FHWA-HEP-15-002

# Air Quality and Congestion Mitigation Measure Outcomes Assessment Study: Final Technical Report

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# Notice

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16. Abstract

Section 1113 (c) of MAP-21 directed the U.S. Department of Transportation (DOT), in consultation with the Environmental Protection Agency (EPA), to conduct an Air Quality and Congestion Mitigation Measure Outcome Study to examine the outcomes of actions funded under the CMAQ program since the enactment of SAFETEA-LU. The goals of this study are three-fold: (1) assess and document estimated emission reduction, air quality, and human health impacts of federally-supported surface transportation actions intended to reduce emissions or lessen traffic congestion and expand on the base of empirical evidence on those impacts; (2) increase the knowledge of other information to more accurately understand the validity of current estimation and modeling routines and ways to improve those routines; and (3) increase the knowledge of factors determining the human health changes associated with these transportation actions.

This Air Quality and Congestion Mitigation Outcomes Assessment Study: Final Technical Report presents the details on study methodologies, case study results, and findings. The separate Air Quality and Congestion Mitigation Outcomes Assessment Study: Summary Report of Findings presents the major findings of the study.

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# Acronyms and Abbreviations

| | |
|---|---|
| AADT | annual average daily traffic |
| ADA | Americans with Disabilities Act |
| ADEC | Alaska Department of Environmental Conservation |
| ADOT | Arizona Department of Transportation |
| ADT | average daily traffic |
| AFDC | Alternative Fuels Data Center |
| AFV | alternative-fuel vehicle |
| ATIS | advanced traveler information system |
| ATMS | active traffic management strategy |
| AVL | automatic vehicle location |
| BART | Bay Area Rapid Transit |
| BRT | Bus Rapid Transit |
| BWI | Baltimore/Washington International Airport |
| CARB | California Air Resources Board |
| CCAP | Center for Clean Air Policy |
| CCC | Colorado Convention Center |
| CCSD | Cobb County School District |
| CG | conventional gas |
| CMAQ | Congestion Mitigation and Air Quality |
| CMF | crash modification factor |
| CNG | compressed natural gas |
| CO | carbon monoxide |
| $CO_2$ | carbon dioxide |
| CRD | Congestion Reduction Demonstration |
| CST | Case Study Team |
| DFH | direct fire heater |
| DMS | dynamic message sign |
| DOC | diesel oxidation catalyst |
| DOT | Department of Transportation |
| DPF | diesel particulate filter |
| E85 | ethanol fuel blend |
| EC | elemental carbon |
| EIA | U.S. Energy Information Administration |
| EICHC™ | Electrically Initiated Chemically Heated Catalyst |
| EJ | Environmental Justice |
| EPA | U.S. Environmental Protection Agency |
| ETC | electronic toll collection |

| | |
|---|---|
| FCV | fuel-cell vehicle |
| FHWA | Federal Highway Administration |
| FIMS | freeway incident management system |
| FPI | Freeway Performance Initiative |
| FTP | flow-through filter |
| FY | fiscal year |
| GCS | Gold Country Stage |
| GPS | global positioning system |
| GREET | Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation |
| HC | hydrocarbon |
| HOT | high occupancy toll |
| HOV | high-occupancy vehicle |
| ITE | Institute of Transportation Engineers |
| ITS | Intelligent Transportation System |
| IVHS | Intelligent Vehicle Highway System |
| LNG | liquefied natural gas |
| LPG | liquid propane gas |
| LRT | light rail transit |
| M85 | methanol fuel blend |
| MAP-21 | Moving Ahead for Progress in the 21st century |
| METRO | Metropolitan Transit Authority of Harris County |
| mph | miles per hour |
| MPO | Metropolitan Planning Organization |
| MTA | Metropolitan Transportation Authority |
| NCHRP | National Cooperative Highway Research Program |
| NMHC | non-methane hydrocarbon |
| NOx | nitrogen oxide |
| OTREC | Oregon Transportation Research and Education Consortium |
| PEMS | portable emission measurement system |
| PM | particulate matter |
| PMI | preventative maintenance inspection |
| PMT | passenger miles traveled |
| PNC | particle number concentration |
| POC | particle oxidation catalyst |
| PR | previously reported |

| | |
|---|---|
| QA | qualitative analysis |
| | |
| ROG | reactive organic gas |
| RSD | remote sensing device |
| | |
| SAFETEA-LU | Safe, Accountable, Flexible, Efficient Transportation Efficiency Act: A Legacy for Users |
| SCATS | Sydney Coordinated Adaptive Traffic System |
| SCR | selective catalytic reduction |
| SIDRA | Signalized and Unsignalized Intersection Design and Research Aid |
| SIP | state implementation plan |
| $SO_2$ | sulfur dioxide |
| SOV | single occupant vehicle |
| SP | shore-power |
| STP | Surface Transportation Program |
| SWB | subjective well-being |
| | |
| TARTA | Toledo Area Regional Transit Authority |
| TCM | transportation control measure |
| TDM | travel demand management |
| TESS | thermal energy storage system |
| TOD | transit-oriented development |
| TSE | truck stop electrification |
| TSP | transit signal priority |
| TTI | Texas A&M Transportation Institute |
| TxDOT | Texas Department of Transportation |
| | |
| UC | University of California |
| UFP | ultrafine particulate matter |
| ULSD | ultra-low sulfur diesel |
| UPA | Urban Partnership Agreement |
| | |
| v/c | volume/capacity |
| VMS | variable message sign |
| VMT | vehicle miles traveled |
| VOC | volatile organic compound |
| VSP | vehicle-specific power |
| | |
| WHO | World Health Organization |

# Executive Summary

Section 1113 (c) of Moving Ahead for Progress in the 21st Century Act (MAP-21) directs the examination of the outcomes of actions funded under the Congestion Mitigation and Air Quality (CMAQ) Improvement program since the enactment of the Safe, Accountable, Flexible, Efficient Transportation Efficiency Act: A Legacy for Users (SAFETEA-LU). In response, a study was undertaken to address the following three goals: (1) assess and document the emission reduction, air quality, and human health impacts of federally-supported surface transportation actions intended to reduce emissions or lessen traffic congestion and expand on the base of empirical evidence on those impacts; (2) increase the knowledge of other information to more accurately understand the validity of current estimation and modeling routines and ways to improve those routines; and (3) increase the knowledge of factors determining the human health changes associated with these types of transportation actions.

Following the approach directed by MAP-21, three separate study components were conducted as part of this effort:

- Analysis of actions funded under the CMAQ program since the enactment of SAFETEA-LU, including the selection of a representative sample of CMAQ projects for detailed data collection and assessment by competitively solicited teams of experts,
- Analysis of a sample of emissions estimation and modeling routines, and
- Assessment of factors affecting air quality and human health changes associated with transportation emission reduction actions.

The CMAQ program is widely used and a variety of projects are funded under this program. Per the CMAQ reporting system, CMAQ funded a total of 8,166 projects for nearly $10.2 billion between fiscal year (FY) 2006 and FY 2012 (the period for this study). Overall, CMAQ funds could be considered a small portion compared to the entire Federal transportation program. Under SAFETEA-LU, CMAQ program authorizations represented 4.4 percent of the total Federal-aid highway program and 3.0 percent of the total Federal surface transportation program funding. Under MAP-21, CMAQ funds are approximately 5.4 percent of the authorized Federal-aid highway funds[1].

For the study, the outcomes assessment focused on understanding the impacts of the types of projects funded under the CMAQ program on emissions, air quality, and human health. For the first study component to assess a sample of CMAQ projects, the research team employed an expert peer review approach. The peer review approach allows for a large number of cases to be reviewed in a short time period and is consistent with MAP-21 requirement to have the case studies selected and reviewed by individual experts. This approach is used widely, including by other Federal agencies to evaluate individual environmental projects. A representative sample of 72 case study projects were selected from the projects funded during the timeframe of SAFETEA-LU (over 8,000 projects) for peer review. The

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[1] Source: U.S. Department of Transportation, Federal Highway Administration, Highway Authorizations, https://www.fhwa.dot.gov/map21/ha.cfm

peer reviewers participated in the selection of representative case study projects and assessed the methods and assumptions used in estimating the travel impacts and emissions impacts of each case study project.  Other approaches to outcomes research may employ individual project measurements or metrics; however, individual quantification of traffic changes specifically induced by the CMAQ project, corresponding emissions changes, subsequent air quality changes in concentration of pollutants, and ultimately changes in health effects are challenging endeavors.  Field measurements are costly and extremely challenging to employ for a transportation facility; measuring the incremental change due to an emission reduction or congestion reduction measure is difficult given the number of variables that impact travel habits and concentrations of emitted pollutants in the atmosphere.  Quantification of impacts from CMAQ projects using field measurements also depends on the availability of sufficient measurement data collected before project implementation, which again is costly and challenging.  Field assessments of CMAQ projects are rare and when such a study is undertaken, practitioners will most often only measure the change in transportation parameters and still rely on estimates of any the corresponding emissions changes.  For this study, the case study analysis is supplemented with two additional components—an analysis of a sample of emissions estimation and modeling techniques and a literature review assessment of factors affecting air quality and human health changes.  The literature review complements the case study analysis in providing a thorough review of published literature demonstrating emissions reductions, travel impacts, and human health impacts studies.  Although the parameters laid out in MAP-21 Sec. 1113(c) did not allow for a outcomes assessment involving measurements of environmental impact before and after CMAQ projects, the research team asserts that the information from the case study peer review and the analysis of modeling techniques, complemented by the literature review, provides a good assessment of the impacts of CMAQ project implementation.

After a review of the reported CMAQ-funded projects, a representative sample of 72 projects was selected for detailed data collection and analysis with an objective to gather and assess the reported emissions and travel impacts.  It is important to note that technical limitations in verifying benefits, differences in estimation methodology from project sponsors, considerations of when CMAQ project benefits begin and how long they are effective, and differences in project scope and scale make project comparisons and aggregations difficult.

For the 72 case studies, estimated emissions impacts were reported most frequently for volatile organic compounds (VOC) and nitrogen oxides (NOx).  Specifically, changes in VOC emissions were estimated for 61 case study projects, or over 85 percent of all analyzed projects, and NOx emissions reductions were estimated for 63 case studies, which is nearly 88 percent of all analyzed projects.  Changes in carbon monoxide (CO) emissions were estimated for 39 case studies, or 54 percent.  Particulate matter (PM) emissions reductions were estimated for less than half of case study projects.  Specifically, $PM_{10}$ changes were estimated for 24 case study projects (33 percent) and $PM_{2.5}$ changes were estimated for 20 case study projects (almost 28 percent).  (See information in Table 7 on page 27.)

Similarly, of the case studies analyzed in this study, 52 projects (72 percent) reported estimates of traffic or congestion mitigation impacts for the project.  The percentage of projects reporting these impacts should not be interpreted as being equal to the percentage of projects having a traffic or congestion impact.  First, not all CMAQ projects or project subcategories are expected to result in traffic or congestion mitigation impacts.  For example, alternative fuel vehicle replacement projects, idle reduction programs, or dust mitigation programs involving street sweepers have a focus on emissions reductions, and would not likely result in any impacts to traffic or congestion.  Second, reporting travel impacts is not a requirement for CMAQ funding eligibility, and subsequently not all case study project sponsors comprehensively or consistently reported findings for these impacts.  For instance, some case study project sponsors reported changes in emissions that were likely derived from assumed traffic or congestion mitigation impacts, but the case study sites did not report the estimated travel impacts as a separate category of project benefits.

For human health, of the 72 case studies analyzed in this study, 22 projects (30 percent) reported estimated human health impacts as a result of the project.  The reason that so few case study sites reported estimated human health impacts associated with the CMAQ projects is likely due in part to the fact that it is not required as part of the CMAQ program and the case study project sponsors often referred back to the CMAQ funding applications for information.  For example, despite an estimated increase in biking or walking, some case studies did not report any associated human health impact.  The CMAQ program does not require the estimating and reporting of human health impacts and no standardized methodology is available to account for human health impacts.  The majority of the estimated human health impact feedback from the project sponsors could be described as anecdotal—rather than from actual estimates or analysis.  Three of the 72 case study projects provided estimated quantitative human health impact benefits.

Case study information was reviewed by Case Study teams who were well-versed with air quality modeling, travel estimation techniques, and the CMAQ program.  They noted that in most cases across all project categories, the methodology and the reported emissions and travel impacts were reasonable and consistent with their expectations of projects of a similar type, subject to the limitations of the available data reported by the project sponsors.

Recognizing the importance of the estimation processes used by project sponsors, the second part of the study looked at the suitability of a representative set of modeling techniques.  Ten emission estimation models used to evaluate the expected air quality outcomes for transportation emission reduction projects were identified and reviewed.  The validity of these models, and the methods used by each, was assessed resulting in recommendations for further development and application improvement of the methods.  The CMAQ project sponsors are not required to use specific analysis methods and many agencies have developed their own process for estimating emission benefits of strategies.  In addition, the emission factor model inputs used for the quantitative CMAQ evaluations were compared with the model inputs used for other regulatory applications.  The use of best available local inputs to generate a more representative emission factor is considered good practice,.  The 10 models were able to cover a wide variety of CMAQ-funded actions except three of 17 subcategories.  The fact that no public education/outreach, extreme low-temperature cold start program, or car sharing equation or methodology was identified does not mean that a method does not exist, merely that the 10 models chosen for this study do not offer a method to analyze these project types.

Overall, the Study team recommends the following as methods to improve analysis methods:

- Foremost importance is maintaining a focus on the dimensional analysis of equations.  Align the input units, so that the equation can better provide a valid benefit estimate.

- Make efforts to use the best available local inputs when generating emission factors used in the project-level analysis.  Vigilant quality control/quality analysis is a must.  Ensure that input data collected meets the units of what is expected in the equation.
- All equations should strive to compute and report in kilograms/day to follow CMAQ guidance.  Showing the conversions within the equations to kilograms/day reinforces to the user how and where this is performed in the equation.  This simple conversion can sometimes be a source of error if not applied correctly.
- Build or expand new equations and methodologies from other agency estimation techniques.  Often, logic or components in other project type equations can be transferred with little or no modification to another project type.
- Performing some before and after studies could help improve emission estimation methods; however conducting before and after studies can be challenging and resource intensive.

The CMAQ-funded projects can impact a variety of parameters, such as vehicle emission, or travel mode choice, thereby introducing several potential pathways to impact human health.  The MAP-21 directed a review of available information in this area to expand the body of knowledge as it pertains to the CMAQ program.  Four primary pathways were explored.  First and foremost, air quality is improved through the reduction or elimination of vehicle emissions and associated harmful air pollutants.  The health effects from reduced vehicle emissions generally relate to improvement in regional air quality that impact respiratory illnesses.  Secondly, projects can impact physical and mental health of individuals in ways not limited to disease, but also including their general well-being and quality of life.  Third, injury prevention can also be a benefit received when the risk of vehicle crashes or injury severity is reduced.  Finally, access equity is another potential pathway to human health impacts.  Access equity refers to project impacts that provide improved access to healthcare, education, jobs, nutritional food, and safe recreational areas, reducing inequitable benefits to residents.  This human health impacts assessment was completed via a thorough literature review, based on published literature (such as scientific articles and reports) on transportation, air quality, and health effects.

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# 1 Introduction

## 1.1 Congestion Mitigation and Air Quality Improvement (CMAQ) Program

The Congestion Mitigation and Air Quality Improvement (CMAQ) Program was created in 1991 under the Intermodal Surface Transportation Efficiency Act (and provides funding for transportation projects designed to reduce congestion and improve air quality. The CMAQ program was reauthorized in 1998 under the Transportation Equity Act for the 21st Century, in 2005 under the Safe, Accountable, Flexible, Efficient Transportation Efficiency Act: A Legacy for Users (SAFETEA-LU), and most recently in 2012 under the Moving Ahead for Progress in the 21st Century Act (MAP-21).

Since its inception, the CMAQ program has provided over $30 billion for more than 29,000 projects across the country. Overall, CMAQ funds could be considered a small portion compared to the entire Federal transportation program. Under SAFETEA-LU, CMAQ program authorizations represented 4.4 percent of the total Federal-aid highway program and 3.0 percent of the total Federal surface transportation program funding. Under MAP-21, CMAQ funds are approximately 5.4 percent of the authorized Federal-aid highway funds[2].

## 1.2 Report Purpose

Section 1113 (c) of MAP-21 directed the U.S. Department of Transportation (DOT), in consultation with the Environmental Protection Agency (EPA), to conduct an Air Quality and Congestion Mitigation Measure Outcome Study to examine the outcomes of actions funded under the CMAQ program since the enactment of SAFETEA-LU. The goals of this study are three-fold: (1) assess and document estimated emission reduction, air quality, and human health impacts of federally-supported surface transportation actions intended to reduce emissions or lessen traffic congestion and expand on the base of empirical evidence on those impacts; (2) increase the knowledge of other information to more accurately understand the validity of current estimation and modeling routines and ways to improve those routines; and (3) increase the knowledge of factors determining the human health changes associated with these transportation actions.

Details on study methodologies, case study results, and findings are presented in this “Air Quality and Congestion Mitigation Outcomes Assessment Study: Final Technical Report.” A “Summary Report of Findings” presents the major findings of the study.

## 1.3 Types of CMAQ Projects

Projects or programs funded under CMAQ must meet a variety of eligibility criteria and must be designed to reduce carbon monoxide (CO), ozone precursors, or particulate matter (PM) or PM precursor emissions. An estimate of the emission reduction benefit expected from the implementation of projects must be provided.

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[2] Source: U.S. Department of Transportation, Federal Highway Administration, Highway Authorizations, https://www.fhwa.dot.gov/map21/ha.cfm

It is important to note for the purposes of this study, all projects funded with CMAQ funds as reported in FHWA's CMAQ database, described below, were included. Under SAFETEA-LU, each State was guaranteed a minimum apportionment of one-half percent of the year's total program funding regardless of whether the State has any nonattainment or maintenance areas. These minimum apportionment funds could be used anywhere in the State for projects eligible for either CMAQ or Surface Transportation Program (STP) funds. MAP-21 eliminated the minimum apportionment provision of SAFETEA-LU and past transportation authorizations and replaced it with a section on State Flexibility . The period of time for this study did not include projects funded under MAP-21. The CMAQ Interim Program Guidance dated November 12, 2013 ("CMAQ Guidance") lists 17 project types generally considered eligible for CMAQ funding (shown in Table 1). This updated guidance under MAP-21 reordered the eligibility categories and added carsharing as an explicit category; however, generally CMAQ project eligibility did not change between SAFETEA-LU (the period of this study) and MAP-21. Because there is some repetition and overlap in this list of eligible project types, the list was adapted for this study into CMAQ project subcategories and grouped into major project types used in the study analysis. Further details are provided in Section 1.4.

The Federal Highway Administration (FHWA) has developed a CMAQ tracking system to serve as a database of all CMAQ funded projects. The database grouped all of the projects into the following seven major project reporting categories:

- Demand Management,
- Inspection/Maintenance and other Transportation Control Measures (TCM),
- Pedestrian/Bicycle,
- Shared Ride,
- STP/CMAQ,
- Transit, or
- Traffic Flow Improvements.

Figure 1 shows the total CMAQ funding and number of projects for each reporting category. An analysis of these numbers shows that traffic flow improvements accounted for the largest fraction of CMAQ projects having 36 percent of the total number of projects funded and 36 percent of the total funding obligations. Pedestrian/bicycle projects accounted for 16 percent of the total number of projects funded, but accounted for only 8 percent of the funding obligations. Alternatively, transit-related projects accounted for 15 percent of the projects, but accounted for 27 percent of the funding obligations. The STP/CMAQ reporting category refers to the minimum apportionment provision of SAFETEA-LU whereby States may choose to transfer a limited portion of their CMAQ apportionment to State STP projects.

## Table 1. Summary of Project Types Eligible for CMAQ Funding

| |
|---|
| **1. Diesel Engine Retrofits & Other Advanced Truck Technologies** |
| **2. Idle Reduction** |
| **3. Congestion Reduction & Traffic Flow Improvements** |
| • Roundabouts, HOV lanes, left-turn, or other managed lanes |
| • Intelligent Transportation Systems (ITS) |
| • Value/Congestion Pricing |
| **4. Freight/Intermodal** |
| **5. Transportation Control Measures (TCM)** |
| **6. Transit Improvements** |
| • Facilities |
| • Vehicles and Equipment |
| • Fuel |
| • Operating Assistance |
| • Transit Fare Subsidies |
| **7. Bicycle and Pedestrian Facilities and Programs** |
| **8. Travel Demand Management (TDM)** |
| • Fringe parking |
| • Traveler information services |
| • Shuttle services |
| • Guaranteed ride home programs |
| • Carpools, vanpools (TDM-related) |
| • Traffic calming measures |
| • Parking pricing |
| • Variable road pricing |
| • Telecommuting/Teleworking |
| • Employer-based commuter choice programs. |
| **9. Public Education and Outreach Activities** |
| **10. Transportation Management Associations** |
| **11. Carpooling and Vanpooling** |
| • Carpool/vanpool marketing |
| • Vanpool vehicle capital costs |
| **12. Car sharing** |
| **13. Extreme Low-Temperature Cold Start Programs** |
| **14. Training** |
| **15. Inspection/Maintenance (I&M) Programs** |
| **16. Innovative Projects** |
| **17. Alternative Fuels and Vehicles** |
| • Infrastructure |
| • Non-transit Vehicles |
| • Hybrid Vehicles |

Source: CMAQ Improvement Program under MAP-21, Interim Program Guidance, Nov. 12, 2013, http://www.fhwa.dot.gov/environment/air_quality/cmaq/policy_and_guidance/2013_guidance/cmaq2013.pdf

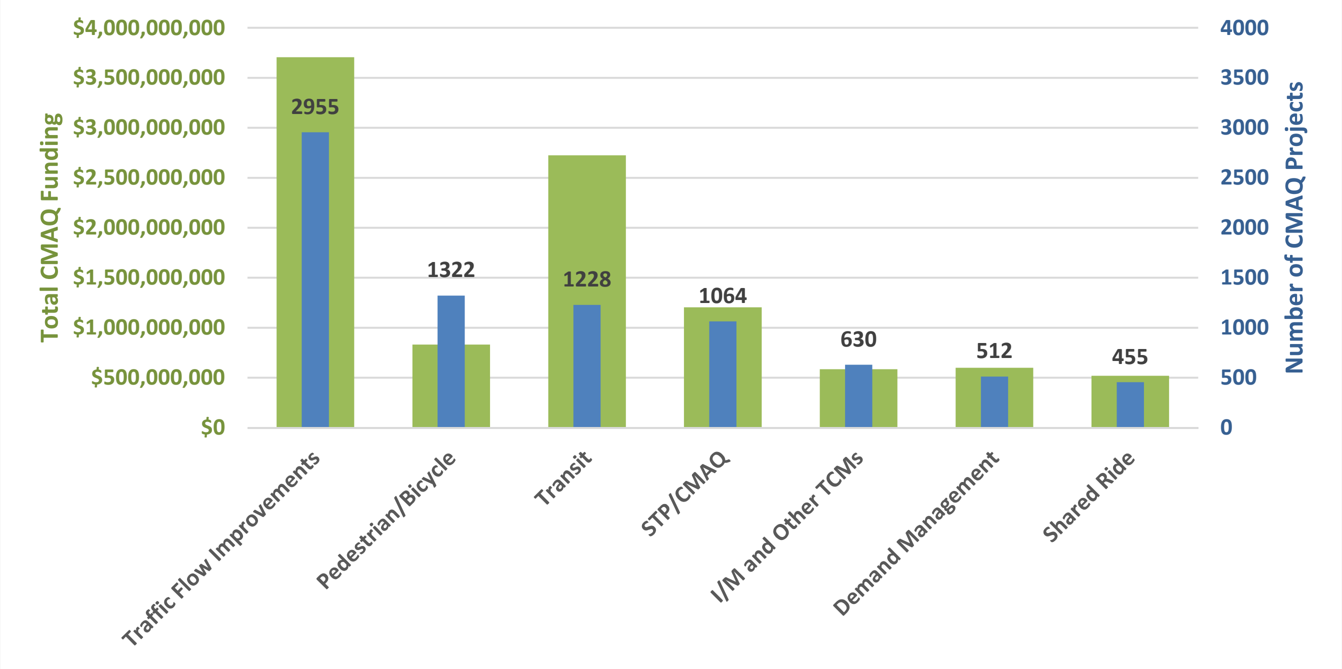

**Figure 1. Funding and Number of CMAQ Projects by Reporting Category**

## 1.4 Report Organization

The rest of the document is divided into six sections with the following information. Additional information is included in six Appendices.

- Section 2, Study Approach
- Section 3, Findings on Distribution of CMAQ Project Obligations
- Section 4, Findings from CMAQ Case Studies
- Section 5, Findings of Analysis of Emission Estimation and Modeling Techniques
- Section 6, Findings on a Review of Transportation and Health Impacts with a Focus on CMAQ Project Types
- Appendix A, CMAQ Study Major Project Types and Trends
- Appendix B, Detailed Case Study Findings on CMAQ Project Outcomes
- Appendix C, CMAQ Case Study Team Technical Experts
- Appendix D, CMAQ Study Oversight Committee
- Appendix E, CMAQ Oversight Committee Comments
- Appendix F, References

To assist with analysis and comparisons, this study uses a classification of CMAQ project divisions based on, but slightly different than, the project types shown previously in Table 1 and project categories shown previously in Figure 1. The taxonomy used in this study is detailed in Table 2.

### Table 2. Taxonomy of CMAQ Study Terms

| FHWA CMAQ Term | CMAQ Study Term |
|---|---|
| **Project Types Eligible for CMAQ Funding** (Table 1): the 17 divisions used in the FHWA CMAQ eligibility guidance to describe the different projects and programs. | **CMAQ Study Project Subcategories** (Table 3): the 26 divisions identified by the study authors that encompass all 17 of the divisions in the FHWA guidance but expanded to capture the unique characteristics to facilitate analysis. |
| **CMAQ Reporting Categories** (Figure 1): the 7 divisions used by FHWA in the guidance and the CMAQ project database. | **CMAQ Study Major Project Types** (Figure 7): the 7 divisions identified by the study authors to aggregate similar project subcategories, each subcategory is assigned to only one major project type. |

As noted in the table above, the 26 unique subcategories were defined in this study as means to organize CMAQ-eligible projects of similar scope. These 26 subcategories encompass all 17 of the divisions in the FHWA guidance. Each CMAQ project was assigned to a single subcategory in the study to facilitate analysis.

Similarly, the seven major project types were defined in this study for a high-level comparison of CMAQ subcategories and projects. The Battelle Team assigned each of the 26 subcategories to one of the seven major project types.

The division of the projects into major project types and subcategories is discussed in Section 2.

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# 2 Study Approach

This section presents the approach including the study components and some limitations.

## 2.1 Study Components

Following the approach directed by MAP-21, three separate study components were conducted as part of this effort:

- Analysis of actions funded under the CMAQ program since the enactment of SAFETEA-LU, including the selection of a representative sample of CMAQ projects for detailed data collection and assessment by competitively solicited teams of experts,
- Analysis of a sample of emissions estimation and modeling routines, and
- Assessment of factors affecting air quality and human health changes associated with transportation emission reduction actions.

Figure 2 illustrates the relationship of the various study components.

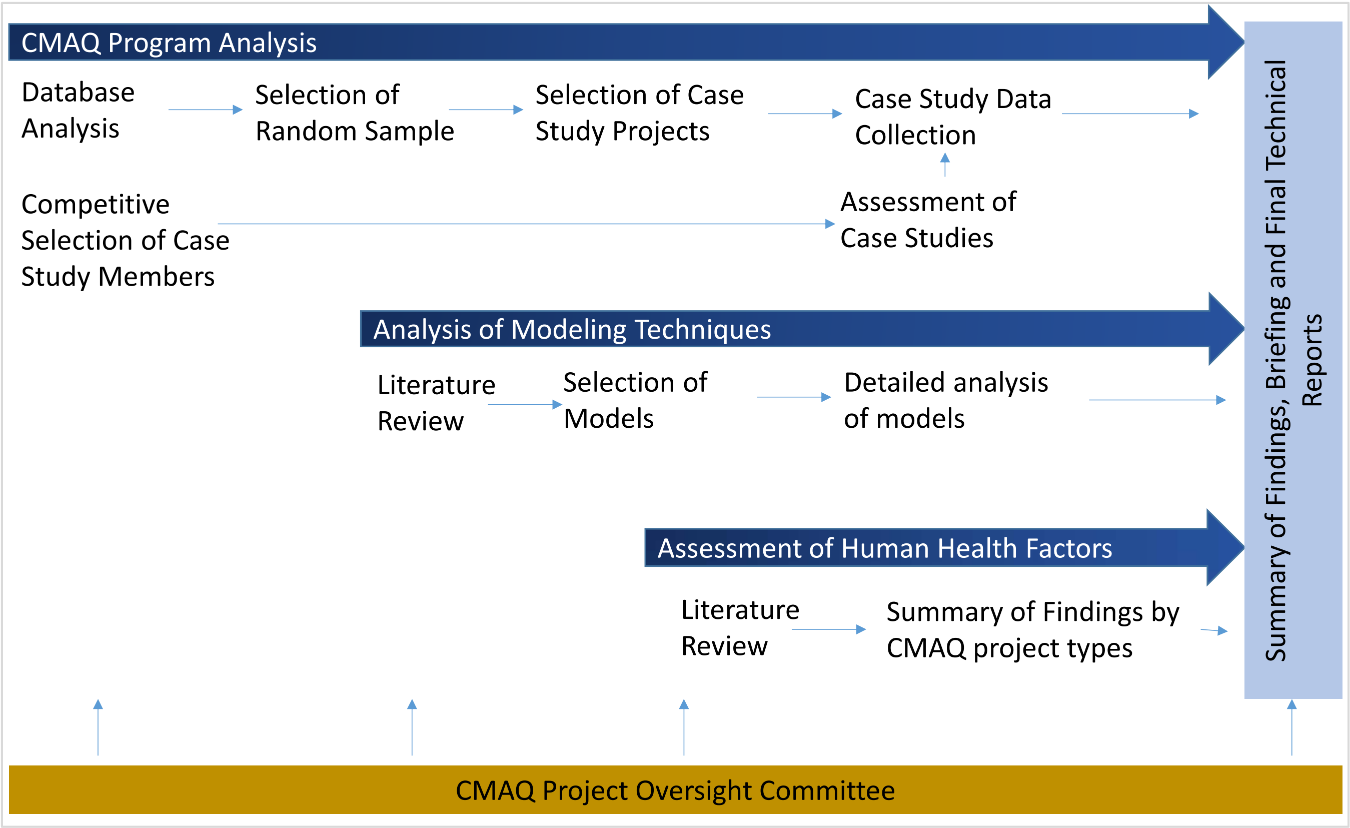

**Figure 2. CMAQ Outcomes Assessment Study Components**

For the study, the outcomes assessment focused on understanding the impacts of the types of projects funded under the CMAQ program on emissions, air quality, and human health. For the first study component to assess a sample of CMAQ projects, the research team employed an expert peer review approach. The peer review approach allows for a large number of cases to be reviewed in a short time period and is consistent with MAP-21 requirement to have the case studies selected and reviewed by individual experts. This approach is used widely, including by other Federal agencies to evaluate individual environmental projects. A representative sample of 72 case study projects were selected from the projects funded during the timeframe of SAFETEA-LU (over 8,000 projects) for peer review. The peer reviewers participated in the selection of representative case study projects and assessed the methods and assumptions used in estimating the travel impacts and emissions impacts of each case study project. Other approaches to outcomes research may employ individual project measurements or metrics; however, individual quantification of traffic changes specifically induced by the CMAQ project, corresponding emissions changes, subsequent air quality changes in concentration of pollutants, and ultimately changes in health effects are challenging endeavors. Field measurements are costly and extremely challenging to employ for a transportation facility; measuring the incremental change due to an emission reduction or congestion reduction measure is difficult given the number of variables that impact travel habits and concentrations of emitted pollutants in the atmosphere. Quantification of impacts from CMAQ projects using field measurements also depends on the availability of sufficient measurement data collected before project implementation, which again is costly and challenging. Field assessments of CMAQ projects are rare and when such a study is undertaken, practitioners will most often only measure the change in transportation parameters and still rely on estimates of any the corresponding emissions changes. For this study, the case study analysis is supplemented with two additional components—an analysis of a sample of emissions estimation and modeling techniques and a literature review assessment of factors affecting air quality and human health changes. The literature review complements the case study analysis in providing a thorough review of published literature demonstrating emissions reductions, travel impacts, and human health impacts studies. Although the parameters laid out in MAP-21 Sec. 1113(c) did not allow for a outcomes assessment involving measurements of environmental impact before and after CMAQ projects, the research team asserts that the information from the case study peer review and the analysis of modeling techniques, complemented by the literature review, provides a good assessment of the impacts of CMAQ project implementation.

### 2.1.1 Selection and Assessment of a Representative Sample of CMAQ Projects

States and the District of Columbia submit annual reports of their CMAQ project obligations in March of every year. The FHWA uses these yearly submissions to maintain an active database of CMAQ investments, trends within the program, and other anecdotal information focusing on the program's performance. An in-depth analysis of this CMAQ database was performed to develop a complete understanding of the types of actions funded through CMAQ, trends, and distributions by funding, locations, and project categories. The available impact data (e.g., estimated emission reductions) were also analyzed.

Information gained from the in-depth analysis of the database was used to identify a representative sample of case studies of projects receiving CMAQ funding. The study team assessed the traffic, emissions and human health impacts of these projects. These findings are described in Section 3. Through a rigorous peer-review approach, the case study information was assessed for reasonableness and technical validity. Activities under this study component included the identification of an oversight committee, a competitively solicited case study team, and a review methodology to identify a representative sample of projects.

### Oversight Committee and Case Study Teams

The MAP-21 directed that the case studies were to be identified and conducted by teams selected via competitive solicitation, overseen by an independent committee of unbiased experts. An Oversight Committee was selected comprising four experts based on their substantial experience in the administration of the CMAQ program as well as transportation and emission strategy analysis (list of members in Apprendx D). The Oversight Committee independently provided input to the development of a representative sample, the selection of case studies, and provided independent peer review of the "Summary Report of Findings" and the "Final Technical Report."

A competitive solicitation was used to assemble a panel of 20 technical experts to serve on Case Study Teams (CST). Members of the CSTs are familiar with the CMAQ program, and are affiliated with academic institutions, consulting firms, Metropolitan Planning Organizations (MPO), and State departments of transportation (state DOT). The median years of experience for CST members is 25 and ranged from 8 years to 38 years. The CST members selected each project to be used as a case study and conducted assessments of the case study projects based on the data.

The CST and Oversight Committee members are identified in Appendices C and D, respectively. The Oversight Committee comments are included in Appendix E.

### Methodology to Devise a Representative Sample of CMAQ-funded Actions

This assessment involves the analysis of a sample of surface transportation projects receiving CMAQ funding obligated from Federal fiscal year 2006 to 2012 (referred to as FY 2006 – FY 2012). This sample of projects was selected from the entries in the CMAQ database based on a number of selection criteria, such as scope, CMAQ funding amount, geographic location, and availability of emissions data. It should be noted that the selection process relied heavily upon the data in the database and are therefore subject to the accuracy of those entries.

To help in the selection of a representative sample, all projects were assigned to subcategories that more clearly identified the scope of the projects based on their given descriptions. The 26 subcategories (shown in Table 3) were derived from the list of the 17 types of projects and programs eligible for CMAQ funding (shown previously in Table 1).

**Table 3. CMAQ Study Major Project Types and Subcategories**

| Major Project Types | Subcategories |
|---|---|
| **Vehicle/Fuel Technology** | Alternative Fuel Vehicles/Fueling Facilities |
| | Conventional Bus and Paratransit Replacements |
| | Diesel Engine Retrofits |
| **Vehicle Activity Programs** | Idle Reduction |
| | Extreme Low-Temperature Cold Start Programs |

| | |
|---|---|
| **Traffic Flow Improvements** | Traffic Signalization |
| | Traffic Engineering (Roadway Improvements) |
| | Intersection Improvements |
| | High-Occupancy Vehicle and Managed Lanes |
| | Roundabouts |
| **Intelligent Transportation Systems** | General ITS |
| | Freeway Management Systems |
| | Traveler Information Systems |
| **Improved Public Transit** | Transit Facilities, Systems, and Services |
| | New Bus Services |
| | New Rail Services |
| **Transportation Demand Management** | Public Education/Outreach (Information/Marketing) |
| | Travel Demand Management |
| | Park and Ride Facilities |
| | Car Sharing |
| | Value/Congestion Pricing |
| **Other** | Pedestrian/Bicycle |
| | Other |
| | Dust Mitigation |
| | Freight/Intermodal |
| | Innovative Projects |

To arrive at a final sample of 76 case studies representing the number, scope, geographic distribution, and funding amount of the entire CMAQ program, a random sample of 604 projects was chosen. This random selection of 604 projects was based on a targeted sample size for each subcategory. For most subcategories, this was 5 times larger than the target final sample size for the subcategory. For project subcategories with greater diversity of scope, geographic distribution, and funding amount, a target sample size that was 10 times larger was used. The minimum sample size was 20 projects per subcategory. If the subcategory had less than 20 projects, all projects were included in the sample. This random sample provided a manageable list to the CST to derive a representative sample of 76 case studies. The target number of case studies per subcategory was based on a combined weighting of the number of projects in each subcategory and the total obligations for each subcategory, excluding the emerging and special interest subcategories that are described in Section 3.2. The 76 case studies were selected by the CST according to their representation of the scope, CMAQ funding amount, and geographic location. For purposes of the case study assessment, projects that had no emissions data reported in the database were substituted with similar projects that contained data. (Note that later in the case study data collection process, 4 of the projects had to be removed due to lack of information, leaving 72 case studies total.)

### Data Collection and Assessment Methodologies

In general, the data used to evaluate each of the case study projects were collected from the CMAQ database. Additional follow-up information was gathered as needed through email inquiries and by making phone calls to the respective project sponsors.  Follow-up inquiries were conducted by professionals who were briefed on the study objectives and goals.  The data gathered included estimated travel impacts, estimated emissions impacts, and estimated health impacts, and the assumptions and methods used to develop the estimates.  For each case study, a CST of three to four experts was assigned to evaluate the methodologies and assumptions used by the project sponsor to estimate the scope, costs, travel impacts, and emission impacts.  This CST assessment included an analysis of both direct and indirect impacts.  Human health impacts as reported by project sposors, was assessed.

### 2.1.2 Analysis of Emission Estimation and Modeling Routines

The effectiveness of the CMAQ program rests on the project sponsor's ability to model the emission reduction impact of a particular project.  This part of the study looked at the typical emissions estimation techniques used around the country to analyze CMAQ projects to provide an assessment of their overall validity in producing reliable emission reduction estimates. .  This study component included three efforts.  First, a critical review and assessment of typical emission estimation methods and models used for CMAQ-funded projects was conducted.  Second, a review of emission factor input file consistency with other emissions estimate applications such as State Implementation Plan (SIP) development and transportation conformity analysis was completed.  Finally, as a common approach for model validity testing, a search and review of before and after evaluations of transportation emission reduction projects, including those funded through the CMAQ program, was undertaken.

To analyze emission estimation and modeling routines, 10 emission analysis models, routines, or techniques were identified and critically reviewed.  The selected models originated from State DOTs, MPO, and research guidebooks.  Most of the models were stand-alone agency guidance for CMAQ analysis either in a document or as Microsoft® Excel-based worksheets available on an agency Web site.  Some were identified as part of an agency's conformity documentation or as a research report.  The models ranged from simple to complex methodologies.  Simple methodologies are sketch-planning equations with a few basic inputs.  The more complex techniques strive to capture the emission reductions through a number of variable equations requiring varied data inputs.  The analysis of emissions estimation and modeling routines can be found in Section 5.

### 2.1.3 Assessment of Factors Affecting Air Quality and Human Health Changes

This component of the study aims at developing and presenting a better understanding of transportation and emission impacts of CMAQ project types and any corresponding health impacts or outcomes.  This broad objective was achieved primarily through a literature review, based on published literature (such as scientific articles and reports) on transportation, air quality, and health effects.  The assessment of factors affecting air quality and human health changes can be found in Section 6.

## 2.2 Study Approach Assumptions and Study Limitations

The methods used for carrying out this portion of the study were developed to address the overall goals within the compressed schedule required to meet technical delivery deadlines, and limitations in the types of data available for assessment.  The study goals were met by recruiting independent subject matter experts  to conduct assessments of the methods and the data reported in a representative sample of case studies—a strategy successfully applied previously to independent reviews of federally funded projects.

There are two main areas that limit the scope and methodology for the study.

- **Data –** These limitations are a result of available and reported data.
    - **Database limitations –** The primary and only comprehensive national data source for all CMAQ projects is the database reporting system used by project sponsors/States, and maintained by FHWA. Any errors in the database will necessarily be carried through to the analysis.
    - **Inability to conduct site visits –** Experience with independent reviews of federally-funded projects has shown that visits to the project site can be very helpful in providing context for the proposed study and, when possible, to compare the project proposal and implementation. Limitations in the project schedule did not allow for site visits. On the other hand, a much larger sample of case study projects could be assessed remotely by not committing resources to travel.
    - **Treatment of projects without reported impact estimates –** In developing the study approach, treatment of projects that did not list emission impact data in the CMAQ database was considered carefully. Since such data are necessary to assess the CMAQ projects, options for selecting projects were considered in relation to potential for introducing bias. To minimize the potential for introducing bias to the final list of case study projects, the reporting of impact emission estimates was addressed only in the final selected list of projects, at which time projects without data were replaced as long as the replacement project equally met the selection criteria.
    - **Lack of human health information –** Since the reporting of specific human health benefits is not a requirement of the CMAQ Program, a vast majority of CMAQ projects do not estimate and/or report on this benefit category as a matter of practice.
    - **Limited modeling/methods assessment –** An extensive data collection effort across all MPOs was not conducted due to schedule and data collection constraints. A sample of models was assembled based on publicly-available information. While the sample of models is representative of a majority of travel and emissions impact models used, there may be other models used for the CMAQ program that were not analyzed.
- **Technical** – These limitations are a function of how projects are implemented and the complexity of transportation and air quality systems.
    - **Verifying benefits –** Even if detailed before and after studies were conducted, it can be difficult to quantify the benefits of CMAQ projects, due to multiple factors (e.g., changes in fuel prices, other transit service changes, etc.) that may be occurring at the same time as the CMAQ project. There is very limited ability to link long-term benefits to a single project. As a result, the travel and emissions impacts reported in the CMAQ database are based on estimates, which may or may not have been realized as a result of the project. To account for this limitation, tools and analytic procedures (referred to in this report as

models) typically used by project sponsors were assessed for reasonableness and capability for estimating reliable emission impacts.

- **Differences in estimation methodology from project sponsors –** Project sponsors are not limited to a prescribed standard analytical methodology and use various approaches to estimate travel impacts and emissions benefits based on the project type. These differences can confound comparisons or aggregations between projects of a similar type. As such, project-to-project comparisons were not conducted and aggregations, where reported, were carefully considered for suitability.
- **Considerations of when CMAQ project benefits begin and how long they are effective** – Project phasing is not consistently incorporated into emissions estimates. Some CMAQ projects might fund the foundational pieces of a technology, which might not result in any air quality benefits until other parts of the project are complete. In such cases, the future benefit of the project may be greater than the estimated emissions reduction. Similarly, the effectiveness of these projects may vary over time. Some projects have on-going impacts of long duration (for instance, a park-and-ride lot, which will enable ridesharing for 20+ years), while other projects generally have short-term impacts (for instance, an outreach or marketing program). The duration of benefits varies significantly among projects, and is not reported in the CMAQ database. Also, since emissions rates will change over time (i.e., emissions rates are generally falling as cleaner vehicles make up a larger share of the fleet), the benefits may decline over time or may not be consistent.Lastly, forecast traffic and emissions changes may not always consider the induced (i.e., latent) demand from congestion improvements; although doing this is considered to be good practice where applicable.
- **Portions of larger projects funded with CMAQ** – Project sponsors are inconsistent in the proportional allocation of benefits by project sponsors when CMAQ funds are added to other sources of project funds in large scale projects.
- **Differences in project scope and scale** – CMAQ funding supports a wide range of different types of projects, even within a single subcategory, at varying scales. This diversity of projects makes it difficult to assess, in general, the travel or emissions impacts of different types of projects.

