b to yield estimated emission impacts. The Study notes that MOVES2014 (EPA's updated emission's model) was released while the Study was in progress. However, the analytical work in the Study was substantially complete, and therefore it was decided to continue with MOVES2010b rather than replicate the range of completed analytical runs in MOVES2014.

Total project cost (CMAQ funds and matching funds) was used to calculate the cost-effectiveness for each pollutant, which was expressed as dollars per ton of each pollutant reduced for each project. To show a representative cost-effectiveness comparison among the projects, the median cost-effectiveness value was selected and presented in a summary table. In addition, a graph for each pollutant was developed showing the median cost-effectiveness value and the lowest project cost for each project type in order to present a range that could be achieved for each project type; however, in most cases there is a significant difference between the low project cost and median-cost and therefore the low project cost is not likely to be representative of general cost-effectiveness.

3. Summary Findings

Figure 1 shows the medium cost-effectiveness for the project types categorized based on dollars per ton of pollutant reduced from highest cost-effectiveness (lowest cost) to lowest cost-effectiveness (highest cost).

[3] The Study – Page 15

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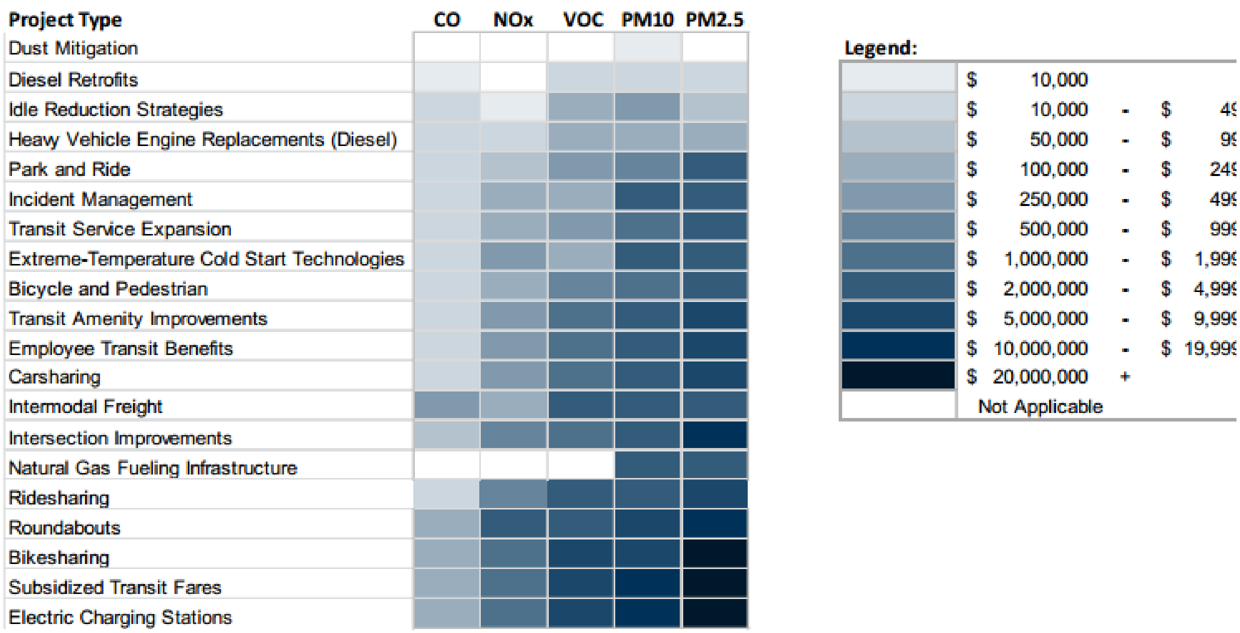

Figure 1: Medium Cost-Effectiveness Estimates
(Dollars per Ton of Pollutant Reduced)

For purposes of looking at the project types from a level of magnitude with respect to cost-effectiveness across all pollutants, the project types can be grouped within ranges of high, medium and low as follows:

High Cost-Effectiveness Project Types
Dust Mitigation
Diesel Retrofits
Idle Reduction Strategies
Heavy Vehicle Engine Replacement (Diesel)
Park and Ride
Incident Management
Transit Service Expansion

Medium Cost-Effectiveness Project Types
Extreme Temperature Cold Start Technologies
Bicycle Pedestrian
Transit Amenity Improvements
Employee Transit Benefits
Carsharing
Intermodal Freight

Low Cost-Effectiveness Project Types
Intersection Improvements
Natural Gas Fueling Infrastructure
Ridesharing

Roundabouts
Bikesharing
Subsidized Transit Fares
Electric Charging Stations

4. Comparison of the Study Methodology and Data Parameters with DRCOG CMAQ Prototype Projects Methodology and Data Parameters

The traditional DRCOG CMAQ Prototype Projects basically can be grouped into two project types in the Study as follows:

Intelligent Transportation Systems/Intersection Improvements

- Travel Time Monitoring System
- Bicycle Detection
- Flashing Yellow Arrow Implementation

Incident Management

- Incident Management Systems Training Modules

The three remaining DRCOG CMAQ Prototype Projects; Data Warehouse and Cognos Licensing, C2C Feasibility Study and Fiber Interconnect, which were classified as "Soft Projects", do not fit directly into any of the Study project types. However, based on the overall purpose of these Soft Projects, which is to improve traffic and travel conditions, it seems reasonable that these projects are analogous with and most suitably fit in this project type.