# 3 Findings on Distribution of CMAQ Project Obligations

This section provides a broad overview of all reported CMAQ projects receiving obligations between FY 2006 and FY 2012. The distribution of these projects is described by State, subcategory, and funding amounts. Per the CMAQ database, a total of 8,166 CMAQ projects were funded for nearly $10.2 billion in this period. A sample of 72 CMAQ projects that were selected as case studies and their representativeness of all CMAQ projects is discussed as part of this section. Results from the case study assessments are presented in Section 4.

## 3.1 CMAQ Projects by Locations

The map in Figure 3 shows the distribution of CMAQ projects across the United States for the study period and the number of projects selected as a case study from each State. Table 4 shows the number of these projects funded by State for this time period (the table cells include histogram bars depicting the relative number of projects). California has the highest number, with 1,490 projects in this time period, followed by Michigan with 785 projects, Texas with 451 projects, Ohio with 436 projects, and Illinois and Virginia with about 400 projects each. This study selected a subset of all 8,166 projects as case studies for analysis, which is the third column listed in the table.

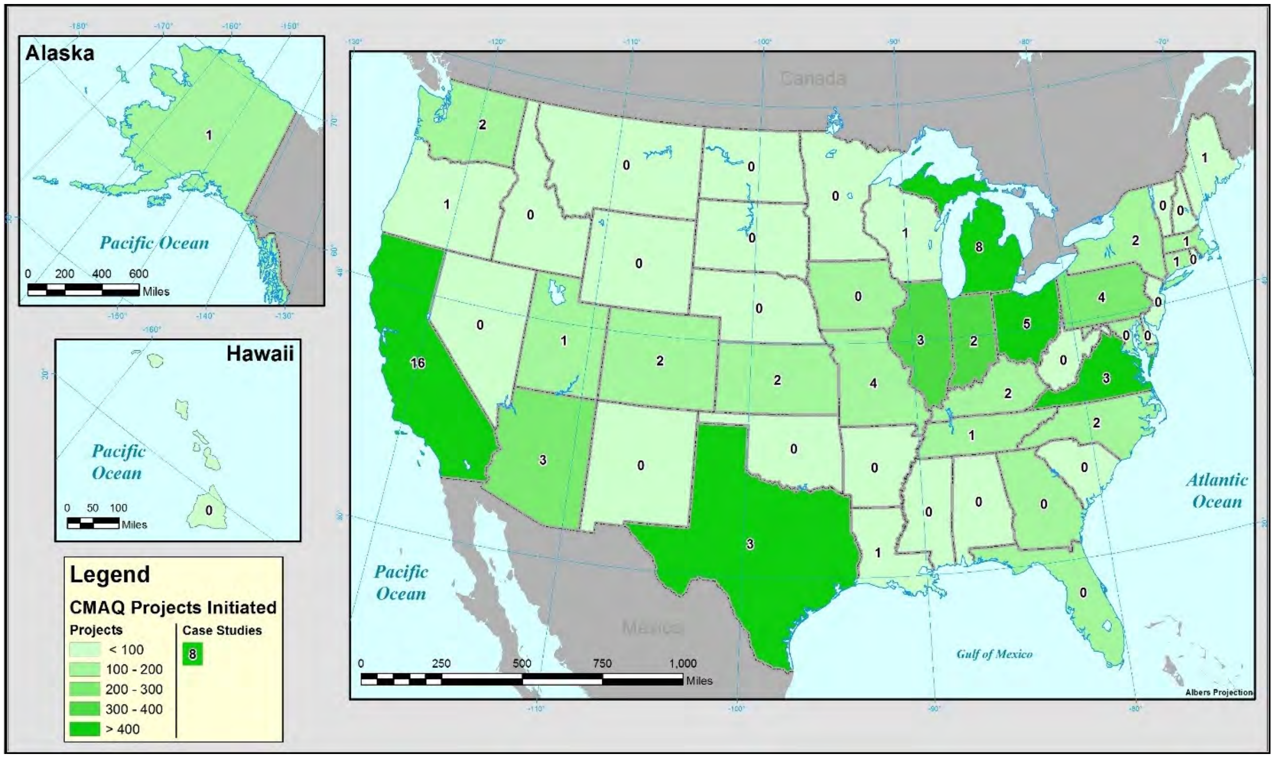

**Figure 3. Map Showing the Distribution of CMAQ Projects across the United States, and the Number of Projects Selected as a Case Study from Each State**

Table 4. CMAQ Projects and Case Studies by State (FY 2006 – 2012)

| State | CMAQ Projects | Case Studies | State | CMAQ Projects | Case Studies |
|---|---|---|---|---|---|
| Alabama | 71 | | Montana | 54 | |
| Alaska | 106 | 1 | Nebraska | 24 | |
| Arizona | 211 | 3 | Nevada | 53 | |
| Arkansas | 11 | | New Hampshire | 37 | |
| California | 1490 | 16 | New Jersey | 34 | |
| Colorado | 112 | 2 | New Mexico | 39 | |
| Connecticut | 190 | 1 | New York | 184 | 2 |
| Delaware | 30 | | North Carolina | 157 | 2 |
| District of Columbia | 46 | | North Dakota | 42 | |
| Florida | 114 | | Ohio | 436 | 5 |
| Georgia | 109 | | Oklahoma | 4 | |
| Hawaii | 29 | | Oregon | 95 | 1 |
| Idaho | 0 | | Pennsylvania | 274 | 4 |
| Illinois | 396 | 3 | Rhode Island | 56 | |
| Indiana | 303 | 2 | South Carolina | 90 | |
| Iowa | 119 | | South Dakota | 90 | |
| Kansas | 136 | 2 | Tennessee | 163 | 1 |
| Kentucky | 152 | 2 | Texas | 451 | 3 |
| Louisiana | 35 | 1 | Utah | 108 | 1 |
| Maine | 51 | 1 | Vermont | 25 | |
| Maryland | 133 | | Virginia | 405 | 3 |
| Massachusetts | 198 | 1 | Washington | 169 | 2 |
| Michigan | 785 | 8 | West Virginia | 57 | |
| Minnesota | 24 | | Wisconsin | 40 | 1 |
| Mississippi | 51 | | Wyoming | 24 | |
| Missouri | 153 | 4 | **Grand Total** | **8166** | **72** |

## 3.2 CMAQ Projects by Subcategories

The CMAQ program guidance describes 17 types of projects that are generally eligible for funding (shown previously in Table 1). Some project types include a disproportionately high number of projects, and for the purposes of this study were divided further into subcategories. For example, the types of projects eligible from the Congestion Reduction and Traffic Flow Improvements categories would include a large number and wide array of projects from intersection improvements to traveler information systems—for the study, this project type was divided into subcategories to provide a more discrete analysis of the different varieties of projects contained therein. Additional subcategories were included for projects in emergent areas or areas of special interest, which did not have a high number of projects, but were sufficiently different from other subcategories. This included the following project eligibility types: car sharing, extreme low-temperature cold start programs, idle reduction, innovative projects, roundabouts, and value/congestion pricing. Table 5 shows the 26 subcategories that were used for this study, and the total number of CMAQ projects in each subcategory from FY 2006 to FY 2012. The table also shows how the 26 subcategories were grouped into 7 major project types.

**Table 5. Number of CMAQ Projects and Case Studies by Major Project Type and Subcategory**

| Major Project Types and Subcategories | CMAQ Projects | Case Studies |
|---|---|---|
| **Vehicle/Fuel Technology** | **918** | **9** |
| Alternative Fuel Vehicles/Fueling Facilities | 468 | 5 |
| Conventional Bus and Paratransit Replacements | 353 | 3 |
| Diesel Engine Retrofits | 97 | 1 |
| **Vehicle Activity Programs** | **21** | **2** |
| Idle Reduction | 13 | 1 |
| Extreme Low-Temperature Cold Start Programs | 8 | 1 |
| **Traffic Flow Improvements** | **2868** | **26** |
| Traffic Signalization | 1349 | 9 |
| Traffic Engineering (Roadway Improvements) | 982 | 9 |
| Intersection Improvements | 387 | 3 |
| High-Occupancy Vehicle and Managed Lanes | 88 | 4 |
| Roundabouts | 62 | 1 |
| **Intelligent Transportation Systems** | **714** | **5** |
| General ITS | 479 | 3 |
| Freeway Management Systems | 153 | 1 |
| Traveler Information Systems | 82 | 1 |
| **Improved Public Transit** | **638** | **8** |
| Transit Facilities, Systems, and Services | 349 | 4 |
| New Bus Services | 212 | 2 |
| New Rail Services | 77 | 2 |
| **Transportation Demand Management** | **1149** | **8** |
| Public Education/Outreach (Information/Marketing) | 605 | 3 |
| Travel Demand Management | 357 | 2 |
| Park and Ride Facilities | 179 | 1 |
| Car Sharing | 5 | 1 |
| Value/Congestion Pricing | 3 | 1 |
| **Other** | **1858** | **14** |
| Pedestrian/Bicycle | 1422 | 9 |
| Other | 227 | 2 |
| Dust Mitigation | 168 | 1 |
| Freight/Intermodal | 38 | 1 |
| Innovative Projects | 3 | 1 |
| **Grand Total** | **8166** | **72** |

Note that these major project types are similar to the seven major CMAQ project reporting categories shown in Figure 1; however, the major project types defined for this study vary slightly because each subcategory is assigned to only one major project type. Projects were selected from each subcategory to proportionately represent each subcategory.

Ultimately, a total of 72 projects were included in this study as representative case studies. The number of case studies by major project type and subcategory is shown in the last column in the table (the table cells include histogram bars depicting the relative number of projects).

## 3.3 CMAQ Projects by Costs

Funding levels for the 8,166 CMAQ projects in the reporting database between FY 2006 and FY 2012 vary in size from year to year. Figure 4 shows the total CMAQ funding (left axis) and number of projects obligated (right axis) each year. The total annual CMAQ funding amounts vary from $874 million in 2006 to $1.69 billion in 2012. The number of projects obligated fluctuates, from 838 in 2006, to a high of 1,278 in 2011.

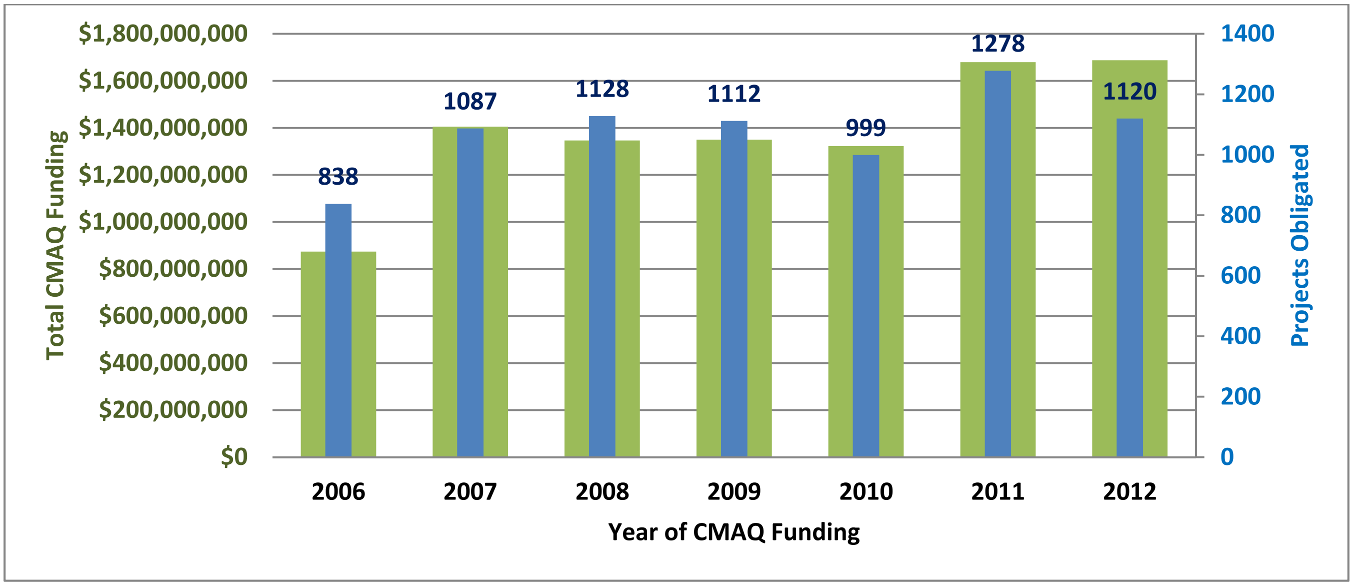

**Figure 4. Funding and Number of CMAQ Projects Per Year**

Figure 5 shows that 4,087 of these projects, approximately half of all 8,166 CMAQ projects in the study timeframe, cost between $100,000 and $1 million. Project funding amounts are grouped on the x-axis by factors of 10 to show the distribution. Projects costing $10,000-$100,000 and $1 million-$10 million comprise 1,768 and 1,818 projects respectively, or 22 percent each of the total of CMAQ projects reporting emissions data for this period. The remaining 6 percent of CMAQ projects cost either under $10,000 or over $10 million.

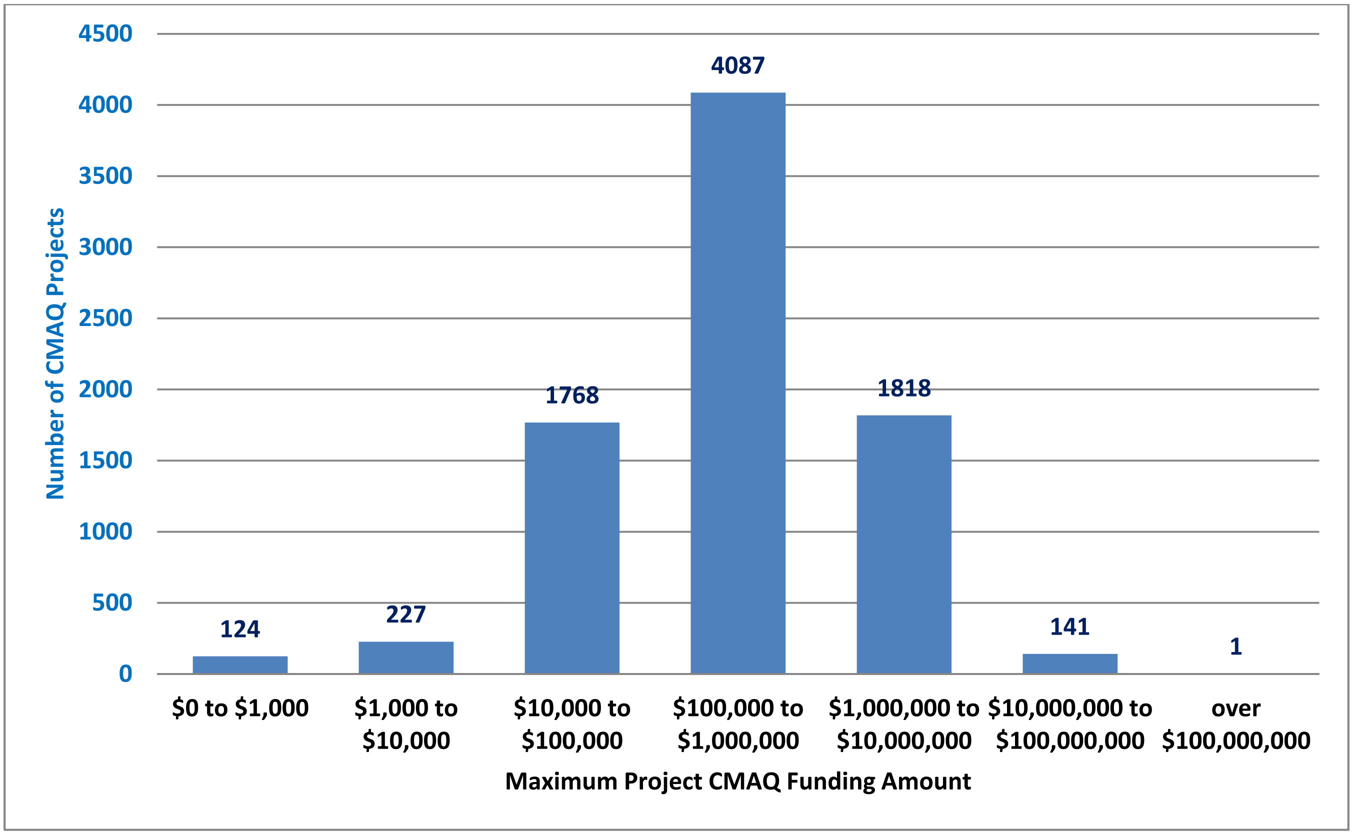

**Figure 5. Log Distribution of Number of Projects by Maximum Funding Amount for All CMAQ Projects**

Figure 6 shows the relative percentage of projects within each funding range. Project funding amounts are grouped on the x-axis by factors of 10 to show the distribution. The case study projects for all funding amounts under $100,000 are under-represented (26 percent versus 8 percent), while projects costing over $100,000 are over-represented (74 percent versus 93 percent). The representation of case study projects appears to favor the middle funding ranges because the selection also had to balance the representation of other characteristics such as project location (see States in Table 4) and project type (see subcategories in Table 5).

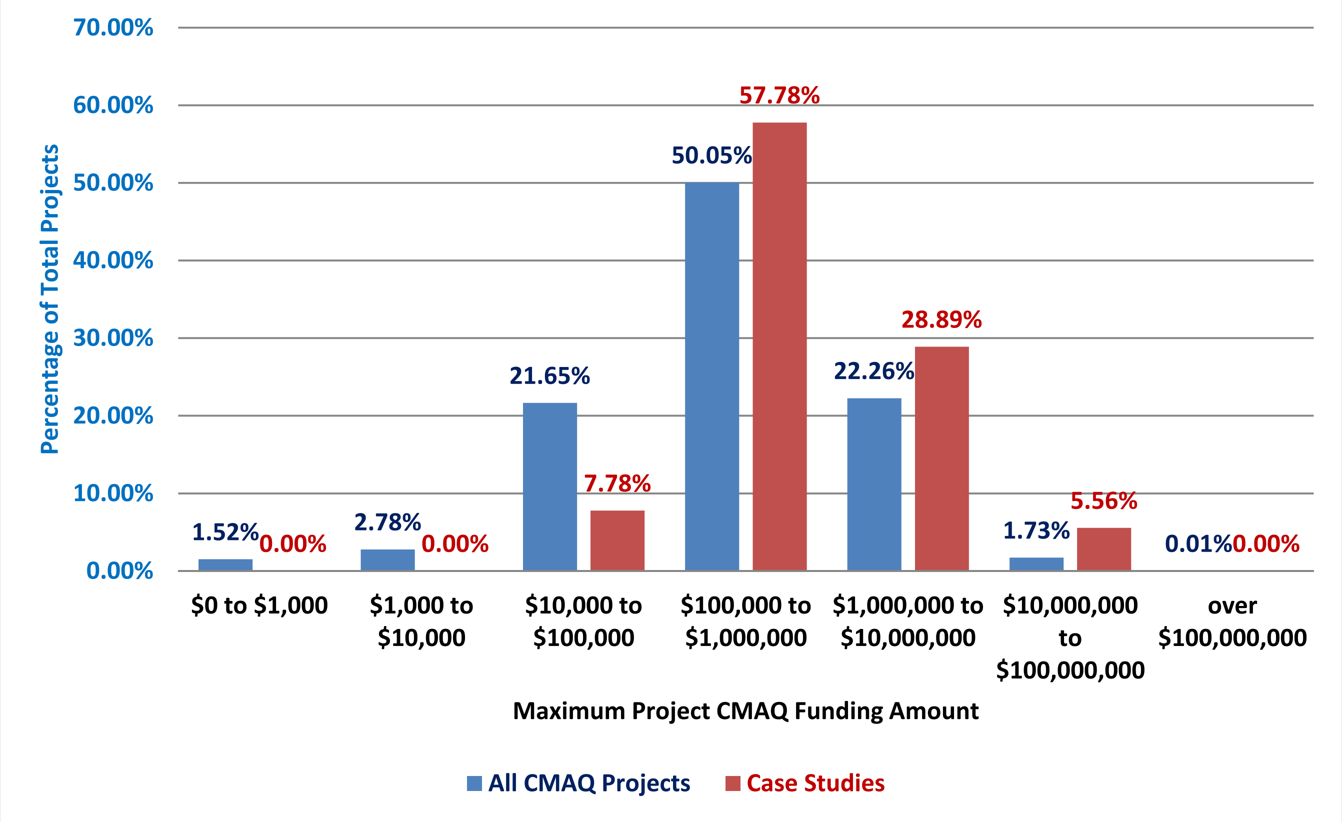

**Figure 6. Log Distribution of Percentage of Projects by Funding Amount for all CMAQ Projects and for All Selected as Case Studies**

Figure 7 shows the funding and number of CMAQ projects obligated in each major project type. The traffic flow improvements major project type had the highest total funding and number of projects—totaling $3.9 billion and 2,868 projects, respectively. It is worth noting that the improved public transit major project type had the second highest total funding and the second lowest number of projects—this contrast can be explained because the transit projects often require a great deal of capital for buses and rail cars and the transit projects are fewer in number. The converse is true for the major project type 'Other' and the transportation demand management major project type—where the projects are greater in number and often lower cost.

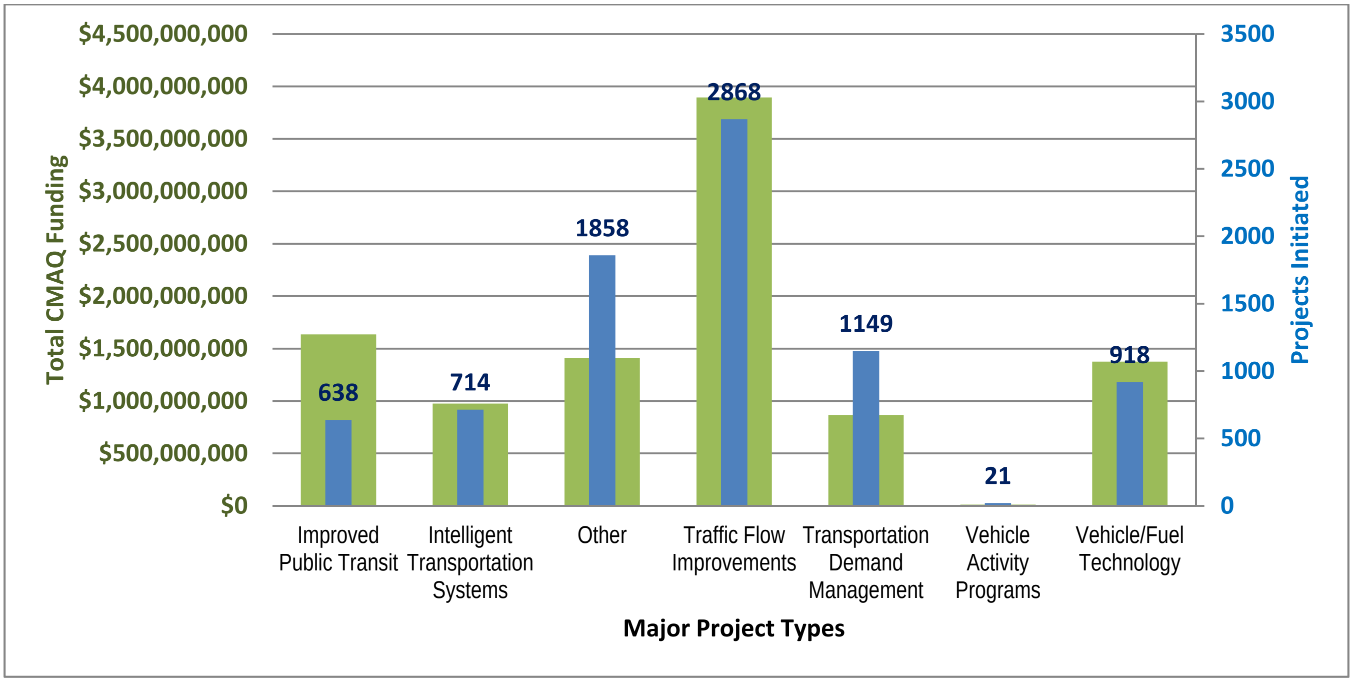

**Figure 7. Funding and Number of CMAQ Projects Obligated in each Major Project Type**

In Appendix A – CMAQ Study Major Project Types and Trends, CMAQ projects were analyzed by major project type to assess the distribution by project type and funding.

Appendix B – Detailed Case Study Findings on CMAQ Project Outcomes, includes an overview of projects in each subcategory, the geographic distribution of projects, the number and size of projects by year, and information about the estimated impacts.

## 3.4 Reported Emissions Reduction Estimates

Figure 8 shows the number of CMAQ projects in the FHWA database with a reported emissions estimate by pollutant type. These data do not include the STP projects, which are not required to calculate or report emissions estimates. There were 7,102 non-STP CMAQ projects, or 87 percent of 8,166. Overall, a majority of projects reported emissions estimates for the volatile organic compounds (VOC) and nitrogen oxides (NOx) pollutant types, with 88 percent and 83 percent of all non-STP CMAQ projects, respectively. According to FHWA CMAQ Guidance, "Benefits and disbenefits should be included for all pollutants for which the area is in nonattainment or maintenance status and should include appropriate precursor emissions." Therefore, it is not necessarily surprising that the number of projects reporting on pollutants will differ, based on the number of projects within areas that are required to report on those pollutants.

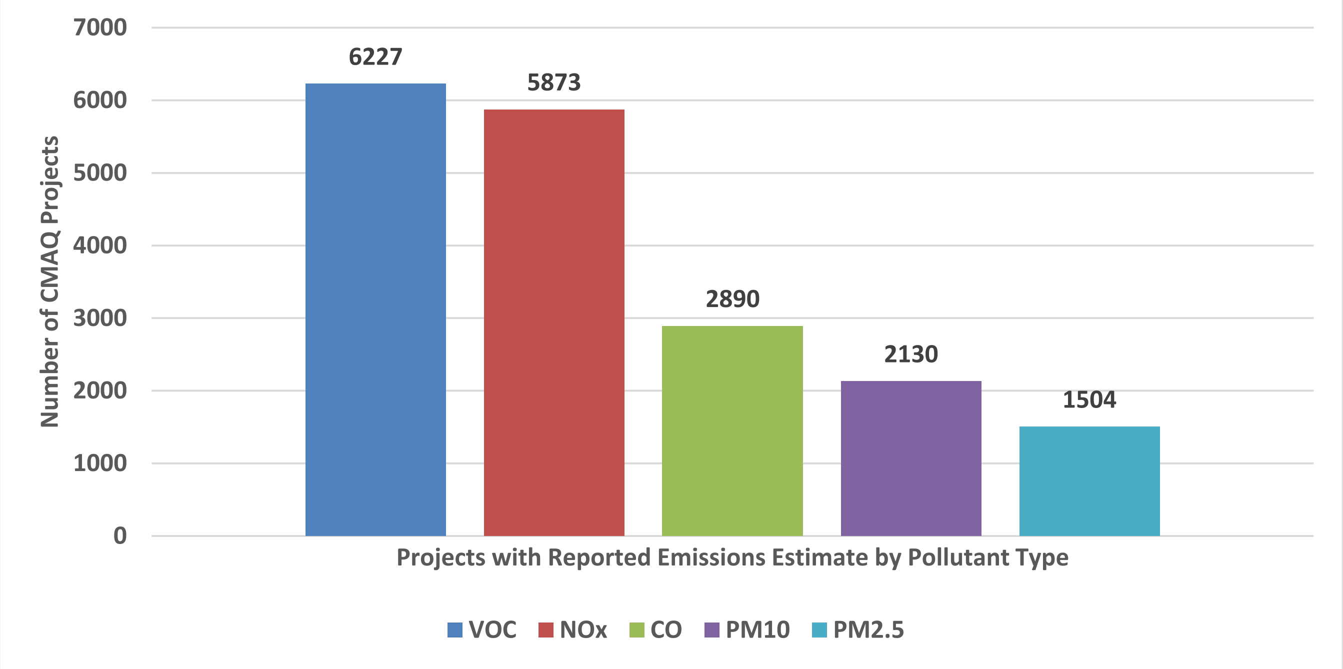

**Figure 8. Count of Projects with Emissions Estimates for each Pollution Type**

Table 6 shows the number of pollutants with estimated emissions reported in the FHWA database for each non-STP CMAQ project. Approximately 97 percent of all non-STP CMAQ projects reported emissions estimates for at least one pollutant (6,920 projects). This also includes CMAQ projects in the database reported as Previously Reported (recorded as "PR") and Qualitative Analysis (recorded as "QA"). The 3 percent that did not report estimated emissions for at least one pollutant may be due to recording errors, not necessarily a lack of emissions estimate calculations. About half of the projects (51 percent) reported estimated emissions for one or two pollutants, and the remainder (46 percent) reported estimated emissions for three or more pollutants.

**Table 6. Reporting of Estimated Emissions for Non-STP CMAQ Projects**

| Number of Pollutants with Reported Emission Estimates | Number of Projects Reporting | Percentage of Projects Reporting |
|---|---|---|
| **0** | 182 | 3% |
| **1** | 1,055 | 15% |
| **2** | 2,573 | 36% |
| **3** | 1,769 | 25% |
| **4** | 499 | 7% |
| **5** | 1,024 | 14% |
| **TOTAL** | 7,102 | 100% |

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# 4 Findings from Selected CMAQ Case Studies

For these 72 case study projects, Case Study Teams assessed estimations on Traffic/Congestion Mitigation Impacts, Emissions/Air Quality Impacts, and Human Health Impacts, which are summarized in separate sections below. Outcomes of the selected case studies are summarized for traffic and congestion mitigation impacts, emissions and air quality impacts, and human health impacts. It should be noted here that project specific information was assessed for this research project, but there is no requirement for a particular type of emissions reporting (or methodology), or reporting of travel impacts, or reporting human health impacts.

## 4.1 Estimated Traffic/Congestion Mitigation Impacts

Of the 72 case studies analyzed in this study, 52 projects (72 percent) reported estimates of traffic or congestion mitigation impacts for the project. The percentage of projects reporting these impacts should not be interpreted as being equal to the percentage of projects having a traffic or congestion impact. First, not all CMAQ projects or project subcategories are expected to result in traffic or congestion mitigation impacts. For example, alternative fuel vehicle replacement projects, idle reduction programs, or dust mitigation programs involving street sweepers have a focus on emissions reductions, and would not likely result in any impacts to traffic or congestion. Second, reporting travel impacts is not a requirement for CMAQ funding eligibility, and subsequently not all case study project sponsors comprehensively or consistently reported findings for these impacts. For instance, some case study project sponsors reported changes in emissions that were likely derived from assumed traffic or congestion mitigation impacts, but the case study sites did not report the estimated travel impacts as a separate category of project benefits. For the purposes of this study, traffic or congestion mitigation impacts were only included if reported by the site.

The text below provides details on the percentage of case study projects by major project type reporting changes for the various travel impacts and details on the average reported traffic/congestion mitigation impact estimates in particular subcategories. Note, however, as stated previously, not all CMAQ projects or project subcategories are expected to result in traffic or congestion mitigation impactsTravel impacts reported by case study sites were included in this report and are summarized below, grouped by major project type.

- Vehicle/Fuel Technology (nine case studies): very few reported traffic or congestion impacts in the case study projects because the project type primarily concerns individual vehicle engine performance, not travel related activity. For example, one case study project reported a potential increase in transit ridership and reduce vehicle trips and VMT with the operation of new biodiesel buses with increased capacity and comfort amenities.
- Vehicle Activity Programs (two case studies): as expected, these case study projects had no reported traffic or congestion impacts because the projects reduce emissions from individual vehicles, not through reduction in travel or improved traffic flow.
- Traffic Flow Improvements (26 case studies): as expected, these case study projects had a high number reporting estimated travel impacts, particularly in the areas of reduced vehicle

trips, reduced vehicle miles traveled (VMT), improved speeds, and reduced delay. Of these 26 case studies, the most frequently reported travel impact was estimated reduction in delay, with 23 percent of the case study projects reporing this data. Overall, 15 of the 26 case study projects reviewed (58 percent) reported estimated improvement in at least 1 travel impact factor.

  - Traffic Signalization case studies estimated an average speed improvement of 11 miles per hour (mph).
  - Traffic Engineering case studies that estimated changes in traffic volume calcuated an average improvement of approximately 4,000 vehicle trips per day and other traffic engineering case studies that estimated changes in delay calculated an average reduction in total delay of approximately 200 hours per day.

- Intelligent Transportation Systems (five case studies): these case study projects had a very high number reporting estimated travel impacts, particularly in the areas of reduced vehicle trips, reduced VMT, improved speeds, and reduced delay. The most frequently reported travel impact was estimated reduction in vehicle trips with 50 percent, of the case study projects reporting this data. Overall, four of the five case study projects reviewed (80 percent) reported estimated improvement in at least one travel impact factor.
  - Intelligent Transportation Systems (ITS) case studies overall reported an estimated average freeway speed improvement of 6 mph.
- Improved Public Transit (eight case studies): these case study projects had the highest percentages reporting estimated travel impacts in the areas of reduced vehicle trips, reduced VMT, and increased transit trips. Reducing VMT was the most widely reported estimate—at 88 percent of the projects. Overall, all eight of the case study projects reviewed (100 percent) reported estimated improvement in at least one travel impact factor.
  - Transit Facilities, Systems, and Services case studies estimated an average transit trip increase of 636 new riders per day.
  - New Bus Services and New Rails Services case studies estimated an average vehicle trip reduction of approximately 4,000 personal auto trips per day.
- Transportation Demand Management (eight case studies): these case study projects had a high number reporting estimated travel impacts in the areas of reduced VMT, reduction in single occupant vehicles (SOV), and increased transit trips. The most frequently reported travel impact was estimated reduction in SOVs, with 25 percent of the case study projects reporting this data. Overall, four of the eight case study projects reviewed (50 percent) reported estimated improvement in at least one travel impact factor.
  - Transportation Demand Management had three case studies reporting an estimated average VMT reduction of approximately 800 miles per day.
- Other (14 case studies): these case study projects had a high number reporting estimated travel impacts in the areas of reduced vehicle trips, reduced VMT, increased bike/walk trips, and increased bike/walk miles traveled. The share of projects reporting an increase in bike/walk trips and an increase in bike/walk miles traveled was 36 percent and 21 percent, respectively. This is not unexpected since this major project type includes the bicycle and pedestrian project subcategory, and was the highest number of any major project type

reporting expected benefits for these factors. Overall, 7 of the 14 case study projects reviewed (50 percent) reported estimated improvement in at least 1 travel impact factor.

- Pedestrian and Bicycle case studies reported an estimated average increase of 374 bike/walk trips per day.

For several subcategories of projects, the CST noted that the methodologies and assumptions used to estimate impacts were reasonable, especially when travel impacts were the focus of the CMAQ effort, although in many cases, the methods and assumptions were not adequately documented. For some case studies in several other subcategories, such as pedestrian/bicycling, TDM, public education/outreach, and roundabouts, the CST Noted that, for some projects, the information available for this study lacked sufficient detail to permit an accurate assessment of the analysis methodology or estimated impacts for those projects.

## 4.2 Estimated Emissions Reduction/Air Quality Impacts

Table 7 shows the number and percentages of CMAQ case study projects reporting estimated emissions reductions for the individual pollutants. The 72 case study projects include the 2 STP projects, which reported estimated emissions reductions even though they are not to be reported for STP projects. The case studies were selected only if they had estimated changes for emissions; and all 72 reported at least qualitative estimates for at least 1 pollutant. Case study projects typically reported emissions reduction estimates for at least two pollutants per case study.

As shown in Table 7 for the case study projects, estimated emissions reductions were reported most frequently for VOCs and NOx. Specifically, reductions in VOC emissions were estimated for 61 case study projects, or over 85 percent of all analyzed projects, while NOx emissions reductions were estimated for 63 case studies, which is nearly 88 percent of all analyzed projects. Reductions in CO emissions were estimated for 39 case studies, or 54 percent. PM emissions reductions were estimated for less than half of case study projects over all. Specifically, $PM_{10}$ changes were estimated for 24 case study projects (33 percent) while $PM_{2.5}$ changes were estimated for 20 case study projects (almost 28 percent).

The text below provides details on the percentage of case study projects reporting estimated emission reduction for individual pollutants by major project type and average reported emissions reduction estimates for some pollutants in specific subcategories. Table 8 shows the maximum values for case study projects reporting estimated emissions impacts by major project type.

### Table 7. Relative Number and Percentage of Case Study Projects Reporting Emissions Estimates for each Pollutant

| Pollutant | Case Study Projects with Emissions Estimates | |
|---|---|---|
| | Count | Percentage |
| **VOC** | 61 | 85% |
| **$NO_x$** | 63 | 88% |
| **CO** | 39 | 54% |
| **$PM_{10}$** | 24 | 33% |
| **$PM_{2.5}$** | 20 | 28% |
| **Total number of Case Studies*** | **72** | **100%** |

* Note: all case study projects estimated emissions reductions for at least one pollutant and many case study projects estimated emissions for more than one pollutant.

### Table 8. Case Study Projects Maximum Estimated Emissions Reductions by Pollutant and Major Project Type

| Major Project Type | Highest Estimated Emission Reductions (kg/day) | | | | |
|---|---|---|---|---|---|
| | VOC | NOx | CO | $PM_{10}$ | $PM_{2.5}$ |
| **Vehicle/Fuel Technology** | 2.64 | 26.00 | 27.15 | 0.48 | 12.10 |
| **Vehicle Activity Programs** | 0.00 | 3.25 | 998.00 | 0.00 | 0.09 |
| **Traffic Flow Improvements** | 873.60 | 601.20 | 373.00 | 3.21 | 4.92 |
| **Intelligent Transportation System** | 143.30 | 65.50 | 373.30 | 13.45 | 0.00 |
| **Improved Public Transit** | 41.11 | 42.92 | 496.80 | 7.46 | 0.06 |
| **Travel Demand Management** | 23.86 | 18.77 | 3.00 | 0.08 | 1.98 |
| **Other** | 17.61 | 126.57 | 82.60 | 437.71 | 26.00 |

Table 8 shows the factor maximums for case study projects reporting estimated emissions impacts by major project type. It is important to understand the nature of these reported emissions reduction estimates. Not all case study project sponsors comprehensively or consistently developed or reported estimated emissions reductions for all pollutants. Estimated emissions reductions reported by case study sites were included in this report and are summarized below, grouped by major project type.

- Vehicle/Fuel Technology (nine case studies): this major project type had a very high percentage of case study projects reporting an estimated 89 percent reduction in NOx emissions. This supports the expectations of the performance of subcategories in this major project type geared toward vehicle engine improvements. This major project type also had high percentages of projects reporting estimated reductions in VOC, CO, $PM_{10}$, and $PM_{2.5}$ pollutants.
    - Alternative Fuel Vehicles/Fueling Facilities reported an estimated average decrease in NOx pollutants of 7.6 kilograms/day.
    - Conventional Bus and Paratransit Replacements reported an estimated average decrease in NOx pollutants of 3.3 kilograms/day.
    - The Diesel Engine Retrofit case study reported an estimated decrease in CO of 27 kilograms/day, an estimated decrease in VOC of 2.6 kilograms/day, and an estimated decrease in $PM_{2.5}$ of 12 kilograms/day.
- Vehicle Activity Programs (two case studies): in this major project type, one case study reported estimated reductions in CO, and the other case study reported estimated reductions in NOx and $PM_{2.5}$. The low number of case studies in this major project type makes it difficult to identify any trends; however, the results are similar to the Vehicle/Fuel Technology major project type. Separate analysis of the individual project data showed one of the highest estimated reductions for CO of all the major project types.
    - The Idle Reduction case study reported an estimated decrease in NOx of 3.2 kilograms/day.
    - The Extreme Low-Temperature Cold Start Program case study reported an estimated decrease in CO of 998 kilograms/winter day (not annualized).
- Traffic Flow Improvements (26 case studies): the case study projects in this major project type had a very high percentage reporting an estimated reduction in VOC, NOx, and CO—100 percent, 92 percent, and 65 percent, respectively. VOC, NOx, and CO reductions are expected for projects that include various traffic and congestion improvements since vehicle emissions decrease with improved traffic flow. Some projects of this type also reported estimated reductions in $PM_{10}$ and $PM_{2.5}$ pollutants. Separate analysis of the individual project data showed the highest estimated reductions for VOC and NOx of all the major project types.

The CST noted that emissions impacts were estimated using various methods; however, for some projects, methods and assumptions were not reported. The estimated reduction in VOC, CO, and NOx emissions appeared reasonable relative to similar CMAQ projects. Methods used by the case study projects to estimate emissions impacts seemed reasonable, though the reported impacts varied and were dependent on the project's assumed travel impacts. Emissions impacts seemed to be lower for some case study projects relative to other similar CMAQ projects.

  - Traffic Signalization case studies reported estimated average decreases in VOC pollutants of 136 kilograms/day and in NOx pollutants of 124 kilograms/day.
  - Traffic Engineering (Roadway Improvements) case studies reported an estimated average decrease in VOC pollutants of 14 kilograms/day, in CO of 89 kilograms/day and in NOx pollutants of 9 kilograms/day.
  - Intersection Improvements case studies reported an estimated average decrease in VOC pollutants of 4 kilograms/day and in NOx pollutants of 2 kilograms/day.
  - High-Occupancy Vehicle (HOV) and Managed Lanes case studies reported an estimated average decrease in VOC pollutants of 27 kilograms/day, in CO of 213 kilograms/day and in NOx pollutants of 49 kilograms/day.

- Intelligent Transportation Systems (five case studies): this major project type had a very high percentage of case study projects reporting an estimated reduction in VOC, NOx, and CO—100 percent, 100 percent, and 60 percent, respectively. Traffic and congestion improvements from ITS projects are expected to improve traffic flow and streamline speeds, resulting in improved engine efficiency and reduced vehicle emissions of VOC, NOx, and CO. Some projects also reported estimated reductions in $PM_{10}$ and $PM_{2.5}$.
  - Intelligent Transportation Systems case studies overall reported an estimated average decrease in VOC pollutants of 54 kilograms/day, in CO of 168 kilograms/day and in NOx pollutants of 18 kilograms/day.

- Improved Public Transit (eight case studies): the case study projects in this major project type had a very high percentage reporting an estimated reduction in VOC, NOx, and CO—88 percent, 88 percent, and 50 percent, respectively. This supports the expectations of the performance of the projects in focused on the improvement of traffic and congestion through public transportation by decreasing the number of VMT. This major project type also had a number of projects reporting estimated reductions in $PM_{10}$ and $PM_{2.5}$. Separate analysis of the individual project data showed some of the highest estimated reductions for CO of all the major project types.
  - Transit Facilities, Systems, and Services case studies reported an estimated average decrease in VOC pollutants of 1.6 kilograms/day and in NOx pollutants of 2.4 kilograms/day.
  - New Bus Services and New Rail Services case studies reported an estimated average decrease in VOC pollutants of 18 kilograms/day, in CO of 309 kilograms/day, in NOx pollutants of 58 kilograms/day, and in $PM_{10}$ pollutants of 4 kilograms/day.

- Transportation Demand Management (eight case studies): this major project type had a high number of projects reporting an estimated reduction in VOC and NOx—75 percent for both—which is consistent with results for a project for reduction of SOV use. There were quite low percentages of case study projects reporting any reduction of CO, $PM_{10}$, and $PM_{2.5}$.
  - Transportation Demand Management case studies overall reported an estimated average decrease in VOC pollutants of 7 kilograms/day and in NOx pollutants of 6 kilograms/day.

- Other (14 case studies): the case study projects in this major project type had a high percentage reporting an estimated reduction in VOC, NOx, and CO—86 percent, 86 percent, and 64 percent, respectively. This major project type also had a number of projects reporting estimated reductions in $PM_{10}$ and $PM_{2.5}$. Separate analysis of the individual project data showed the highest estimated reductions for $PM_{10}$ and $PM_{2.5}$ of all the major project types.
  - Pedestrian/Bicycle case studies reported an estimated average decrease in VOC pollutants of 4 kilograms/day, in CO of 27 kilograms/day and in NOx pollutants of 3 kilograms/day.
  - The Dust Mitigation case study reported an estimated decrease in $PM_{10}$ of 438 kilograms/day from the use of street sweepers in and around a metropolitan area.
  - The Freight/Intermodal case study reported an estimated decrease in NOx pollutants of 126 kilograms/day and in $PM_{2.5}$ of 26 kilograms/day.
  - The Innovative Project case study, which was for development of a continuous flow intersection, reported an estimated average decrease in VOC pollutants of 18 kilograms/day and in NOx pollutants of 4 kilograms/day. The project involved

The CSTs noted that the case studies were representative of the database of CMAQ projects. The assessments noted that, while various methodologies were used to calculate emissions reductions, the methods used by many of the case study projects to estimate emissions impacts seemed reasonable, although in some cases documentation of the methods was not sufficient to conduct an assessment or the CST found that the methods appeared to be inadequate or inappropriate. The reported emissions impacts varied and were dependent on the assumed impacts on travel. The assessment noted that in some cases, the sensitivity of the estimated emission impacts depended greatly on the project scenario assumptions. Examples noted by the CSTs included:

- Emission impacts resulting from non-project changes made at the same time as CMAQ project changes need to be distinguished from the CMAQ project.
- Emissions impacts of the transit projects depend on the age of the replaced vehicles, and
- Emissions impacts of the projects depend greatly on the accuracy of VMT reduction estimates, which were not always well-documented.

For one subcategory, traffic signalization, fewer than half of the nine analyzed case study projects had sufficient information on methods and assumptions to assess reported estimated emission impacts. For other projects, methods and calculations were not provided or not enough detail was provided. In some cases, emissions impacts would be expected for the project scope but were not reported.

## 4.3 Estimated Human Health Impacts

Estimating human health impacts beyond reporting emissions reductions are not required as part of the CMAQ program requirements, but were included in the collection of the case study information to meet the goals of this study. Case study project sponsors were asked as part of this research study to report whether human health impacts were estimated for the following categories:

- Safety/Injury Prevention, e.g., reduced vehicle crash risk, reduced emergency response times, other.

- Estimates of Environmental Impacts, e.g., air and water quality impacts, soil impacts, other.
- Estimates of Impacts to Physical and Mental Health, e.g., mortality, cardiovascular disease, respiratory disease, diabetes, muscular strength and mobility, obesity, other.
- Estimates of Access Equity Impacts, e.g., increased access to better nutrition, improved access to health care providers, improved access to employment opportunities, improved access to education, improved access to recreational facilities, other.

Of the 72 case studies analyzed in this study, 22 projects (30 percent) reported beneficial human health impacts as a result of the project.  The percentage of projects reporting these impacts should not be interpreted as being equal to the percentage of projects having human health impacts.  For example, despite an estimated increase in biking or walking, some case studies did not report any associated human health impact.  The CMAQ program does not require the estimation or reporting of human health impacts.  In general, no standardized methodology is available to account for human health impacts.

The majority of the estimated human health impact feedback from the project sponsors could be described as anecdotal, rather than from actual estimates or analysis.  Three of the 72 case study projects provided estimated quantitative human health impact benefits.  Some examples of the qualitative information provided by the case study project sponsors are included below:

- Safety/Injury Prevention example, “Reduced injuries and property damage:  Transit travel is safer than car travel.”
- Estimates of Environmental Impacts example, “Motor vehicles create the majority of their pollution when idling or accelerating from a stop.  By linking individual traffic signals together, they can be programmed to work as one cohesive unit along a specific corridor.  This coordination timing allows for fewer stops along the specified corridor.  By allowing more vehicles to travel at a consistent speed with less stopping, idling, or accelerating; less air pollution is expelled into the air, thereby improving overall air quality.”
- Estimates of Impacts to Physical and Mental Health example, “By grade separating vehicle and pedestrian traffic from freight, the air quality will improve, and consequently the overall health will improve in the area.  The pedestrian improvements combined with the grade separation project will encourage more people to engage in physical activity that has been proven to improve the overall health of individuals.”
- Estimates of Access Equity Impacts example, “The [CMAQ] project and its added service will enhance accessibility for those in the urban core—an Environmental Justice (EJ) area—to jobs, education, shopping, health services, trails and other recreational opportunities, etc.”

The three case study projects that provided estimated quantitative human health impact benefits are described below:

- A Traffic Flow Improvement case study on a project providing a left turn lane for intersection improvement that reported an improved crash modification factor of 0.66 comparing 2007 to 2012.
- An Improved Public Transit case study on a project involving a light rail transit line that had conducted an independent, before and after study and determined that the opening of the

project was associated with increases in physical activity among approximately 40 percent of the experimental subjects (living closest to the line) who had the lowest physical activity levels before the line opened.
- The Innovative Project case study on a project constructing a continuous flow intersection that reported a reduction in crashes of approximately 40 percent.

Estimated human health impacts were assessed as available.

## 4.4 Case Study Team Findings

In this section, the findings of the CST on the case study projects are presented as summaries by major project type. The summaries were prepared from the individual project-level assessments submitted by each CST expert to represent findings for the CMAQ program, as represented by the case study projects that were included in the assessment.

### 4.4.1 Vehicle/Fuel Technology

The following provides a summary of findings of the CST for case study projects within the Vehicle/Fuel Technology major project type. Subcategories in this group cover alternative fuel vehicles and fueling facilities, conventional bus and paratransit replacements, and diesel engine retrofits.

- **Scope and Cost –** The nature and scope of case study projects in the Vehicle/Fuel Technology major project type fall within the context of CMAQ eligible projects and are consistent with CMAQ program goals. Overall, the costs as understood by the CST appear reasonable based on the available project details and costs for similar projects. Projects in this major project type focus on the replacement of conventional buses, paratransit vehicles, or other fleet vehicles with CNG, diesel electric hybrid, or other alternative fueled vehicles; purchasing alternative fuels; and diesel retrofit projects. The inclusion of a diesel retrofit project in the selection of case studies reflects the special priority of this type of project in the CMAQ program to highlight $PM_{2.5}$ reduction. Some projects involved replacement of vehicles that had reached the end of their useful life; in these cases, the emissions benefits of the project are small or negligible because new, cleaner vehicles would have been purchased by the recipient anyway.
- **Travel Impacts –** No travel impacts are expected for this major project type. Since these projects largely involve the purchase of alternative fuel, alternative fuel vehicles, or retrofitting vehicles. They are not expected to affect vehicle travel or mitigate congestion; however, replacement of buses with new transit vehicles might encourage additional ridership due to improved reliability, comfort and amenities of the vehicles.
- **Emission Impacts** – Case Study projects of the Vehicle/Fuel Technology major project type are expected to reduce vehicle emissions due to lower emissions per vehicle mile traveled, not due to changes in ridership or diversion from private vehicles. The CST found that the methods used to calculate emission impacts were often difficult to determine, and emission factors used in the calculations were generally not well-documented, making it difficult to evaluate the reasonableness of the estimated emission impacts. The age of the replaced vehicles, which is critical for determining emissions benefits, was often not reported. Projects

reported an estimated reduction in emissions of VOCs, NOx, $PM_{10}$ and $PM_{2.5}$, or CO. Emissions reductions could be estimated for a given project using appropriate emission factors for the traditional vehicles and the alternative fuel or hybrid vehicles. For the diesel retrofit project, the CST noted that it did not seem appropriate to include emissions reductions from a fuel change to ULSD along with the diesel particulate filters that were funded through the project. For some projects, the CST expected emissions that were not reported, (e.g., VOC reductions). The reported emissions reductions for several projects were higher than could be reproduced in calculations by the CST.

### 4.4.2 Vehicle Activity Programs

The following provides a summary of findings of the CST for case study projects within the Vehicle Activity Programs major project type. Subcategories in this group cover idle reduction and extreme low-temperature cold start programs.

- **Scope and Cost –** The nature and scope of case study projects in the Vehicle Activity Programs major project type fall within the context of CMAQ eligible projects and are consistent with CMAQ program goals. Overall, the costs as understood by the CST appear reasonable based on the available project details and costs for similar projects. Projects in this major project type focus on installation of anti-idling devices and promoting the installation and use of block heaters.
- **Travel Impacts –** No travel impacts are expected for this major project type. Since the projects in this major project type largely involve the addition of technologies to reduce idle times or decrease emissions from cold starts, they are unlikely to impact general traffic patterns or mitigate congestion.
- **Emission Impacts –** Vehicle Activity Programs projects are expected to reduce vehicle emissions as a result of reduction in idling times and installation of block heaters, which reduce start-up CO emissions. The CST found that the methods and assumptions used to calculate emissions impacts were reasonable, though not always backed up with data. Projects reported an estimated reduction in emissions for at least one pollutant, including either NOx or $PM_{2.5}$ for idling reduction and CO for cold start projects.

### 4.4.3 Traffic Flow Improvements

The following provides a summary of findings of the CST for case study projects within the Traffic Flow Improvements major project type. Subcategories in this group cover traffic signalization, traffic engineering including roadway improvements, intersection improvements, HOV and managed lanes, and roundabouts.

- **Scope and Cost –** The nature and scope of case study projects in the Traffic Flow Improvements major project type fall within the context of CMAQ eligible projects and largely appear consistent with CMAQ program goals, notably for congestion mitigation and air quality improvement. Overall, the costs (e.g., per mile, per signal) as understood by the CST appear reasonable based on the available project details and costs for similar projects. Programs in this major project type focus on traffic signal replacements, upgrades, and synchronization; installation and deployment of signal interconnection and cameras and wireless communication signal systems; lane rehabilitation/ installation; new grade separations; active transportation support infrastructure including bike lanes and sidewalks; ; intersection redesign (e.g., construction of roundabouts); road widening; lane reconfiguration; the installation and maintenance of traffic loops and traffic sensing devices; and HOV lane implementations.  In some instances, the CST found either the project description, specific project improvements, or project costs listed to be unclear or lacking in detail (e.g., lack of accuracy regarding overall project cost, or fraction of total costs equal to CMAQ funds versus other funding).

- **Travel Impacts –** Travel impacts reported for Traffic Flow Improvements major project type projects were generally a result of streamlined speeds, lower delays, and higher traffic flows in and through the project areas (e.g., better timed signals or construction of roundabouts).  In some instances, congestion was reported to be reduced via mode shifts (e.g., projects that encouraged ridesharing modes such as carpools, vanpools, and commuter buses); however, a general concern for traffic signalization project travel impacts was if and how the speed improvements for signalized intersections or corridors accounted for speed/delay impacts on affected cross streets.  The complexity and level of documentation describing the estimates of travel impacts on the Traffic Flow Improvements projects varied significantly from one case study to another, sometimes with supporting calculations making the basis of the computations more easily understood.  For less than half of the case studies, explicit travel impacts were not provided or were developed with inappropriate tools such as regional travel models when localized traffic models or estimates would have been more appropriate. Additional information regarding the assumptions and the reasonableness of the calculations (e.g., peak and off-peak periods or average daily traffic volume) used to derive travel impact estimates would strengthen these traffic flow improvement project proposals.
- **Emission Impacts** – Projects in the Traffic Flow Improvements major project type are expected to reduce vehicle emissions as a result of overall congestion reductions due to improved speeds, decreases in VMT after implementation of the projects, and decreases in traffic delay.  Emissions reductions of VOCs, CO, and NOx, where reported, seem reasonable for these types of projects.  Very few of the projects, with the exception of HOV lanes and managed lanes, which encourage carpooling/ridesharing, reported a reduction in $PM_{10}$ or $PM_{2.5}$.  In some instances, the CST found that the methods and assumptions (e.g., travel forecasts, fleet characterization) used to calculate emission impacts were not well documented (i.e., unable to verify VMT or speed improvements), or they contained errors in math and/or the application of traffic engineering methodology, making it difficult to evaluate the reasonableness of the estimated emission impacts.  In addition, the connection between the travel estimates and the emission calculations was not always clear, and in many cases the emission model used was not the most up to date.  Although the CMAQ program does not require specific software packages, the CST noted that it is a best practice to use the current emissions analysis software as defined by the EPA.

### 4.4.4 Intelligent Transportation Systems

The following provides a summary of findings of the CST for case study projects within the ITS major project type. Subcategories in this group cover general transportation systems, freeway management systems, and traveler information systems.

- **Scope and Cost –** The nature and scope of case study projects in the ITS major project type clearly fall within the context of CMAQ eligible projects and are consistent with CMAQ program goals. Overall, the costs as understood by the CST appear reasonable based on the available project details and costs for similar projects. Projects in this major project type focus on incident management programs, traffic signal optimization (upgrades), installation of CCTV cameras and static incident bypass route signs, fiber optic communication systems related to ramp metering, vehicle monitoring, changeable message signs, and physical assets and services to provide travelers with real-time information (dynamic message signs and microwave vehicle detection units).
- **Travel Impacts –** Travel impacts reported for ITS major project type projects generally resulted from an improvement in travel speed along the project corridor, or an increase in transit trips resulting in a reduction of vehicle trips and VMT. Travel impacts typically were direct and could be significant depending on the ITS strategy and situation. For purposes of estimating travel impacts (e.g., speed improvements or reductions in miles traveled), projects generally relied on a combination of data from project studies, localized data (e.g., existing traffic count data), and assumptions (e.g., increase in transit ridership). Estimates of travel impacts for some of the ITS projects were conservative yet based on reasonable data or assumptions, and the methodology applied was documented, sometimes with supporting calculations making the basis of the calculations more easily understood; however, it should be noted that more information on the methods used (estimated volume of vehicles affected/change in delay) and the reasonableness of the calculations used to derive travel impact estimates would strengthen these ITS projects. In an extreme case, for one of the projects studied, there was no supporting evidence provided to substantiate the claimed expected reductions in travel to be achieved with project implementation; the CST anticipated that implementation of that project would increase, rather than decrease, VMT, in contradiction to the supporting material available.
- **Emission Impacts** – ITS major project type projects are expected to reduce vehicle emissions as a result of overall congestion reduction due to improved speeds along the corridor, decreases in vehicle trips and vehicle-miles traveled after implementation of the projects, and decreases in traffic delay. The CST found that the methods and assumptions used to calculate emission impacts were often not well documented (e.g., unable to verify travel speed changes) or problematic in that they did not utilize actual travel conditions or estimated emissions based on generalized reduction ratios, making it difficult to evaluate the reasonableness of the estimated emission impacts. Emissions reductions of VOC, NOx, CO, and $PM_{10}$ were reported and seem reasonable for these types of projects; reductions in $PM_{2.5}$ were not reported.

### 4.4.5 Improved Public Transit

The following provides a summary of findings of the CST for case study projects within the Improved Public Transit major project type. Subcategories in this group cover transit facilities, systems, and services and new services for bus and rail.

- **Scope and Cost** - The nature and scope of case study projects in the Improved Public Transit major project type generally appear to fall within the context of CMAQ eligible projects and are consistent with CMAQ program goals. Although the costs as understood by the CST technical experts appear reasonable for the majority of projects based on the available project details and costs for similar projects, the CST found either the documentation of the scope or project costs listed for some to be unclear or lacking in detail. Projects in this major project type focus on bus service improvements, including the installation of bus shelters, new or expanded bus service to increase transit capacity and related commuter and student transit services, as well as new commuter rail and light rail services.
- **Travel Impacts –** Travel impacts reported for Improved Public Transit major project type projects were generally viewed as reasonable by the CST and result from mode shifts (e.g., shift from single occupancy vehicle travel to using bus or rail transit). The improved public transit services are expected to generate increased transit ridership, with some of those new riders switching from driving personal vehicles, resulting in a reduction of vehicle trips and VMT. For purposes of estimating travel impacts, projects generally relied on a combination of data from project studies, localized data (e.g., on trip lengths, frequency of riding), and assumptions (e.g., increase in transit ridership). Estimates of travel impacts for some of the Improved Public Transit projects were based on reasonable data or assumptions. The methodology applied was often documented, sometimes with supporting calculations making the basis of the calculations more easily understood. In other cases, data and assumptions were not well documented, travel impacts appeared to be overstated, and/or stated assumptions were not internally consistent. It appears that about 60% of the projects utilized appropriate assumptions that were well documented. More information on the basis of the assumptions and on the calculations used to estimate travel impacts would strengthen confidence in the accuracy of estimates for the transit projects.
- **Emission Impacts –** Improved Public Transit major project type Case Study projects are expected to reduce vehicle emissions as a result of decreases in vehicle trips and vehicle-miles traveled. The CST technical experts found that the emissions calculations for most of the projects were well-documented a little more than half the time, making it possible to evaluate the reasonableness of the estimated emission impacts. Projects within this group estimated emissions reductions (from light-duty vehicles) for VOCs, CO, NOx, $PM_{10}$ and $PM_{2.5}$ for each of the new bus services case studies and new rail service case studies; however, generally the calculations did not account for any offsetting increase in emissions due to the new transit vehicles.

### 4.4.6 Transportation Demand Management

The following provides a summary of findings of the CST for case study projects within the Transportation Demand Management major project type. Subcategories in this group cover public education and outreach activities (ozone action day activities), travel demand management (TDM), park and ride facilities, car sharing, and value/congestion pricing.

- **Scope and Cost** - The nature and scope of case study projects in the Transportation Demand Management major project type generally fall within the context of CMAQ eligible projects and are consistent with CMAQ program goals. Overall, the costs as understood by the CST technical experts appear reasonable for the majority of projects based on the available project details and costs for similar projects, although some discrepancies were noted including high costs and uncertainty regarding the precise use of CMAQ funds. Programs in this major project type focus on promoting use of alternatives to single-occupant-vehicle (SOV) travel through use of ridesharing, bus transit, car-sharing, walking, telecommuting, or other alternatives. It also includes strategies such as value/congestion pricing that create incentives to shift travel from peak to off-peak periods, and information on alternatives, using pricing as a tool to change travel behavior.
- **Travel Impacts –** Travel impacts reported for Transportation Demand Management major project type projects were generally as expected by the CST and result from mode shifts (e.g., shift from SOV travel to carpooling, using bus transit, or other options). These shifts were difficult to quantify without ride tracking systems or data garnered from surveys or in-vehicle technology. For purposes of estimating travel impacts, projects generally relied on a combination of data from project studies, localized data (e.g., trip lengths), and assumptions (e.g., share of park-and-ride spaces that will be utilized). Among the relatively few that reported travel impact estimates, TDM projects were based on reasonable data and/or assumptions. The complexity and level of documentation describing the methodology varied significantly from one case study to another, sometimes with supporting calculations making the basis of the computations more easily understood. It should be noted that travel impact estimates that are based on assumptions about mode shifts resulting from project implementation would not be as reliable as those based on empirical data from similar projects. This is because of the range of variables at play that influence travel choice.
- **Emission Impacts –** Projects in the Transportation Demand Management major project type are expected to reduce vehicle emissions as a result of decreases in vehicle-mile traveled and other effects like shifts to off-peak times of day, allowing for higher speeds and improvements in congestion (such as reduced vehicle delay) that avoid low-speed emission rates after implementation of the projects. The CST technical experts found that the methods used to calculate emission impacts were straightforward; however, the software used to conduct the emissions modeling, the emission factors used in the calculations, and other factors, such as average trip length, access mode assumptions, cold start versus running impacts were generally not well-documented, making it difficult to evaluate the reasonableness of the estimated emission impacts. Although most projects primarily reported reductions in NOx and/or VOCs, reductions in CO, $PM_{2.5}$ and $PM_{10}$ were also sometimes estimated.

### 4.4.7 Other

The following provides a summary of findings of the CST for case study projects within the other major project type. Subcategories in this group cover a broad set of activities including pedestrian and bicycle projects, dust mitigation, freight and intermodal projects, innovative projects, and other miscellaneous.

Given the great diversity of project types, especially the nine pedestrian and bicycle projects, a broad overview of these case studies is more problematic within this category. In order to provide a meaningful assessment, specific examples of these various subcategory cost and scope, travel, and emissions impacts in this major project type are described below.

- **Scope and Cost -** The nature and scope of case study projects in the other major project type are well documented and generally fall within the context of CMAQ projects and are generally consistent with the goals of CMAQ. Overall, the costs as understood by the CST technical experts appear reasonable based on the available project details and costs for similar projects. The effectiveness of the projects, in most cases, cannot be reasonably calculated from the information provided and some pedestrian and bicycle projects had little or no state/local funding matches. Programs in this major project type primarily focus on pedestrian and bicycle infrastructure projects designed to encourage and facilitate the use of non-motorized modes of transportation; however, programs in this type also include a pilot test of a local high-emitting vehicle remote sensing program, a voluntary “change of vehicle ownership” program to provide emissions data to people who are buying a used car, alternatively fueled vehicles, the purchase of street sweepers, improvements to port facilities (i.e., rail corridor improvements), and the creation of a Continuous Flow Intersection (CFI) in order to potentially reduce delays and improve air quality.
- **Travel Impacts –** Since the projects in the other major project type vary widely in scope, travel or congestion impacts were also expected to vary by project. Travel impacts reported for the majority of the projects were observed by the CST to be a result of an increased number of bicycle and pedestrian trips, changes in vehicle delay, or changes in travel mode, depending on the nature of the project. Some results, which were generally well documented, impacted travel patterns and mitigated congestion by removing vehicle trips, reducing delay at intersections, and reducing truck trips by shifting freight to rail though the addition of double stack capability. Many projects, including a great majority of the pedestrian and bicycle projects, did not estimate any travel or congestion mitigation impacts. Furthermore, the case study to reduce dust emissions from road dust and pollution from street sweepers would not be expected to impact VMT or mitigate congestion. Several CST technical experts noted that a sub-set of the pedestrian and bicycle projects were intended for amenity or recreational purposes and would not reduce vehicle trips and therefore did not address the CMAQ goals of congestion reduction or air quality improvement.
- **Emission Impacts –** Other major project type projects are expected to reduce vehicle emissions as a result of vehicle trips that have shifted to bicycle or pedestrian trips, engine technology improvements, reductions in vehicle delay, or reductions in $PM_{10}$ from paving unsurfaced roads or removing dust from paved roads. With the exception of the pedestrian and bicycle projects, the CST technical experts found that the emissions calculations for the majority of the projects in the other major project type to be well-documented, making it straightforward to evaluate the reasonableness of the estimated emission impacts. The pedestrian and bicycle projects did not present sufficient information or evidence to estimate a reduction in vehicle trips or congestion that could be tied to a reduction in emissions. Another concern is that at least one case study involving mode shift reported decreased travel and therefore emissions for one travel mode, but did not appear to take into account the resulting

increased in travel in the shifted mode and how that may impact emissions. Analysis of the case studies indicated that individual projects were likely to reduce emissions for at least one pollutant and oftentimes, multiple pollutants, including emissions reductions of VOCs, CO, $NO_x$, $PM_{10}$, or $PM_{2.5}$.

# 5 Findings of Analysis of Emission Estimation and Modeling Techniques

The research team conducted a critical review and assessment of typical emission estimation methods and models used for CMAQ projects. Second, researchers completed a review of emission factor input file consistency with SIP development and conformity analysis. Finally, the research team conducted a search for before and after evaluations of CMAQ projects, to identify if any such assessments exist, and to review the findings.

As discussed in the CMAQ guidance (FHWA, 2013), CMAQ funded projects should include an assessment of the project's expected emissions reductions benefits prior to project selection. Quantitative emissions benefits should be included in all project proposals, except where it is not possible to quantify emissions benefits. The analysis should include all pollutants for which an area is in nonattainment or maintenance status (e.g., ozone, particulate matter, carbon monoxide) and should include any precursor emissions ($NO_x$ and VOC for ozone). The potential benefits of all projects should be reported in a consistent fashion (i.e., kilograms/day).

All potential benefits from all emissions sources involved should be included in the analysis. State and local transportation and air quality agencies conduct CMAQ-project emissions analyses with different approaches, analytical capabilities, and technical expertise. While no single method is specified by FHWA, every effort should be taken by agencies, within their resources and capabilities, to ensure that their analyses are credible and based on a reproducible and logical analytical procedure.

The evaluation began with the identification of emission analysis models, routines, or techniques and the critical review of 10 models, routines, or techniques. The models originated from state DOTs, MPOs, air agencies, and research guidebooks. Most of the models were stand-alone agency guidance for CMAQ project emissions analysis either in a document or as Microsoft® Excel-based worksheets available on an agency web site. Some were found as part of an agency's conformity documentation or as a research report. The models ranged from simple to complex methodologies. Simple methodologies are sketch-planning equations with a few basic inputs. The more complex techniques strive to capture more of the emission reductions from a strategy through a larger number of equation variables requiring more and different types of data.

In determining the final group of 10 models, the research team placed importance on the number of CMAQ project types analyzed within the method, the availability of individual equations, sufficient available detail explaining equations and assumptions, and national geographic distribution.

Within the 10 models, the research team analyzed 94 analysis equations over 21 CMAQ project types. Overall, no major problems were found in the review and assessment of the models. The vast majority of the equations seek to identify the specific source and activity leading to an emissions benefit from a strategy (i.e., new participants, number of former SOV drivers, and type of affected vehicle).

Minor issues were also identified with the analysis equations. Dimensional analysis errors occur when the final unit of measurement (kilograms/day) cannot be calculated based on the units specified in the equation variables.  Five of the 94 equations reviewed, distributed across the 10 models and project types, were shown to have these errors.  Also, 10 equations across 6 different strategy types missed travel or emissions segments that could potentially show greater emissions benefit for the strategy.

Most models reviewed provided instructions for using the equations and methodologies but very few provided “real world” examples.  The development of online CMAQ project application and emission analysis processes has made the experience more user-friendly.  These electronic worksheets are supported by underlying lookup tables of regional or statewide emission factors.  Default values are made available for some of the inputs.

The research team conducted an emission project input consistency review to examine if emission factor model inputs for CMAQ evaluations are consistent with those used for conformity and SIP development.  This was done through a two-step process.  First, a sample of 45 case studies collected as part of this study was compiled.  Researchers then performed a secondary and more thorough examination of 10 CMAQ projects from the pool of the case studies reviewed in this assessment report to establish a better understanding of the state-of-the-practice with regards to the emissions factors used in the evaluation of CMAQ projects.  Conclusions from the review are:

- In some states, the state air agency has established a set of statewide emissions factor tables and tools for CMAQ analyses.  It appears that the majority of CMAQ analyses in such states use these tables and tools.
- Some projects use available national-level emission factor information from FHWA or EPA.
- It is not a common practice to include detailed assumptions, input values, and data sources for CMAQ project analysis.
- A few larger MPOs appear to have used local emission rates based on the latest planning assumption at the time of analysis.  The research team expects that emissions input files for CMAQ projects from these MPOs are very likely to be consistent with SIP and/or conformity input files; however, this could not be verified based on the information found and reviewed.

Ten selected before and after studies were reviewed and evaluated by the research team.  The selected projects covered a range of projects with scopes similar to projects funded under CMAQ, though none of these projects are confirmed to have been funded through the CMAQ program.

The following recommendations for improving estimation methods and models from the critical analysis and assessment of the 10 methods/models are offered for consideration.

Inputs

- Make efforts to use the best available local inputs when generating emission factors used in the project-level analysis

Robustness

- A simpler equation does not mean lesser quality results; an agency can only analyze projects to the detail that its available resources allow.

- Consider using more conservative inputs to avoid inflated emissions benefits.

Structure

- It is important to maintain a focus on the dimensional analysis of equations. Align the input units, so that the equation can better provide a valid benefit estimate..
- Vigilant quality control/quality analysis is a must. Ensure that input data collected meets the units of what is expected in the equation.
- All equations should strive to compute and report in kilograms/day to follow CMAQ guidance. Showing the conversions within the equations to kilograms/day reinforces to the user how and where this is performed in the equation.
- Build new or expand existing equations and methodologies from other agency estimation techniques. Often, logic or components in other project type equations can be transferred with little or no modification to another project type.

Logic

- Always ask if there are more travel or emission segments that could be captured by the analysis method? Can we fit it in the current equation? Are the data readily available?

Application

- Provide clear instructions and good examples for each strategy analysis.

Advancing the state-of-the-practice

- Before and after studies are not required by the CMAQ program; however, having some before and after studies would help practitioners improve their emission estimation methods. This is especially true to measure, compare, and improve those inputs and assumptions used to estimate travel activity changes (e.g., average trip length or percentage of users that shift from a single occupant vehicle to an alternative mode). Conducting before and after studies can be challenging. Depending on the project type, project implementation, and the scale and measured outcomes of the before and after study, these studies can be resource-intensive for an agency with limited funding.

## 5.1 Introduction

This research consisted of three separate efforts. First, the research team reviewed, summarized, and evaluated the current state of the practice in estimation and modeling techniques used to assess emission reductions CMAQ strategies. Through a literature and Internet search, 10 CMAQ analysis methodologies were identified for more detailed analysis. The team assessed the validity of these methods and proposed recommendations to improve further development and application of the methods. Second, the team searched for emission factor model inputs used for the quantitative CMAQ evaluations to assess if those model inputs were consistent with those model inputs used for SIP development and regional conformity determinations.  Finally, the research team searched for ground truth studies (before and after studies) of CMAQ-funded projects.

Transportation/air quality analysis typically refers to two types of analyses: on-model and off-model. *On-model* refers to those projects whose travel effects can be quantified using travel demand model networks and other methods.  For those projects that cannot be adequately represented within a travel demand model, *off-model* techniques are used.  The 10 models reviewed provide off-model methods and equations for CMAQ strategy analysis.

Off-model techniques vary widely.  Some techniques are simple, manual calculations whereas others are in the form of computer interfaces using a set of generalized equations.

A simplified approach to mobile source emission reduction strategy analysis does exist, as described by TxDOT (2008), with the four components shown in Figure 9.  In general, mobile source emission models use a similar approach, using different inputs depending on the component and type of proposed strategy.  Mobile source emission reduction strategy analysis attempts to capture the changing relationships between the components resulting from implementation of the proposed strategy.

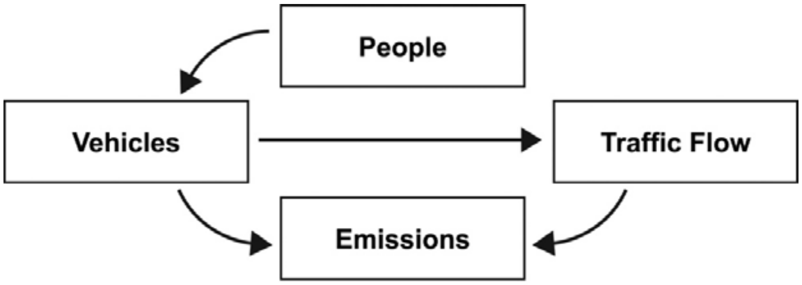

**Figure 9.  Four Analysis Blocks (TxDOT, 2008)**

*People* refers to the population that is affected by the project.  This may be as small as an office building or as large as regional participation in a specific program.  This analysis block can be expressed as number of participants, person trips, mode share, and trip ends.

*Vehicles* refers to the activity people conduct with their personal mode of transportation.  This can be vehicle trips, peak hour vehicle trips, VMT, and engine starts.

*Traffic flow* refers to how the participants' mode of travel is improved.  This can be a change in overall travel speed, regional speed, or corridor speed, as well as reduced numbers of vehicle accelerations and idling times.

Finally, *emissions* refers to how pollutants from the personal mode of transportation are affected.  In most cases, differences between before and after emission rates (based on changes in travel speed) are used to determine benefits.  Comprehensive emissions assessments include running, evaporative, crankcase, engine start, and diurnal emissions.  The comprehensive emissions assessment is important to capture benefits from strategies that reduce the number of physical vehicles in a region, and thereby reduce the amount of evaporative emissions that come from vehicles.

Emission factors, or emission rates, for each component are provided by EPA's MOVES2010 or MOBILE6.2 emission factor model, used in areas outside of California. California uses the EMFAC model. EMFAC is maintained by the CARB. The emission factors reflect daily temperatures, vehicle mix and age distribution, fuel characteristics, inspection and maintenance (I/M) programs, and other factors representative of the local area.

Emission factor models such as MOVES2010 or others approved by EPA were not evaluated, as these widely used models are assumed to be validated. Several of the 10 models reviewed and analyzed were created with MOBILE 6.2 emission factors with some using the more recent MOVES emission factor model. MOVES is a software program used to estimate emissions at a more detailed level. The model also allows users to incorporate a variety of activity data to better estimate emission differences such as those resulting from changes to vehicle speed and acceleration patterns. For example, the improvements in MOVES2010 allow project-level $PM_{2.5}$ and $PM_{10}$ emissions to be estimated. The 10 models evaluated require use of emission factors generated from an emissions factor model. Despite being a new generation model, the emission factors generated with MOVES can be used in equations used to compute the emissions benefit for a CMAQ project.

The research team excluded emission benefit models and techniques considered to be proprietary because of expectations that consultants would not grant access to what would be considered trade secrets.

## 5.2 Organization

This section is organized by first describing the research methods used for the three efforts documented within. Then the results for each effort—critical analysis review of emission methods and models, emission factor input file consistency assessment, and before and after study summaries—are presented.

### 5.2.1 Research Methods

The research team utilized several methods to accomplish this work. These include a comprehensive literature search, an internet scan of all MPO and state DOT Web sites in designated nonattainment areas of CMAQ project analysis material, and use of information gained through the case study process documented in Section 4 of this report.

### 5.2.2 Literature Review

The research team submitted a focused but extensive search term list to the TRID and ProQuest databases of transportation articles. The term "CMAQ" was used to focus on literature specifically identified with the CMAQ program and was matched with each project type along with emission analysis model terms. The search focused on articles since 2004. In all, 31 documents, articles, and reports were deemed relevant and were reviewed; 4 of these proved useful to this work. The literature review yielded 2 models for potential inclusion in the 10 chosen methodologies along with 2 before and after studies.

### 5.2.3 Internet Search of Nonattainment Area MPO and State DOT Web Sites

The agency Web sites of every MPO in a federally-designated nonattainment area was searched for publicly available documentation of CMAQ analysis methodology, emission factor input files, and funded project ground truth studies. The research team also searched Web sites for several state DOTs. The research team reviewed more than 131 Web sites. As relevant information or documentation were identified, it was downloaded and evaluated for inclusion as a potential methodology for analysis.

### 5.2.4 Case Study Findings

Information gained from this project's case study effort was incorporated where feasible. The response received from the case study surveys were reviewed for usefulness to the methodology analysis, emission factor input file consistency review, and available ground truth studies.

## 5.3 Results

### 5.3.1 Critical Analysis of Emission Estimation Methods and Models

The research team was tasked to study up to 10 CMAQ emission analysis models, routines, or techniques. The Internet search and literature review yielded 16 models for possible analysis. The models originated from state DOTs, MPOs, and research guidebooks. Most of the models were stand-alone agency guidance for CMAQ analysis either in a document or as Microsoft® Excel-based worksheets available on an agency Web site. Some were found as part of an agency's conformity documentation or as a research report. The models also ranged from simple to complex methodologies. Simple methodologies are sketch-planning equations with a few basic inputs. The more complex techniques strive to capture more of the emission reductions from a strategy through a larger number of equation variables requiring more and different types of data.

In determining the final group of 10 models, the research team placed importance on the number of CMAQ project types analyzed using the method, the availability of individual equations, sufficient available detail explaining equations and assumptions, and national geographic distribution. The 10 models selected for critical analysis were:

A. California Air Resources Board – Methods to Find the Cost-Effectiveness of Funding Air Quality Projects
B. Center for Clean Air Policy – Transportation Emissions Guidebook
C. Maricopa Association of Governments (Phoenix, Arizona)
D. Metropolitan Washington Council of Governments
E. Michigan Department of Transportation
F. Montana Department of Transportation
G. Multi-Pollutant Emissions Benefits of Transportation Strategies (FHWA-HEP-07-004)
H. Regional Transportation Council of Southern Nevada (Las Vegas, Nevada)
I. Texas Department of Transportation (TxDOT) – The Texas Guide to Accepted Mobile Source Emission Reduction Strategies
J. Wasatch Front Regional Council (Salt Lake City, Utah)

The CARB CMAQ method is found in the May 2005 agency guidance “Methods to Find the Cost-Effectiveness of Funding Air Quality Projects.” The methods are used in conjunction with updated 2013 emission factor tables to analyze potential CMAQ projects. (CARB, 2005) This assessment’s case studies provided evidence that this method is still being used by MPOs in California. The research team notes that several of the individual CARB equations and methodologies form the basis for strategy analysis by both MPOs and state DOTs outside of California.

The Center for Clean Air Policy (CCAP) Transportation Emissions Guidebook provides basic information to calculate emissions reductions from the implementation of specific transportation and land use policies” (CCAP, 2005). The guidebook consists of a main document providing detail on strategy analysis along with a two-part Microsoft® Excel-based spreadsheet tool (Guidebook Emissions Calculator) enabling users to quantify the emissions benefits from a variety of projects and policies. Use of these methods by agencies could not be verified but it is a detailed, publicly-available model that could be used for CMAQ analysis.

FHWA published a November 2006 report on “Multi-Pollutant Emissions Benefits of Transportation Strategies.” The report is a compilation of existing methods and equations used by agencies presented in sketch planning techniques (FHWA, 2006).

The Maricopa Association of Governments in Phoenix, Arizona provides their comprehensive “Methodologies for Evaluating Congestion Mitigation and Air Quality Improvements Projects” on their agency Web site. The research team used the September 30, 2011 version for this analysis (MAG, 2011).

The Metropolitan Washington Council of Governments methodologies were documented in the July 2013 Air Quality Conformity Determination of the 2013 Constrained Long Range Plan and the FY 2013-2018 Transportation Improvement Program for the Washington Metropolitan Region (WMCOG, 2013).

The Michigan Department of Transportation provides Microsoft® Excel-based worksheets by project type for CMAQ project applicants on the department Web site. As the user enters required project information in individual cells, the worksheet calculates key equation variables and uses hard-coded emission factors to calculate potential benefits (MDOT, 2012).

Montana Department of Transportation re-evaluated its air quality program in 2013. As part of the effort, the agency developed Microsoft® Excel-based worksheets to aid staff in performing the emission benefit analysis of their four main project types (MDT, 2013).

Regional Transportation Council of Southern Nevada methodologies were referenced in the agency conformity determination documentation. Agency staff provided the research team with more details on strategy equations and analysis (RTCSN, 2014).

The 2008 version of the Texas Guide to Accepted Mobile Source Emission Reduction Strategies (MOSER) provides analysis equations and methodologies for use by transportation and air quality staff at MPOs in nonattainment areas in the state. The guidebook equations were accepted as the basis for strategy analysis in the state (TxDOT, 2008).

The Wasatch Front Regional Council in Salt Lake City, UT provides an online CMAQ project application process to regional planners that include performing the emissions benefit analysis. Each project type has its own Microsoft® Excel-based spreadsheet with a template for applicants to input project information. The worksheet applies regional emissions rates linked within the file. The results of the emissions analysis are calculated immediately after data input (WFRC, 2014).

Each model, method, and equation was subjected to a more in-depth review by CMAQ project type. The research team identified and evaluated:

- Analysis equation input variables and assumptions (i.e., annual average daily traffic (AADT), number of participants, mode shift, and emission factor)
- Types of emissions (running, start, etc.) included in the strategy analysis
- Appropriate fleet mix for a strategy (e.g., bicycle programs limited to light duty passenger vehicles)
- Pollutant types and units of measurement
- Specific equations used to determine emission benefits
- Dimensional analysis – is the final unit of measurement from the equation correct based on the variables and inputs used?
- Simple or complex equation?
- Project lifetime
- Double counting of benefits
- Missing possible travel or emission segments in the equation
- Over crediting of reductions (e.g., a modest bicycle program yielding several kilograms per day)?
- How the equation is presented? Is it presented clearly, and are there instructions and examples for CMAQ project applicants?

For the purposes of this work, *model* refers to the 10 examples chosen for review. *Method* considers the approach to strategy analysis for a project type provided by the model, including the equation. The *equation* is the specific computation performed along with the travel and emission variables used in it. *Inputs* refer to the data needed for a method or equation variables. Standardized values given to variables in the equations are *defaults*.

## 5.4 Inventory

The methods found and analyzed in the 10 models were organized by CMAQ project type defined in this project. The research team reviewed 94 analysis equations and methodologies. Table 9 shows the strategy analysis methodology count by project type.

### Table 9. Number of Model Equations by CMAQ Project Type

| CMAQ Project Type | Number |
|---|---|
| Pedestrian/Bicycle | 10 |
| Travel Demand Management | 9 |
| Traffic Signalization | 9 |
| New Bus Services | 7 |
| Intersection Improvements | 6 |
| Transit Facilities, Systems, and Services | 5 |
| Park and Ride Facilities | 5 |
| Traffic Engineering (Roadway Improvements) | 5 |
| Diesel Engine Retrofits | 4 |
| Dust Mitigation | 4 |
| Idle Reduction | 4 |
| Conventional Bus and Paratransit Replacements | 4 |
| General ITS | 4 |
| Freeway Management Systems | 3 |
| Alternative Fuel Vehicles/Fueling Facilities | 3 |
| New Rail Services | 3 |
| Value/Congestion Pricing | 2 |
| Freight/Intermodal | 2 |
| High-Occupancy Vehicle and Managed Lanes | 2 |
| Traveler Information Systems | 2 |
| Roundabouts | 1 |
| Public Education/Outreach (Information/Marketing) | 0 |
| Extreme Low-Temperature Cold Start Programs | 0 |
| Car sharing | 0 |

The fact that no public education/outreach, extreme low temperature cold start program, or car sharing equation or methodology was found does not mean that a method does not exist; it merely means that the 10 models chosen for this review do not offer a method to analyze these project types.

The analysis equation count from the 10 models chosen reflects somewhat the proportion of project types in the federal CMAQ project database. Pedestrian/bicycle projects are the largest percentage of projects in the project database and are the most analyzed here. Traveler information systems, extreme low temperature cold start programs, roundabouts, and car sharing are all less than 1 percent of projects in the database. The distribution of equations and methodologies in the 10 models chosen for this review provide a representative sample of CMAQ project types.

### 5.4.1 Vehicle/Fuel Technology

#### 5.4.1.1 Alternative Fuel Vehicles/Fueling Facilities

CMAQ provides for purchase of vehicles that use gasoline to alternative fuels and for certain types of refueling facilities for these types of vehicles. Some alternative fuels are cleaner burning than gasoline and diesel and produce fewer tailpipe emissions.

Three equations for estimating the emission benefits of these projects were found. All three equations are based on multiplying the estimated VMT of the vehicle fleet using the alternative fuel and then multiplying it by the difference between the before and after emissions factors. One method is more complex than the others. It attaches weighting factors to each pollutant while estimating total emissions benefit. It is provided below:

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

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

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, $NO_x$, and $PM_{10}$, respectively
250/356 = factor to convert from an average weekday to an annual average day

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

where: N = number of gasoline vehicles being replaced
VMT = average weekday miles to be traveled by each new vehicle
ONF = the on-road light duty vehicle emission factor for each pollutant

One of the models provides default values for project effectiveness period for individual vehicle types affected and the annual VMT for specific vehicle types. The project effectiveness defaults (in years) given are:

| | |
|---|---|
| Heavy-duty transit/urban bus | 12 |

| | |
|---|---|
| School bus | 20 |
| Heavy-duty trucks | 10 |
| Medium-duty vehicles | 10 |
| Light-duty vehicles | 8 |

Table 10 below provides the variables used in the travel and emissions segments of the equations reviewed.

All three models passed dimensional analysis and logic review.  However, only two computed the final emission benefit in kilograms/day.  The other one reported in tons per day.  No evidence of double-crediting or missed travel or emission segments was identified.

#### 5.4.1.2 Conventional Bus and Paratransit Replacements

Bus and paratransit vehicle operating and maintenance costs increase as these vehicles age making it an option for agencies to replace them when appropriate for the age of the vehicle (Feng and Figliozzi, 2012; Boudart, 2011).  When replacing older buses, there is a variety of cleaner and more fuel efficient options such as CNG, LNG, and hybrid or electric buses.

Four methods for computing emission benefits for this strategy were found and reviewed.  Similar to alternative fuel strategies, the essential computation is the current activity (e.g., VMT) of the vehicles being replaced and multiplying it by the difference in before and after replacement emission factors.  One example is shown below:

Emissions from buses (g/year)

Number of buses * Annual vehicle hours per bus * Vehicle brake hp rating in bhp * Emission factor in grams per bhp

Annual change in emissions (kg/year)

(Emissions from old buses - Emissions from new buses)/1000 g)

Then multiply annual change by 0.0011 for tons/yr and divide by the number of service days in a year for kg/day values

The example equation makes clear that, when estimating bus emissions in CMAQ strategies, analysts must use vehicle brake horsepower rating in their computations.  It also shows the conversion of results to kilograms/day as per CMAQ guidance.

Table 11 provides the variables used in the travel and emissions segments of the equations reviewed.