Regarding Intelligent Transportation System/Intersection Improvements, the Study used the same data parameters as were used for the DRCOG CMAQ Prototype Projects such as; annual vehicle miles traveled, travel speed, projected increase in travel speed, pollutant rates and project cost. One minor difference was that the project lifetime period, which was identified as 20 years for this project type, was used to calculate cost-effectiveness over the project's lifetime. Other than this, the methodology and data parameters were the same as was the projected increase in travel speed of 5 miles per hour (MPH) that was applied to the DRCOG CMAQ Prototype Projects, which was stated in the Study as follows:

> "Distinct to other project types, each of the intersection improvement scenarios involved a specific improvement in travel speeds (or a reduction in delay, in the case of left-turn lanes), generally around five miles per hour (from bases ranging from 15 to 40 miles per hour). In all, 20 scenarios were included in the analysis."[4]

As mentioned, the Study assessed five pollutants. DRCOG assesses four pollutants including CO and NOx, which are in common with the Study, and Hydrocarbons (HC) and Carbon dioxide (CO_2) that is reported to respond to the DRCOG Board commitment to reducing greenhouse gases.

Figure 2 shows the Study medium cost-effectiveness per ton of pollutant reduced for CO and NOx and the lowest project cost for the Intelligent Transportation Systems/Intersection Improvements project

[4] The Study - Page 67

type and the cost-effectiveness per ton of pollutant reduced for the DRCOG CMAQ Prototype Projects for the project lifetime period of 20 years.

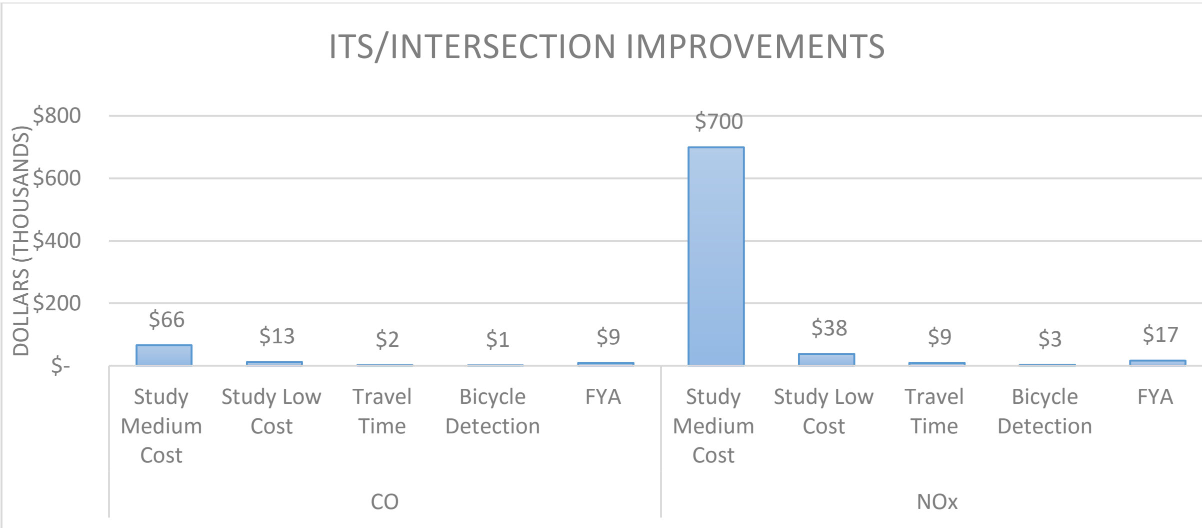

Figure 2: ITS/Intersection Improvements Cost-Effectiveness – Study and DRCOG CMAQ Projects (Dollars per Ton of Pollutant Reduced)

As can be seen, the DRCOG CMAQ Prototype Projects cost-effectiveness is greater than both the Study medium cost-effectiveness and the Study lowest project cost for CO and NOx.