**Table 10. Alternative Fuel/ Fueling Facilities Equation Variables**

| **Alternative Fuel Vehicles/Fueling Facilities** | |
|---|---|
| **Equation Inputs** | **Number of Uses** |
| *Travel Segments* | |
| VMT | ● |
| Annual Vehicle Operating Hours | ● |
| Horsepower (HP) | ● |
| Load | ● |
| Total Fleet Vehicles | ● |
| Percent of fleet replaced | ● |
| Annual VMT per vehicle | ● |
| Average Fuel Economy | ● |
| Fleet VMT using E-85 fuel | ● |
| Number of vehicles by fuel type and vehicle type | ● |
| Average VMT per weekday by vehicle being replaced | ● |
| Model year and type of gasoline vehicles being replaced | ● |
| *Emissions Segments* | |
| Speed-based running exhaust emission factor for older vehicle | ●●● |
| Speed-based running exhaust emission factor for alternative fuel vehicle | ●●● |
| Weighting factor for each pollutant | ● |
| *Project Lifetime (Depends on type of vehicle)* | |
| 8 years | ● |
| 10 years | ●●● |
| 12 years | ● |
| 18 years | ● |
| 20 years | ● |

**Table 11. Conventional Bus and Paratransit Replacements Equation Variables**

| **Conventional Bus and Paratransit Replacement** | |
|---|---|
| **Equation Inputs** | **Number of Uses** |
| *Travel Segments* | |
| Annual VMT - baseline | ●● |
| Annual VMT - new bus | ●● |
| Daily VMT of Bus Fleet | ● |
| Number of new buses | ● |
| Number of old buses | ● |
| Annual vehicle hours/bus (hours) (old and new) | ● |
| Number of service equivalent days per year | ● |
| *Emissions Segments* | |
| Speed based running exhaust emissions before replacement | ●●● |
| Speed based running exhaust emissions after replacement | ●●● |
| *Project Lifetime* | |
| Remaining life of vehicle replaced | ● |

None of the models provided default values for use in calculations. No project lifetimes were given with the equation, but one model took into account the remaining lifetime of the vehicle being replaced. All models limited application to specific vehicle types affected by the strategy for the emission factors.

All of the equations passed dimensional analysis and logic review. All 4 methods provided instructions for use; however, only one model provided a clear example for the equation.

#### 5.4.1.3 Diesel Engine Retrofits

Diesel engine retrofit technologies are products that may be installed on older, less efficient diesel engines to further reduce emissions. Retrofit technologies can include diesel particulate filters, crankcase emission control devices, engine component upgrades, or other modifications that reduce emissions.

Four methods for analysis for this strategy were provided from the 10 models selected. They are based on the number of vehicles being retrofitted, their current VMT, and then comparing the difference between the previous vehicle emissions and the retrofitted vehicles. The equations below provide a robust example. Weighting factors for the different pollutants are used, assumptions are provided, and focus is on heavy duty diesel vehicles.

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

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

where: $VMT_i$ = the annual miles driven by vehicles of model year i
BEF = the heavy duty diesel emission factor for each pollutant in model year I, assuming ultra-low sulfur fuel (15 ppm) for on-road vehicles or low sulfur fuel (500 ppm) for nonroad vehicles/engines
AEF = the on-road heavy duty diesel factor for each pollutant in model year 2015
w1-w4 = weighting factors for CO, TOG, $NO_x$, and $PM_{10}$, respectively.

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

None of the models provided default values for use in calculations.  All four equations used running emissions.  Only one model provided a project lifetime of “at least 5 years.”

The equation variables used in the travel and emissions segments are provided in Table 12.

**Table 12.  Diesel Engine Retrofits Equation Variables**

| **Diesel Engine Retrofits** | |
|---|---|
| **Equation Inputs** | **Number of Uses** |
| *Travel Segments* | |
| Number of fleet trucks to receive technological advancements | ●● |
| Average daily truck VMT | ●●● |
| Daily VMT of truck fleet | ● |
| *Emissions Segments* | |
| Vehicle emission factor before implementation | ●●●● |
| Vehicle emission factor after implementation | ●●●● |
| Model year of the vehicles to be retrofitted | ● |
| *Project Lifetime* | |
| 5 years | ● |

One model has an issue with dimensional analysis.  In calculating emissions, it is not clear how the equation converted grams/mile of fleet emissions into grams/day by multiplying the computed value by the estimated efficiency obtained from EPA guidance.  Only two of the four equations computed kilograms/day as the final unit of measurement.

One model has an issue with equation logic.  It uses 365 days a year as number of strategy operating days and that may lead to over-estimating the emission benefits because it is unlikely those vehicles would be operated every day of the year.  Three of the models provided adequate examples and instructions for equation use.

### 5.4.2 Vehicle Activity Programs

#### 5.4.2.1 Idle Reduction

Idle reduction and operational strategies reduce emissions by maximizing efficient use of equipment and limiting the amount of time an engine needs to operate.  The strategy focuses primarily on heavy-duty vehicles.  Specific projects for reducing idling by vehicles include truck stop electrification, reduction in school bus idling time, and business drive-thru limitations.

Four of the models reviewed included idle reduction equations and analysis methodologies.  In general, the analysis methods focus on calculating the amount of time spent idling by the affected vehicle type(s) and multiplying that time by the appropriate idling emission factor.  Examples are provided below.

Two of the models used both start and idling emission factors in the analysis.  One model used weighting factors for each pollutant in the analysis based on regional air quality goals while still following the same equation structure (idle time * emission factor by time).

For Truck Stop Electrification:

Step 1: Estimate daily hours of truck idling reduced

Truck idling hours reduced =

(Number of TSE truck stops) *

(Average number of truck parking spaces utilized) *

[(Average daily idling hours per truck) - (Estimated daily idling hours per truck with project)]

Step 2: Calculate annual idling emissions reduced

Truck idling emissions reduced = (Step 1) x (Idling emission factor)

For Drive-Thru Restrictions:

Variables:

$EF_I$: Idling emission factor (grams/hour)

$F_{park}$: Percent of vehicles that park instead of using the drive-through facility due to imposed control (decimal)

$N_V$: Average number of vehicles using the drive-through facility

$t_A$: Time spent in queue after implementation of control (hours)

$t_B$: Time spent in queue before implementation of control (hours)

$TEF_{auto}$: Auto trip-end emission factor (grams/trip)

Daily Emission Reduction = A – B + C

where:

$A = N_V * t_B * EF_I$

The amount of idling exhaust emissions generated before the control

$B = (1 – F_{park}) * N_V * t_A * EF_I$

The idling exhaust emissions after the control is in place

$C = F_{park} * N_V * (TEF_{auto})$

The increase in start exhaust emissions resulting from consumers now parking their vehicle in lieu of idling their vehicle

Table 13 provides the equation variables used in the equations reviewed.

All four models passed the dimensional analysis and logic review. No evidence of double counting of emission benefits was seen. No missing travel or emission segments were noted. All four models provided instructions for use of the equation. No project lifetimes were given for the strategy.

#### 5.4.2.2 Extreme Low-Temperature Cold Start Programs

This emission reduction strategy consists of actions that can be taken by states and local areas over and above the federal cold temperature CO standard and that are applicable under extremely cold conditions (e.g., temperatures in the range of 0°F to –20°F or even colder). These measures normally are directed at reducing vehicle startup emissions during these extremely cold temperature episodes.

No specific technique for estimating emission benefits from this strategy was found in the 10 models; however, one of the models provides an overview of extreme low temperature cold start programs. It further notes that the strategy is not applicable to the region because ambient temperatures rarely are in the range of extreme cold conditions.

**Table 13. Idle Reduction Equation Variables**

| **Idle Reduction** | |
|---|---|
| **Equation Inputs** | **Number of Uses** |
| *Travel Segments* | |
| Idling hours per truck | ● |
| Idling Hours Reduced per day | ●●● |
| Number of parking spaces | ● |
| Hours of use per space | ● |
| Number of vehicles in drive thru | ●● |
| Percent vehicles parked | ● |
| Number of vehicles parked | ● |
| Average time spent idling | ● |
| *Emissions Segments* | |
| Idling Emissions Factor | ●●● |
| Idling Emissions Factor for trucks | ●●● |
| Start emissions factor | ●● |

### 5.4.3 Traffic Flow Improvements

#### 5.4.3.1 Traffic Signalization

Traffic signalization represents the most common traffic management technique applied in the United States. Traffic signal improvements can include the following:

- Updating traffic signal hardware to utilize more modern technology, allowing for more sophisticated traffic flow strategies to be planned
- Timing traffic signals to correspond with current traffic flows, reducing unnecessary delays
- Coordinating and interconnecting signals to better interface pre-timed and traffic actuated signals, actively managed timing plans, and master controllers to minimize the number and frequency of stops necessary at intersections
- Removing signals at intersections no longer requiring signalized stop control to reduce vehicle delays and unwarranted stops on the major street.

Nine of the 10 models provided equations and methodologies for traffic signalization projects. Seven of the nine equations were based on estimating the delay reduction at intersections as a result of the program and applying it to the daily volume or VMT at the project location. Two equations used a speed-based analysis capturing the effects on average speed along a segment or a corridor and applying the emission changes to the daily VMT affected. Two methods computed emission changes for both peak and off-peak hours, including the one below. One robust model applies weighting factors along with AADT conversion factors to its equation.

Daily Emission Reduction = A + B

$A = (D_B - D_A) * EF_I * V_{D,\,P}$

Change in idling emissions from reduced vehicle delay times during the peak period

$B = (D_B - D_A) * EF_I * V_{D,\,OP}$

Change in idling emissions from reduced vehicle delay times during the off-peak period

where:

$D_A$: Average vehicle delay at intersection after implementation (hours)

$D_B$: Average vehicle delay at intersection before implementation (hours)

$EF_I$: Idling emission factor (grams/hour)

$V_{D,\,OP}$: Average daily volume for the corridor during off-peak hours

$V_{D,\,P}$: Average daily volume for the corridor during peak hours

Only two of the nine models provided project lifetimes: 3 and 5 years. Seven of the nine reported the results as kilograms/day.

For reference, the equation variables used in the travel and emissions segments are provided in Table 14.

**Table 14. Traffic Signalization Equation Variables**

| **Traffic Signalization** | |
|---|---|
| **Equation Inputs** | **Number of Uses** |
| *Travel Segments* | |
| Operating Days | ●●●● |
| Rebound Effect (induced demand) | ●● |
| Daily VMT of Signalized Region | ● |
| Improved Traffic Signalization | ● |
| Fleet wide Fuel Economy | ● |
| Average Daily Traffic | ●●●●●●●● |

## Table 14. Traffic Signalization Equation Variables (Continued)

| **Traffic Signalization** | |
|---|---|
| **Equation Inputs** | **Number of Uses** |
| Peak Period Travel Percent | ●●● |
| Peak Intersection Delay (seconds) | ●●● |
| Off-peak Intersection Delay (seconds) | ●●● |
| Daily Peak Hours | ● |
| Link Average Peak Hour Traffic (all vehicle categories combined) | ● |
| ADT - Peak Hours | ●●●●●● |
| ADT - Off-peak Hours | ●●●●●● |
| Average peak intersection delay | ●●●●●● |
| Average off-peak intersection delay | ●●●●●● |
| Reduced Vehicle Daily Delay (vehicle hours per day) | ● |
| Length of Project (miles) | ●● |
| Peak Hour Traffic | ● |
| Average Speed Before Signal Change | ●● |
| Average Speed After Signal Change | ●● |
| Synchronization Fraction of Annual Operating Days in each Season | ● |
| Default vehicle traffic type fractions | ● |
| Peak hour volume | ● |
| *Emissions Segments* | |
| Speed-based running exhaust emission factor during off-peak hours before implementation | ●●●●●● |
| Speed-based running exhaust emission factor during peak hours before implementation | ●●●●●● |
| Speed-based running exhaust emission factor during off-peak hours after implementation | ●●●●●● |
| Speed-based running exhaust emission factor during peak hours after implementation | ●●●●●● |
| Idling emission factor | ●● |
| Peak Period Idle Emission Factor | ● |

**Table 14. Traffic Signalization Equation Variables (Continued)**

| **Traffic Signalization** | |
|---|---|
| **Equation Inputs** | **Number of Uses** |
| *Project Lifetime* | |
| 3 years | ● |
| 5 years | ● |

Each of the methods maintained good dimensional analysis; however, one method had an issue with equation logic. It applies a 10 percent factor to the average daily traffic (ADT) to get a peak hour volume estimate and then converts to an annual amount by applying it to 365 days per year instead of 240 days for weekday peak hour traffic. This will lead to a greater emission benefit for the strategy than should be realistically assumed.

### 5.4.3.2 Traffic Engineering (Roadway Improvements)

Roadway improvements that improve traffic flow can be effective. Examples may include road re-alignment, intersection channelization, or access management techniques.

Five equations were provided for analyzing Traffic Engineering (Roadway Improvements) strategies. The models included projects focusing on arterials with vehicle delays caused by at-grade rail crossings and where bus turnouts might be implemented, as well as where corridor signal improvements were implemented. All five equations seek to estimate the vehicle delay reduction achieved from the improvement. The number of affected vehicles and the amount of delay before the project are the key inputs to the equations. Two of the models used speed-based running exhaust emission factors to determine the emission rates while three models used idling emission factors to determine emission rates.

The improvement of an at-grade rail crossing provides an example of an equation that contains the basic input variables and an idling emission factor.

Daily Emission Reduction = A * B

$A = t_{H,C} / t_H * V$

The number of vehicles affected by rail crossing delays

$B = t_C / 2 * EF_I$

The average idling emissions resulting from affected traffic idling at the closed crossing (assumed to be half of the average time the roadway is closed per train crossing)

where:

$EF_I$: Idling emission factor (grams/hour)

$t_C$: Average amount of time rail crossing is closed due to train crossing (hours/crossing)

$t_H$: Duration of analysis period (hours)

$t_{H,C}$: Hours per analysis period roadway is closed due to train crossing (hours)

V: Bi-directional arterial volume for analysis period (vehicles)

The equation variables found in the traffic engineering equations found in the review are provided in Table 15.

All equations passed the dimensional analysis and logic review.  Three of the five compute kilograms/day as the final unit of measurement.  Two of the models give project lifetimes, both assuming 20 years.  No double counting of benefits or missing travel or emissions segments was noted.  Four of the 5 models provide instructions for equation use.  Three provide examples.

### 5.4.3.3 Intersection Improvements

Intersection improvements are projects that increase the efficiency of the flow of traffic through an intersection.  The primary source of emissions benefit is delay reduction of vehicles.  These are differentiated from traffic signalization by focusing more on the physical roadway than the electronic signalization or monitoring of the location.

Six models provided techniques for intersection improvements analysis.  Four out of six used a delay reduction approach.  The equations calculate the number of vehicles affected and their total amount of delay and then estimate before and after idling emissions.  The difference between the two factors is the emissions benefit.  The other two methods use speed-based emission factors to derive an emissions benefit from the change in average speed along the affected roadway before and after project implementation.  Neither of these two models uses a length of affected roadway value in the computations.  Without defining the limits of project effect, practitioners could assume more traffic volume affected and greater average speeds for the project leading to an over credit for the emissions benefit.  It also creates problems for resolving units of measurement in an analysis equation.

Table 16 provides the equation variables used in the travel and emissions segments.  No missing travel or emission segments were noted in the methodologies.  Two of the models limited the operating days of the improvements to number of workdays (240 and 250 days, respectively) assuming that the primary benefit will occur then.  One of the equations is presented below.

Daily Emission Reduction (kg/day) =

[(Reduced Vehicle Delay/day) * Idle Emission Rate * 2.5 mph] * (Effective days/365)

The project lifetimes presented by the six methods range from 2 to 20 years.  This is not unexpected due to the wide range of project types in this strategy with significant differences in scope.

**Table 15. Traffic Engineering Equation Variables**

| **Traffic Engineering** | |
|---|---|
| **Equation Inputs** | **Number of Uses** |
| *Travel Segments* | |
| Average amount of time rail crossing is closed due to train | ● |
| Duration of analysis period | ● |
| Hours per analysis period roadway is closed due to train | ● |
| Bi-directional volume for analysis period | ● |
| Average daily traffic | ●● |
| PM peak hour traffic | ●● |
| Operating days | ●● |
| Rebound effect (induced demand) | ● |
| Average Speed Before Signal Change | ●● |
| Average Speed After Signal Change | ●● |
| Length of project (miles) | ●● |
| Daily Peak Hours | ● |
| Synchronization Fraction of Annual Operating Days in each Season (must sum to 1) | ● |
| Default vehicle traffic type fractions | ● |
| Reduction vehicle hours of delay (vehicle hours per weekday) | ● |
| Conversion Factor (convert Avg weekday traffic to ADT) | ● |
| *Emissions Segments* | |
| Speed-based running exhaust emission factor before implementation | ●● |
| Speed-based running exhaust emission factor after implementation | ●● |
| Idling emissions | ●●● |
| *Project Lifetime* | |
| 20 years | ●● |

### Table 16. Intersection Improvements Equation Variables

| **Intersection Improvements** | |
|---|---|
| **Equation Inputs** | **Number of Uses** |
| *Travel Segments* | |
| Average daily traffic | ●●●●● |
| Peak hour volume | ● |
| Percent of travel in peak period | ● |
| Before average peak period speed | ●● |
| Before average off-peak period speed | ●● |
| Expected increase in peak period speed | ●● |
| Expected increase in peak period speed | ●● |
| Estimated delay reduction during peak period | ●●● |
| Estimated delay reduction during off-peak period | ●●● |
| Length of affected roadway | ●●● |
| *Emissions Segments* | |
| Idling emission factor | ●●● |
| Speed-based running exhaust emission factor during the off-peak period after implementation | ●●●●● |
| Speed-based running exhaust emission factor during the peak period after implementation | ●●●●● |
| Speed-based running exhaust emission factor during the off-peak period before implementation | ●●●●● |
| Speed-based running exhaust emission factor during the peak period before implementation | ●●●●● |
| Weighting factor for each pollutant | ● |
| *Project Lifetime* | |
| 1-2 years | ●●● |
| 5-10 years | ● |
| 20 years | ● |

Two intersection improvements projects identified in this project's case study assessment (Section 4) used 1 of the methodologies in 2 of the 10 models to determine the emissions benefit from adding right turn lanes to an intersection. The estimated benefits from both analyses (e.g., VOC: 0.13 kg/day; $NO_x$: 0.06 kg/day; CO: 0.55 kg/day; $PM_{10}$: 0.0010 kg/day) appear reasonable given the details of the projects.

Each of the methods maintained good dimensional analysis; 5 of the 6 equations calculated kilograms/day as the final result. One method had an issue with equation logic. The method applies a 10 percent factor to the ADT to get a peak hour volume estimate and then converts to an annual amount by applying it to 365 days per year instead of 240 days for weekday peak hour traffic. Because it is applied to every day of the year, this will lead to a greater emission benefit for the strategy than should be realistically assumed.

#### 5.4.3.4 High-Occupancy Vehicle and Managed Lanes

HOV facilities include carpool lanes, bus lanes, and exclusive HOV ramps and lots directly connected to HOV lanes. An HOV lane, the most common type of HOV facility, is reserved for carpools of at least two passengers, vanpools, buses, green vehicles, and motorcycles. These lanes allow eligible vehicles to bypass congested traffic on the general purpose lanes, offering a more reliable, congestion-free commute. Managed lanes are specialized lanes in corridors that control lane usage by vehicle eligibility, price, or access control. Managed lanes can charge usage fees to drivers and allow lower occupancy cars access to HOV lanes, including single-occupant vehicles.

Two of the 10 models provided emission analysis equations for high-occupancy vehicle and managed lanes. Both equations attempt to estimate the number of previous single occupant vehicle travelers now using the HOV lane as rideshare or transit passenger. Those participants are the primary emission reduction of the strategy due to less vehicle trips and VMT. One of the two models calculates potential emission benefit from the improved traffic flow on the main lanes as a result of the HOV. This approach is useful when estimating benefits from managed lanes.

Daily Emission Reduction = A+ B + C + D

$A = V_{H,A} * (EF_B - EF_{H,A}) * N_{PH} * L$

Change in running exhaust emissions from vehicles shifting from general purpose lanes to HOV lanes

$B = (V_{GP,B} * EF_B - V_{GP,A} * EF_{GP,A}) * N_{PH} * L$

Change in running exhaust emissions of vehicles in general purpose lanes as a result of vehicles shifted away from general purpose lanes

$C = VT_R * TEF_{AUTO}$

Reduction in auto start exhaust emissions from trip reductions

$D = VMT_R * EF_B$

Reduction in auto running exhaust emissions from trip reductions

where:

$VT_R = N_P * (F_T * F_{T,\,SOV} + F_{RS} * F_{RS,\,SOV}) * (1 - 1/AVO_{RS})$

Number of HOV users multiplied by the sum of the fraction of users selecting transit multiplied by the percentage that previously drove SOVs added by the fraction of users selecting ridesharing multiplied by the percentage that previously drove SOVs multiplied by the percentage of ridesharers that are passengers

$VMT_R = VT_R * TL_W$

Number of vehicle trips reduced multiplied by the average auto trip length

Table 17 provides the variables for the travel and emissions segments in the equations found in the review.

**Table 17. High-Occupancy Vehicle and Managed Lanes Equation Variables**

| **High-Occupancy Vehicle and Managed Lanes** | |
|---|---|
| **Equation Inputs** | **Number of Uses** |
| *Travel Segments* | |
| Average vehicle occupancy of rideshare | ●● |
| Percent people attracted to the HOV facility using rideshare (decimal) | ● |
| Percent people attracted to HOV facility using rideshare that previously were vehicle drivers (decimal) | ●● |
| Percent people attracted to the HOV facility using a transit vehicle | ● |
| Percent people using a transit vehicle that previously were SOV drivers | ● |
| Length of HOV facility (miles) | ● |
| Total number of expected people using the HOV lanes per day | ●● |
| Number of peak hours (AM and/or PM) | ● |
| Average auto trip length | ●● |
| Average hourly volumes on GP lanes during peak hours after implementing HOV | ● |

**Table 17. High-Occupancy Vehicle and Managed Lanes Equation Variables (Continued)**

| **High-Occupancy Vehicle and Managed Lanes** | |
|---|---|
| **Equation Inputs** | **Number of Uses** |
| Average hourly volumes on GP lanes during peak hours before implementing HOV | ● |
| Average hourly volumes on HOV lanes during peak hours | ● |
| Reduction in daily automobile VMT | ● |
| Reduction in number of daily automobile vehicle trips (estimate) | ● |
| Corridor traffic count per peak hour | ● |
| Number of hours with HOV restrictions | ● |
| Percent HOVs in region before implementation | ● |
| *Emissions Segments* | |
| Speed-based running exhaust emission factor before implementation on general purpose lane | ●● |
| Speed-based running exhaust emission factor after implementation on general purpose lane | ●● |
| Speed-based running exhaust emission factor after implementation on HOV lane | ●● |
| Start emissions factor | ● |
| *Project Lifetime* | |
| 20 years | ● |

One model assumes a project lifetime for HOV lanes of 20 years. Both equations passed dimensional analysis and logic review. One model did not attempt to estimate emission benefits from the improved traffic flow in the main lanes. Limiting the emission benefit to the HOV/managed lane is the more conservative approach, but there are benefits that are not captured with the improved flow on the main lanes less the latent demand. One model gives an example. Both give instructions for the equation.

#### 5.4.3.5 Roundabouts

Roundabouts are a type of traffic intersection that provides continuous flow through the intersection. Unlike the usual signalized intersection, the roundabout intersection is a circular one in which the traffic flow moves continuously through one direction around a central island.

Of the 10 models, only 1 provided an equation for analysis of roundabouts. Similar to roadway improvement project analysis techniques, the equation computes the emission benefit through the reduction in vehicle delay at the intersection and the subsequent reduction in idling emissions.

Weighting factors for each pollutant are used. It also uses a factor to convert ADT to AADT. The project lifetime is assumed to be 20 years. The equation is presented below.

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

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 (grams/hr)

CF = factor to convert from ADT to AADT; for freeways, multiply ADT by 0.92; for arterials, multiply ADT by 0.93

w1-w4 = weighting factors for CO, TOG, $NO_x$, and $PM_{10}$, respectively.

The travel and emissions segments used in the equation are provided for reference in Table 18.

**Table 18. Roundabout Equation Variables**

| **Roundabouts** | |
|---|---|
| **Equation Inputs** | **Number of Uses** |
| *Travel Segments* | |
| Reduction Vehicle Hours of Delay (vehicle hours per weekday) | ● |
| Average Daily Traffic | ● |
| Conversion Factor (Average weekday traffic to ADT) | ● |
| *Emissions Segments* | |
| Idle emissions factor | ● |

It can be inferred that if an agency has an emissions benefit analysis equation or methodology for intersection improvements, based on delay reduction, it can be effectively used to analyze proposed roundabout projects.

The equation passed dimensional analysis and logic review. The equation is relatively complex but the weighting factors are provided along with instructions and examples.

### 5.4.4 Intelligent Transportation Systems

#### 5.4.4.1 General ITS

ITS provide strategies and applications to address many aspects of transportation - congestion, safety, mobility, and environment – by integrating advanced communication technology into transportation infrastructure and vehicles and providing real-time travel information. ITS encompasses a wide range of services, such as freeway management, crash prevention and safety, roadway operations and maintenance, traffic incident management, transit management, and traveler information.

Four equations for emissions analysis of ITS projects were found in the 10 models. The general ITS equations address traffic management centers for high- volume roads, Intelligent Vehicle Highway System (IVHS) freeway systems, and active traffic management strategies (ATMS) and techniques. The focus for three equations is estimating the reduction in running emissions on the ITS project length, mainly freeway miles. The primary travel input is AADT in the project length. For emission inputs, the entire regional vehicle fleet is represented. The fourth equation provides a simple method focusing on the benefits from vehicle delay reduction along the affected freeway length. It uses idling emission rates. An example of the speed-based approach is below.

Daily Emission Reduction =

$$\sum_{i=1}^{n}[\mathbf{L}_i * \mathbf{ADT}_i * (\mathbf{EF}_B - \mathbf{EF}_A)_i]$$

The sum of each ITS link’s change in running exhaust emissions resulting from improved traffic flow

Peak and off-peak hours can be split in equation.

where:

$ADT_i$: Average daily traffic for each affected roadway (vehicles)

$EF_A$: Speed-based running exhaust emission factor after implementation (grams/mile )

$EF_B$: Speed-based running exhaust emission factor before implementation (grams/mile)

$L_i$: Length of each freeway affected by ITS (miles)

N: Number of affected corridors

All four equations passed the dimensional analysis and logic review. No default values were provided. Two project lifetimes were given: 5 and 10 to 12 years. The 5-year estimate is a 2013 assumption; the source for the 10 to 12 years estimate is from 2000. The variables from the four equations used in the travel and emissions segments of the equations are provided in Table 19.

## Table 19.  General ITS Equation Variables

| **General ITS** | |
|---|---|
| **Equation Inputs** | **Number of Uses** |
| *Travel Segments* | |
| Length of facility (miles) | ●● |
| Number of affected corridors | ● |
| Percent of roadway system coverage with ITS | ● |
| Daily VMT | ● |
| Average Daily Traffic | ● |
| Before Average Peak Hour Travel Speeds | ● |
| Before Average Off-Peak Hour Travel Speeds | ● |
| Expected increase in Peak Hour Speed | ● |
| Expected increase in Off-Peak Hour Speed | ● |
| Operating Days | ● |
| Reduced Vehicle Daily Delay (vehicle hours per day) | ● |
| Percent of nonrecurrent congestion eliminated on roadways with ITS peak and off-peak | ● |
| Percent of recurrent congestion eliminated on roadways with ITS peak and off-peak | ● |
| *Emissions Segments* | |
| Speed-based running exhaust emission factor for mainlane after implementation, peak and off-peak | ●●●● |
| Speed-based running exhaust emission factor for mainlane before implementation, peak and off-peak | ●●●● |
| Idle Emission Factor Rates | ●● |
| Percent of roadway system emissions caused by nonrecurring congestion in peak and off-peak | ● |
| *Project Lifetime (Depends on type of vehicle)* | |
| 5 years | ● |
| 10-12 years | ● |

When estimating regional or corridor emissions and the strategies that produce regional or corridor-wide effects, it is possible to overestimate benefits. Regional ITS is usually implemented in phases over many years. Proportionality needs to be considered when assigning benefit to a smaller piece of the system. Conversely, it is also difficult to pinpoint the specific effect from the strategy especially if the ITS project is part of a corridor improvement program or is combined with major arterial improvements.

Another note of caution for ITS projects: many of them are implemented in phases, component by component. For example, a region can install digital fiber optic cable as part of a future ITS program. Until activated and used as part of the program, the cable is not providing any direct emission benefit. Transportation/air quality planners and staff should be careful to assign a proportional benefit to the individual pieces rather than the entire future benefit from the active ITS program to one individual component. None of the models provided good, clear examples to show how the equation works in a real world situation.

### 5.4.4.2 Freeway Management Systems

Freeway management systems have the ability to detect traffic flow problems, while providing up-to-date information to transportation agencies to improve coordination and response times. Freeway management methods include entrance ramp control, ramp closures, roadway travel monitoring and cameras, and dynamic message signs.

The 10 models yielded three equations for emissions analysis of freeway management systems. The equations addressed incident management programs and ramp metering. For incident management, the equations calculate a regional freeway emissions rate and estimate the emission reduction based on delay reduction (less idling emissions) or improved traffic flow (speed) on affected freeways. The ramp metering equations calculate the benefits from reduced delay and improved speeds on main lanes along the metered segment. Examples of each are provided below.

Equation for Incident Management:

Daily Emission Reduction =

$$\mathbf{E}_{REG} * \mathbf{F}_{NR} * \sum_{i=1}^{n} \mathbf{F}_{Eff\ i} * \left( \frac{\mathbf{ADT}_i}{\mathbf{ADT}_T} \right)$$

The amount of regional nonrecurring congestion emissions multiplied by the sum of each link’s effectiveness and proportion to the total regional ADT.

where:

$ADT_i$: Average daily traffic for each affected link

$ADT_T$: Total average daily traffic for affected system (vehicles/day)

$E_{REG}$: Regional freeway emissions (grams)

$F_{Eff}$: Project effectiveness factor for each affected freeway

$F_{NR}$: Nonrecurring emissions (decimal)

Equation for Ramp Metering:

Daily Emission Reduction = A – B

$A = [(V_B * EF_B) – (V_A * EF_A)] * L$

The change in running exhaust emissions on the freeway along the metered section

$B = N_V * t_q * EF_I$

The increase in idling exhaust emissions from queuing at the metered ramps

where:

$EF_A$: Speed-based running exhaust emission factor for mainline after implementation (grams/mile)

$EF_B$: Speed-based running exhaust emission factor for mainline before implementation (grams/mile)

$EF_I$: Idling emission factor (grams/hour)

L: Length of freeway corridor impacted by ramp metering (miles)

$t_q$: Average time spent in queue waiting to enter freeway (hours)

$N_V$: Number of vehicles using metered ramps

$V_A$: Average traffic volume per operating period on main lanes after implementing ramp metering

$V_B$: Average traffic volume per operating period on main lanes before implementing ramp metering

Two of the three models are data-intensive and complex, as the example shows, relative to other strategy analysis equations. Only one of the models provided a project lifetime for incident management programs: 1 year. None were given for ramp metering.

Table 20 provides the variables used in the travel and emissions segments of the three equations. All of the equations passed the dimensional analysis and logic review. None of the models provided good, clear examples to show how the model performed in a real world situation.

### Table 20. Freeway Management Systems Equation Variables

| **Freeway Management Systems** | |
|---|---|
| **Equation Inputs** | **Number of Uses** |
| *Travel Segments* | |
| Major incident queue VMT | ● |
| Minor incident queue VMT | ● |
| VMT | ●● |
| Before travel speeds | ●● |
| Project design life | ●●● |
| Operating Days | ● |
| Reduced daily vehicle delay (vehicle hours per day) | ● |
| Average daily traffic | ●●● |
| Project effectiveness factor for detection and response | ●●● |
| Project effectiveness factor for MAP | ● |
| Project effectiveness factor for surveillance | ● |
| Length of Corridor | ● |
| Time in meter queue | ● |
| Average traffic volume before implementation | ● |
| Average traffic volume after implementation | ● |
| Number of vehicles using metered ramp | ● |
| *Emissions Segments* | |
| Regional emission rates | ● |
| Emission factor before implementation | ● |
| Emission factor after implementation | ● |
| Non-recurring congestion emissions factor percent | ● |
| Regional freeway emissions | ● |
| Speed-based running exhaust emission factor for main lane after implementation | ● |
| Speed-based running exhaust emission factor for main lane before implementation | ● |
| Idling emission factor | ●● |
| *Project Lifetime* | |
| 1 year | ● |

### 5.4.4.3 Traveler Information Systems

An important component of ITS, ATIS provides the information travelers need from their origin to their destination. ATIS can be classified by:

- The type of information the system provides, for example, robust or static traffic information, road conditions and weather, incidents and events, and traveler information.
- How the system provides information, e.g., via radio, television, wireless devices, roadside message boards, or GIS-based navigation systems.

The information is used by travelers to minimize the impact of nonrecurring congestion on major roadways in a region. The impact of information system programs is similar to that of incident management programs. Transportation agencies developing traveler information systems can adapt existing incident management equations for initial emissions analysis.

Two equations were found in the group of 10 models. Both of them calculated the emissions benefit from delay reduction from nonrecurring congestion by comparing before and after idling emissions of all vehicle types. The example given below requires more data than the other equation found but regional incident data are available to many MPOs.

Step 1: Estimate the average incident duration without and with the project (hours)

Step 2: Calculate the average incident delay without and with project implementation.

Incident delay without project =

$e^{-10.19}$ *

(Traffic volume)$^{2.8}$ *

(Avg. no. of blocked lanes during incidents/Total no. of lanes in project corridor)$^{1.4}$ *

(Incident duration prior to project)$^{1.78}$

Incident delay with project =

$e^{-10.19}$ *

Traffic volume)$^{2.8}$ *(Avg. no. of blocked lanes during incidents/Total no. of lanes in project corridor)$^{1.4}$ * (Incident duration with project)$^{1.78}$

Step 3: Calculate the change in delay per incident.

(Incident delay without project) – (Incident delay with project)

Step 4: Calculate emission reductions per incident.

(Change in delay) * (Idle emissions factor)

Step 5: Calculate annual emission reductions.

(Emissions reduced per incident) * (Number of incidents per year)

Convert reductions to kilograms/day

The models passed the logic review but, due to limited information provided for the travel inputs, the dimensional analysis was unable to be verified on one equation. No project lifetimes were provided but practitioners can use incident management project effectiveness as a basis to assume. Instructions were provided for each equation. One equation gave an example but the computations using the numbers given stopped in the middle of the equation and was not finished. Table 21 provides the variables used in the travel and emissions segments of the three equations.

**Table 21. Traveler Information Systems Equation Variables**

| **Traveler Information Systems** | |
|---|---|
| **Equation Inputs** | **Number of Uses** |
| *Travel Segments* | |
| Change in delay | ● |
| Number induced travel or travel diversion assumed | ● |
| Vehicles per lane per hour | ● |
| Average incident duration, before and after | ● |
| Average incident delay, before and after | ● |
| Average number of blocked lanes during incidents | ● |
| Total number of lanes in project corridor | ● |
| Number of incidents per year | ● |
| *Emissions Segments* | |
| Idle emissions factor | ● |

### 5.4.5 Improved Public Transit

#### 5.4.5.1 Transit Facilities, Systems, and Services

This category of CMAQ projects includes strategies that focus on geographic coverage and scheduling changes that make mass transit a more attractive option to residents and commuters. For example, improved transfer procedures between transportation modes such as car/transit, pedestrian/transit, and bicycle/transit can encourage increased ridership on public transportation.

Five methods for analyzing transit facilities, systems, and services projects were noted. The primary input for an analysis of these project types is the number of new transit users resulting from the project that previously drove a single occupant vehicle. Four of the methodologies attempt to estimate that number and the previous vehicle activity (VMT and number of starts). They are then multiplied by the start and running emission factors for light duty vehicles in the local fleet to calculate the benefit. Only two of the equations report the final unit of measurement as kilograms/day. The equation below from one of the models calculates annual emissions but provides the capability of computing kilograms/day. This model also suggests default values for inputs, i.e., 255 effective days.

Annual Emission Reduction =

[(Light duty vehicle VT Reduced * Start Emission Rates) * (Light duty vehicle VT Reduced Running Emission Rates)] * Effective Days

Two of the five equations were complex compared to the other three. One of these two used a large number of data inputs to calculate the result. On the other hand, it was also a user-friendly method. Table 22 provides the variables used in the travel and emissions segments of the three equations.

One model had an issue with the dimensional analysis review. The equation in the guidance did not properly use brackets in the formula resulting in an incorrectly calculated emissions benefit. One equation had a concern in the logic review. It assumes 365 operating days and could potentially over credit the strategy benefit.

All five models provided instructions on equation use. Three of the five models provided example uses of the equations.

#### 5.4.5.2 New Bus Services

New bus service projects attempt to increase ridership by providing new and/or expanding bus services. New and expanded bus service improvement projects improve both air quality and congestion levels in the local community by increasing the use of transit services and reducing the number of auto trips.

Seven of the 10 models provided a methodology for new bus service. As with all transit projects, the key input for air quality benefits is the number of new transit users resulting from the project that previously drove a single occupant vehicle. In the case of new bus service, five of the equations account for the increase in emissions due to the increase in number and/or activity of the buses. One robust equation factored in the VMT for those new participants driving to transit, rather than assuming all previous VMT is removed as a result of the strategy. The example given below from the seven is a simpler, more straightforward version of the basic strategy calculations:

Daily Emission Reduction = A + B – C – D

$$A = VT_{R} * TEF_{AUTO}$$

**Table 22.  Transit Facilities, Systems, and Services Equation Variables**

| **Transit Facilities, Systems, and Services** | |
|---|---|
| **Equation Inputs** | **Number of Uses** |
| *Travel Segments* | |
| Total Trips Per Day | ●●●● |
| Mode Split - Automobile | ●●●●● |
| Mode Split - Transit/Walking/Biking | ●●●●● |
| Average Automobile Trip Length | ●●●● |
| Percent ridership increase | ●●●●● |
| Average speed | ● |
| Percent new drivers drive to the transit service | ●●●● |
| Number of pass program recipients | ● |
| Percent of pass recipients who are new transit riders | ● |
| Percent of new transit riders previously driving to work | ● |
| Operating days | ●● |
| Number of trips eliminated per day | ●●● |
| Average length of eliminated trips (miles) | ●●● |
| Number of shortened trips | ●●● |
| Average decrease in mile for shortened trips | ●●● |
| Number of new trips added per day | ● |
| Average new trip length | ● |
| Number of lengthened trips | ● |
| Average increase in miles per trip for lengthened trips | ● |
| Optional Road type VMT fractions | ●● |
| Auto occupancy | ● |
| One-way passenger trip distance (miles) | ● |
| *Emissions Segments* | |
| Speed-based running exhaust emission factor | ●●●●●● |
| Start emission factor | ●●●● |
| Soak emissions | ● |
| *Project Lifetime* | |
| 1-2 years | ●● |
| 5 years | ● |

Reduction in auto start emissions from trips reduced

$VT_{R} = N_{TR} * F_{T, SOV}$

Number of new transit riders multiplied by the percentage of riders shifting from single-occupant auto use

$B= VMT_{R} * EF_{B}$

Reduction in auto running exhaust emissions from VMT reductions

$VMT_{R} = VT_{R} * TL_{W}$

Number of vehicle trips reduced multiplied by the average auto trip length

$C = VT_{BUS} * TEF_{BUS}$

Increase in emissions from additional bus starts

$D = VMT_{BUS} * EF_{BUS}$

Increase in emissions from additional bus running exhaust emissions

where:

$EF_{B}$: Speed-based running exhaust emission factor for affected roadway before implementation (grams/mile)

$EF_{BUS}$: Speed-based running exhaust emission factor for transit vehicle (grams/mile)

$F_{T, SOV}$: Percentage of people using a transit vehicle that previously were vehicle drivers (decimal)

$N_{TR}$: New transit ridership

$TEF_{AUTO}$: Auto trip-end emission factor (grams/trip)

$TEF_{BUS}$: Bus (or other transit vehicle) trip-end emission factor (grams/trip)

$TL_{W}$: Average auto trip length (miles)

$VMT_{BUS}$: VMT by transit vehicle

$VMT_{R}$: Reduction in daily automobile VMT

$VT_{BUS}$: Daily vehicle trips by bus or other transit vehicle

$VT_R$: Reduction in number of daily automobile vehicle trips

Three of the models provided project lifetimes: 1, 10 to 12, and 20 years. This is a very wide range for the strategy. Two of the models provide default input values over a myriad of variables (trip lengths, previous SOV drivers, bus activity, etc.). Five methods reported results as kilograms/day.

The travel and emissions variables used in the equations found in the review are provided in Table 23.

All of the equations passed dimensional analysis review, but there are issues with missing emission segments and over credits. Two of the equations are not including future bus starts and running emissions. One model equation assumes that 100 percent of new bus riders resulting from the project were SOV drivers before shifting to transit. All equations provided instructions, but only two equations provided clear examples for using the equations.

#### 5.4.5.3 New Rail Services

New passenger rail services involves establishing new routes, increasing the frequency of current service, expanding the hours of operation, or the overall coverage of transit corridors. New and expanded rail services provide mobility improvements in the form of increased transportation mode options for users in a nonattainment area. Air quality benefits are directly gained through VMT reduction by attracting riders who previously drove their own vehicles.

Review of the 10 models yielded three approaches to estimating emissions benefits from new or increased rail services. As with new bus services, the key input is the estimated number of new riders who previously drove a single occupant vehicle and now use the rail service for all or a fraction of their previous VMT.

One of the models provides a simple, straightforward equation for analysis. The two others involve more complex calculations. The example presented below uses pollutant weighting factors, provides default values for some inputs, and includes off-network vehicle emissions.

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

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

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

where:

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

## Table 23. New Bus Services

| New Bus Services | |
|---|---|
| **Equation Inputs** | **Number of Uses** |
| *Travel Segments* | |
| Total trips per day | ● |
| Mode Split - Automobile | ● |
| Mode Split - Transit/Walking/Biking | ● |
| Average automobile trip length | ●●●● |
| Number of new buses in service | ● |
| Estimated occupancy per bus | ●● |
| Number of daily bus trips | ●● |
| Average daily bus ridership | ●●● |
| Percent of riders who previously drove alone | ●●●● |
| Percent using auto to access transit service | ●●● |
| Average auto round trip length | ● |
| Average bus round trip length | ●● |
| Average speed | ● |
| Operating days | ●●● |
| Auto occupancy | ● |
| 1-way passenger trip distance (miles) | ● |
| Daily bus VMT | ● |
| Average daily ridership of new service | ●●● |
| Annual VMT for new bus service | ● |
| Trip length for auto access to and from transit | ●● |
| Reduction in daily automobile VMT | ● |
| Reduction in number of daily automobile vehicle trips | ● |
| *Emissions Segments* | |
| Speed-based running exhaust emission factor | ●●●●●●● |
| Start emissions factor | ●●● |
| Idling emissions | ●● |
| Bus Rapid Transit emission factor | ●● |
| *Project Lifetime* | |
| 1 years | ● |
| 10-12 years | ● |
| 20 years | ● |

$$\begin{aligned} &Onroad\ Vehicle\ Emissions\ Reduced\ (VER_1) \\ &\quad = (VMT_{REP} - VMT_{ADD}) + (\frac{w1 *\ ONF_{CO}}{4} + \frac{w2 * ONF_{TOG}}{2} + \frac{w2 * ONF_{NOx}}{2} \\ &\quad + \left(w4 * (ONF_{PM} + PEF)\right) * \frac{1}{1000} = kilograms/day \end{aligned}$$

$$\begin{aligned} &Onroad\ Vehicle\ Emissions\ Reduced\ (VER_2) \\ &\quad = VR * (\frac{w1 *\ OFF_{CO}}{4} + \frac{w2 * OFF_{TOG}}{2} + \frac{w2 * OFF_{NOx}}{2} + (w4 * OFF_{PM}) * \frac{1}{1000} \\ &\quad = kilograms/day \end{aligned}$$

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

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 on-road 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, $NO_x$, and $PM_{10}$, respectively.

One model had an issue with dimensional analysis when an equation variable should be displayed as a decimal value to match the rest of the equation. All three models passed the logic review. No evidence of over crediting or double counting was found. Two project lifetimes are given by the models: 20 years and 30 to 35 years.

Table 24 provides the variables used in the travel and emissions segments of the three equations. All three models provide instructions for use of the methodology; however, one model provides an unclear example equation.

### 5.4.6 Transportation Demand Management

#### 5.4.6.1 Public Education/Outreach (Information/Marketing)

Public education, marketing, and other outreach efforts include advertising available alternatives to SOV travel in a nonattainment area, employer outreach, and public education campaigns about transportation and air quality. The primary benefit of these activities is enhanced communication and outreach that is expected to influence travel behavior and air quality. Ozone Action Days is an example of this type of project.

According to the FHWA interim CMAQ program guidance of November 2013 these strategies may fall into the category of Qualitative Assessment. Although quantitative analysis of air quality impacts is expected for almost all project types, an exception is made when it is not possible to accurately quantify

**Table 24. New Rail Services Equation Variables**

| **New Rail Services** | |
|---|---|
| **Equation Inputs** | **Number of Uses** |
| *Travel Segments* | |
| Total Trips Per Day - Base Case | ● |
| Mode Split - Automobile - Base Case | ● |
| Mode Split - Transit/Walking/Biking - Base Case | ● |
| Average Automobile Trip Length - Base Case | ● |
| Total Trips Per Day - LRT | ● |
| Mode Split - Automobile - LRT | ● |
| Mode Split - Transit/Walking/Biking - LRT | ● |
| Average Automobile Trip Length - LRT | ● |
| Fraction of riders who previously drove to their destination | ● |
| Fraction of riders who drive to reach rail | ● |
| Average length of vehicle trips | ● |
| Total annual average daily ridership on the rail line | ● |
| Average length of trip driving from home to rail | ● |
| *Emissions Segments* | |
| Speed-based running exhaust emission factor, light duty passenger and truck | ●● |
| *Project Lifetime* | |
| 20 years | ● |
| 30-35 years | ● |

emissions benefits. In the case of public education, marketing, and other outreach efforts, qualitative assessments based on reasoned and logical determinations that the projects or programs will decrease emissions and contribute to attainment or maintenance of a NAAQS are acceptable (FHWA, 2013).

No equation or methodology for these types of projects was found in the 10 models.

#### 5.4.6.2 Travel Demand Management

TDM is a broad-ranged strategy that encourages the systematic reduction or redistribution of traffic demand away from traffic congestion. Various TDM measures have been developed to manage travel demand with the recognition of increased congestion and emission problems associated with significantly increased travel demand.  TDM programs typically focus on reducing the number of vehicle trips by commuters during peak hours.

TDM strategies are popular CMAQ projects and so 9 of 10 models provide a methodology to analyze TDM strategies for emission benefits.  The wide range of project types under the rubric of TDM creates numerous different inputs specific to the program, project, or strategy being implemented.  Vanpool programs require vanpool occupancy as an input, some programs require number of vehicle trips or VMT, and still others need the number of commuters or students or new participants.  Regardless of the project type, all of the equations attempt to calculate new VMT reductions or vehicle trips reductions by the TDM strategy, and then multiply that VMT reduction by an appropriate emission factor.  One of the TDM equations found provides the essential components of a strategy analysis.  It is presented below:

Daily Emission Reduction = A + B

$A = (VT_{R} * TEF_{AUTO})$

Reduction in auto start emissions from trip reductions

$B = (\Sigma VMT_{R} * EF_{B})$

Reduction in auto running exhaust emissions from trip reductions

where:

$N_{P} = (N_{RS} * F_{RS, SOV}) + (N_{T} * F_{T, SOV}) + (N_{BW} * F_{BW, SOV})$

Number of rideshare participants previously driving SOVs added to number of transit participants previously driving SOVs added to number of bike and pedestrian participants previously driving SOVs

$VT_{R} = N_{P} * 2$ trips/day

Number of participants multiplied by 2 trips per day (round trip)

$VMT_{R} = VT_{R} * TL_{W}$

The vehicle trips reduced multiplied by the average auto commute trip length

Table 25 provides the variables used in the travel and emissions segments of the TDM equations.

All nine equations used running emission factors and seven methods included start emissions.  Two methods included soak and evaporative emissions for their TDM strategies.  All nine equations specified light duty vehicles for analysis.  Five out of nine reported kilograms/day as the final unit of measurement.

**Table 25. Travel Demand Management Equation Variables**

| **Travel Demand Management** | |
|---|---|
| **Equation Inputs** | **Number of Uses** |
| *Travel Segments* | |
| Annual VT reduced | ●●●● |
| Annual VMT reduced | ●●●● |
| New auto trips | ● |
| Number of weeks | ● |
| Number of operating days | ●●●● |
| Number of trips | ● |
| Average trip length | ●●●● |
| Percent auto | ● |
| Number of commuters affected | ●●● |
| Number of new participants | ● |
| HBW trip rate | ● |
| Percent of alternate mode use attributable to the Trip Reduction Program | ● |
| Students participating in the TRP program in the CMAQ funding year | ● |
| Daily VMT in affected area | ● |
| Peak period VMT | ● |
| Number of peak hours | ●● |
| Weighted average proportion reduction in work trips due to TDM programs at 11 national sites | ● |
| Speed | ●● |
| Percentage of new participants | ● |
| Vanpool Occupancy | ● |
| Number of new vans | ● |
| Auto Occupancy | ● |
| *Emissions Segments* | |
| Start emission factor | ●●●● |
| Running emissions factor | ●●●●●●● |
| *Project Lifetime* | |
| 1 years | ●●● |
| 5 years | ● |

All models passed dimensional analysis review.  Three equations had issues with equation logic.  Two of the models did not include start emissions for TDM strategies that would have those emission benefits.

Seven models provided instructions for equation use.  Four models provided example analyses using the equation.

#### 5.4.6.3 Park and Ride Facilities

Park-and-ride facilities are specially-designated lots that allow commuters to park their personal vehicles and then transfer to rail or bus transit, or other high-occupancy modes such as carpools, vanpools, express bus, or rail for the remainder of their trip.  Benefits of park-and-ride facilities include cost savings to users, travel time savings, peak period traffic reduction, reduced auto emissions, enhanced mobility, increased transit ridership, and improved transit system efficiency.

Five models provided equations to analyze the effect park-and-ride facilities have on regional emissions.  For park-and-ride analysis, key inputs are (1) the average trip length from home to the facility so that it may be subtracted from the average home–to-work trip length in the region to avoid over credit and (2) the actual parking lot utilization rate as it is more accurate for strategy participation than assuming full utilization of the facility.  All five equations include the utilization rate as variables; two equations include the portion of the commute trip to the facility.  All five equations limit themselves to running emissions for light duty passenger vehicles as this strategy does not remove start emissions from vehicle activity.  Three of the equations reported kilograms/day as the final unit of measurement.  The equation provided below is one that contains the key elements:

Daily Emission Reduction =

$$N_{PK} * U_P * (TL_W - TL_{PR}) * EF_B * 2 \text{ trips/day}$$

Reduction in running exhaust emissions from reduced VMT resulting from park-and-ride lot use

where:

$EF_B$: Speed-based running exhaust emission factor before implementation (grams/mile)

$N_{PK}$: Number of parking spaces

$TL_{PR}$: Average auto trip length from home to parking facility (miles)

$TL_W$: Average auto work trip length (miles)

$U_P$: Parking lot utilization rate

The travel and emissions variables used in the 5 equations found in the review are provided in Table 26.

**Table 26. Park-and-Ride Facilities Equation Variables**

| **Park-and-Ride Facilities** | |
|---|---|
| **Equation Inputs** | **Number of Uses** |
| *Travel Segments* | |
| Number of parking spaces | ●●●●● |
| Parking lot utilization rate | ●●●●● |
| Number of operation days (workdays) | ●● |
| Average trip length to work | ●●●●● |
| Average trip length from home to lot | ●● |
| Number of commute trips removed | ● |
| VMT of previous SOV trips | ● |
| Auto occupancy rate | ● |
| *Emissions Segments* | |
| Speed-based running exhaust emission factor before implementation | ●●●●● |
| Paved road emission factor for PM-10 | ● |
| Weighting factor for each pollutant | ● |
| *Project Lifetime* | |
| 10-12 years | ● |
| 20 years | ●● |

Two models gave a project lifetime of 20 years. One assumed 10 to 12 years of effectiveness. The 20-year assumption is from 2013, while the source for 10 to 12 years is from 2000.

The five models passed the dimensional analysis review. Three models had an issue with equation logic by not subtracting the trip length segment from home to the lot, as noted above. All five models provided instructions for the equations. Two gave examples of their use.

#### 5.4.6.4 Car Sharing

Car sharing allows people to rent cars on a short-term (hourly or daily), as-needed basis, paying only for the time they use the car and the mileage they drive. The term “shared-use vehicle” is a broader concept that encompasses both car sharing and station car programs. Station car programs are designed to facilitate transit access in the cases where the final destination of a person who uses public transportation is located too far away from the endpoint of the transit route; people can drive station cars to complete the final leg of their trip.

No specific technique for estimating emission benefits from this strategy was found in the 10 models.

#### 5.4.6.5 Value/Congestion Pricing

Value/congestion pricing strategies are TDM projects that regulate roadway demand and discourage travel during peak periods or in highly congested areas by charging fees to system users. The strategy allows the possibility of managing travel demand without adding to roadway capacity.

Two pricing equations were found. Both include price elasticities and facility price. One equation analyzed alternate facilities. Both equations used start and running emission factors. Only one reported kilograms/day as the final unit of measurement. The example equation below was developed for a fixed rate toll on a regional freeway network:

Step 1: Calculate expected percentage vehicle mile reduction

(Percent increase in cost per vehicle mile) * (Price elasticity of travel)

Step 2: Calculate expected reduction in daily VMT

(Percent reduction) * (Daily VMT)

Step 3: Calculate trip start emission reductions

(Percent reduction) * [(Daily VMT)/ (Average trip length)] * (365 days/year) *

(Trip starts emissions factor)

Step 4: Calculate annual running emissions reductions

(Daily VMT reduction) * (365 days/year) * (Auto running emissions factor)

Step 5: Calculate total annual emissions reductions

(Auto trip starts emissions reduction) + (Auto running emissions reduction)

Table 27 provides the variables used in the travel and emissions segments of the two equations. The two models passed the dimensional analysis review. Equation logic is adequate for both. Instructions were provided for the two equations; one provided an example.

**Table 27. Value/Congestion Pricing Equation Variables**

| **Value/Congestion Pricing** | |
|---|---|
| **Equation Inputs** | **Number of Uses** |
| *Travel Segments* | |
| Percent increase in cost per vehicle mile | ● |
| Price elasticity of travel | ● |
| Daily VMT | ●● |
| Average trip length | ●●● |
| Days per year | ● |
| Mode Split | ● |
| Vehicle Trips per day | ●● |
| Price for facility use | ● |
| *Emissions Segments* | |
| Trip start emissions factor | ●● |
| Auto running emissions factor | ●●● |
| Emission factor grams per VMT | ● |

### 5.4.7 Other

#### 5.4.7.1 Pedestrian/Bicycle

Bicycling and walking represent viable alternatives to most SOV trips. Every trip shifted from an SOV to a bicycle or walking results in a reduction in vehicle trips and VMT.

Bicycling and walking can substitute for short trips, 5 miles or less in length for bicycle trips and less than 1/2 mile for walking trips. The amount of VMT reduced is small, but the emissions benefits can be much greater because cold-start and hot-soak emissions comprise a large portion of the total emissions per vehicle trip.

Section 4 of this report established that pedestrian/bicycle projects are the most numerous types in the federal CMAQ database. All 10 models offer a pedestrian/bicycle equation and methodology for analyzing this project type. The 10 equations approach the strategy in distinctive ways with 22 different inputs for travel variables. Nevertheless, all 10 use the same basic process in their calculation. They attempt to quantify the VMT and vehicle-trip reductions from previous SOV driver’s use of the bike lane or pedestrian facility, and then multiply the reductions by a speed-based and start emission factor. The result is the emission benefit.

All 10 methodologies limit the analysis to light duty passenger automobiles and trucks. Six of the equations reported kilograms/day as the final unit of measurement. Project lifetimes ranged from 10 to 20 years. The example equation below shows a slightly different variation to the basic approach described above. For a bicycle facility parallel to an existing roadway, it uses a mode shift percentage on AADT and the facility length to arrive at VMT reduction, and then is multiplied by an emission factor.

Daily Emission Reduction = AADT * PMS * L * $EF_B$

The average annual daily traffic of the corridor multiplied by the percentage of drivers shifting to bike/pedestrian multiplied by the length of the project facility multiplied by the speed-based running exhaust emission factor for participants' trip before participating in the bike/pedestrian program

where:

AADT: Average annual daily traffic in corridor (vehicles/day)

$EF_B$: Speed-based running exhaust emission factor for participants' trip before participating in the bike/pedestrian program (grams/mile)

L: Length of facility (miles)

PMS: Percentage mode shift from driving to bike/pedestrian (decimal)

$TL_B$: Average auto trip length before implementation (miles)

The 10 models passed the dimensional analysis and logic reviews. Instructions were provided for nine equations; three provided an example.

Table 28 provides the equation variables from the travel and emissions segments found in the review of the 10 pedestrian/bicycle equations.

#### 5.4.7.2 Dust Mitigation

Dust mitigation strategies are of particular concern to nonattainment areas for particulate matter ($PM_{2.5}$, $PM_{10}$). There are two main types of projects within the strategy: road paving and street sweeping. Road paving is one of the most efficient methods of controlling dust from unpaved surfaces. Unpaved roads are a major source of dust. Street sweeping, either manual or mechanical, has been a common operation for municipalities.

The 10 models reviewed produced 4 equations for analysis of road paving and/or street sweeping programs. For road paving equations, the basic approach is to determine the VMT within the project scope and calculate the current PM emissions factor on the unpaved road and estimate the future PM emissions factor on the paved roadway segment, multiplying the VMT by each emission factor. For street sweeping, the focus for the emission factor is on the pre-swept road and then the factor for the swept road. VMT on the affected roadway remains an input.

## Table 28. Pedestrian/Bicycle Equation Variables

| **Pedestrian/Bicycle** | |
|---|---|
| **Equation Inputs** | **Number of Uses** |
| *Travel Segments* | |
| Number of operating days per year | ●●●●● |
| Average length of bicycle trips | ●●●● |
| (Annual) average daily traffic volume on roadway parallel to bicycle project | ●●●●●●●● |
| City population | ● |
| Types of activity centers in the vicinity of the bicycle project (credit) | ●●● |
| Length of bicycle/pedestrian path or lane | ●●●●●● |
| ADT adjustment for VT SOV reduced | ●●●●● |
| Trip Length | ●●●● |
| Mode split | ●●● |
| VMT reduced | ●●●●● |
| Within 4 miles of $PM_{10}$ monitor? | ● |
| Weighting factor for pollutant type | ● |
| Percentage home based work bike trips | ● |
| Home based work trips | ● |
| Average speed on affected roadway | ●● |
| VMT fraction of road type affected | ● |
| Number of households in affected area | ● |
| Average number of trips per household in area | ● |
| Number of daily bicycle commuters | ● |
| Auto occupancy | ● |
| Vehicle trips reduced | ●● |
| *Emissions Segments* | |
| Speed-based running exhaust emission factor, light duty passenger and truck | ●●●●●●●●●● |
| Start emissions factor | ●●●●●●●● |
| Paved road $PM_{10}$ emission factor for non-freeways | ● |
| Weighting factor for pollutants | ● |
| *Project Lifetime (Depends on type of vehicle)* | |
| 10-12 years | ●● |
| 15-20 years | ●● |

Two of the equations have extensive inputs for both project types. For street sweeper replacement with a more efficient engine, greater attention is paid to fuel consumption. One of the models allows analysts to consider road surface silt loading factors, number of wet days in winter, and antiskid abrasive applications, silt content, moisture content in both project types. The basic equation remains straightforward and provides an annual estimate as shown:

For Road Paving: (Daily VMT * EF unpaved) – (Daily VMT * EF paved) * 365

For Street Sweeping: (Daily VMT * EF unswept) – (Daily VMT * EF swept) * 365

The four equations estimate running emissions. Three include the street sweeper emissions in the calculations. Two equations reported kg/day as the final unit of measurement. As expected, all four focus solely on $PM_{2.5}$ and $PM_{10}$.

All four models passed the dimensional analysis and logic reviews. Instructions were provided for four equations; three provided an example. Table 29 provides the travel and emissions segments used in the dust mitigation equations found in the review.

#### 5.4.7.3 Freight/Intermodal

Intermodal freight transportation is the movement of freight using more than one mode of travel where all parts of the transportation network are effectively connected and coordinated. Projects to address freight/intermodal emissions can include engine retrofits or improvements to infrastructure.

Two equations for intermodal freight movements were found in the review of the 10 models. The first equation calculates the emission benefit for mode shifting trucks to rail. The number of trucks shifted to rail is multiplied by the truck annual VMT multiplied by a load factor and then the truck emission factor. The second equation calculates the benefit from shifting truck traffic to off-peak hours and is shown below

Step 1: Calculate Freight VMT affected by program

(Daily freight trips) * (Road segment length)

Step 2: Calculate emissions reduction

(Freight VMT) * [(freight emissions factor without project) – (freight emissions factor with project)]

Neither model specifies the targeted vehicle fleet determining the emission factor. Neither model reports the final result as kilograms/day. No project lifetimes are given for either project. Table 30 lists the equation variables found in the two models.

### Table 29. Dust Mitigation Equation Variables

| **Dust Mitigation** | |
|---|---|
| **Equation Inputs** | **Number of Uses** |
| *Travel Segments* | |
| Annual Gallons of Fuel Used for Main Engine | ● |
| Annual Gallons of Fuel Used for Auxiliary Engine | ● |
| Annual Miles Swept | ● |
| Energy Consumption Factor | ● |
| Average daily traffic | ●●● |
| Number of lane miles | ● |
| Project length | ●● |
| Number of access points to be paved | ● |
| Weighting factor (4 miles or less to $PM_{10}$ monitoring point) | ● |
| AADT conversion factor (0.93) | ● |
| Road Length (miles) | ● |
| Annual days with application of antiskid abrasive | ● |
| Average delay between application of antiskid abrasive (days) | ● |
| Winter Months (with frozen precipitation) | ● |
| Number of "wet" days during non-winter months | ● |
| Number of "wet" days during winter months | ● |
| Vehicle Weight (tons) | ● |
| *Emissions Segments* | |
| Main emission factor before implementation | ● |
| Main emission factor after implementation | ● |
| Aux emission factor before implementation | ● |
| Aux emission factor after implementation | ● |
| Emission factor paved and unpaved road | ●● |
| Reduction factor | ● |
| $PM_{10}$ Equipment Control Efficiency (%) - Silt Removal Only | ● |
| $PM_{2.5}$ Equipment Control Efficiency (%) - Silt Removal Only | ● |
| Penetration Factor | ● |
| *Project Lifetime* | |
| 20 years | ● |
| 10 years | ● |

**Table 30. Freight/Intermodal Equation Variables**

| **Freight/Intermodal** | |
|---|---|
| **Equation Inputs** | **Number of Uses** |
| *Travel Segments* | |
| Daily Freight Trips | ● |
| Road Segment Length | ● |
| Trucks displaced | ● |
| VMT per year | ● |
| Average Load (tons) | ● |
| *Emissions Segments* | |
| Speed based running exhaust emissions before replacement (trucks) | ●● |
| Speed based running exhaust emissions after replacement (trucks) | ●● |

Both models pass the dimensional analysis and logic review. Both models provide instructions and one model gives an example.

## 5.5 Conclusions from Emission Estimation Models Review

The 10 models chosen for review provided a wide range of CMAQ project type analysis for air quality benefits. Overall, the models provided 94 methods and equations for 21 CMAQ project types. The 94 equations reviewed ranged from basic, sketch planning techniques to complex, data-intensive analyses. Overall, no major flaws were identified from the critical review and assessment of the models. The vast majority of the equations sought to identify the specific source and activity leading to an emissions benefit from a strategy (i.e., new participants, number of former SOV drivers, and type of affected vehicle). The equations allowed for analysis of all criteria pollutants.

Minor issues were also identified with the analysis equations. Dimensional analysis errors occur when the final unit of measurement (kilograms/day) cannot be calculated based on the units specified in the equation variables. Five of the 94 equations reviewed, distributed across the 10 models and project types, were shown to have these errors. Also, 10 equations across 6 different strategy types missed travel or emissions segments that could potentially show greater emissions benefit for the strategy. Examples of missing segments include bus start emissions for new bus services and a mode shift factor for a bicycle/pedestrian project analysis. Modifications to an equation are relatively easy for planning and air quality staff if it captures more of an emission benefit in a region.

Most models provide instructions for using the equations and methodologies but very few provided real world examples. The development of online CMAQ project application and emission analysis processes by one state DOT and one MPO provide a more user-friendly experience. The electronic worksheets are supported by underlying lookup tables of regional emission factors. Default values are made available.

### 5.6 Results of Emission Factor Input Consistency

The objective of this effort was to examine if emission factor model inputs for CMAQ evaluations are consistent with those used for conformity and SIP development. The research team conducted this evaluation through a two-step process. First, the research team obtained a sample of 45 case studies and conducted an initial screening of the available information for them. This initial screening revealed that emission factor input files were available for only one project (CMAQ ID: AK20030003). This project involved providing incentives for installing block heaters for passenger vehicles in Anchorage, Alaska. The input files for this project were based on the 2003 Anchorage SIP update. The research team was not able to locate and obtain the input files for the conformity determination and therefore unable to evaluate the consistency of the input files with the conformity inputs.

The research team performed a secondary and more thorough examination of nine additional CMAQ projects for a total sample of 10 projects (shown in Table 31) from the pool of the case studies to establish a better understanding of the state-of-the-practice with regard to the emissions factors used in the evaluation of CMAQ projects. The research team identified the project types and number of projects to randomly select within each project type category examined. The research team conducted a thorough search of the available information on any relevant information on how emissions factors were prepared for the CMAQ analyses, including project-specific, regional, and state-level documents. The team reviewed these documents and summarized the relevant information in Table 32.

The following provides a summary of the observations for this effort:

- Three projects used a set of statewide emissions factor tables developed by the State air agency.
- Two projects used available national-level emission factor information from the US Environmental Protection Agency (EPA).
- Two MPOs appear to have used local emission rates based on the latest planning assumptions at the time of analysis. The research team believes that emissions input files for CMAQ projects from these MPOs are very likely to be consistent with SIP and/or conformity input files; however, this could not be verified based on the information found and reviewed.

For this review, it wss not common for agencies to provide easily-accessible documentation of detailed assumptions, input values, and data sources for CMAQ projects.

## Table 31. Selected Small Sample of CMAQ Projects Used for Emission Factor Input File Consistency Review

| Group and Subcategory | City or County | State | CMAQ ID | Project Description |
|---|---|---|---|---|
| ***Vehicle/Fuel Technology*** | | | | |
| Alternative Fuel Vehicles/Fueling Facilities | Clovis | CA | CA20070042 | Purchase 10 CNG powered school buses |
| ***Vehicle Activity Programs*** | | | | |
| Extreme Low-Temperature Cold Start Programs | Anchorage | AK | AK20030003 | Private sector block heater incentive program |
| ***Other*** | | | | |
| Pedestrian/Bicycle | Milwaukee | WI | WI20070003 | Ped-bike path |
| ***Traffic Flow Improvements*** | | | | |
| Traffic Signalization | Uniontown | PA | PA20110110 | Traffic signal upgrades |
| Traffic Engineering | Petaluma | CA | CA20120117 | Lane reconfiguration |
| High-Occupancy Vehicle and Managed Lanes | Arlington | TX | TX20090099 | HOV lanes on I-30 |
| ***Intelligent Transportation Systems*** | | | | |
| General ITS | Clark County | WA | WA20110036 | Signals and communications upgrades, new cameras |
| ***Improved Public Transit*** | | | | |
| Transit Facilities, Systems, and Services | Johnson County | KS | KS20070016 | Establish commuter and student transit services |
| ***Transportation Demand Management*** | | | | |
| Travel Demand Management | Richmond | VA | VA20090012 | City employee trip reduction program |
| Car Sharing | Chicago | IL | IL20080052 | I-GO car sharing |

## 5.7 Selected Before and After Studies

Before and after studies can improve project analysis assumptions, inputs, and analysis equations for future emissions benefit estimates. The objective of this section was to find and review any before and after studies of CMAQ-funded projects since 2006. These types of studies are not required in the CMAQ program; however, any examples found could show the capability of these studies to provide a method to improve emission benefits analysis.

Transportation research databases were searched using various, relevant keywords. The research team also looked for these types of studies on agency Web sites in nonattainment areas. No example was found of a before and after study focused on a specific CMAQ-funded project. The literature and Internet search yielded 10 before and after studies of projects that may be CMAQ eligible. One project describes the emission changes from use of biodiesel in transit buses. Two studies present idle reduction strategies through a truck stop electrification example and the other an idle monitoring and feedback program. Three projects describe emission changes from traffic signalization. One example investigated the performance changes combining an adaptive signal system with a transit priority system. Two examples present findings from signal coordination. Impacts associated with roundabouts are described in two examples. An assessment of emission changes associated with a managed lane is presented. The final study describes an academic assessment of the impact from an ecodriving campaign.

### 5.7.1 Vehicle/Fuel Technology – Alternative Fuel Vehicles

### Toledo, Ohio

**Introduction**
Researchers from the University of Toledo (Vijayan, 2008) investigated the emissions rate of diesel transit buses under idling and on-road conditions with regards to different vehicle operation parameters. Tailpipe emissions data were collected from a sample of more than 120 buses. The research team analyzed the data to characterize the impact of various factors, including preventative maintenance and a biodiesel alternative fuel, on the tailpipe emissions of transit buses.

**Methodology**
The Toledo Area Regional Transit Authority (TARTA) provided access to a sample of more than 120 of their diesel-powered transit buses for this study. University of Toledo researchers used a hand-held emissions analyzer, Testo™ 350XL, to measure tailpipe concentrations of $CO_2$, CO, $SO_2$, NO, and $NO_2$ at 1 Hz frequency from the buses. Emission data were collected from idling, on-road, and dynamometer test runs. The study involved an investigation of the impact of B20 (20 percent biodiesel and 80 percent ultra-low sulfur diesel [ULSD]) and a before and after evaluation of the impact of preventative maintenance inspections (PMI). All the sample buses with B20 fuel were allowed to run on B20 for at least 6 months before the start of the testing. Researchers collected high idling (approximately 1200 rpm) emissions from 2 medium-duty bus models, 300 series Bluebird and Thomas to characterize the impact of B20 on emissions. A total of 24 B20-powered and 23 ULSD-powered buses were tested for this purpose. The team used data from a single bus for the PMI analysis. Idling emissions data were collected the day before and after the bus received a Category C PMI (air filter, fuel filter, oil filter, and coolant filter change).

## Table 32. Emission Factor Input File Consistency Findings

| Group and Subcategory | City or County | State | Source of Emission Factors (EFs) or Rates (ERs) | Scale of EFs or ERs | Input Files Available To Research Team? | Consistent with SIP? | Consistent with Conformity? | Note |
|---|---|---|---|---|---|---|---|---|
| ***Vehicle/Fuel Technology*** | | | | | | | | |
| Alternative Fuel Vehicles/Fueling Facilities | Clovis | CA | ARB Emission Factors for CMAQ | Statewide Average | No | N/A | N/A | SIP and Conformity require local (county or regional-level) emission rates |
| ***Vehicle Activity Programs*** | | | | | | | | |
| Extreme Low-Temperature Cold Start Programs | Anchorage | AK | AKMOBILE runs based on local data | Local | Yes | Yes | N/A | Based on a study done by Sierra Research for Alaska Department of Environmental Conservation using AKMOBILE. The study has the input files for Anchorage, AK. These files are consistent with 2003 Anchorage SIP update. |
| ***Other*** | | | | | | | | |
| Pedestrian/Bicycle | Milwaukee | WI | MOBILE6.2 runs based on local data | Local | No | N/A | N/A | Based on MOBILE6 using local data for the project area |
| ***Traffic Flow Improvements*** | | | | | | | | |
| Traffic Signalization | Uniontown | PA | PAQONE | N/A | No | N/A | N/A | Emissions analysis was done using PAQONE version 5.0. PAQONE uses local planning assumptions and default data. |
| Traffic Engineering | Petaluma | CA | EMFAC | N/A | No | N/A | N/A | Calculation sheet provided. Emission rates are from a lookup table which uses EMFAC 2007, Version 2.3 and provided by CARB in December 2007. |
| High-Occupancy Vehicle and Managed Lanes | Arlington | TX | North Central Texas Council of Governments (NCTCOG) | N/A | N/A | N/A | N/A | A sample calculation sheet was provided to the research team. The calculations are based on TTI's Texas Guide to Accepted Mobile Source Emissions Reduction Strategies. |

## Table 32. Emission Factor Input File Consistency Findings (Continued)

| Group and Subcategory | City or County | State | Source of Emission Factors (EFs) or Rates (ERs) | Scale of EFs or ERs | Input Files Available To Research Team? | Consistent with SIP? | Consistent with Conformity? | Note |
|---|---|---|---|---|---|---|---|---|
| ***Intelligent Transportation Systems*** | | | | | | | | |
| General ITS | Clark County | WA | FHWA cost/benefit database | N/A | No | N/A | N/A | Emission rates were developed based on FHWA cost/benefit database. A generic emission reduction table was developed listing reductions per intersection. |
| ***Improved Public Transit*** | | | | | | | | |
| Transit Facilities, Systems, and Services | Johnson County | KS | MOBILE | N/A | No | N/A | N/A | |
| ***Transportation Demand Management*** | | | | | | | | |
| Travel Demand Management | Richmond | VA | N/A | N/A | No | N/A | N/A | |
| Car Sharing | Chicago | IL | Not specified | N/A | No | N/A | N/A | Emission rates for a single make/model (Honda Civic) for two model years, 1995 and 2004, were used in the analysis. |

**Results**
The University of Toledo research team found that the average idling emissions concentrations for all pollutants were reduced by 15 to 20 percent after the PMI. Their B20 fuel impact analysis revealed that in average the 300 series buses running on B20 had 55 percent higher CO, 25 percent higher $NO_2$, 14 percent lower NO, and 3 percent lower $CO_2$ concentration levels than the ULSD buses when idling. The average emissions results from the Thomas buses (19 B20 and 18 ULSD) indicated that B20 on these buses resulted in 15 percent reduction in CO, 5 percent reduction in $SO_2$, 6 percent reduction in $NO_2$, no statistically significant changes in NO, and a 2.6 percent of increase in $CO_2$ concentrations compared to ULSD.

### 5.7.2 Vehicle Activity Programs – Idle Reduction

#### Cobb County School District, Georgia

**Introduction**
Researchers from the Georgia Institute of Technology [Georgia Tech] (Xu, 2013) investigated the before and after air quality impacts of an idle detection and reduction system developed and implemented by the research team. The system consists of hardware and Web-based software system to detect school bus idling and alert dispatchers of extended idling events. The system was tested on school buses in Cobb County School District (CCSD), Georgia.

**Methodology**
Georgia Tech researchers equipped 480 buses in CCSD with global positioning system units and the idle reduction system developed by Georgia Institute of Technology. Idle reductions were monitored from December 2010 to December 2011. The team collected data for a spring session (baseline/before) and a fall session (after). In the after case, bus dispatchers not only monitored bus activity with a Web-based system in real-time, they made phone calls to the bus drivers when an idle event exceeded 10 minutes. The analysis used the operation mode bins in MOVES, classified by scaled tractive power. The research team ran the MOVES model to obtain emission rates for each operating mode (opMode) bin. The amount of emissions for each of opMode 1 (idling) and opMode 200 (extended idle) bins was calculated by multiplying the emission rate by the amount of time the vehicles operated under the specific opMode bin. The idle reduction per bus per day was calculated by comparing the idle duration per bus per day for the spring semester to the fall semester after the idle warning call system was implemented.

**Results**
Georgia Tech researchers found that overall idle duration per bus decreased by 247 seconds per day. This idling reduction translated into annual emissions reductions of 1.27 tons of $NO_x$, 0.025 tons of $PM_{2.5}$, 0.024 tons of $PM_{10}$, and 0.50 tons of CO. The idle warning system saved about 5,340 hours of idling per school year. Researchers estimated that if the idle detection and warning system were implemented on all 1,150 buses in CCSD, the fuel savings would amount to 6,400 gallons per year.

### 5.7.3 Truck Stop Electrification

#### Knoxville, Tennessee

**Introduction**
Researchers from the University of Tennessee (Indale, 2004) conducted this study to characterize the activity and emissions implications of a truck stop as well as the potential emission reductions of a truck stop electrification technology named IdleAire™. The team examined and recorded all related activities that contribute to pollutant emissions in a truck stop and also monitored $PM_{2.5}$ and $NO_x$ at the truck stop. The research team used the data to develop a calibrated model that can be applied to estimate pollutant concentrations in other truck stops and travel centers.

**Methodology**
University of Tennessee researchers measured ambient concentrations of $PM_{2.5}$ and $NO_x$ emissions at two different locations in an IdleAire-equipped truck stop near Knoxville, Tennessee. The measurements covered both summer and winter time. Out of the 216 available spaces in the trucks stop, 110 spaces were IdleAire-equipped. The research team used computer-based modeling (ISC dispersion model) to predict $PM_{2.5}$ and $NO_x$ at the truck stop and compared these concentrations to the observed values. They also developed a profile of the major activities of trucks in the truck stop and conducted counts of these activities to characterize their patterns. The researchers also estimated the effectiveness of the IdleAire technology in reducing emissions based on the average idling emission rate of heavy-duty diesel trucks reported by EPA, the observed average truck utilization rate of the available IdleAire-equipped spaces, and the average occupancy rate of them.

**Results**
Measurements of $NO_x$ and $PM_{2.5}$ concentrations in the ambient air confirmed the existence of significant emissions from idling trucks. The modeling results were consistent with the observation of high idling emissions. The University of Tennessee research team found that the average wintertime $PM_{2.5}$ emissions inside the truck stop were approximately 35 percent higher than the summertime average. They also observed a clear trend in the ambient concentrations of pollutants with respect to the time of the day; concentrations were high at night when a large number of trucks were present. Researchers observed an average daily use rate of the IdleAire™ equipment of 33 percent that was estimated to result in a daily reduction of 0.13 tons/day (117.9 kg/day) of $NO_x$ and 7.1 lb/day (3.2 kg/day) of $PM_{2.5}$ during the ozone season.

### 5.7.4 Traffic Flow Improvements – Traffic Signalization/Arterial Signal Coordination

#### Cary, North Carolina

**Introduction**
This study by North Carolina State University (Unal, 2003) investigated the effect of arterial traffic signal timing and coordination on the vehicular emission on the basis of before and after field data collection. The team developed and executed an empirical approach to measure real-world and on-road vehicle emissions.

**Methodology**
The North Carolina State University team studied the effect of signal coordination on vehicle emissions by comparing vehicle activity and emissions data collected before and after signal coordination plans were implemented. The research team instrumented eight individual vehicles with a PEMS equipment and directly measured tailpipe emissions on two signalized arterial corridors, Walnut Street and Chapel Hill Road, in Cary, North Carolina. A total of 824 one-way runs representing 100 hours and 2,020 vehicle miles of travel were conducted by 4 drivers and 8 gasoline-fueled light-duty vehicles. The emissions data were divided into four modes of operation: acceleration, cruise, deceleration, and idle. Repeated travel runs were made to characterize variability between runs and to develop a stable estimation of average total emissions for each mode of operation. The modal distribution was determined for before and after signal coordination scenarios. Total emissions for before and after cased were calculated based on modal emission rates and activity distribution and then were used in the comparison analysis. The researchers included only the hot-stabilized emissions in their analysis.

**Results**
The findings of this study support the assumption that signal coordination and congestion management are effective tools for controlling emissions. The North Carolina State University researchers observed that coordinated signal timing improves traffic flow (travel time, average speed, delay, and stops per mile) on Walnut Street by 15 to 60 percent and estimated reductions of hydrocarbons (HC), $NO_x$, and CO emissions by 10 to 20 percent, in most cases. The signal timing improvements on Chapel Hill Road had little to no improvement on traffic flow because the corridor was already operating at capacity during peak periods; however, there was 35 to 60 percent decrease in HC, $NO_x$, and CO emissions under uncongested conditions. Researchers found there is substantial variability in real-world on-road modal emissions rates. These differences suggest that acceleration produces the highest emissions rate and idle produces the lowest rate. Therefore, efforts aimed at reducing only stop time may not always be successful in achieving overall reductions in emissions of air pollution.

### 5.7.5 Signal Coordination

#### Houston, Texas

**Introduction**
Researchers at Texas Southern University (Tao, 2011) through a pilot study evaluated the effectiveness of signal coordination in reducing traffic-related emissions during peak and nonpeak hours. The emission data were gathered from on-road tests of two cars under two scenarios: coordinated and simulated non-coordinated signals.

**Methodology**
The Texas Southern University researchers collected emissions and vehicle activity data from on-road tests of two cars equipped with PEMS and/or GPS devices near downtown Houston, Texas. One car was equipped with a PEMS, and a GPS. The second car was equipped with only a GPS unit to collect vehicle activity data. The data was collected during afternoon nonpeak (3:30 to 5:00 p.m.) and peak hours (5:00 to 6:00 p.m.) near downtown Houston, Texas. Both cars were driven simultaneously on a 1.6-mile test route consisting of 26 coordinated signalized intersections. To simulate the non-coordinated scenario for one of the cars (non-coordinated vehicle), the team developed a set of rules to

force artificial stops along the test route, i.e., the non-coordinated vehicle stopped even when signal was green. The study adopted the concept of vehicle-specific power (VSP) and the operating mode (opMode) binning from the MOVES model to calculate the emission rates. The difference of emission between nonpeak and peak hours was considered as a measurement of effectiveness. GPS data were used to develop operating mode distributions for different scenarios. Total emissions were calculated combining opMode distributions with emission rates for each opMode.

**Results**

The results show that coordinated signal control is effective in lowering vehicle emissions in the following sequence: $NO_x$ by 27 to 52 percent, $CO_2$ by 17 to 42 percent, HC by 7 to 42 percent, and CO by 1 to 28 percent. The impact of signal coordination on emissions appeared to be lessened during peak hours when the average speed was lower. Researchers observed that the emissions reductions were gradually decreased during the transition from nonpeak hours to peak hours.

### 5.7.6 Combining SCATS and Transit Signal Priority

#### Portland, Oregon

**Introduction**

The Oregon Transportation Research and Education Consortium (OTREC) (Figliozzi, 2013) investigated the combined performance of the Sydney Coordinated Adaptive Traffic System (SCATS), a dynamic on-line traffic signal management system, and TSP along an urban arterial corridor in Portland, Oregon. Researchers also studied the key factors affecting pedestrian and transit user’s exposure to on-road air pollutants at an intersections and bus shelters. The team conducted a series of before and after studies characterize the changes of traffic and transit operations along the study corridor.

**Methodology**

OTREC researchers used a variety of data sources to obtain the required information. Traffic volumes and speeds were recorded using radar traffic detector units installed on the roadside. They used portable ambient monitoring units to measure ambient concentrations of PM ($PM_{2.5}$ and ultrafine particulate matter [UFP]). The team obtained the transit bus data from Portland’s local transit agency (TriMet), which included automatic vehicle location (AVL) and passenger counts. To obtain the data necessary for investigating the pedestrian exposure to PM emissions, the research team conducted a limited field data collection at an intersection and three bus-stop shelters. They simultaneously measured and recorded $PM_{2.5}$ and UFP concentrations, atmospheric factors, and traffic-related data. Researchers used a series of regression analyses to characterize the changes in different performance measures including traffic and transit performance, pedestrian exposure at intersections, and the impact of bus-stop shelter design on transit passenger exposure to $PM_{2.5}$ emissions.

**Results**

Researchers found that the general traffic conditions before and after SCATS were significantly different in terms of speed and volume. The OTREC research team noted that the traffic performance measures’ changes due to the SCATS implementation varied for different times of day and travel directions. They concluded that the traffic results were mixed and inconclusive with regard to the direction of the changes. The transit performance results suggested that SCATS did not negatively affect transit performance and TSP was not affected by SCATS. The research team noted that the transit operation changes as a result of SCATS, and varied depending on the time of day and the direction of travel. They also observed that SCATS implementation resulted in a reduced travel time in both directions during the off-peak period; however, only one direction showed a reduction of bus travel time during the peak periods. Passenger ridership did not change significantly between the pre- and post-SCAT implementation. Researchers also found that signal timing of an intersection has a high impact on the level of nearby pedestrian exposure. They indicated that that the volume of heavy-duty diesel vehicles including transit buses is a significant factor affecting this exposure level. Their analysis also showed that shelters facing toward the roadway have greater PM concentrations inside the shelter than those shelters facing away from the roadway.

### 5.7.7 Traffic Flow Improvements – Roundabouts

#### Oxford, Mississippi

**Introduction**

This study was conducted by a research team from the University of Mississippi (Uddin, 2011) to evaluate the performance of two roundabouts in Oxford, Mississippi which replaced a stop sign and a signal-controlled intersection at a location in Oxford, Mississippi. The study area consisted of two ramp intersections with a highway. The research team used pre- and post-construction traffic and crash data to evaluate the performance of these roundabouts with respect to traffic flow, capacity, safety improvements, and air quality impact of traffic. The team also investigated the public perception of the roundabouts through an opinion survey.

**Methodology**

The University of Mississippi team manually collected post-construction on-site traffic count data characterizing the traffic activity at the roundabouts. Pre-construction historical traffic volume data were obtained from the MDOT Web site. The researchers used the roundabout analysis methods of Highway Capacity Manual to analyze traffic capacity and level of service of the roundabouts. The team also used the S-Paramics microsimulation software to analyze traffic capacity, flow, and delay for the peak hour. Pre- and post-construction crash data were obtained and analyzed to characterize the safety implications. Vehicle emissions were calculated using average idling emission rates obtained through the EPA Web site. The team also conducted an anonymous public opinion survey to evaluate public perception of the roundabouts and favorability to the construction of more roundabouts.

**Results**

The University of Mississippi researchers found significant improvement in traffic flow, crash reduction, and reduction in vehicle emissions. The results showed that the conversion of the stop sign and signal-controlled intersections to roundabouts resulted in an improved traffic flow. They observed that average delay, idling time, and fuel consumption were reduced by 24 percent, 77 percent, and 56 percent, respectively. The results showed that for the two roundabouts the overall vehicle emissions from idling were reduced significantly as follows: $CO_2$ by 56 percent, VOC by 80 percent, and 77 percent reduction in CO, $NO_x$, and $PM_{10}$. The team estimated a safety performance improvement of 37.5 percent reduction in crashes and a 60 percent reduction in the number of crashes resulting in injury. The estimated annual user cost saving as a result of reductions in travel time, fuel consumption, and crash was $806,018.  The results of the anonymous public opinion survey demonstrated a strong public support for more roundabouts in place of traditional intersections.

### 5.7.8 Stop-controlled Intersection Conversion to Modern Roundabout

#### Kansas and Nevada

**Introduction**
Kansas State University (Mandavilli, 2003) studied the emissions implication of converting a stop controlled intersection to a modern roundabout.  The team collected before and after data from six intersections, five in Kansas and one in Nevada.  They used an intersection analysis software tool to estimate the changes in the rates of $CO_2$, CO, $NO_x$, and HC.

**Methodology**
Prior to the installation of the roundabouts, five of the selected sites were all-way stop controlled and one was a two-way stop control.  Kansas State University researchers used specially designed 360° omnidirectional video cameras to collect before and after implementation traffic data during morning and afternoon hours (7:00AM-1:00PM and 1:00PM-7:00PM) on normal weekdays.  They extracted 15-minute traffic volumes and hourly turning movements from the video recordings.  The team then used these data to prepare input file to Signalized and Unsignalized Intersection Design and Research Aid (SIDRA), an intersection analysis software tool developed by the Australian Road Research Board. SIDRA's outputs include emission rates for HC, CO, NOx and $CO_2$.  Researchers conducted statistical analyses on these emissions rates to characterize their changes as the result of roundabouts.

**Results**
Researchers concluded that the modern roundabouts can significantly reduce the vehicular emissions of the intersections by making a more orderly traffic flow through the intersections.  They observed a 21 to 42 percent decrease in CO, a 16 to 59 percent decrease in $CO_2$, a 20 to 48 percent decrease in $NO_x$, and an 18 to 65 percent reduction in HC emissions for the after installation scenario.  The Kansas State University team also found a reduction in delays, queues, and the proportion of vehicles stopped at the intersection after the roundabouts were installed.  All the reductions were statistically significant for both morning and afternoon periods.

### 5.7.9 Traffic Flow Improvements – Managed Lanes

#### Florida's I-95 Managed Lanes

**Introduction**
A University of South Florida research team (Stuart, 2010) conducted research to investigate changes in vehicular emissions from a managed lane project.  The study evaluated the emissions of transit buses before and after converting a single HOV lane into two managed High occupancy toll (HOT) lanes on I-95 between Miami, Florida and Fort Lauderdale, Florida.