Regarding Incident Management the Study approached this project type from the perspective of mitigating vehicle delay rather than increasing vehicle speed as was used in the DRCOG CMAQ Prototype Projects. The Study data parameters were the estimated number of annual incidents that would be mitigated by the project, average hours of vehicle delay per incident, pollutant rates at idle, project cost and the project lifetime period, which was identified as 10 years for this project type. The Study also stated that:

> "These projects center on the provision of equipment or personnel to advise or re-route drivers during incidents of **non-recurring congestion** [bold added] (e.g., accidents, special events). Information on incident management projects was obtained from CMAQ assessment studies and supplementary project information on equipment used within incident project (chiefly, **variable message signs** [bold added]). In all, 18 incident management projects were included in the analysis."[5]

Figure 3 shows the Study medium cost-effectiveness per ton of pollutant reduced for CO and NOx and the lowest project cost for the Incident Management Improvements project type and the cost-effectiveness per ton of pollutant reduced for the DRCOG CMAQ Prototype Project for the project lifetime period of 10 years.

[5] The Study – Page 100

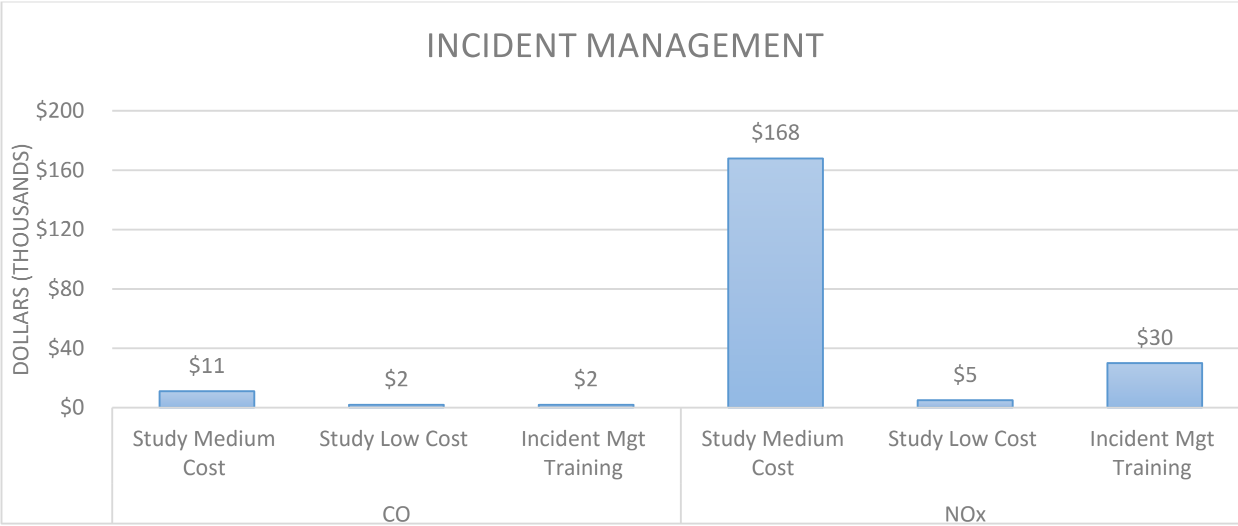

Figure 3: Incident Management Cost-Effectiveness – Study and DRCOG CMAQ Project (Dollars per Ton of Pollutant Reduced)

As can be seen, the DRCOG CMAQ Prototype Project cost-effectiveness is greater than both the Study medium cost-effectiveness for CO and NOx the same as the Study lowest project cost for CO, but is less than the Study lowest project cost for NOx.

5. Other Considerations

It is important to recognize other factors may need to be considered as part of the project prioritization process. For example, DRCOG Regional strategic goals and priorities with respect to coordinating and implementing projects to achieve the regional vision may need to be a factor regarding project prioritization, as well as minimum project thresholds to maximize project effectiveness. These are policy decisions that only DRCOG can address and determine how they best apply within the project prioritization process. Regarding this, the Study notes:

> "It is important to acknowledge that cost-effectiveness with respect to reducing pollutant emissions and congestion is not necessarily the primary reason to implement a given project. Rather, there can be a wide range of benefits provided by projects (e.g., greenhouse gas mitigation, reductions in fuel consumption, safety improvements). In this analysis, we are focusing on the two central issues relevant to the CMAQ program air quality improvement and reductions in traffic congestion. While other benefits may be of critical importance to State and local organizations, benefits other than reductions in traffic congestion and pollutants associated with CMAQ Program objectives are outside the scope of this analysis."[6]

6. Conclusion

Based on the comparison of the Study methodology and data parameters with the DRCOG CMAQ Prototype Projects methodology and data parameters, it appears that the DRCOG CMAQ Prototype Project methodology and data parameters is a sound process that provides reasonably quantifiable emissions/air quality benefits and project cost-effectiveness with respect to reducing subject pollutants. The DRCOG CMAQ Prototype Projects methodology and data parameters seem to be very consistent

[6] The Study – Page 46

with the Study methodology and data parameters, which provides a creditable validation and a very high-level of confidence with the DRCOG CMAQ Prototype Projects methodology and data parameters and the process.