**Methodology**
University of South Florida researchers analyzed ambient concentrations of selected air pollutants from available monitoring data and the EPA air quality database to characterize the concentration in the study

area.  They used CORSIM traffic microsimulation software to simulate traffic operations, particularly transit buses, for before and after implementation of the HOT lane project.  The traffic flow data from the simulation were combined with MOBILE 6.2 emissions factors to determine the changes in emissions for five pollutants: CO, $NO_x$, $PM_{10}$, HC, and benzene.  The team used AERMOD dispersion modeling to investigate the changes in the ambient concentrations of these pollutants.

**Results**

University of South Florida researchers found that overall estimated changes in pollutant emissions and concentrations were small, indicating only small expected impacts from the HOT lane project on air quality.  More specifically, speeds on the corridor improved with the HOT lanes, especially for the northbound direction during the afternoon peak period.  Bus travel times were reduced by 9 minutes on average.  There were mixed results on changes in emissions.  There were small increases in the total (i.e., from mixed traffic) annual estimated emissions of CO, $NO_x$, $PM_{10}$, and benzene with the highest being a 3.5 percent increase for CO.  But, there was a small decrease of HC emissions (1.5 percent).  Emissions from buses alone were estimated to decrease 1 to 12.5 percent for the five pollutants.  The overall increases in emissions were due to the increase in modeled vehicle volumes but there was significant uncertainty in the volume changes.  On average the annual VMT increased by 2 percent as a result of stochastic nature of the CORSIM model.  At the same time, speeds in the northbound increased from 20-30 mph to 40-50 mph which resulted in an increase in CO, $NO_x$, and $PM_{10}$ emission factors from MOBILE6.2.  Additionally, ambient concentrations of CO, $NO_x$, and benzene increased slightly due to the overall increase in corridor emissions.

### 5.7.10  Transportation Demand Management – Public Education

### Ecodriving Education

**Introduction**

A University of California (UC), Berkeley research team (Elliot et al., 2012) conducted research to investigate the extent that the exposure to static Web-based ecodriving information would impact people's driving behavior and maintenance practices.  The researchers used before and after surveys to collect data from a group of approximately 100 faculty, staff, and students at UC-Berkeley.

**Methodology**

The participants were assigned into an experimental and a control group with equal numbers in each group.  Both groups were asked to complete a set of before and after surveys.  The before survey was the same for both groups and consisted of 62 questions to assess participant's current driving and vehicle maintenance practices.  The UC Berkeley team also collected participant's demographics, existing vehicle ownership, and views on climate change.  Researchers asked the experimental group to visit the EcoDrivingUSA Web site developed by the Alliance of Automobile Manufacturers to educate the public on ecodriving.  The experimental group then participated in a 25-question treatment survey about the ecodriving information provided on the Web site.  The control group was not shown the Web sites and did not take the treatment survey.  After a period of three months, both groups took the identical after survey that consisted of comparable questions to the before survey.  The researchers used nonparametric statistical tests to evaluate the statistical significance of observed behavioral changes including change in participants' ecodriving scores as a result of exposure to static Web-based information. The research team analyzed the data with regard to parameters such as gender, age, and household size.

**Results**
UC Berkeley researchers found that providing static ecodriving information results in a statistically significant improvement in driving behavior; however, their results also indicated that not everyone modifies their behavior in response to such information and some may only do so in small ways. The participants who received ecodriving information improved their driving and vehicle maintenance behavior including lower highway speeds, reduced vehicle idling, more gradual accelerating and braking, and maintaining proper tire inflation. The research team observed that overall 57 percent of the experimental group (N = 51) increased their ecodriving score. These individuals were more likely to be female, live in a smaller household, and drive a more fuel efficient vehicle than the rest of the group. Only 16 percent of respondents significantly changed their maintenance practices whereas 71 percent altered some driving practices suggesting that drivers are more likely to change their driving behaviors than maintenance practices as a result of the ecodriving information. Researchers did not estimate the potential emissions reductions of the studied treatment; however, they concluded that because of the low cost of the treatment they are very cost efficient.

## 5.8 Results of Before and After Study Review

Very few before and after studies of CMAQ projects have been conducted since 2006. The 10 examples reviewed show that these types of studies are being performed, but generally not as part of the CMAQ program. Before and after studies can provide ground truth effects of specific project types and allow agencies to more accurately estimate the emissions benefits of their strategies. The range of emission reductions found from these studies can help practitioners validate strategy equations and inputs. Because before and after studies are not a requirement of the CMAQ program, agency willingness to conduct a study is limited by resources and available funding.

## 5.9 Recommendations for Improving Estimation Methods and Models

The research team developed the following recommendations for improving estimation methods and models from the critical analysis and assessment of 10 methods/models.

Inputs

- Make efforts to use the best available local inputs when generating emission factors used in the project-level analysis.

Robustness

- A simpler equation does not mean lesser quality results from it. An agency can only analyze to the detail that its available resources allow.
- Take care to use conservative inputs so that estimated benefits are not inflated.

Structure

- Foremost importance is maintaining a focus on the dimensional analysis of equations. Align the input units so that the equation can better provide a valid benefit estimate.
- Vigilant quality control/quality analysis is a must. Ensure that input data collected meets the units of what is expected in the equation.
- All equations should strive to compute and report in kilograms/day to follow CMAQ guidance. Showing the conversions within the equations to kilograms/day reinforces to the user how and where this is performed in the equation.
- Build or expand new equations and methodologies from other agency estimation techniques. Often, logic or components in other project type equations can be transferred with little or no modification to another project type.

Logic

- Always ask if there are more travel or emission segments that could be captured by the analysis method? Can we fit it in the current equation? Are the data readily available?

Application

- Provide clear instructions and good examples for each strategy analysis.

Advancing the state-of-the-practice

- Before and after studies are not required by the CMAQ program; however, performing some before and after studies would help improve emission estimation methods. This is especially true to measure, compare, and improve those inputs and assumptions used to estimate travel activity changes (e.g., average trip length or percentage of users that shift from a SOV to an alternative mode). Conducting before and after studies can be challenging. Depending on the project type, project implementation, and the scale and measured outcomes of the before and after study, these studies can be resource-intensive for an agency with limited funding.

# 6 Findings on a Review of Transportation and Health Impacts with a Focus on CMAQ Project Types

A goal of MAP-21's CMAQ program assessment was an expanded base of empirical evidence on the human health impacts of actions funded under the CMAQ program. To obtain a better understanding of the actual and potential transportation and health links of projects supported by the CMAQ program, the research team conducted a literature review focused on transportation and human health impacts from 21 CMAQ project types. The intent of this review was to provide a well-established, evidence-based foundation for insights into both transportation and human health impacts resulting from the CMAQ program beyond vehicle emissions reductions. Vehicle emission reductions achieved through the CMAQ program help areas reduce their mobile source emissions inventories as they work to achieve National Ambient Air Quality Standards set through the Clean Air Act.

In the literature review, the CMAQ project types were found to have impacts directly and/or indirectly tied to a number of human health impacts/outcomes including air quality, injury prevention, physical and mental health, and access equity. Many CMAQ projects were shown to impact the transportation system through reduction or elimination of vehicle trips, changes when travel occurs, or improvements in vehicle operating speeds in order to alleviate traffic congestion. These transportation changes impact the amount of vehicle emissions generated. The reduction or elimination of vehicle trips lessens the amount of vehicle emissions generated from the trip. When vehicle speeds are increased away from congested conditions, vehicle emission rates generally improve so that fewer emissions are generated. Shifting vehicle travel to less congested times when more roadway capacity is available, also known as peak spreading, can result in improved travel speeds for those shifting their trip and may also improve peak period travel speeds because of the lessened demand.

Some CMAQ projects do not impact the operations of the transportation system. These CMAQ projects either limit certain vehicle engine activity off the roadway or they improve the performance of the vehicle's engine, catalytic system, and/or fuel performance. For example, when vehicle idling is limited, typically through local regulations, those vehicle emissions generated from idling are reduced. Vehicle technology improvements also directly impact the emissions generated from the vehicle.

One of the issues when considering human health impacts in the context of transportation air quality analysis is current emission reduction analyses performed by agencies address only mass estimates (kilograms/day) of pollutant reductions from these types of projects. These mass emissions estimates are generally not extrapolated by the transportation field into changes in either pollutant concentrations or exposure resulting from the project. Regional pollutant concentrations are estimated in a more complex process of air dispersion modeling typically performed by the state environmental agency. Human health impact studies require the more focused pollutant concentrations and exposures instead of regional mass estimates to form linkages between projects and health effects and may be highly uncertain at the project level.

Quantification of the link between a reduction in emissions of harmful pollutants from an emissions reduction project such those funded under CMAQ and the corresponding change in the human health impact have limited evidence and very few examples in published literature. There are various uncertainties in quantifying this link since the process might be influenced by various factors, such as changes in fuels or technology or land use, that make discerning a single project's impacts to adjacent or nearby populations extremely difficult and challenging.

Each project type was observed to have links between transportation and health impacts at varying quantitative and qualitative levels. This variance in the literature on the impacts of CMAQ project types suggests the need for more evidence-based research. The ability to compare CMAQ programs and projects is limited and it should be recognized that this information is collected and analyzed differently in each situation.

## 6.1 Introduction

The link between transportation and health has attracted considerable attention from many researchers, policy makers, and practitioners due to the opportunity to develop effective solutions to transportation problems while simultaneously improving human health. As noted by the World Health Organization (WHO, 1946), "health is a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity."

In the literature review, the CMAQ project types were found to have impacts directly and/or indirectly tied to a number of human health impacts/outcomes including air quality, injury prevention, physical and mental health, and access equity. The health effects from reduced vehicle emissions is generally expected to be related to improvements in regional air quality that might be resulting from emissions reductions as areas meet air quality standards. Injury prevention can be a benefit received when the risk of vehicle crashes or injury severity is reduced. Projects can impact physical and mental health of individuals in ways not limited to disease but also their general well-being and quality of life. Access equity refers to project impacts that provide improved access to healthcare, education, jobs, nutritional food, and safe recreational areas, providing equitable benefits to all residents.

This effort aims at developing and presenting a better understanding of transportation impacts of CMAQ project types and their linkage with corresponding human health impacts and outcomes. This broad objective was achieved primarily through a review of published literature on transportation and health effects for various CMAQ project types.

## 6.2 Literature Review of CMAQ Project Types

This section presents a literature review conducted for 21 CMAQ program project types categorized into the following 7 groups:

- Vehicle fuel technology.
- Vehicle activity programs.
- Traffic flow improvements.
- Intelligent transportation systems.
- Improved public transportation.
- Transportation demand management.
- Other project types.

The discussion of each project type includes an introductory description of the strategy and then presents information found in the literature review.

## 6.2.1 Vehicle Fuel Technology

### 6.2.1.1 Alternative-Fuel Vehicles/Fueling Facilities

Different from conventional fuels, alternative fuels include ethanol (E85), compressed natural gas (CNG), liquefied natural gas (LNG), methanol (M85), liquid propane gas (LPG), biodiesel, electricity, and hydrogen. The National Defense Authorization Act of 2008 expanded the definition of an alternative fuel vehicle to include:

- Any vehicle achieving a significant reduction in petroleum consumption,
- Advanced lean burn technology vehicles,
- Fuel cell vehicles, and
- Hybrid electric vehicles (GSA, 2014).

Since 2011, alternative-fuel vehicles (AFV) are becoming more prevalent; they make up a small but expanding proportion of United States' vehicle fleet. According to the Alternative Fuels Data Center (AFDC) of the U.S. Department of Energy, the number of alternative-fuel vehicles increased from 534,000 in 2003 to nearly 940,000 in 2010—a 76 percent increase (AFDC, 2013). During the same period the number of registered vehicles in the United States increased from 236,760,033 in 2003 to 250,070,048 in 2011—a 6 percent increase (BTS, 2014). In addition, according to the U.S. Energy Information Administration (EIA), "Overall consumption of alternative transportation fuels increased almost 13 percent in 2011, to a total of 515,920 thousand gasoline-equivalent gallons, compared to 457,755 thousand gasoline-equivalent gallons in 2010" (EIA, 2011). Federal regulations are in place to make alternative-fuel vehicles a larger percentage of the overall fleet, and alternative-fuel vehicles have the potential to provide air quality benefits at lower costs (EPA, 2013a; AACOG, 2011).

**Links to Transportation/Emission Impacts**

AFV reduce vehicles' tailpipe emissions. These projects have no direct transportation effects to reduce VMT or improve congested speeds. Alternative-fuel engines typically offer lower emission rates for PM, $NO_x$, and non-methane hydrocarbons NMHC) than diesels, and CNG fuel systems do not produce evaporative emissions due to complete sealing (assuming no leaking) (FTA, 2006; AFDC 2013). As indicated by St. Denis (2010), natural gas, propane, and electricity offer alternatives to diesel fuel and produce fewer polluting emissions. Vehicles powered by hydrogen fuel cells emit zero air pollutants (EPA, 2013a). Although hydrogen fuel cell vehicles and electric vehicles emit no exhaust or evaporative gases themselves, their environmental benefit depends on the amount of emissions produced from the fuel used to generate electricity (AFDC, 2013).

Alternative fuel vehicles are becoming a viable part of transportation systems. AFV are becoming more of a priority for many agencies and vehicle manufacturers because of environmental concerns, high oil prices, and the development of cleaner alternative fuels and advanced systems to power vehicles (FTA, 2006). For example, in 2002, the Delaware Valley Regional Planning Commission in Philadelphia, Pennsylvania, secured funding to purchase 12 new alternative-fuel buses. The buses, through the combination of an internal-combustion engine (which produces electricity), storage batteries, and an electric propulsion system, provide a quieter ride for riders, reduce exhaust emissions and fuel consumption, and improve brake life through regenerative braking (FHWA, 2011a).

One point to consider came from research conducted by Kazimi (1997) that concluded that benefits derived from AFV use may be counterbalanced by two effects: replacing a conventional gas (CG) vehicle with an AFV reduces total emissions, but using a limited range vehicle may lead to increased emissions due to use of older (i.e., less efficient fuel burning) CG vehicle in multi-vehicle households.

Karavalakis et al. (2012) found that HC and CO emissions declined across a range of ethanol blends for a variety of light-duty vehicles, while results for $NO_x$ and carbon dioxide ($CO_2$) emissions were inconclusive. LPG and CNG also outperformed diesel, with emissions 8 to 12 percent lower. During their well-to-wheel assessment, Huo et al. (2009) evaluated emissions for individual criteria pollutants, determining significantly reduced VOC and CO emissions for electric vehicles and hydrogen fuel-cell vehicles (FCVs), but increased PM for FCVs due to the hydrogen production process. Xie et al. (2012) demonstrated a technique for the integration of a microscopic traffic simulation model in Greenville, South Carolina, to better simulate vehicle behavior when estimating emissions; the researchers found that CNG vehicles resulted in increased CO emissions but decreased $NO_x$, sulfur dioxide ($SO_2$), and $CO_2$, while electric vehicles demonstrated decreases across all criteria pollutants. Nylund et al. (2004) also found that CNG buses have considerably lower PM emissions compared to base diesel vehicles and showed great emissions performance concerning $NO_x$ and HC emissions.

In general, alternative fuels appear to offer net emissions reductions, though quantifying these effects is difficult because they are based upon a variety of intricate mechanisms. For instance, in their comprehensive review of ethanol studies, von Blottnitz and Curran (2007) found general agreement for a net environmental gain when it came to ethanol use, though there was a disagreement when it came to specific impacts. Much of the disagreement can be attributed to the fact that effects will vary substantially depending on feedstocks and location. However, Jacobson (2007) concluded with confidence that due to the uncertainty in future emission regulations that E85 ethanol fuel is unlikely to improve air quality over future gasoline vehicles because unburned ethanol emissions from E85 may result in a global-scale source of acetaldehyde larger than that of direct emissions.

### Links to Human Health Impacts

Alternative fuel vehicles reduce emissions of pollutants considered harmful to human health. FHWA states that the reduction of tailpipe emissions is “the single greatest environmental benefit of alternative fuel” (FHWA, 2011a). According to the U.S. Environmental Protection Agency (EPA), “natural gas reduces 60-90 percent of smog-producing pollutants, and lowers 30-40 percent greenhouse gas emissions” (EPA, 2013a). Motivated by the increasing knowledge of the benefits of alternative fuels (especially in terms of cleaner-burning fuels resulting in lower tailpipe emissions), there is extensive research in the field identifying a number of potential emission benefits from alternative-fuel vehicles. On the other hand, very few studies have documented the human health impacts of implementing this emissions reduction strategy to improve air quality.

Research conducted by Winebrake et al. (2000) using the Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation (GREET) fuel-cycle model to estimate air toxics emissions found that when the modeling results for the four air toxics are considered together with their cancer risk factors, all the fuels and vehicle technologies demonstrate air toxics emission reduction benefits. They evaluated fuels and vehicle technologies for conventional gasoline, conventional diesel, federal reformulated gasoline, California reformulated gasoline, CNG, LNG, methanol, ethanol, battery-powered electric vehicles, and hybrid electric vehicles to determine the fuel cycle effects of VOC, $NO_x$, CO, acetaldehyde, benzene, 1,3-butadiene, and formaldehyde. The analysis for all types showed an overall reduction of benzene emissions and almost all types reduce 1,3-butadiene emissions. Use of ethanol in E85 or reformulated gasoline, however, leads to increased acetaldehyde emissions, and use of methanol, ethanol, and compressed natural gas may result in increased formaldehyde emissions. A study by Jacobson (2007) found similar results for emissions impacts of E85. He used a base-case emission scenario that accounted for projected improvements in gasoline and E85 vehicle emission controls and found that E85 may increase ozone-related mortality, hospitalization, and asthma by about 9 percent in Los Angeles and 4 percent in the United States as a whole relative to 100 percent gasoline.

In addition to reduced tailpipe emissions, AFV projects are likely to provide human health impacts through safer conditions for fueling, operating, and passenger health (FHWA, 2009). According to the Alamo Area Council of Governments, alternative fuels may be safer than gasoline and diesel fuels, stating that “natural gas is unlikely to leak,” “more difficult to ignite than gasoline and diesel,” and “the closed fuel system and heavy-duty tanks used in natural gas vehicles can withstand crashes and heat far better than standard fuel tanks” (AACOG, 2011). Differences in the production, combustion, storage, and flammability properties of alternative fuels impact their safety effects. Fuels for spark-ignited engines, including alternative and conventional fuels, are inherently flammable, posing different fire and explosion hazards, while electric and hydrogen vehicles present their own unique safety risks.

When used as a transportation fuel, natural gas must be either liquefied or compressed for storage purposes. LNG requires cryogenic storage, which can cause cryogenic burns due to extremely low temperatures when coming into contact with skin (Bernatik et al., 2011). CNG is stored under high pressure, making leaks from connections more of a hazard, especially if stored in enclosed areas such as a garage. Like LNG, the spillage would result in a large, highly flammable environment that would dissipate more quickly than gasoline (Astbury, 2008). Hydrogen is most commonly stored in a compressed form, as a liquid at extremely cold temperatures or as a metal hydride (Pollet et al., 2012). When compressed, hydrogen presents the same hazards as CNG but is also more prone to leakage due to its smaller molecular size. Compressed hydrogen is also highly flammable, requires lower energy levels for ignition, detonates more easily, and has a high flame speed and wide flammable limits, and its leakage can result in spontaneous ignition (Astbury, 2008; Dryer et al., 2007).

Alternative-fuel vehicles must meet the same Federal Motor Vehicle Safety Standards and undergo the same safety testing as conventional vehicles sold in the United States (AFDC, 2013). Also, battery packs used in hybrid and electric vehicles are sealed and must meet testing standards that subject batteries to a vast array of conditions such as vibration, extreme temperatures, overcharge, short circuit, humidity, fire, collision, and water immersion (AFDC, 2013). Additionally, electric vehicles often have a lower center of gravity than conventional vehicles and are therefore less likely to roll over (AFDC, 2013).

Similar to the vehicle itself, alternative-fuel fueling stations must meet the same safety standards as conventional fueling facilities, including posting signs alerting drivers to keep ignition sources away from fuel and prohibiting the use of cell phones, matches, and smoking on the fueling facility. Additionally, each fueling station must regularly inspect fueling nozzles, dispensers, and receptacles (USC, 2009). One potential safety concern when storing or using ethanol and ethanol blends is their greater potential for explosion in the fuel tank. Unlike diesel or gasoline, ethanol's flash point of 13°C (the temperature at which ethanol will catch fire with an ignition source) indicates that it will generate flammable vapors during a wide range of normal ambient temperatures (Astbury, 2008; Hansen et al., 2005).

#### 6.2.1.2 Conventional Bus and Paratransit Replacements

Conventional bus and paratransit bus replacements include the replacement of aging fleet vehicles with a variety of cleaner and more fuel-efficient options to reduce emissions. In response to government mandates, buses must be manufactured or refurbished to meet stricter air quality standards than those for the older buses they will replace (FHWA, 2011b). New buses are often equipped with newer emission control technology to reduce $NO_x$ and diesel particulate emissions, achieved by altering the intake air system, combustion chamber, and fuel injection system (UNEP, 2009; Schimek, 2001; EPA, 2013b).

In the United States, 11 million diesel engines are used in public transportation buses, the freight trucking industry, locomotives, surface ships, and construction equipment, which contribute to ambient air pollutants and result in approximately 21,000 premature deaths annually (OEHHA, 2001). Another estimate based on the EPA's National-Scale Air Toxics Assessment placed the figure at about 35,000 diesel-related mortalities in 2002 (McCubbin, 2009). The risk of cancer from diesel emissions is estimated to be 7 times greater than that from the intermixing of 181 other air toxins tracked by EPA.

In 2013, buses provided more than 50 percent of the 10.6 billion transit passenger trips in the United States (APTA, 2014). Data describing bus fleets show that vehicle operating and maintenance costs increase as vehicles age (Feng and Figliozzi, 2012; Boudart, 2011), making it important for agencies to make replacements when appropriate for the age of the vehicle. The FTA capital assistance funding guidelines require transit agencies to keep heavy-duty buses a minimum of 12 years or 500,000 miles, whichever comes first; however, the average bus age is over 15 years (Laver et al., 2007).

**Links to Transportation/Emission Impacts**

Similar to alternative fuel vehicles, conventional bus replacement does not reduce VMT or improve operating speeds. However, replacing older buses allows agencies to integrate technology improvements into their systems. New buses generally come equipped with ITS equipment, which can be linked to transportation management systems to allow real-time travel data to be transmitted to users for expected wait times. This is beneficial to transit agencies but also to users so that they know when the next bus will arrive (FHWA, 2011b; Papadimitratos et al., 2009).

Replacing aging or heavily used buses with new vehicles provides an emission impact via reduced tailpipe emissions. Frey et al. (2007) used a vehicle specific power-based modeling approach to evaluate the tailpipe emissions reductions achieved by replacing conventional diesel buses with hydrogen-fueled buses. The results quantified as differences in fuel cycle emissions and the change in energy consumption indicate that hydrogen-fueled buses may result in an increase in energy consumption and $CO_2$ emissions but substantial decreases in HC, CO, and $NO_x$ emissions. Wayne at al. (2009) also compared alternative fuels and bus types to include new diesel buses running on ultra-low sulfur diesel (ULSD) fuel, diesel-electric hybrid buses, gasoline-electric hybrid buses, compressed natural gas and biodiesel. Results showed reductions in emissions of CO, NMHC, $NO_x$, PM and $CO_2$. The authors estimated that the introduction of diesel-electric hybrid buses in 15 percent of the U.S. transit bus fleet would reduce annual end-use emissions by nearly 1,800 tons of CO, 400 tons of NMHC, 4,400 tons of $NO_x$, 200 tons of PM, 491,400 tons of $CO_2$, and fuel consumption by 50.66 million gallons of diesel fuel (Wayne et al., 2009). Hallmark et al. (2012) evaluated the emissions differences between hybrid-electric and conventional transit buses. They found that CO emissions were 1.5 to 3.9 times higher for the conventional buses than hybrid-electric. HC levels at the highest range fell between 92.5 and 231.8 percent higher for conventional buses. However, the average $NO_x$ emissions were higher for the hybrid-electric buses.

Several studies reported that PM was greatly reduced when new diesel buses, or those with retrofitted engines, were equipped with oxidation catalysts or various types of particulate filters (Stasko and Gao, 2010; Cadle et al., 2004). Conventional bus replacement with more advanced fuel technologies will help reduce emissions.

### Links to Human Health Impacts

Given its impact on reduced emissions, conventional bus replacement is expected to reduce pollutants considered harmful to human health, leading to improved air quality, similar to alternative fuel vehicles project types. However, no studies were found during the review specifically documenting the human health impacts of the emissions reductions associated with the conventional bus replacement strategy.

Conventional bus replacement projects may provide impacts to human health, namely in terms of safety. The potential safety benefits of newer buses include better technology that provides a safer riding experience in various ways. For instance, conventional or paratransit bus replacement allows agencies to provide enhanced safety measures for users, such as collision warning and avoidance systems, driver assistance, automated operation, and wheelchair lifts (Bishop, 2000; Papadimitratos et al., 2009; Inglewood, 2009). New buses are equipped with security cameras that increase security and create a greater sense of safety for riders (FHWA, 2011b). A 2006 survey of transit agencies across the nation revealed that most agencies use various types of safety measures to ensure a safe environment for users, such as closed-circuit television cameras, panic/alarm buttons, and public address systems (Loukaitou-Sideris and Fink, 2009), which might help riders feel secure and safe, potentially improving riders' mental health.

Newer buses may also provide additional health benefits by creating greater accessibility and active transportation opportunities. As discussed in details for other project types related to public transportation, an increase in transit use likely brings important health benefits from stimulating more active transportation through walking and biking. Newer transit vehicles often provide bicycle storage racks that can encourage active transportation (FHWA, 2011b; Hegger, 2007). New buses may also be equipped with lift technology or appropriate interior space, providing disabled people access to transit (Wright, 2002).

### 6.2.1.3 Diesel Engine Retrofits

Diesel engine retrofit strategies consist of the installation of various emission control technologies to improve emissions from older diesel engines. Heavy-duty on-road diesel vehicles manufactured prior to 2007 do not have emission controls. After market add-on "retrofits" are available that can be installed on the exhaust pipe of the older diesel vehicles. Retrofit strategies can offer a number of emissions reduction benefits including cost effectiveness, immediate reductions, and no new infrastructure requirements (DTF, 2014).

The importance of diesel engine retrofit strategies/technologies lies in the fact that diesel fuel is a cost-effective energy source used throughout the world to power automobiles, freight vehicles, intercity transit, agricultural equipment, and diesel-electrical transmission systems such as locomotives, surface ships, and submarines. EPA has mandated strict emission standards for new diesel engines; however, older-model heavy-duty diesel engines are not subject to the same standards. The rate of turnover to new and cleaner engines is slow, in part because of economics, with owners focused on extending engine life by way of a complete rebuild. This private cost-saving action contributes to a delay in fleet turnover to cleaner diesel technology and mutes pollution control efforts (CATF, 2014).

**Links to Transportation/Emission Impacts**

Diesel engine retrofits are mainly linked to emission impacts, and do not reduce VMT or improve operating speeds. PM and $NO_x$ are the primary emissions concerns regarding diesel engines. Emission reductions by pollutant type will depend on the type of retrofit technology (FHWA, 2006). Diesel engine tailpipe retrofits are used to mitigate the emissions leaving the tailpipe. Tailpipe retrofit types found in the literature, in descending order of effectiveness at removing fine PM mass, include:

- Diesel particulate filters (DPF) with a removal rate of 85 percent or greater (EDF, 2104),
- Flow-through filters (FTP) which remove between 50 and 70 percent (EDF, 2014), and
- Particle oxidation catalysts (POC) which have a particulate control efficiency higher than that of the diesel oxidation catalyst (DOC), but lower than DPF (Heikkilä et al., 2009).

Testing of these systems indicates their ability to reduce harmful diesel emissions. Rutherford and Ortolano (2008) analyzed the effect of DPF and DOC technologies in Tokyo, where diesel emissions regulations have been successfully implemented to reduce overall PM and $NO_x$ emissions. Their air quality model attributed 21 percent of the estimated 2000 ton reduction in PM in 2004, and 3 percent of the estimated 17,500 tons of $NO_x$ reductions to DPF and DOC systems. Herner et al. (2009) assessed the efficacy of four DPF devices and two selective catalytic reduction (SCR) devices on medium- and heavy-duty diesel vehicles. The DPF devices successfully removed over 95 percent of PM emissions, while the SCR systems decreased $NO_x$ emissions by over 75 percent during operation. No reductions in $NO_x$ were measured while idling due to efficiency limitations in cold temperatures, suggesting that relatively more $NO_x$ emissions will occur in stop-and-go traffic than at highway speeds for SCR-equipped vehicles. Liu et al. (2012) reported a reduction in PM emissions of over 85 percent for two DPF systems with integrated DOCs, as well as a reduction of over 90 percent in HC emissions and 95 percent in CO emissions. Likewise, Hu et al. (2009) found an 85 percent reduction in PM emissions for DPF devices, to go along with a similar reduction in trace elements and metals, though the distribution of metals differed depending on driving characteristics.

Other studies have focused on the reduction of diesel school bus emissions due to the greater susceptibility of children to the adverse effects of diesel emissions.  PM concentrations can build up around school buses, particularly when the bus doors are open and when a line of buses is loading and/or unloading children.  Hill et al. (2005) found that DPFs removed nearly all ultrafine PM and black carbon for idling school buses, but surprisingly had little effect on fine particle mass ($PM_{2.5}$).  DOCs had little measurable effect, though HC and CO levels were not measured.  As the direct in-vehicle emissions impacts are of particular concern for school buses, Hammond et al. (2007) measured on-board PM concentrations on school buses retrofitted with DOCs.  The devices were found to reduce PM concentrations by 15 to 26 percent.

In general, diesel emissions and control technology efficiency can vary widely depending upon driving conditions and vehicle type.  For this reason, on-road tests can result in more realistic performance measures than carefully controlled experimental settings (Lemaire, 2007).  Conducting on-road tests of heavy trucks retrofit with DPF devices, van Asch et al. (2009) reported lower filtration efficiency rates (20 to 44 percent) than other researchers under various driving conditions and truck types.  Burgard and Provinsal (2009) conducted on-road tests of DPFs and DOCs in school buses, finding a reduction in HC of over 85 percent for both systems, more in line with previous research.

Diesel emission control programs include exhaust trap retrofits and regularly scheduled smoke inspections intended to circumvent the slow turnover of existing vehicles and equipment (Lloyd and Cackette, 2001; St. Denis and Lindner, 2005).  In addition, advances in technology including engine and fuel modifications, exhaust gas recirculation, and catalytic after treatment will result in reductions in emissions improving human health (Lloyd and Cackette, 2001).  For example, modifying diesel fuel to lower sulfur content (secondary PM formation) and converting to natural gas, a zero-sulfur fuel, will reduce overall diesel emissions (Lloyd and Cackette, 2001).  Natural gas, propane, and electricity offer alternatives to diesel fuel and produce fewer polluting emissions (St. Denis and Lindner, 2005).

It is now a federal mandate that all new diesel engines must be equipped with a tailpipe filter. Retrofitting diesel engines with tailpipe filters can provide immediate reductions in pollution exposure up to 90 percent, complementing long-term efforts to reduce $CO_2$ emissions (CATF, 2014).  As previously mentioned, a gap in this policy excludes older-model diesel engines.  Flow-through filters can be an alternative for vehicles that cannot be retrofitted with tailpipe filters, such as transit buses, school buses, port trucks, and other fleets (CATF, 2014).  These filters reduce PM and black carbon soot by about 50 percent.  The most ineffective retrofit option is a diesel oxidation catalyst, which fails to eliminate black carbon soot and only reduces PM by 20 percent (CATF, 2014).  Other alternatives include financial incentives to facilitate early replacement of older diesel fleet engines; anti-idling measures; and use of modified low-sulfur fuel for construction, locomotives, and marine vessels (CATF, 2014).

### Links to Human Health Impacts

Diesel retrofit projects have demonstrated reductions of emissions of pollutants considered harmful to human health.  The health benefits of the diesel retrofit strategies may not be realized soon because older diesel engines could be in use for several more years.  However, the systematic reduction of emissions from diesel engines over time is expected to eventually have a positive impact on human health.

The impetus behind reducing diesel emissions comes in part because the exhaust emitted from diesel engines has become an increasing public concern due to its visibility and negative impacts on health. Diesel exhaust is a toxic ambient air contaminant composed of a complex mixture of gaseous emissions such as benzene, arsenic, formaldehyde, and ultrafine PM (OEHHA, 2001). Many of these substances have negative effects on immune system components such as bone marrow, the circulatory system, the spleen, and lymph nodes (OEHHA, 2001). In addition, research studies on diesel exhaust have identified a causal association between diesel ultrafine PM/black carbon soot and adverse health effects, including acute asthma exacerbations, cardiovascular disease (e.g., hypertension, stroke, and degeneration of blood vessels), cancer, damage to the central nervous system, and premature death (OEHHA, 2001).

Some researchers have attempted to quantify the overall air quality and other health impacts of diesel retrofit technologies using air quality and cost-benefit models. Minjares et al. (2014) adopted this strategy by simulating the effects of a DPF retrofit of 300 buses in Istanbul, Turkey. Estimates of the air quality modeling indicated a reduction in black carbon emissions of 94 metric tons from 2013 to 2035, resulting in the avoidance of 47 premature deaths. The net health benefits were then quantified and monetized in a cost-benefit approach, resulting in a valuation of approximately $120 to 134 million, though estimates were sensitive to uncertain determinations of value. Using a similar approach, Stevens et al. (2005) modeled the costs and benefits of a catalyzed DPF and a DPF with DOC technology to replace different vehicle types in Mexico City. Health and emissions benefits varied under the different scenarios, but net benefits were found in each scenario. Although the catalyzed DPF provided the greatest overall benefits, it was noted that changing technology costs could make other technologies more beneficial in the future.

Beatty and Shimshack (2011) compared the health outcomes of children between districts that adopted school bus retrofit technologies and non-adopting districts. Results of their regression analysis indicated that retrofit technologies resulted in a reduction in respiratory ailments, even after controlling for population characteristics. Although long-term health impacts were not able to be measured, school districts that adopted retrofit programs experienced 23 percent fewer children's bronchitis and asthma cases per month, relative to a control group. These same districts also experienced 37 percent fewer children's pneumonia cases per month. The study results indicated greater effects for the crankcase ventilation filter (CCV) retrofits, suggesting that the more modern crankcase ventilation filters may play a larger role in health improvements than diesel oxidation catalysts alone.

### 6.2.2 Vehicle Activity Programs

#### 6.2.2.1 Idle Reduction

Engine idling occurs when the engine is running and the vehicle is not moving. People often warm up their vehicle engine before they start to drive and leave it running while waiting either in a drive-through lane or parking lot. Heavy-duty vehicle idling occurs mostly during driver rest periods. These drivers idle their engines to provide heat or air conditioning for the sleeper compartment, generate electrical power for appliances such as microwaves, and avoid trouble with cold starts during cold weather (Lim, 2002).

Several technological solutions have been proposed in an attempt to limit engine idle time. EPA launched the SmartWay Technology Program to develop idle reduction technologies that save fuel and reduce emissions. Various idle reduction technologies have been developed and verified by EPA, such as auxiliary power units and generator sets, battery air-conditioning systems on a vehicle or electrified parking space, and truck stop electrification (TSE). Other strategies include automatic shutdown/start-up devices, visual reminders, reassurance that shutting off engines is recommended, and awareness of cost savings and pollution reduction. These can have a positive effect on influencing driver behavior when it comes to idling (Ziring and Srinaj, 2012).

**Links to Transportation/Emission Impacts**

While alternative fuels, vehicle replacements, and engine retrofits help reduce emission of diesel vehicles, they do very little unless the vehicle is in motion. The emissions generated during idling are at relatively higher rates than when the vehicle is in motion, especially from heavy-duty engines. No studies specifically connected implementation of idle reduction strategies to effects on the transportation system. Most of the research focused on the use of idle reduction technologies and incentives to change driver behavior to reduce idling time (i.e., assurance that it is safe, environmentally beneficial, and fuel efficient to minimize idling to “warm up” a vehicle).

Excessive idling is of particular concern for heavy-duty trucks, whose drivers may idle their engines at truck stops for significant periods of time. During rest periods, truck drivers will often need to keep the engine running to maintain interior heating or cooling and to power other amenities. Although PM emissions are typically low for diesel trucks while idling, measurements of 75 heavy-duty trucks found that those with mechanical fuel injection systems averaged 48 g/hr of $NO_x$ emissions while electronic fuel injection trucks averaged 86 g/hr (Khan et al., 2006).

Truck stop electrification is another approach that allows trucks to plug directly into outlets to power heating/cooling systems and small appliances. Frey and Kuo (2009) estimated the emissions benefits of APU devices and TSE based on fuel use data for 20 long-haul trucks. APU devices were determined to have reduced $CO_2$ emissions by 36 to 47 percent and $NO_x$ by 80 to 90 percent in mild temperatures, with somewhat lower figures in the high temperature scenario. TSE emissions benefits were even greater, with an 80 percent reduction in $CO_2$, 90 percent reduction in $NO_x$, and a 93 percent reduction in PM (TSE emissions savings were calculated based on the U.S. power generation mix). The $NO_x$ reductions from the use of an APU were similar to those reported by Lim (2002), who additionally determined that a DFH system could nearly eliminate all $NO_x$ emissions (99 percent).

Idle reduction technologies, such as APUs and shore-power (SP) technologies help long-haul freight trucks reduce their idle emissions. In their study, Frey and Kuo (2009) tested APUs and SPs for idle fuel consumption and emissions. The sample size was 20 trucks monitored for more than 1 year during 2.76 million vehicle miles of activity. Base engine fuel use was 0.46 to 0.65 gallons per hour, whereas fuel consumption with APUs was reduced to 0.24 to 0.41 gallons per hour. TSE emissions savings were calculated based on the U.S. power generation mix; and benefits were even greater; the emissions of $CO_2$ and $SO_2$ were reduced by 36 to 47 percent, $NO_x$ emissions were reduced by 80 to 90 percent, and PM, CO, and HC emissions were reduced by 10 to 50 percent. The researchers also found SP technology provided more reductions, except for $SO_2$. The $NO_x$ reductions from the use of an APU were similar to those reported by Lim (2002), who additionally determined that a direct fire heaters

(DFH) system could nearly eliminate all $NO_x$ emissions (99 percent). Storey et al. (2003) conducted a similar study on APUs and DFHs. The findings showed that APU use reduced fuel consumption by 60 to 85 percent and reduced $NO_x$, CO, and HC by 50 to 97 percent. The DFH showed limited impact on fuel consumption; however, the DFH eliminated almost all emissions of $NO_x$, CO, and HC.

Rahman et al. (2013) conducted a comprehensive review summarizing various studies of the impact of idling on fuel consumption and exhaust emissions. The results suggested a substantially higher amount of fuel consumption and emissions during idling compared to the driving cycle. The authors concluded their study with important evidence regarding idling emissions and the effects of idle reduction methodologies, such as:

- "Emissions during idling can be as high as 86.4 g/hr, 16,500 g/hr, 5130 g/hr, 4 g/hr, 375 g/hr for HC, $CO_2$, CO, PM, and $NO_x$, respectively.
- An increase in idling speed increases emissions: for $CO_2$ emissions, the increase ranged from 90 percent to 220 percent; for PM emissions, the increase ranged between 70 percent and 100 percent; for $NO_x$ emissions, the increase ranged between 53 percent and 284 percent; and for CO emissions, the increase was from 165 percent to as high as 460 percent.
- Idling fuel consumption rate can be as high as 1.85 gallons/hour.
- For APUs, the reduction of emissions was as high as 97 percent; in most cases, it ranged between 34 percent and 95 percent, but for DFHs emissions were reduced by 94 to 99 percent. However, TSE can cause a reduction of emissions by 68 to 99 percent" (Rahman et al., 2013).

Other technologies have demonstrated their potential as additional solutions to idling reduction. Den Berg and Joseph (1996) conducted a study of TSE. The exchange rate (i.e., rate of using electricity to replace diesel) of electric power to diesel was about 8.62 GW to 2 billion gallons of diesel. The emissions reduction of VOC, $NO_x$, CO, and $CO_2$ was estimated at 99 percent, 98 percent, 68 percent, and 98 percent, respectively. Perrot et al. (2004) conducted a similar study to evaluate the environmental impact of TSE. The total fuel consumption savings were 14,918 gallons per year in New York State. Emissions of PM, $NO_x$, CO, HC, and $CO_2$ were reduced 58.2 kg per year, 2,297 kg per year, 1,158 kg per year, 656 kg per year, and 141,364 kg per year, respectively. Calcagno (2005) conducted a study to estimate the emission reduction rate by the length of rest time. With the application of TSE, the PM, CO, and $NO_x$ reduction rates were 2.84 g/hr, 59.1 g/hr, and 158 g/hr, respectively.

Idling school buses might increase the concentration of various pollutants such as $PM_{2.5}$ (Ryan et al., 2013). Based on the analysis results of 4 schools, the $PM_{2.5}$ concentration was greatest ($4.11\ \mu g\ m^{-3}$ $p < 0.01$) at schools with the most buses. However, after an anti-idling campaign, the average difference in $PM_{2.5}$ at the schools with the most buses decreased from $4.11\ \mu g/m^{-3}$ to $0.99\ \mu g/m^{-3}$ ($p < 0.05$). The results showed an increased level of $PM_{2.5}$ in the presence of idling school buses while revealing the importance of anti-idling campaigns in reducing various pollutants, especially at schools with a high number of buses and cars.

Beyond technological innovations, the other method to limit idling is to alter driver behavior. Although behavioral modification is unable to influence involuntary idling (e.g., idling in congestion and at traffic signals), it can have an impact on voluntary idling such as idling by school bus drivers when waiting for children.  Xu et al. (2013) analyzed the effects of a real-time idle detection and notification system for school bus drivers in which dispatcher contacted drivers idling longer than 5 minutes.  The simple act of notification was found to decrease idling by 4 minutes per bus each day.  Emissions modeling indicated that this led to an overall reduction over the course of the school year of 1.27 tons of $NO_x$, 0.025 tons of $PM_{2.5}$, 0.50 tons of CO, and 53.3 tons of $CO_2$.  In a less direct method to raise bus driver awareness, another study attempted to quantify the emissions impact of an anti-idling campaign at four different schools (Kim et al., 2014).  A significant reduction in $PM_{2.5}$ concentrations was found only at the school that had the highest bus traffic.

Finally, excessive idling by private vehicles is also a concern, especially in congested urban areas. Shipchandler et al. (2008) estimated that if all vehicles in the Chicago area reduced their idle time by 5 minutes a day, 1.89 tons of $NO_x$, 6.5 tons of VOC, and 8.395 tons of smog precursors would be eliminated each day.  Emissions calculations are sensitive to a number of variables including temperature variations and the selection of emissions factors, but these results give an indication of the potential impact of idle reduction programs.

### Links to Human Health Impacts

Exposure to emissions from idling vehicles, especially those with diesel engines, is considered harmful to human health.  The benefits derived from reduced idling generally relate to emissions that impact respiratory illnesses.  However, there are very few examples in the literature that link quantification of a CMAQ-funded idling reduction project and the corresponding benefits to human health.  There is an extensive body of research on the human health impacts of diesel exhaust emissions, emphasizing the substantial role of diesel exhaust on generating PM pollution and many other pollutants (Salvi et al., 2000; Brook et al., 2004; Pope and Dockery, 2006).  With the recognition of idling’s contribution to regional pollution, several communities have adopted regulations and implemented anti-idling campaigns (i.e., EPA’s Clean School Bus Idle Reduction Campaign) to prevent excessive idling.  .

Diesel retrofit technologies have greatly reduced the impacts of excessive idling through emissions reductions.  As mentioned previously Hammond et al. (2007) measured on-board PM concentrations on school buses retrofitted with DOCs.  The devices were found to reduce PM concentrations by 15 to 26 percent.  A study conducted by Wargo and Brown (2002) found that idling school buses in the drop off/pick-up queue elevate bus interior particulate levels quickly, up to 10 to 15 times higher than background levels recorded by state monitoring efforts.

Some communities have adopted regulations to mitigate excessive idling.  One example of a successful program comes from the Burlington School District in Vermont (VTDEC, 2014).  They implemented an anti-idling policy in 2004 and developed agreements with delivery vendors to reduce idling.  This policy helped solve their indoor air quality problems that were created by air intake systems located near school loading docks.  One school in the district reported a drop in the rate of absenteeism among asthmatic students from 31 days to 2 days during the first year.

Hoelscher (2010) also considered the potential benefits of anti-idling to students.  In this study, Hoelscher found that many families living in the 2-mile perimeter of a school (walk zones) opted to drive their children to school.  The increased vehicle traffic resulted in safety concerns, congestion, and emissions in front of schools, which discouraged children who lived closer to the school to walk or bike and they lost the physical activity benefits gained from active school commuting. An idle reduction program offered an offset to the cost of increased bus services to reduce the minimum distance for these families and create a safer and better environment. The findings from this analysis indicated that idling was reduced by 50 percent; the estimated reduction of $NO_x$ emissions was over 5,000 kg per year, and the fuel consumption dropped by 12,000 gallons annually. The total savings were about $36,000 in fuel and $NO_x$ emissions each year.

#### 6.2.2.2 Extreme Low-Temperature Cold-Start Programs

A cold start is an attempt to start the vehicle engine in a lower than normal temperature operating environment, usually a 12 hour or longer soak time or engine-off time before an ignition attempt (Brzezinski, 1998). Most vehicles are cold started daily. However, an extreme low-temperature cold-start is categorized as vehicle starts in very low ambient temperature and low initial temperature of the vehicle. The extreme cold start strategy is used to reduce the amount of time it takes to warm the catalytic converter to an efficient working temperature. Exhaust emissions are highest within the first 2-3 minutes after engine cranking following a cold start (Murphy et al., 1999).

Summarized by EPA (1992), fuel under low ambient temperature conditions has low volatility, which leads to incomplete combustion and results in partially combusted fuel with CO emissions and unburned fuel with HC emissions. The engine cranking time is extended, and internal friction inside the engine is greater. Extreme low temperatures of less than 0° F increase the emissions and fuel consumption of cold starts. Several technical solutions such as chemically heated catalyst, electrically initiate chemically heated catalyst, pre-catalyst method, catalyst surface control method, close-coupled catalyst system, exhaust gas ignition system, latent heat storage system, heat exchanger method, and electric engine heaters are used to mitigate cold starts in cold weather (Gumus, 2009).

**Links to Transportation/Emission Impacts**

The projects involved in extreme low-temperature cold-start programs aim at reducing the emissions generated from these extreme cold-start conditions; aside from cold starts' strong connection to air quality effects, these projects do not affect the transportation system.

Weilenmann et al. (2005) state that cold-start emissions impacts are even more significant than effects of driving style, particularly for HC and CO emissions. To mitigate the adverse effects of cold starts and meet suitable emissions standards, the vehicle's catalyst must first be heated to higher temperatures. Rapidly increasing the catalyst temperature of a catalytic converter is of paramount importance in curtailing tailpipe emissions. The heating strategy based on an Electrically Initiated Chemically Heated Catalyst (EICHC™) approach reduces the time required to achieve catalyst light-off temperature (Murphy et al., 1999). Gumus (2009) developed a thermal energy storage system (TESS) for pre-heating of internal combustion engines with an average temperature increase 17.4°C. The maximum thermal efficiency of the TESS system is 57.5 percent after a 12 hour soak time. CO and HC emissions decrease about 64 percent and 15 percent, respectively, with effect of pre-heating engine at cold start and warming-up period.

Aside from heating systems, other techniques to improve cold-start efficiency include fuel/air ratio variation, ignition delay, and the pre-catalyst method. Many of these methods, along with heating systems, can be costly or difficult to apply. Karkanis et al. (2004) found that more efficient catalyst performance could be simply achieved by directing the gas flow during cold-start towards the center core. Their method results in HC reductions of approximately 20 percent, as well as reductions in CO. Another technique tested by Iliyas et al. (2007) trapped HC upstream of the catalytic converter through adsorption, demonstrating the potential of molecular sieves.

**Links to Human Health Impacts**
Cold start technologies used in extreme low temperatures are expected to reduce emissions of pollutants considered harmful to human health. No studies specifically documented the human health impacts of the emissions reductions associated with these project types

### 6.2.3 Traffic Flow Improvements

#### 6.2.3.1 Traffic Signalization

Today, there are more than 272,000 traffic signals in the United States (NTOC, 2007). Traffic signals are widely used at road intersections to control the right-of-way of traffic from different directions. The coordination of traffic signals through signal re-timing along arterial routes improves travel speeds and reduces stopped delay. Traditional signal systems also may include pedestrian crossing signals. With active transportation growing in popularity, there is increasing interest in bicycle signals.

**Links to Transportation/Emission Impacts**
As traffic signal systems have developed, multiple studies have evaluated different engineering technologies for traffic signalization. Improved signalization can increase average speeds and reduce travel times via the reduction in stops, and reduce vehicle acceleration and deceleration events which can, in turn, reduce emissions.

Various air quality and transportation benefits can be derived from the impact of signal retiming or optimization as summarized by Sunkari (2004):

- Travel with minimal or no stopping.
- Reduce the delay to an intersection by balancing the green time, and reduce the frustration caused by the delay.
- Adjust to the change of travel demand or an incident (such as a crash or event).
- Optimize emissions and fuel consumption.
- Reduce risk by reducing speed variability.
- Postpone reconstruction and serve as a cost-effective method to improve traffic operation.

Table 33 provides several additional examples by Sunkari (2004), and indicates major decreases in traffic delay, the numbers of stops, fuel consumption, and the number of accidents.

**Table 33. Summary of Area-Based Benefits of Signal Retiming or Optimization (Sunkari, 2004)**

| Project Area | Number of Intersections | Percentage of Delay Reduced | Percentage of Number of Stops Reduced | Fuel Consumption Reduced | Crashes Reduced (Safety) | Annual Cost Savings or Benefit/Cost Ratio |
|---|---|---|---|---|---|---|
| **Washington, D.C. (2002)** | 245 | 13% | 10% | 2% | N/A | N/A |
| **Lexington, KY** | N/A | 40% | N/A | N/A | 31% | N/A |
| **California (1988)** | 3,172 | 15% | 16% | 8.6% | N/A | 58:1 |
| **Texas (1992)** | N/A | 24.6% | 14.2% | 9.1% | N/A | 62:1 |
| **Kitchener-Waterloo, Canada (1996)** | 89 | 27% | 20% | N/A | N/A | N/A |
| **Burlington, Canada (2001)** | 62 | 17% | 11% | 6% | N/A | $1.06 million |
| **US 1 in St. Augustine, FL (2001)** | 11 | 36% | 49% | 26,000 gallons annually | N/A | $1.1 million |
| **RS 26 in Gainesville, FL (2001)** | 8 | 94% | 77% | 3,300 gallons annually | N/A | $93,000 |
| **San Jose Boulevard in Jacksonville, FL** | 25 | 35% | 39% | 65,000 gallons annually | N/A | $2.5 million |

N/A = not applicable.

A review of CMAQ projects for cost and emissions impacts conducted for EPA (Hagler Bailly, Inc., 1999) reviewed two traffic signalization projects, an arterial street signal interconnect and a signal systemization. The estimated annual emissions reductions for these projects are from 3 to 3,000 tons for VOC, and 0.25 to 1,000 tons of $NO_x$. A study for the California Air Resources Board (CARB, 1995) also found potential emissions reductions with the implementation of alternative traffic signalizations. Changes to traffic signal timing for two projects is expected to reduce reactive organic gases (ROG) by an average of 13 kg/day and $NO_x$ by 2 kg/day.

Dion et al. (2004) used a simulation model to show the impact of the optimization of transit signal priority along an arterial corridor in Arlington, Virginia. The transit priority strategy was tested during both the morning peak and midday. The results showed public buses benefited from the transit priority strategy. Researchers found that the cost to the entire traffic network could be negligible when there is less overall travel demand. Ngan (2004) suggested that the transit priority signals would perform most effectively "under a traffic condition that has moderate-to-heavy bus approach volume, little to no turning volume hindering bus movement, slight-to-moderate cross street volume/capacity (v/c) ratio, far side bus stop, and signal coordination for traffic running in the peak direction."

More recently, signalization for bicyclists has garnered more attention in the United States. Many different bicycle signalization systems are currently in use or being experimented with to respond to emerging transportation needs and address new safety technologies (MUTCD, 2009). A literature review conducted by Weigand (2008) discussed two signal treatments used at intersections (bicycle scramble signals and bicycle-only signal phasing) that protected bicycle movement by stopping all vehicular traffic to provide safe bicycle movement. Bicycle scramble allows bicyclists to cross the intersection in any direction contrasted to bicycle-only signal phasing allows movement only in designated directions. Wolfe et al. (2006) conducted a before and after study to evaluate the use and effectiveness of a bicycle scramble treatment installed at an intersection in Portland, Oregon. The results of their study indicated a substantial decrease (from 78.1 percent to 4.2 percent) in the number of bicyclists crossing the intersection illegally after the installation of the bicycle scramble. The number of illegal right turns across motorists was also found to be small—specifically, 30 illegal right turns for 895 activated scramble signals.

In addition to the aforementioned transportation effects, traffic signalization project types might result in emission impacts. Typical local emissions such as CO, HCs, $NO_x$, and PM were studied under arterial signalization (Unal et al., 2003). The estimated emissions were substantially lower under uncongested conditions than congested conditions (i.e., a decrease of 35 to 60 percent in emissions for three pollutants [HC, NO, and CO] on Chapel Hill Road in North Carolina). A field evaluation by Rakha et al. (2000) of coordinated traffic signals across jurisdictional boundaries showed an increase in the average speed on the main line by 6 percent over any time of day. The number of vehicle stops was estimated to be reduced by 3.6 percent, on average, whereas fuel consumption would drop by 1.6 percent. The emissions of HCs and $NO_x$ remained constant, and CO emissions increased by 1.2 percent. In another study, Halkias and Schauer (2004) examined how traffic signal timing can help emission reduction in Oakland County, Michigan, and Syracuse, New York. In Michigan, 640 traffic signals were re-timed, reducing CO between 1.7 and 2.5 percent, $NO_x$ between 1.9 and 3.5 percent, and HCs between 2.7 and 4.2 percent. In New York, signals at 145 intersections were re-timed, resulting in a 13 percent reduction in vehicle emissions.

### Links to Human Health Impacts

Traffic signal re-timing and coordination projects have various human health impacts. Traffic signalization improvements are expected to reduce emissions of pollutants considered harmful to human health though no study was documented to quantify this effect during this review.

There were many studies found documenting the safety benefits of traffic signalization project types. Rakha et al. (2000) evaluated the safety impacts of a corridor with 11 coordinated traffic signals in Arizona and found a crash risk reduction of 6.7 percent. Different intervals of traffic signals also change the risk of crashes (Retting et al., 2002). For a three-year period of signal timing changes on 40 intersections, Retting et al. (2002) found an 8 percent reduction of reportable vehicle crashes and a 12 percent reduction of injury crashes; pedestrian and cyclist accidents decreased by 37 percent. The results of the investigation by Retting et al. (1997) also indicated that setting signal intervals closer to Institute of Transportation Engineers (ITE)’s recommended time can reduce red-light running and potential vehicle conflicts.

Using a cost-benefit analysis framework, Korve and Niemeier (2002) examined the benefits of implementing a separate signal phase for bicycles at intersections and found key safety benefits for bicyclists. The number of motor vehicle-bicycle crashes decreased from 10 to none in the 35-month period after the installation. Bike signal coordination offers safety benefits particularly to prevent bicycle-related crashes and might also help minimize the disruption in flow and the delay times for both bicyclists and motorists.

Research suggests that bike traffic signals may promote additional bicycling on major streets that presumably would be eliminating vehicle trips on the street. The study from Aultman-Hall et al. (1997) on 397 bike routes in Guelph, Ontario, Canada, indicated that improvements to cycling conditions, such as more actuated traffic signal detectors, could encourage a higher level of commuter cycling activities. Dill (2009) also suggested that bicycle signals allow bikes to safely cross busy streets. Using data from 166 regular cyclists in Portland, Oregon, Dill's analysis supported the importance of a well-connected network, including some bicycle boulevards to help bicycles cross major arterial roads. Interestingly, such an infrastructure might stimulate more bicycling on major streets with high motor vehicle traffic, suggesting the potential effectiveness of bicycle signal coordination policies (even compared to simply adding more bike lanes).

Access equity is an issue that requires attention in the context of traffic signalization. Public transportation access impacts and benefits can be gained through traffic signal priority and retiming (Daniel et al., 2004). Delays and the numbers of stops could be minimized by altering the traffic signal phases. The potential savings in bus travel times can provide more reliable and better services, but the study also pointed out the limitation of the system for the overall traffic network, especially when the overall traffic volume is high (Daniel et al., 2004).

#### 6.2.3.2 Traffic Engineering (Roadway Improvements)

Traffic engineering is the application of technologies to improve accessibility and roadway safety, and manage traffic flow. It mainly deals with construction (or reconstruction) to improve traffic flow (e.g., improved speeds, reduced idling) on the roadway. The basic theory behind traditional traffic engineering projects is the lane flow equation, which is the relationship between service flow, speed, and density. Engineering solutions may improve sight distance, construction grade separation to reduce traffic conflicts and improve operations, and reconfigure the roadway to improve flow.

**Links to Transportation/Emission Impacts**
Roadway improvements could result in various environmental impacts by relieving congestion, smoothing traffic speed, redistributing traffic, and adding new infrastructure. Several scientific studies have been done to provide an understanding of multiple traffic engineering concepts, such as lane configuration and width revisions, and grade changes, applied to roadway improvement projects for better vehicle operations.

In April 1996, a 5.1-mile (8.16 km) four-lane section of New Haven Avenue (US 192) in Melborne, Florida was modified to include the closure of 16 median openings and the modification of 42 full openings into directional median openings. Before construction, there had been a total of 12 signalized median openings and 65 unsignalized full median openings. None of the signalized median openings were eliminated. The before and after effects of this project were:

- rates of collisions decreased 15 percent,
- injury rates decreased 24 percent,
- traffic volumes increased dramatically,
- travel speeds increased, and
- left turn collisions decreased by a considerable amount (Wu, 1998).

Through case study compilations, Crawford et al. (2011) found examples of traffic engineering improvements such as deceleration/acceleration auxiliary lanes at interchanges. These were found to benefit traffic by increasing average speed on highways, reducing delays on ramps and arterials and increasing safety. Some relatively minor reconstruction projects to improve facilities may result in increases in mobility for large portions of the facility. Examples include:

- Remove roadway bottlenecks
  - Upgrade a two-lane bridge serving four lanes on either side to a four-lane bridge.
  - Upgrade limiting sections of roadway to match the number of lanes of adjoining sections.
- Redesign locations with substandard vertical and/or horizontal alignment for prevailing volumes and speeds (TTI, 2001).

**Links to Human Health Impacts**

Roadway improvement project types have various human health impacts. The improvements are expected to reduce emissions of pollutants considered harmful to human health by relieving congestion, smoothing traffic speed, redistributing traffic, and adding new infrastructure. However, no studies were documented during this review quantifying the health benefits of emissions reductions through a CMAQ-funded roadway improvement projects.

Many studies were found documenting the safety objectives and benefits derived from roadway improvement projects, with safety being the most prominent health related impact. Implementation strategies include modification of turn lanes and lane widths to achieve a roadway improvement goal. Neuman et al. (2003) pointed out that two-way left-turn lanes could result in fewer head-to-head collisions on two-lane roads. With the conversion of two-way streets to one-way streets, research has documented a 26 percent reduction in all intersection crash types and between a 33 and 43 percent reduction in all mid-block crash types (FHWA, 2007a; Gan et al., 2005; Agent et al., 1996). Crawford et al. (2011) found evidence through case study reviews that turn bays reduced vehicle conflicts by efficiently removing turning vehicles from the through traffic stream. The positive effects of adding left-turn lanes include:

- 25 percent to 50 percent reduction in crashes on 4-lane roads
- Up to 75 percent reduction in total crashes at unsignalized access points
- 25 percent increase in capacity (Crawford, 2011).

Huang et al. (2002) studied the crash frequency per mile and crash rate road diet (the number of travel lanes and/or effective width of the road is reduced in order to achieve systemic improvements) with the rate of accidents. In their study, the rate of crashes was reduced by 6 percent, but they also pointed out the effect of road diet (removing a travel lane in each direction of a four-lane undivided roadway to create a two-lane roadway with two-way left turn lane) should be analyzed case by case However, Potts et al. (2007) determined that the impact of lane width on crash frequencies was minimal. The results of a similar study conducted by Gross et al. (2009) indicated that a lane width of 11 feet and 12 feet performed equally in safety when the total paved widths are 34 feet to 36 feet.

#### 6.2.3.3 Intersection Improvements

Intersection improvements are projects that increase the efficiency of the flow of traffic through an intersection. The primary source of emissions benefit is delay reduction of vehicles. These are differentiated from traffic signalization by focusing more on the physical roadway than the electronic signalization or monitoring of the location. Intersection improvements may consist of turn restrictions, turn lane additions, construction of interchanges instead of signalized intersections, and grade separations at transitway/railroad crossings (ICF, 2006).

**Links to Transportation/Emission Impacts**
Intersection improvements do not generally reduce VMT; however, designs can prioritize traffic flow conditions to reduce the emissions impacts of delays, idling and, acceleration/deceleration. These improvements also aim to enhance safety not only for vehicles but also for bicycles and pedestrians.

The impact of risk factors such as geometric design features, traffic control, and traffic flow characteristics at intersections within close spatial proximity along a corridor were found to be correlated due to interacting traffic flows, road design, and environmental characteristics (Guo, 2010). Several different engineering facility treatments are designed to respond to the traffic and safety problems associated with intersections. For instance, the Michigan left turn (median U-turn intersection treatment) is a design feature used to reduce congestion and improve corridor safety at intersections. This easy-access design eliminates left-turn channeling at signal-controlled intersections. Drivers proceed along an at-grade roadway and then complete a U-turn at the median opening downstream of the intersection (FHWA, 2014b). Research has demonstrated a 20 to 50 percent reduction in overall crash incidents when a Michigan left turn is implemented as compared to a conventional 4-way intersection. An added safety benefit is the reduction of injury severity and crashes, with fewer head-on and angle crashes (FHWA, 2014b).

Traffic flow improvements aimed at reducing congestion also helps reduce emissions of most pollutants by minimizing stop-and-go conditions and idling. These benefits may be decreased if the improvements increase travel speeds because VOC emissions generally decline with increasing speeds, and CO and $NO_x$ emissions begin to increase at speeds above about 32-35 miles per hour. ICF (2006) determined that if a traffic flow strategy is examined solely as a speed change, no impact will be determined; however, if reduction in idling is accounted for, the strategy will typically show a reduction in all pollutants (ICF, 2006).

Hoving (2008) modeled the emissions impact for $NO_x$ and $PM_{10}$ of 5 intersection designs and found that the intersections with more levels (grade separated junctions and multi-level exchanges) performed better than those with ground-level crossings (crossing with priority road, crossing with traffic signal and roundabout). The ground-level intersections showed a 39.4 percent greater emissions rate for $NO_x$ and 34 percent for $PM_{10}$.

Mandavilli et al. (2003) compared 6 sites with different traffic volume ranges where a modern roundabout replaced existing intersection control (i.e., stop signs). Using the Signalized and Unsignalized Intersection Design and Research Aid (SIDRA) software, the authors compared before and after traffic volume and determined that the roundabout reduced emissions to a greater extent than the other intersection designs. Using the SIDRA software, Hesch (2007) found that intersection design replacements that used roundabouts achieved a 16.3 percent reduction in $NO_x$ and approximately 26 percent reduction in HC as compared to an intersection with traffic signals.

### Links to Human Health Impacts

Intersection improvements help reduce the production of and exposure to harmful emissions through traffic management techniques, and improving safety for vehicles, pedestrians and bicycle users.

No research was found that specifically linked CMAQ-funded improved intersection designs to human health benefits of reduced emissions during the review. However, intersection improvements designed to reduce delays, idling, and acceleration/deceleration will beneficially impact emissions levels.

Intersection treatments can contribute to human health by improving intersection vehicle and pedestrian safety. Automatic pedestrian detectors, larger visible traffic signals, strategically positioned signs to prevent motorists from false-start stop-phase approaches, and pedestrian countdown signals (FHWA, 2014b) are used to promote the safety of active transport within communities.

Assessing the impact of converting intersections to roundabouts, a review of non-U.S. studies found that accidents were reduced by 30 to 50 percent and effects were greater for four-leg intersections than three-leg intersections (Elvik, 2003). Because most studies regarding roundabout conversion examine their impact at formerly unsignalized intersection, Gross et al. (2013) assessed the safety effects of converting signalized intersections into roundabouts. Twenty-eight such conversions were identified in the U.S., with a significant reduction in crash rate and injuries found. The aggregate crash modification factor (CMF) for vehicle accidents was 0.792, and safety benefits tended to decrease with increasing traffic volume.

As mentioned above, not all intersection design improvements have achieved greater safety for both vehicles and pedestrians. In the United States, it is estimated that 21 percent of traffic fatalities and 50 percent of serious injuries are the result of an intersection crash (FWHA, 2014b). Leden (2002) analyzed data involving pedestrian-vehicle crashes, intersection geometry, and estimates of pedestrian and vehicle flows from 1983 to 1986 at 300 signalized intersections in Hamilton, Ontario, Canada. The author observed that left-turn-channeled vehicles posed a higher risk to pedestrians as compared to right-turn-channeled vehicles. According to Leden (2002), “At low vehicular flows right turns and semi-protected left turns seemed to be equally safe for pedestrians.” Leden also noted that pedestrian risk decreases with increasing pedestrian flows so that communities that promote active transport tend to have a positive safety effect at signal-controlled intersections. Correspondingly, pedestrian WALK/DON'T WALK signals are commonly installed as an adjunct to conventional signal-controlled intersections to ensure safe crossing at vehicle left-turn signals, school zones, exclusive pedestrian intervals, and wide streets void of an island median (FHWA, 2014b). Some intersection improvements have created unforeseen problems upon implementation such as those intersection improvements that decrease crash incidents and improve traffic flow but inadvertently diminish pedestrian safety.

### 6.2.3.4 High-Occupancy Vehicle and Managed Lanes

HOV and managed lane facilities include carpool lanes, bus lanes, and exclusive HOV ramps and lots directly connected to HOV lanes. An HOV lane, is reserved for carpools of at least two passengers, vanpools, and buses. Green vehicles and motorcycles can be eligible for HOV lanes depending on state rules, but are not necessarily high occupancy and will not be considered in this discussion. These lanes allow eligible vehicles to bypass congested traffic on the general-purpose lanes, offering a more reliable, congestion-free commute (FHWA, 2013). HOV lanes are typically located in highly congested corridors, and some have designated ingress and egress points along the facility, either from the general-purpose lanes or by designated ramps (Stockton et al., 1999).

Managed lanes are defined as "highway facilities or set of lanes where operational strategies are proactively implemented and managed in response to changing conditions" (FHWA, 2008). Managed lanes, which includes facilities such as HOT lanes or express toll lanes, are specialized lanes in corridors that control lane usage by vehicle eligibility, dynamic pricing, or access control. This concept has evolved since the 1990s (Goodall and Smith, 2010; Fan and Naga, 2010; Ungemah et al., 2007). Managed lanes can charge usage fees to drivers and allow lower-occupancy cars, including single-occupant vehicles, access to HOV lanes. The price of the lane is adjusted based on the demand for the facility so the optimum excess capacity can be sold and the facility can still maintain a minimum travel speed for reliability.

Many metropolitan areas around the country have implemented HOV facilities as a response to increasing corridor congestion, environmental concerns, and reduced mobility (Turnbull, 1992; EPA, 1992). Today, there are over 300 HOV and managed lane facilities across the nation (FHWA, 2013).

**Links to Transportation/Emission Impacts**

HOV facilities are used in many metropolitan areas to address growing traffic congestion and air quality problems. According to EPA (1998a), HOV lanes may reduce air pollution emissions by reducing running emissions and by reducing trip-end emissions. Running emissions may be reduced because the increased use of buses, vanpools, and carpools results in fewer VMT, and because of higher speeds associated with uncongested operations in HOV lanes.

HOV lanes encourage carpooling and transit use by providing reliable travel times and operating speeds compared to the congested general-purpose lanes (Carrion-Madera and Levinson, 2013; Shewmake, 2010; Ungemah et al., 2007; Cervero and Grisenbeck, 1998; Bullard, 1991). Schreffler (2004) and Stockton et al. (1999) determined rideshare programs were more effective when HOV lanes were available, suggesting that nearly half of current HOV carpoolers created their carpool as a result of the facility. Studies in Texas found that HOV lanes increased carpooling and bus ridership by as much as

60 percent when implemented in areas not predominantly served by transit (Stockton, 1999; EPA, 1992).

Case study reviews conducted by Crawford et al. (1998) found a significant increase in transit use and carpooling with the addition of HOV lanes. An evaluation of HOV facilities in Texas indicates that public opinion concerning the HOV lanes was favorable by both users and non-users. A survey conducted in 1994 showed that 66 percent of the freeway motorists thought that the East R.L. Thornton HOV lane in Dallas, Texas was a good transportation improvement. Sixty-five percent of bus riders felt that the HOV lane was very important in their decision to ride the bus because the actual travel time is cut in half by using this facility. Another example in Minneapolis, MN is an 11 mile HOV lane in the I-394 corridor that includes 3 miles (5 km) of reversible HOV lanes and 8 miles (12 km) of concurrent-flow HOV lanes completed in 1992. The initial objectives of the project were to increase peak-hour transit modal split; improve level of service for carpools and vanpools; improve or maintain the existing level of service for mixed traffic; decrease the accident rate; achieve and maintain high-occupancy compliance, and construct a cost-effective HOV facility. The actual performance of the HOV lane and level-of-service was higher than projected to include a 26 percent increase in transit ridership (Skowronek, 1996).

By encouraging ridesharing and transit use, HOV lanes also increase vehicle occupancy and person throughput, particularly during peak travel times (Jang et al., 2009; Ungemah et al., 2007; EPA, 1992; Stockton et al., 1999; FHWA, 1998). Corridor efficiency, a measure combining the number of people using the facility during the peak hours and their travel speed, is also improved, ranging from 30 to 140 percent according to an analysis of HOV lanes in Texas (Stockton et al., 1999). Increased transit and auto occupancy on HOV lanes can result in fewer vehicle trips and VMT, as well as decreased emissions and congestion (Jang et al., 2009; Boriboonsomsin and Barth, 2008; Varaiya, 2005; Bieberitz, 1994).

Managed lanes typically provide users with decreased trip time and reliable operating speeds because the toll is dynamically adjusted to maintain free-flow conditions (Carrion-Madera and Levinson, 2013; Goodall and Smith, 2010. Devarasetty et al., 2012). For example, travel time savings on the Katy Managed Lanes in Houston, Texas, are measured between 5 and 15 minutes, depending on time of day (Goodin et al., 2013). This produces an alternative to congestion and generates revenue that can offset the cost of implementation and also fund ongoing maintenance of the managed lanes. If HOV lanes are not operating at capacity, managed lanes may be promoted as an effective way of using the excess lane capacity during peak hours, and to alleviate more congestion on the general-purpose lanes (Ungemah et al., 2007; Swisher et al., 2002; Lowery, 2010; Fuhs and Obenberger, 2002).

A before and after study conducted in California (Wherry and Supernak, 1991) determined that the implementation of an HOV lane at I-15 in San Diego in 1988 reduced CO emissions by 25 percent per user mile from the 1988 level. They also concluded 1990 CO emissions would be 65 percent greater if the HOV lane had not been constructed. However, the effectiveness of emissions reductions depends upon several factors that include:

- “Existing number of carpools and vanpools on the roadway.” The extent to which travelers shift from SOVs to HOVs, or from transit to HOVs,

- Travel speeds without the HOV lane and with implementation of the new HOV lane, and
- Duration of HOV operational restrictions and the level of enforcement, which will affect compliance” (ICF, 2006).

HOV and managed lane facilities encourage carpooling and transit use, which results in reduced emissions, reduced fuel consumption, and reduced congestion (Ungemah et al., 2007; Fuhs and Obenberger, 2002). For instance, according to the results of Boriboonsomsin and Barth (2007), in Southern California, HOVs produced 10 to 15 percent less HC and $NO_x$ emission compared than those traveling in mixed-flow lanes due to a better flow of traffic in the lanes. On uncongested freeways, though the emissions were higher due to higher speed, the emissions mass per lane was lower due to lower VMT. In another study, Shi and Yu (2011) developed experiments using test vehicles and computed the emission reduction rate by using HOV lanes. The analysis results showed lower $CO_2$ emissions per mile by using HOV lanes during peak periods. Researchers noted that “without the consideration of the effect of HOV lane on VMT, the emission reduction rate on the first testing day is 3.56 percent, and due to an increased traffic demand on the corresponding mixed-flow lane on the second testing day, the emission reduction rate by using HOV lane increased to 10.42 percent.”

### Links to Human Health Impacts

Numerous studies identify potential transportation and emission benefits of HOV and managed lanes, such as reduced VMT, many of which have an impact on human health. There was no health-based evidence found to link HOV lanes and the health benefits of reduced emissions. However, there is research on safety and mental health impacts.

From a safety perspective, in a comparison of limited- and continuous-access HOV lanes in California, Jang et al. (2009) found no safety advantages to limited-access facilities, which had more crashes. Using statewide collision data between 1999 and 2003, Jang et al. (2009) found that while 57 percent of collisions were rear-end crashes and 34 percent were sideswipe crashes in continuous-access HOV lanes, the numbers were 64 percent and 26 percent, respectively, in limited-access HOV lanes.

HOV lanes with a buffer separated system are associated with negative injury effects. According to FHWA, the safest HOV lane application is one where it is separated from the adjacent lanes with a barrier (FHWA, 2013). From a safety perspective, the speed differential between the concurrent-flow HOV lane and the general-purpose lanes can potentially be hazardous when the lanes are not separated by a barrier. A 2003 study determined that injury crashes increased by 50 percent on concurrent-flow HOV lanes without barrier separations in Dallas, Texas, due to the speed differential (Cothron et al., 2003). Cooner and Ranft (2006) had similar results in their analysis of the buffer-separated facilities in Dallas, Texas. In addition, based on their analysis of over 1,000 reported crashes that occurred between 1997 and 2000 on the I-35E and I-635 corridors, Cooner and Ranft (2006) discovered important trends for the crashes that occurred on either the buffer-separated HOV lane or the adjacent inside general-purpose lane. These trends included crashes caused by making illegal lane changes (causing rear-end and sideswipe crashes), moving into the HOV lane to avoid congestion in the general-purpose lane (causing crashes with a fast-moving HOV vehicle), moving into the HOV lane to avoid suddenly stopped general-purpose lane traffic (causing crashes with a fast-moving HOV), and suddenly moving from the HOV lane (causing rear-end crashes with another lane that is not able to stop).

HOV projects can impact mental health of individuals. HOV users benefit from less stress and travel time savings. Carpooling lets riders arrive at their final destination without the stress of driving in congestion (Pollution Probe, 2002; Ungemeh et al., 2007).

### 6.2.3.5 Roundabouts

Roundabouts are a type of traffic intersections that provide continuous flow through the intersection. Unlike the usual signalized intersection, the roundabout intersection is a circular one in which the traffic flow moves continuously in one direction around a central island. Roundabouts reduce the number of traffic conflict points (where vehicle paths may cross) and prevent possible T-bone traffic crashes. The traffic inside the roundabout has the highest right-of-way; all incoming vehicles to the roundabout yield to the circulating traffic movement.

The modern roundabout emerged in the 1990s in the United States; as of 2011, 3,000 roundabouts were operational. The rise in popularity of the modern roundabout has generated more recent research than other project types that have been adopted.

**Links to Transportation/Emission Impacts**

Implementation of roundabouts as an alternative intersection design is expected to reduce delays and stops, accelerations and decelerations and increase flow of traffic, which then potentially contributes to emission reductions.

Several researchers have studied the characteristics of traffic operations of roundabouts. Russel (2005) found that roundabouts considerably reduced delay, provided fewer stops, and decreased idling time in 5 study locations in Kansas. The before and after study showed that the maximum delay was reduced from 34.4 seconds to 8.0 seconds, and average intersection delay was reduced from 20.2 seconds to 10.4 seconds. The 95 percent queue length decreased from 195 feet to 104 feet. The proportion of vehicles stopped was reduced by 50 percent, while the maximum proportion of vehicle stopped was reduced by 42 percent.

In another study, Al-Madani (2003) compared roundabouts with signalized intersections for their performance in controlling vehicular delays. In his study, the operation of signalized intersections was worse when queue length was less than 80 meters, but the operation of the traffic signal functioned better if there were higher queue lengths. Al-Ghandour et al. (2012) examined the traffic impact of different exit types of single-lane roundabouts. The results indicated that a free-flow right-turn slip lane exit type could reduce average delays in the roundabout and in the slip lane most significantly.

Using emissions analysis, several researchers have also studied the emission impacts of roundabouts. For instance, Varhelyi (2001) studied the effects of small roundabouts on vehicle emissions and compared different intersections in a before and after analysis. The results showed that, compared to a signalized intersection, when a small roundabout is used, CO emissions decreased by 29 percent and $NO_x$ emissions by 21 percent. On the other hand, compared to yield intersections, CO emissions increased by 4 percent, $NO_x$ emissions increased by 6 percent, and fuel consumption increased by 3 percent on average. The environmental benefits of modern roundabouts were also studied in Kansas by Mandavilli et al. (2003). In their study, researchers observed an average 40 percent decrease in CO emissions, 60 percent decrease in $CO_2$ emissions, 47 percent decrease in $NO_x$ emissions, and 65 percent decrease in HC emissions for AM peak periods and PM peak periods.

**Links to Human Health Impacts**
Intersection designs using roundabouts are expected to reduce emissions of pollutants considered harmful to human health. However, quantification of the link between emissions reduction from a CMAQ-funded roundabout project and corresponding health benefits were not found during this review.

Safety impacts provide one of the important human health links of roundabout project types. Injury prevention can be a benefit received when the risk of vehicle crashes or injury severity is reduced. Using multiple methodologies, National Cooperative Highway Research Program (NCHRP) Report 572 (Rodegerdts et al., 2007) provides a comprehensive analysis assessing the safety and operational impacts of roundabouts and design characteristics. This study observed that the reduction in total crashes was 5 percent. Compared to signalized intersections and stop-sign-regulated intersections, injury crashes were reduced by 76 percent. In another study, Persaud et al. (2007) analyzed the safety impact of modern roundabouts. The authors studied a sample of 23 intersections that were converted to roundabouts. The before and after analysis showed a 40 percent reduction in all crash severities combined and an 80 percent reduction in all injury crashes. The reduction in fatal injury crashes was estimated at 90 percent.

Roundabouts are designed to improve traffic flow and vehicle and pedestrian safety at existing 4-way intersections. Several studies have confirmed this added value, but study observations from signal-controlled intersection conversions have been inconsistent. As also discussed in the intersection improvements project type, using data from 28 states, Gross et al. (2013) conducted an observational before and after study to estimate the safety and efficacy of converting signal-controlled intersections to roundabouts. The results indicated a safety benefit (decreasing the number and severity of crashes) for converting signal-controlled intersections to roundabouts. A key safety benefit of roundabouts was a decrease in the total number of crashes with increases in traffic volume. The authors also note that "results may vary by traffic volume, area type, and number of approaches and lanes" (Gross et al., 2013).

Lenters (2003) also studied the capacity and safety advantages of roundabouts and found benefits for moderate to high traffic flows. The single-lane roundabout with single-lane entries and exits was recommended to provide a safe form of intersection control without compromising operating efficiency, and the design operating speed of 30 to 40 km/h was achieved. A before-and-after analysis was conducted to evaluate the performance of 2 roundabouts in Oxford, Mississippi, that replaced a stop-sign-controlled and a signal-controlled intersection. The results showed significant improvements in traffic flow and crash reduction, with "improved safety performance through a 37.5 percent reduction in crashes and a 60 percent reduction in the number of crashes resulting in injury," which resulted in a 54.5 percent reduction in comprehensive cost (Uddin, 2011).

While aimed at improving traffic flow and mitigating congestion, not all roundabout project types have a positive effect on human health. One negative safety impact from roundabout implementation regards the difficulty with which the visually impaired negotiate street crossings at roundabout locations. In Baltimore, Maryland, in April 2000, Guth et al. (2005) conducted a study of non-visual gap detection at roundabouts by pedestrians who are blind.  In the study, the exit lane with high traffic volumes was the most problematic for blind people to make crossing decisions, with 70 percent of the activities judged in the risky category.  When traffic was low, the average delay for an acceptable gap was around three seconds, which resulted in the impossibility of blind people detecting such gaps at roundabouts when traffic volume was high.  The results found by Guth et al. (2005) showed that 6 percent of blind people's crossings were considered dangerous, while not-blind pedestrians had none.  Also, the authors found that blind people had difficulty recognizing drivers' yields on the entry lanes.  Following these studies, NCHRP Report 674 establishes safe crossings at roundabouts and turn lanes for pedestrians who are blind (Schroeder, 2011).

Modern-design roundabouts might also create a better environment for the cyclist, encouraging more physically active behavior.  Campbell et al. (2006) suggested that the C-roundabout design reduces traffic speed and allows cyclists to use the road equally with other vehicle users.  Cumming (2011) showed that the C1-roundabout is a bicycle-friendly roundabout that provides clear routes to cyclists to move to the middle of the lane.  De Vries et al. (2010) examined the relationship between infrastructure and children's walking and cycling behaviors with a sample size of 448 children in the Netherlands.  The activity type of walking for transportation and walking for school were found to be highly associated with roundabouts in the neighborhood.

Lu et al. (2010) also showed that roundabouts with intelligent management systems could improve accessibility for pedestrians.  The crossing solutions for accessibility challenges of roundabouts for pedestrians with vision disabilities presented in NCHRP Report 674 (Schroeder, 2011) provided the applicable treatments, such as raised crosswalk or specialized accessible pedestrian signal, for establishing a safe and accessible crossing at roundabouts for blind pedestrians.  The before and after study showed an effective improvement in pedestrian delays and a significant reduction in the numbers of risky activities.  Russell (2008) noted the importance of installing these treatments at all roundabouts with 2 or more lanes on pedestrian-accessible routes for accessibility for elementary-aged pedestrians and people with disabilities.

### 6.2.4 Intelligent Transportation Systems

#### 6.2.4.1 General ITS

ITS provides strategies and applications to address many aspects of transportation—congestion, safety, mobility, and the environment—by integrating advanced communication technology into infrastructure and vehicles and providing real-time travel information.  ITS encompasses a wide range of services, such as freeway management, crash prevention and safety, roadway operations and maintenance, traffic incident management, transit management, and traveler information (Wu et al., 2014).

Numerous studies have identified the potential benefits of ITS.  Benefits include impacts on health and the transportation system, including reduced vehicle emissions, reduced congestion, increased mobility, and increased safety.

**Links to Transportation/Emission Impacts**
ITS applications can be used to manage traffic congestion and enhance mobility, which then also leads to reduced emissions.  For instance, North Central Texas Council of Governments reported that

implementing ITS strategies has led to a 68,000-person-hour-per-day reduction in recurring congestion in Dallas-Fort Worth, Texas (NCTCOG, 2014). Birst and Smadi (2000) conducted a study on the impact of a freeway incident management system (FIMS) on I-29 corridor in Fargo, North Dakota. The results showed that the FIMS (combining advanced traveler management and traveler information systems) "reduced incident travel times by 13 percent (city arterials), 28 percent (freeways), and 18 percent (overall network); average trip times were reduced by 20 percent (overall network); and average speeds increased by 21 percent (overall network)". Kington (2012) analyzed travel time information from both private vehicle toll tags and city taxi global positioning system (GPS) transponders to determine that the effort led to a 10 percent improvement in travel time in the area, increasing the average speed from 6.5 mph to 7.2 mph.

ITS enhances mobility by using a range of strategies, including ramp metering, transit signal priority (TSP), and traveler information systems. For instance, the I-435 corridor in Kansas City experienced peak-period congestion largely due to merging at on-ramp locations. Ramp meters were installed at 7 interchanges along a 5-mile section of the corridor, spanning both Kansas and Missouri. Shah et al. (2013) studied before and after data and determined that although travel times were not significantly reduced, the ramp meters increased corridor throughput by as much as 20 percent.

Transit signal priority is an ITS strategy used to make travel by transit faster and more reliable (Smith et al., 2005). Snohomish County, Washington, implemented a TSP system on 17 intersections in 2 corridors to reduce transit delay and travel time. Wang et al. (2008) analyzed in-vehicle GPS data to determine that transit corridor travel time was reduced by 4.9 percent on average as a result of the project.

Traveler information is disseminated many ways, including through dynamic message signs (DMS). In San Francisco, California, a pilot study used DMSs to display highway and transit trip times, under the premise that motorists would choose transit, rather than drive in congested conditions, if there were travel time savings. Mortazavi et al. (2009) studied the results of this pilot to determine how the displayed messages affected commuter behavior. The data revealed that a travel time savings of 20 minutes or greater resulted in 7.9 percent of motorists switching to transit.

ITS is beneficial to the environment by reducing vehicle emissions through methods such as route guidance and signal detection. For example, Sadek and Guo (2012) assessed the likely environmental benefits of environmentally based route guidance, or green routing, to travelers in a real-world case study in Buffalo, New York. Green routing chooses routes with the lowest fuel consumption and least amount of emissions. Using the TRANSIMS and MOVES2010 models, the study determined that CO and $NO_x$ emissions could be reduced in passenger cars by 16 percent and 19 percent, respectively, and CO could be reduced by 18 percent in long-haul trucks.

An indirect emission reduction might also be obtained by improving driving behavior through ITS. As exemplified in the study by Marell and Westin (1999), ITS can play an important role in reducing risky, aggressive driving behavior. De Vlieger et al. (2000) also found that aggressive driving resulted in a sharp increase in fuel consumption and emissions compared to normal driving. Fuel consumption increased by 12 to 40 percent and CO emissions increased by a factor of 1 to 8 for an aggressive driver compared to those of a normal driver. For VOC and $NO_x$, the increase in emissions due to aggressive driving ranged from 15 to 400 percent and 20 to 150 percent, respectively. These results, in combination, indicate the potential of ITS in reducing aggressive driving, and decreasing resultant emissions.

**Links to Human Health Impacts**

ITS includes a wide variety of safety and injury prevention strategies and technologies, including work zone management, traffic and speed enforcement, and road weather information systems. However, no evidence was found in the literature reviewed linking ITS strategies and health benefits of emissions reductions from the project.

Projects of this type have demonstrated a benefit regarding injury prevention and reduced risk of vehicle crashes or injury severity. Roadway weather information systems can improve safety by detecting adverse driving conditions and communicating those hazards to motorists. The Tennessee Department of Transportation implemented a low-visibility/fog detection/warning system to control traffic along I-75 after heavy fog caused a catastrophic crash in 1990 involving 99 vehicles, killing 12 people and injuring 42 others. Over 200 crashes have occurred on this highway section since opening in 1973, but only one fog-related incident has occurred since implementing the system in 1993 (Dahlinger and McCombs, 2005; FHWA, 2012).

There has been little research linking physical and mental health and ITS. ITS can improve mobility and help reduce stress and frustration while driving and parking. For instance, advanced parking management systems give drivers real-time parking information, including parking space inventories and navigation to specific parking spaces. A parking guidance system was deployed at the Baltimore/Washington International Airport (BWI) that provided turn-by-turn directions to individual parking spaces. This system relieved drivers of the stress of finding an available space; the results of a customer satisfaction survey revealed 81 percent of users surveyed thought parking was easier at BWI compared to other airports (SAIC, 2007).

### 6.2.4.2 Freeway Management Systems

Freeway management systems have the ability to detect traffic flow problems, while providing up-to-date information to transportation agencies to improve coordination and response times. The systems consist of strategies and technology to monitor, control, and manage freeway traffic efficiently. Freeway management methods include entrance ramp control, ramp closures, roadway cameras, and DMS. These methods can provide positive impacts to human health through vehicle emissions reduction and safety/injury prevention.

Freeway management methods can include the following and are controlled by a network of computer and communication systems located in a traffic operations center:

- Ramp meters/control—signals located at freeway entrances to regulate the timing of merging vehicles onto freeways at peak commute times. Transportation agencies use meters to help the flow of traffic entering the freeways during peak traffic hours, reducing the impact of operational bottlenecks. The meters allow freeways to accommodate more vehicles per hour, help traffic move at a steadier speed, shorten commute times, and provide a higher degree of safety.

- DMS—electronic overhead signs that display timely and important traffic information such as incidents, upcoming construction and lane closures, restrictions on freeway lanes, or even special event venue traffic guidance.
- Cameras—equipment that provides a real-time view of traffic flow along roadways and can assist emergency personnel to respond to accidents quickly.

**Links to Transportation/Emission Impacts**

Freeway management systems monitor and manage traffic conditions to improve traffic flow characteristics, such as speed, and the resulting change in vehicle speed (or reduced vehicle delay) can have the effect of reducing emission rates in most situations. Rapid dissemination of information allows the user to make travel adjustments that can reduce delays and help mitigate congestion.

In December 2001, the University of Wisconsin conducted a survey of drivers living near major freeways in Wisconsin about whether they used information from DMS to adjust their travel routes (Ran et al., 2004). The survey found that during winter 12 percent of respondents used the information more than 5 times a month to adjust their travel routes, and during summer 18 percent used the information 5 times a month to re-route. The use of message signs warning commuters of possible delays helps alleviate congestion as commuters seek and use alternate routes. The City of Scottsdale, Arizona, also found that with the implementation of 50 cameras and 25 DMS throughout the city, there was a reduction/prevention of traffic congestion, and improved roadway safety. The Oregon Department of Transportation estimates that users of pre-trip travel information compiled from roadway cameras and disseminated through DMS improve travel time by as much as 5 percent to 16 percent.

Bertini et al. (2004) found that, in Oregon, the implementation of ramp meters increased the average speed during peak hours from approximately 16 mph to 40 mph. According to Dowling et al. (2005), the increased travel speed increased fuel consumption and canceled out any emissions savings from the improved traffic flow due to freeway management methods. Bigazzi and Figliozzi (2012) also found that freeway congestion mitigation techniques can lead to higher overall emissions in the long run because of increased travel speeds. The researchers concluded “the emissions-speed relations is that the potential for marginal emissions rate reductions through average travel speed adjustments between 30 and 65 mph is small—though larger rate reductions are possible by moderating speeds” that are not within that speed range. Therefore, the net benefits from implementing freeway management techniques on air quality from emissions reductions are unknown because of uncertainties and assumptions made during emissions reduction estimation.

**Links to Human Health Impacts**

As traffic operations become more efficient with the implementation of freeway management methods, vehicles use less fuel and emit less emissions adding to an overall health benefit. However, the improvement in the traffic flow could lead to increased freeway capacity and correspondingly increased travel speed, subsequently possibly increasing emissions. The literature review did not provide a quantified link between emissions reductions from this project type and beneficial health effects.

Transportation safety may be enhanced through appropriate freeway management methods. For instance, entrance ramp controls allow smoother ramp merging during peak traffic hours. Safety concerns from vehicles merging onto freeways at high traffic times include rear-end and lane-change collisions. Ramp metering addresses these safety concerns by breaking up the heavy stream of vehicles merging onto the freeway and forces single-vehicle entry. Single-vehicle entry reduces the number of vehicles competing for limited merging space on the congested freeway. As indicated by Lee et al. (2006), “empirical studies have shown that ramp metering reduces turbulence in the merge zone, reduces variance in speed distributions, and thereby improves traffic safety (i.e., reduces sideswipe and rear-end crashes).” In their analysis, researchers also found that crash potential was reduced by 5 to 37 percent when using a ramp metering strategy compared to a no-control case scenario. They also noted that the safety benefits were limited to the freeway section near the ramp and were influenced by existing traffic conditions.

A similar method used to improve safety is ramp closure during peak hours. Transportation agencies temporarily close ramps when freeway traffic is operating at capacity near the closed ramp or when the ramp does not allow traffic to safely merge onto the freeway or introduces traffic weaving problems. The Puget Sound Region of Washington State (Nee, 2001) implemented a freeway management system and found a decrease of 61 percent in emergency response time from over 9 minutes to 5.8 minutes. The reduced response time yielded an estimated reduced annual vehicle hour delay of 13,048 hours and a yearly cost saving of $200,000.

The implementation of freeway management methods also provides a positive impact on human health from a safety perspective. Real-time monitoring from cameras can assist emergency personnel to quickly identify crashes or trouble spots on freeways. For example, the Arizona Department of Transportation (ADOT) uses cameras to provide real-time views of traffic along roadways. ADOT monitors these cameras along freeways to identify congestion or crashes. If a crash occurs, ADOT can easily coordinate with emergency crews and police to assess and clear the accident from the roadway.

Olmstead (2001) investigated the use of a freeway management system on the occurrence of reported vehicle crashes in Phoenix, Arizona. He found that the system “reduced the frequency of crashes involving property damage only, possible injury, and minor injury by 25, 30, and 21 percent respectively.” The researcher used a fixed effects negative binomial regression model and found no effect on single-vehicle crashes. He noted that depending on the assumption made of the value of pain and suffering, the estimate of annual crash benefits from the implementation of freeway management systems in Phoenix, Arizona, ranged from $4.8 million to $13.2 million.

A study conducted in the Minneapolis-St. Paul region by the Minnesota Department of Transportation (1995) found that the use of a freeway management system reduced rear-end injury crashes 18 to 28 percent and reduced non-rear-end injury crashes 1 to 8 percent. A study in Seattle, Washington, of the peak-period total crash rate found a 39 percent reduction (Henry and Mehyar, 1989). The savings estimated from the use of a freeway management system that reduced the frequency of crashes correlated to a net benefit on human health and public safety. Bertini (2005) noted freeway management systems can reduce crashes up to 41 percent based on a study comparing crashes before and after the installation of a freeway management system in San Antonio, Texas. The study found the system reduced primary crashes by 35 percent, secondary crashes by 30 percent, and inclement-weather crashes by 40 percent.

#### 6.2.4.3 Traveler Information Systems

Traveler information systems are increasingly incorporated into vehicles and regional transportation systems. The information is used by travelers to minimize the impact of nonrecurring congestion on major roadways in a region. The impact of information system programs is similar to that of incident management programs.

Advanced traveler information systems (ATIS) are designed to provide travelers with information that will facilitate their decisions concerning route choice, departure time, trip delay or elimination, and mode of transportation. An important component of ITS, ATIS provides the information travelers need from their origin to their destination. ATIS can be classified by:

- The type of information the system provides, for example, robust or static traffic information, road conditions and weather, incidents and events, and traveler information (Noonan, 1998).
- How the system provides information, for example, via radio, television, wireless devices, and roadside message boards (Yin and Yang, 2003).

Links to Transportation/Emissions Impacts

Implementation of ITS strategies focuses on their ability to increase transportation system efficiency, and improve safety. They also aim to reduce VMT and improve travel time reliability.

Liu (2000) states that, "ATIS are among the Intelligent Vehicle Highway System (IVHS) technologies beginning to appear in new vehicles to reduce traffic congestion, energy consumption, and increase mobility and productivity." Erke et al., (2007) conducted a study of route guidance of variable message signs (VMS). Two different VMSs, "which displayed information about a closed road section downstream on the motorways and recommendations for alternative routes," were applied in the study, and 3,342 vehicles were selected as the sample. The results indicated that VMSs were effective in rerouting traffic. Signs with rerouting messages were effective about 20 percent more than those without a message about drivers' route choices. The upstream speed reductions were about 6 km/hour to 4.7 km/hour with the rerouting information provided.

Levinson (2003) indicated that reliable ATIS provided travel time benefits to users and the overall public. ATIS prevented both non-recurring congestion and induced travel demand by improving drivers' willingness to switch routes.

Wunderlich et al. (2001) conducted a case study of the impact of ATIS reliability in Washington, D.C. The results collected by both survey and field study revealed that drivers who do not use ATIS information were three to 6 times more likely to arrive late and experienced 50 percent more traffic delay compared to people who use ATIS information. The number of cases in which ATIS was clearly beneficial was 5 times more than the number of cases where ATIS was clearly not helpful. Abdel-Aty (2001) conducted a study of the impact of ATIS on transit usage. In the study, 38 percent of survey respondents said they might consider transit use if the transit information was appropriate and easily available.

Most of the emissions impacts found in the available literature resulting from implementation of ATIS come from the reduction in VMT, fuel use from acceleration/deceleration, cold starts, and idling. However, one study using the SCRITS analysis tool indicated that traveler information programs may cause an increase in VMT (due to shifting to longer but faster routes) that roughly offsets the emissions benefits from reduced delay on the mainline (SAIC, 1999).

Wunderlich et al. (1999) modeled the implementation of an integrated deployment combining ATIS and ATMS technologies improve system throughput and efficiency. They found a reduction in $NO_x$ emissions of 1.3 percent and reduced HC and CO emissions. Washington (1993) also showed that ATIS can improve air quality by affecting driving behavior and promoting modal shifts to alternative modes. These modal changes may impact emissions by reducing the VMT and number of vehicle cold starts. For example, Li et al., (2009) pointed out that ATIS could be beneficial in energy savings and emission reductions. In their study, the results indicated altering drivers' behavior can reduce the number of unnecessary accelerations and hard braking, which cause a significant amount of energy loss and emissions. A VMS with travel time to the next intersection and advanced signal status information could provide information that helps drivers make decisions about the vehicle cruising trajectory to the intersection. The results from simulation showed that the total savings in fuel consumption could reach 8 percent per day per vehicle which will reduce overall emissions.

Links to Human Health Impact

Traveler information systems are expected to reduce emissions of pollutants considered harmful to human health. No studies were found in the review specifically documenting the human health impacts of the emissions reductions associated with these types of CMAQ-funded projects.

The primary health benefit of traveler information systems are related to the safety impacts. The information provided by ATIS might help travelers make more appropriate travel decisions to avoid traffic accidents. For instance, Rama et al. (2000) evaluated the safety effects of VMSs. The results indicated that slippery road condition signs have reduced the mean speed on slippery roads by 1 to 2 km/hr and decreased the proportion of headways shorter than 1.5 seconds for cars in car-following situation by 9 to 17 percent. Abdel-Aty et al. (2006) assessed VMSs with variable speed limit (VSL) strategies on I-4 in the Orlando, Florida, metropolitan area. The results indicated that a change of 15 mph produced the best speed control strategy. The results also indicated safety improvements by VSL implementation "by simultaneously implementing lower speed limits upstream and higher speed limits downstream of the location where crash likelihood is observed in real-time". The best case showed a significant decrease in the crash likelihood by 0.4; this case changed the speed limit by 15 mph change in 30 minutes, both decreasing the speed limit 2 miles upstream of the crash location and increasing the speed limit 2 miles downstream of the crash location. A study conducted in Pennsylvania (Cortelazzi et al., 2006) found an immediate reduction in truck rollovers with the installation of the Truck Rollover Warning System. Incidents were reduced from five rollovers to one in the 21 months after installation.

Stanley et al. (2005) measured an increase in crash rate by a factor of 3.0 to 3.8 when evaluating drivers' performance while accessing a "511" highway information line with their phones in a simulator. The increase in crash rate is similar to other research measuring the driving performance of cell-phone users.  The true accident risk may be even higher, as the study incentivized safe driving by offering bonus compensation to subjects who completed the simulation accident-free.

Kenyon and Lyons (2003) conducted a study about the value of multimodal traveler information to modal change.  The results indicated that the majority of travelers do not consider their modal choice when only information about alternative modes is shown to them.  However, the results also showed that if the information also presented the associated comfort and convenience factors, in addition to cost and duration, it might change travelers' habitual reaction to alternative modes and cause a modal change. This study implied that changing the general public perception that "public transport is uncomfortable, unsafe or inconvenient, despite not having travelled by or enquired about public transport" may be a valuable tool in alternative modal use shifts through the use of ATIS.

Several tools are available to increase the public's accessibility to travel information.  Web-based applications that provide readily accessible user information may help the traveler decide to take an alternative mode and/or affect their route decisions.

Stress and anxiety can be impacted.  Travel as a passenger in an alternative mode can decrease the stress from driving (Zhang et al., 2013; Liao et al., 2012; Majumdar and Letz, 2012; Karamychev and Reevan, 2011; CEC, 2011).  The case study results of Wunderlich et al. (2001) showed that "late shock, the surprise of arriving late, is reduced by 81 percent through ATIS use" (Wunderlich et al., 2001).

### 6.2.5 Improved Public Transportation

Improving public transportation is done through several types of projects.  Adding or modifying transit facilities, systems, and services includes strategies that focus on geographic coverage and scheduling changes that make mass transit a more attractive option to residents and commuters.  For example, improved transfer procedures between transportation modes such as car/transit, pedestrian/transit, and bicycle/transit can encourage increased ridership on public transportation.

New bus service projects attempt to increase ridership by providing new and/or expanding bus services. New and expanded bus service improvement projects improve both air quality and congestion levels in the local community by increasing the use of transit services and reducing the number of auto trips.

New passenger rail services involves establishing new routes, increasing the frequency of current service, expanding the hours of operation, or the overall coverage of transit corridors.  New and expanded rail services provide mobility improvements in the form of increased transportation mode options for users in a nonattainment area.  Air quality benefits are directly gained through VMT reduction by attracting riders who previously drove their own vehicles.

**Links to Transportation/Emission Impacts**

The effectiveness of public transportation for regional air quality and traffic congestion has been explored by comparing the passenger miles traveled (PMT) to VMT.  The results of the study by Holtzclaw (2000) posited that "VMT reductions of 1.4 to 4 for each PMT on transit can be achieved within 20 years." Although the total trip length grows when people use transit for the daily commute, the driving distance is 25 percent to 50 percent less when residents live in suburban areas.

A study conducted by Anderson (2013) examined experiences with traffic congestion during a 35-day strike by Los Angeles County Metropolitan Transportation Authority (MTA) workers in 2003. This strike shut down MTA bus and rail lines. Using a prediction model, they estimated a 47 percent increase in congestion during peak hours using hourly data on traffic speeds for all major Los Angeles freeways. While the effects were much larger on freeways that parallel transit lines with heavy ridership, they were relatively smaller and statistically insignificant in neighborhoods unaffected by the transit strike. The estimates also indicated that “annualized congestion relief benefit of operating the Los Angeles transit system is between $1.2 billion to $4.1 billion, or $1.20 to $4.10 per peak-hour transit passenger mile”. The results found a much greater role and benefit of transit in mitigating traffic congestion than expected (Anderson, 2013).

Haas (2010) examined the reduction potential of the growth of VMT-related carbon-based emissions. Focusing on the case of Chicago, Illinois, the researchers found that a household’s VMT and carbon footprint could be reduced by living in a transit-oriented neighborhood. Rodier et al. (2002) conducted research that modeled scenarios in Sacramento, California. Results showed that transit investments with supportive land use policies or pricing policies may be very effective in reducing VMT and emissions; may provide congestion reduction that is as great, if not greater, than highway investment policies; and may provide greater benefits (i.e., change in travel time and cost) than highway investment.

According to APTA (2002), compared to private automobiles, public transportation produced 95 percent less CO per passenger mile and 92 percent fewer VOCs per passenger mile. Similar results have also been found in many other studies. For instance, Friedman (2001) found during the 1996 Atlanta Olympic Games, the expanded public transportation services reduced automobile use by 22.5 percent during morning peak hours.

Puchalsky (2005) conducted a comparative analysis of the pollution impacts of Bus Rapid Transit (BRT) and light rail transit (LRT). The study compared LRT, buses, CNG buses, and hybrid electric buses. He found even though diesel technology has vastly improved over the years, LRT still produces less regional or urban emissions than BRT systems. Chen and Whalley (2012) also found an emissions reduction with LRT. They evaluated the emissions impact of a new rail transit system in Taipei. The researchers found that the new system reduced CO by 5 to 15 percent and also achieved a reduction in $NO_x$. Porter et al. (2012) assessed a light rail project and an electric commuter rail project, finding that $NO_x$ emission rates per passenger mile were approximately 1/3 of those for highway vehicle emissions; $PM_{10}$ emissions were 1/4 those of highway vehicles.

Improving public transit is expected to not only reduce emissions but may also reduce transit user exposures to emissions. A before and after study conducted by Wöhrnschimmel et al. (2008) evaluated the BRT system in Mexico City that replaced their conventional bus system. They found that commuters had reduced exposure to CO, benzene, and $PM_{2.5}$. When BRT was compared to minibuses, commuter exposure was reduced by an average of 45 percent for CO, 69 percent for benzene and 30 percent for $PM_{2.5}$. As compared to conventional buses, the level was reduced by an average of 25 percent for CO, 54 percent for benzene and 20 percent for $PM_{2.5}$. No significant reductions in $PM_{10}$ exposure were observed.

**Links to Human Health Impacts**

When all impacts are considered, improving public transportation can be a cost-effective way to achieve human health benefits. Grabow et al. (2012) quantified and calculated the general health benefits of reduced private car travel. Researchers estimated that the annual average urban $PM_{2.5}$ reduction is 0.1 $\mu g/m^3$ by eliminating short automobile trips. With improved air quality and increased exercise, the projected mortality rate declined by approximately 1,295 per year in the study region of 31.3 million people and 37,000 square miles. Innovative fuel technology used in public buses could further reduce the emissions per passenger mile.

One aspect often overlooked when discussing transit's emissions impacts is the increasing popularity of streetscapes in urban areas. Streetscapes generally consist of street-side gathering places such as outdoor cafes with higher pedestrian congestion and traffic. Some even include pocket parks directly adjacent to travel lanes. The importance of street level emissions should not be underemphasized. Transient levels of certain pollutants can be up to 10 times higher than ambient levels at distances of up to 10 meters from a bus stop. Light rail and alternative fuel vehicles have a lesser impact at these locations (Booz Allen Hamilton, 2004).

Personal exposure to traffic pollution while traveling by transit is another concern. For example, the results from a 4-month study by Kingham et al. (2011) indicated that auto users are exposed 40 to 100 percent more to the average level of CO than bus passengers. However, both auto drivers and bus passengers are exposed to a higher level of ultrafine particles than cyclists.

From a safety perspective, accidents related to public transit are fewer than accidents related to private vehicles. According to National Safety Council data, bus travel is 170 times safer than private automobile travel (APTA, 2005). Public transportation trips led to 190,000 fewer deaths, injuries, and accidents than car trips, which were calculated in the Campaign for Efficient Passenger Transportation's 1997 report (Camph, 1997). Based on the data from the National Safety Council (NSC, 2003), the rate of fatalities associated with a subway was much lower than the fatality rate associated with automobiles (0.15 versus 0.87 per 100 million passenger miles) (NSC, 2003). Litman (2005) states that there are lower per-capita traffic fatality rates in transit-oriented regions (cities with 333 to 1,004 annual transit passenger miles) compared to automobile-oriented regions (cities with 15 to 114 annual transit passenger miles) among 10 cities in the United States (7.3 versus 12.7 deaths per 100,000 population).

Another impact of public transportation improvements project types are their link to improved physical and mental health. Most public transportation does not have door to door service, meaning that riders have to find another means of travel, often walking or biking, to move between a transit stop and their final destination. Transit-friendly communities are usually walkable, increasing the activity level of transit users and decreasing obesity levels due to an increased level of activity (APTA, 2005).

Several researchers have studied the relationship of physical activity and travel behavior. For example, analysis of 2001 NHTS data indicates that the median daily walking time to and from transit was 19 minutes (Besser and Dannenberg, 2010). Among those transit users, 29 percent achieved more than the recommended physical activity minimums (30 minutes per day) simply by walking to and from transit. An increase in transit trips has been found to be a significant predictor of meeting physical activity recommendations (Lachapelle and Frank, 2009). The implementation of light rail has also been associated with physical health benefits. MacDonald et al. (2010) examined physical activity levels and BMI before and after the installation of light rail in Charlotte, North Carolina. Those who commuted by rail on a daily basis reported an average BMI decrease of -1.18 and were more likely to meet physical activity guidelines. Brown and Werner (2007) also examined physical activity measures before and after light-rail implementation. The number of rail trips was positively associated with number of moderate physical activity events after controlling for individual characteristics. An increase in physical activity found even beyond the transit trips themselves suggests that for some users, light rail encouraged additional physical activity in other areas of their lives.

Mumford et al. (2011) conducted a case study of 101 adults and examined their behavior in a mixed-use development. The results showed increases in walking for recreation or fitness and walking for transportation after moving into the mixed-use development. Respondents reported reduced automobile travel and increased time spent using public transportation, which might eventually increase the level of travel-related physical activity (e.g., walking to/from the bus stop). Edwards (2008) concluded that “taking public transit is associated with walking 8.3 more minutes per day on average, or an additional 25.7 to 39.0 kcal.” Samimi and Mohammadian (2010) showed that every percent decrease in auto use reduced the chance of obesity by 0.4 percent, high blood pressure by 0.3 percent, high blood cholesterol by 1.3 percent, and heart attack by 1 percent.

Where road congestion is a major problem, public transportation might also ease stress to the traveler through reduced commute time. Wener (2003) found that riders of New Jersey Transit had lower levels of stress due to reduced travel time. Using subjective well-being (SWB), Gallup-Healthways survey data provided higher SWB scores (a combination of walk scores, transit scores, and bike scores) in suburban areas of the top 10 cities (NEUTC, 2013). While high alternative transportation service level was not a major factor, commute time was a significant negative factor in SWB.

Transit-oriented developments (TOD) could motivate people to be more physically active in their daily routines and have a healthier lifestyle. The Portland Development Commission runs the CMAQ TOD Program funded with $3.5 million in CMAQ funds to acquire land, and design and construct transit amenities as part of TODs. A total of nine projects have received funding (Parsons, 2004). High-quality public transportation (fast rail and bus transport that are convenient and comfortable) and transit-oriented neighborhood development (walkable, mixed-use communities located around transit stations) affect travel activity and promote health benefits, including reduced risk of traffic crashes and pollutant emissions, increased physical activities, improved mental health, improved basic access to medical care and healthy food, and increased affordability to lower-income households (Litman, 2010).

Finally, using a San Francisco activity-based travel demand model, Castiglione (2006) assessed both mobility and accessibility for various transportation projects, including additional transit networks. The results of the study showed that accessibility to job and shopping by transit share increased notably “across all population segments, due to the transit improvements associated with the build alternative”.

### 6.2.6 Transportation Demand Management

#### 6.2.6.1 Public Education/Outreach (Information/Marketing)

Public education and outreach play an important role in educating the general public about traffic congestion's impact on vehicle emissions, regional air quality and the impacts on human health. Outreach materials can be aimed at specific audiences or have a general public reach. Methods for disseminating information can include:

- Printed materials - Brochures, flyers, advertisements and letter writing campaigns
- Broadcast - Public service announcements and local TV programming
- Electronic – Web site and instructional videos
- Signage - Street signs and outdoor advertising (Stites, 2008).

Agencies can encourage the public to participate in programs that improve regional air quality through changes in their trip planning, trip making, and travel modes. Education and outreach are directed at a diverse audience and provide greater awareness to the lay public. Efforts teach the general public how they can individually respond to help clean their region's air, such as telecommuting or reducing the time they idle their vehicles. An informed community is also more likely to support projects that improve transportation flow, such as reducing congestion at intersections, for long-term benefits.

**Links to Transportation/Emission Impacts**
The County of Nevada, California implemented a public outreach project: "Be Like Us…Ride the Bus!" was the tag line applied by Gold Country Stage (GCS) to enhance the image of GCS riders. The "Us on the Bus" marketing campaign was developed to expand the tag line by telling the story of why riders chose GCS and where they went. Radio talk shows and newspaper ads with free coupons were added as outreach channels to encourage participation. The project was evaluated through a three-day onboard passenger survey with a sample of 41 origination-to-destination runs on 6 routes, with a total of 167 surveys. Although the bus fare increased and bus service was reduced in 2009, the results indicated that the decline in ridership between July and November 2009 was limited to 17 percent, compared to a 22 percent decline in these months in 2008. Eleven percent of respondents reported that they started to ride GCS when the marketing campaign began. Over 93 percent of respondents were familiar with the outreach project, and 12.5 percent of respondents used the free coupon in the newspaper. Over 75 percent of respondents thought the outreach project was effective or very effective, giving good reasons to ride GCS. (Majic Consulting Group, 2010)

A similar community-based media campaign was used in San Joseph, Missouri. Wray et al. (2005) conducted an analysis of the "Walk Missouri" campaign with 297 telephone surveys. The results showed that 4.3 percent of respondents reported participation in community-sponsored walking compared to 0.5 percent of unexposed respondents. Also, the exposed respondents reported walking for at least 10 minutes per day and averaged 5.2 days per week, compared to an average 4.5 days per week for the unexposed population.

Educational outreach could also help improve public awareness of environmental issues and change travel behaviors. Alcott and DeCindis (1991) evaluated the effort of the Clean Air Force Campaign held from 1989 to 1990 in Phoenix, Arizona. The results indicated that around 36 percent of commuters used alternatives to their normal travel (21 percent used carpools, and 15 percent used buses, biking, or walking), which was an 80 percent increase from the prior year. The proportion of trips by alternative modes also increased during the year from 18 percent to 22 percent. Henry and Gordon (2003) conducted an analysis to understand the impacts of a public information campaign on air quality issues. In this study, the authors found that after an ozone alert during the summer of 1998 in Atlanta, Georgia, the awareness of ozone was up by 1.5 points on a 4-point scale. Statistical analysis showed the overall miles traveled were reduced on alert days, down to 29.9 miles per person per day from 35.4 miles per person per day. The number of work-related and personal trips by government workers taken on alert days (4.0) was smaller than that on non-alert days (4.9).

A study conducted by GBSM (2008) evaluated the Colorado Convention Center (CCC) in Denver, Colorado implementation of a pilot social marketing campaign called “Engines OFF!” This program’s goal was to evaluate a social marketing approach to effectively reducing the idling of commercial vehicles at large public venues such as the CCC. The program consisted of signage, security guard training, written program introduction, pledge, idling education, vehicle magnets and clocks, and an idling sounding board. Results include:

- Idling reduction from 81 percent to 45 percent, with charter buses the most common vehicle still idling.
- Idling 10 minutes or longer reduced from 50 percent to 19 percent.
- “Transportation companies, vendors and drivers have been receptive to idling reduction education and Engines OFF! program, although more education could be used.”
- “Perceived enforcement “threat” has been effective in raising awareness of the idling ordinance, but has caused some wariness among transportation companies” (GBSM, 2008).

**Links to Human Health Impacts**

No studies were found in the review specifically documenting the human health impacts of the emissions reductions associated with air quality public outreach strategies.

Information dissemination can provide general information of healthier lifestyles that encourages physical activity such as active transportation. California Safe Routes to School programs use education, law enforcement, and engineering improvement to encourage active commuting from and to school.

Many of the anti-idling campaigns in progress throughout the nation focus on methods to alleviate the health risks of asthma and other respiratory conditions by reducing exposure time. Reducing exposure to emissions has been demonstrated to beneficially impact health and anti-idling campaigns have seen successful in this. Children are particularly susceptible to the impacts of emissions exposure, especially $PM_{2.5}$. Ryan et al. (2013) evaluated the impact of an anti-idling campaign conducted at four schools for 5 days in Cincinnati, Ohio. The concentrations of $PM_{2.5}$, elemental carbon (EC), and particle number concentration (PNC) were evaluated between morning arrival of buses and their afternoon departure. The before and after study (i.e., after the idling campaign) showed that the concentration of PM, EC, and PNC after 5 days decreased from 4.11 $\mu g/m^3$ to 0.99 $\mu g/m^3$, from 0.40 $\mu g/m^3$ to 0.15 $\mu g/m^3$, and from 11,560 particles/$cm^3$ to 1,690 particles/$cm^3$, respectively.

Public outreach is an effective tool for publicizing information designed to encourage a behavioral change in some manner. This can be information regarding the health benefits of walking and biking for short trips instead of using a vehicle or promoting other modes of transportation that reduce the environmental effects of vehicle travel. Research by Boarnet (2005) showed that children who participated in educational outreach were more likely to increase their walking or biking travel than children who were not (15 percent versus 4 percent), based on parents' responses. Participating schools reported a significant increase in school trips by walking (64 percent), biking (114 percent), and carpooling (91 percent) and a decrease in trips by private vehicles (39 percent). Reger-Nash et al., (2002) evaluated the campaign of "Wheeling Walks" by mass media to encourage walking among older adults. The sample was selected in West Virginia of 31,420 people aged 50 to 65 years. The results showed a 23 percent increase in the number of walkers in the intervention community compared to no change in the comparison community. Around 32 percent of the baseline sedentary population in the intervention community met the CDC/ACSM/Surgeon General recommendation for moderate-intensity physical activity general recommendation of walking at least 30 minutes 5 times per week as compared to 18 percent in the comparison community.

### 6.2.6.2 Travel Demand Management

TDM is a broad-ranged strategy that encourages the systematic reduction or redistribution of traffic demand away from traffic congestion. Various TDM measures have been developed to manage travel demand with the recognition of increased congestion and emission problems associated with significantly increased travel demand. TDM programs typically focus on reducing the number of vehicle trips by commuters during peak hours.

**Links to Transportation/Emission Impacts**

Various TDM measures have been developed to manage travel demand to counteract increased congestion and emission problems associated with significantly increased travel demand. TDM measures have the potential to provide transportation benefits in these areas, such as reduced or eliminated VMT, or a shift outside the peak period, found to be widely studied in the literature.

Henderson and Mokhtarian (1996) conducted a study to assess the benefits of center-based telecommuting. In their study, VMT was reduced significantly from 69.25 miles to 29.31 miles per person per day on telecommuting days. The evident reduction of VMT also led to a 49 percent decrease in $NO_x$ and a 53 percent decrease in PM by comparing the telecommuting days and non-telecommuting days in the study area.

Alternative work schedules (flextime or compressed work weeks) shift commuting times outside of normal peak periods. Shifting single-occupant vehicle traffic demand outside of peak periods can result in increased operating speeds in peak periods and a more efficient use of the transportation system when system demand is lower (Karamychev and Reevan, 2011; EPA, 1992).

Rodier and Shaheen (2010) evaluated smart parking services at transit stations by using San Francisco Bay Area Rapid Transit (BART). In the study, among 177 survey participants, the average reduction in total VMT was 9.7 per participant per month. With local park-and-ride lots, the average commute time was reduced to 47.5 minutes compared to 50.1 minutes without parking availability. The before and after analysis based on the survey results also found that “smart parking encouraged 30.8 percent of respondents to use BART instead of driving alone to their on-site work location and 13.3 percent of respondents to divert to BART from carpooling.” In addition, 55.9 percent of respondents used BART instead of driving alone for off-site work commutes when smart parking was available.

Various TDM measures have been studied for environmental benefits in emission reduction, vehicle type choice, and inducement of large travel demand by events. Schreffler et al. (1996) developed a standardized methodology and evaluated the travel and emissions impact of 15 TDM demonstration projects (including carpool, shuttle, bus transit, bicycle, and telecommunications projects) funded under the AB 2766 vehicle registration fee program in Southern California. The emissions impact analysis of these projects indicated an annual emissions reduction ranging from 45 lb to almost 17 tons of pollutants. Researchers indicated that “the carpool and telecenters projects produced the greatest VMT and emission impacts, even though the telecenter reduced no trips.”

**Links to Human Health Impacts**

TDM strategies are expected to reduce emissions of pollutants considered harmful to human health. No studies were found in the review specifically documenting the human health impacts of the emissions reductions associated with TDM measures.

Traffic safety is not the main purpose of TDM measures, but various researchers have studied the potential traffic safety benefits (Litman, 2004). Litman (2004) pointed out that the per-capita crash risk has a direct relation to the per-capita traffic demand. TDM measures could reduce crash risk indirectly by either reducing automotive travel or increasing travel alternatives. TDM is a proven cost-effective traffic safety strategy.

From a mental health perspective, based on the results of the study by Rodier and Shaheen (2010) on transit-based smart parking, 66 percent of respondents who joined smart parking indicated significant reductions in their stress level. According to a study conducted by Sener and Reeder (2014), individuals with flexible work-start times and individuals who only work at home were more likely to be to choose active travel, which could result in improved physical and mental health.

Access equity in developing TDM strategies tis noted in the research. Litman (2013a) concluded that transport improvement strategies, such as TDM, are more cost effective and beneficial to all income groups rather than an automobile-dependent transportation system. Improved walking and cycling conditions, improved rideshare and public transportation services, and more affordable housing in accessible locations benefit all residents, especially those who are physically, economically, or socially disadvantaged (Litman, 2011).

### 6.2.6.3 Park-and-Ride Facilities

Park-and-ride facilities are specially-designated lots that allow commuters to park their personal vehicles and then transfer to rail or bus transit, or other high-occupancy modes such as carpools, vanpools, express bus, or rail for the remainder of their trip. Benefits of park-and-ride facilities include cost savings to users, travel time savings, peak period traffic reduction, reduced auto emissions, enhanced mobility, increased transit ridership, and improved transit system efficiency.

Park-and-ride facilities are often served by other forms of public transportation, including local fixed routes, express bus, bus rapid transit, and rail (Shaheen and Lipman, 2007; VTPI, 2010; TCRP, 2004; Spillar, 1997; Hounsell et al., 2011). Many transit agencies around the country provide park-and-ride opportunities as part of their transit system. Although most commuters drive alone to access park-and-ride facilities, those using active transportation modes, such as walking or cycling, reap the benefits of increased physical activity and improved health. Holguin-Veras et al. (2012b) noted the need to develop a sidewalk network connecting park-and-ride lots to the surrounding area to encourage pedestrian and bicycling activity, and maximize facility usage.

### Links to Transportation/Emission Impacts

Park-and-ride facilities impact the transportation system and air quality in several ways, including reduced congestion, reduced travel time, reduced VMT, reduced emissions, and reduced parking demand at the final destination. In addition, park-and-ride lots attract users from a large area and can act as intermodal transfer facilities by encouraging the use of other modes of transportation such as bus, rail, or car/vanpool. (Holguin-Veras et al., 2012a; VPTI, 2010; SCDHEC, 2013).

Shirgaokar and Deakin (2005) distributed surveys at park-and-ride lots in the San Francisco Bay area of California to determine characteristics of users and facilities, and how users arrived at their final destination. In the US 101 corridor, 86 percent of respondents took a bus to their final destination, and in the I-80 corridor, 62 percent of respondents participated in a carpool (Shirgaokar and Deakin, 2005). The results of a survey conducted by the Texas A&M Transportation Institute (Turnbull, 1992) found 38 to 46 percent of drive-alone travelers switched to park-and-ride buses in Houston, Texas.

Park-and-ride facilities can reduce congestion by lessening the number of, or demand from, single-occupant vehicles on the road, especially during peak travel times and in areas where congestion is the worst (Holguin-Veras et al., 2012a; VPTI, 2010; SCDHEC, 2013; JTA, 2009; Spillar, 1997).

Encouraging the use of park-and-ride facilities can also reduce parking demand at the final destination, especially in urban areas and downtown where parking is scarce and often expensive (Duncan and Christensen, 2013; VTPI, 2010; Liao et al., 2012; EPA, 1992). Cities such as Philadelphia, Pennsylvania, and Toronto, Ontario, Canada, have very few long-term parking spaces available downtown, resulting in over 60 percent of commuters using transit to access downtown employment (Morrall and Bolger, 1996).

The quality of connecting transportation modes is an important characteristic for successful park-and-ride facilities, including the frequency of connections and destinations of transit routes (Bos et al., 2004; VTPI, 2010; Spillar, 1997; EPA, 1992). Users benefit from transit availability when park-and-ride lots are located adjacent to priority- and high-occupancy lanes, as well as rail transit lines (Holguin-Veras et al., 2012a; Horner and Groves, 2007; Cornejo et al., 2014; Duncan and Christensen, 2013). For instance, in Houston, Texas, the Metropolitan Transit Authority of Harris County (METRO) has over 25 park-and-ride lots with direct access to HOV lanes in major corridors, giving buses priority (METRO, 2013).

Emissions benefits from park-and-ride facilities are derived from the potential to reduce overall VMT by replacing some of the single-occupant trips with high-occupancy modes (CEC, 2011; EPA, 1992) and improved speeds (Gan and Wang, 2013; Holgiun-Veras et al., 2012a).

### Links to Human Health Impacts

Park-and-ride facilities are expected to reduce emissions of pollutants considered harmful to human health through reduced VMT and use of higher occupancy vehicles. No studies were found in the review specifically documenting the human health impacts of the emissions reductions associated with park-and-ride strategies.

The safety aspect of park-and-ride lots is important. Well-lit, fenced facilities with video detection and a security presence provide a safe environment for users to leave their vehicles unattended, as well as while walking to and from the transfer station (Bos et al., 2004; Loukaitou-Sideris et al., 2002; CEC, 2011). Several studies found that integrating park-and-ride facilities into the surrounding community increases the perception of the safety and security of park-and-ride lots (Holguin-Veras et al., 2012a; Loukaitou-Sideris et al., 2002; Spillar, 1997; EPA, 1992). For instance, in a study of the Green Line light rail in Los Angeles, California, Loukaitou-Sideris et al., (2002) found that 60 percent of serious crimes reported occurred in the park-and-ride lots. The parking lots were "void of pedestrians" and desolate, which seemed to contribute to crime (Loukaitou-Sideria et al., 2002). Spillar (1997) reported that removing graffiti, trash, and overgrown vegetation creates the perception of a safe and secure environment for park-and-ride users.

Many commuters use park-and-ride facilities to transfer to other modes for a portion of their commute. Becoming a passenger on a different mode can decrease the stress from driving and increase the comfort of the trip by not being responsible for driving (Zhang et al., 2013; Liao et al., 2012; Majumdar and Letz, 2012; Karamychev and Reevan, 2011; CEC, 2011). Majumdar and Lentz (2012) and Zhang et al., (2013) reported that transit riders often experience less travel-related stress compared to those who drive alone because their transit trip is more productive and pleasurable. Wener et al., (2006) conducted an analysis to understand the stress levels of auto commuters (with a sample size of 122) compared to rail commuters (with a sample size of 164) with similar commuter trips. The results, which are based on New Jersey TRANSIT's Midtown Direct and Montclair Direct services, showed significantly higher levels of reported stress and more negative mood across auto commuters. Based on the regression results, it was found that, for auto commuters, "the trip was significantly more effort and felt that their trip was significantly less predictable compared to that of train commuters".

Park-and-ride lots can improve access to employment because of access to other modes to complete the work trip, and either reduce the cost of automobile ownership or make available travel modes not previously accessible through walking or bicycle trips (CEC, 2011; EPA, 1992). Shaheen and Lipman (2007) report the "development and management of park-and-ride lots is important to promoting sustainable transportation." Existing transit users can benefit from park-and-ride facilities that provide additional transit services, such as connections to bus and rail routes (Karamychev and Reevan, 2011; Duncan and Christensen, 2013; EPA, 1992). Karamychev and Reevan (2011) found that the ability to directly access the "mainline public transportation network" made park-and-ride facilities popular among drivers. Furthermore, non-drivers benefit from park-and-ride facilities because of increased transit and ridesharing availability (VTPI, 2010).

The availability of commercial amenities such as retail, grocery, and shopping at or adjacent to park-and-ride lots increases the attractiveness of the facility and encourages pedestrian activity (National Research Council, 2004; CEC, 2011; EPA, 1992). Shopping located adjacent to park-and-ride lots provides commuters with more convenient opportunities for errands and to make fewer vehicle trips (CEC, 2011; Wambalaba and Goodwill, 2004; VTPI, 2010; Bos et al., 2004; Spillar, 1997).

#### 6.2.6.4 Car Sharing

Car sharing is a short-term car rental service allowing members access to a fleet of vehicles dispersed throughout a city. The membership-based model distributes vehicle costs across all users, minimizing individual financial burden and providing an inexpensive alternative to vehicle ownership for those requiring the occasional use of a car. Free-floating operations allow users to pick up and drop off vehicles at any point within a specified area, while station-based operations require vehicles to be parked at fixed locations, often near transit hubs.

Car sharing has been suggested to increase mobility for those without cars, and the demographics of car sharing participants appears to bear this out, with more than half of members typically coming from carless households (Burkhardt and Millard-Ball, 2006; Cervero et al., 2007; Martin and Shaheen, 2011a).

**Links to Transportation/Emission Impacts**
Researchers have identified a number of other potential benefits of car sharing, many of which can have an impact on health, including a reduction in VMT, transportation costs, environmental impacts, accidents, and congestion, as well as increased usage of alternative modes (Firnkorn and Muller, 2011; Litman, 2000). These benefits are generally predicated on a reduction in private vehicle usage and its associated impacts through the encouragement of alternative mode usage, the increased fuel efficiency of car sharing vehicles, and drivers being more cognizant of the cost of trips. Emissions impacts for car sharing are generally viewed as a reduction in VMT which translates to an emission reduction as with many other TDMs.

A cross-sectional study of car sharing in Philadelphia, Pennsylvania 1 year into the PhillyCarShare program found that participants in households without cars slightly increased their average VMT, but this was more than offset by reductions in VMT by participants in households with cars (Lane, 2005). These results were consistent with the more extensive study of members of 10 North American car sharing operations conducted by Martin and Shaheen (2011a), which found that over half of participants came from carless households that increased their VMT, but these increases were relatively smaller than the reductions in VMT reported by individuals with cars. Overall, they estimated a net decline in VMT of 27 percent. Although self-reported travel estimates are frequently unreliable, statistical significance held when conducting a sensitivity analysis to help account for overestimates and underestimates.

Cervero et al. (2007) conducted the most comprehensive longitudinal research to date regarding the impact of car sharing on VMT. Their research is unique in that they obtained pre-car sharing travel survey data and examined participants of the City CarShare program in San Francisco, California, after 1, 2, and 4 years, comparing results against a nonmember control group to account for outside factors such as fuel prices. VMT declined in the first year for members, but less so than for the control group, indicating that car sharing may have actually induced vehicle trips following implementation (Cervero, 2003). The studies proposed that this may have been because early car share adopters were attracted to its environmental benefits and were more likely to live without cars. Evidence of VMT suppression began to appear 2 years after implementation, though not at a statistically significant level (Cervero and Tsai, 2004). Four years into the program VMT had declined further, with a 67 percent overall decrease, which was statistically significant when compared to the nonmember control group (Cervero et al., 2007). Although results of the study revealed a significant decline in VMT due to car sharing, Lane (2005) cautioned that differences in baseline travel behavior between the experiment and control groups made it difficult to accurately assess car sharing impact.

The availability of car sharing may also impact vehicle ownership by replacing personal vehicles or by discouraging the purchase of a new vehicle. In their 4-year City CarShare study, Cervero et al., (2007) found that car share members were half as likely as nonmembers to acquire a new vehicle and 12 percent more likely to have shed a vehicle, while Martin et al., (2010) reported that the number of vehicles per household was significantly reduced from 0.47 to 0.24 in their survey of North American car sharing members. The authors also calculated that each car sharing vehicle replaced an average of 9 to 13 private cars, and car sharing vehicles had an increased fuel efficiency of 10 mpg compared to the average vehicle shed by respondents. Lane (2005) similarly attempted to quantify the number of vehicles replaced by each PhillyCarShare vehicle, though the reported figure of 23 vehicles may be unreliable because it is based on every car shed by participants, even though it cannot be determined that these decisions were directly attributable to car sharing.

By increasing access to alternative modes of transportation, the assumption is that car sharing encourages increased use of public transportation and active travel modes. A longitudinal study of a small car sharing pilot program targeted at commuters from seven companies in the San Francisco Bay area found a 23 percent increase in public transportation usage for commutes, an increase in commute travel time by over 30 minutes, and a decrease in commute stress for the majority of participants (Shaheen and Rodier, 2005). Though these results cannot be generalized to city-wide car sharing programs, they demonstrate the impact of car sharing on public transportation usage. Martin and Shaheen (2011b) noted that the effects of car sharing on modal shift varied somewhat by operator and location, though at an aggregate level, households with cars increased their public transportation usage, while the opposite was true for households without cars. They additionally found that active travel was influenced by car sharing because there was a net increase in walking and bicycling among members. A survey of Montreal car share users also reported significantly less vehicle usage along with increased walking and cycling compared to general Montreal residents, although without baseline pre-car sharing data it is not possible to determine whether this difference was due to car sharing or the fact that members may have already been predisposed to active travel modes (Sioui et al., 2013).

As car sharing continues to expand its reach, several European and North American studies have attempted to empirically test these assumptions by focusing specifically on how car sharing is impacting VMT, emissions, vehicle holdings, and mode choice. VMT reduction is the most commonly calculated benefit from car sharing programs. At an aggregate level, it appears that car sharing may reduce vehicle trips (Duncan, 2011). Car sharing vehicles also tend to be smaller and more fuel efficient than the average private vehicle; a study of North American car sharing users found that car sharing vehicles had an increased fuel efficiency of 10 mpg compared to the average vehicle shed by respondents (Martin et al., 2010). Therefore, the environmental health benefits of car sharing are tied to a general reduction in driving and vehicle emissions and the resultant reduction in the negative externalities associated with vehicle use. Martin and Shaheen's study (2011) across North American car sharing members found a decrease in annual household greenhouse gas emissions of 0.58 tons per year. A 2014 study attempted to estimate the effects of car sharing in Sacramento using regional transportation forecasts (Rodier and Shaheen, 2004). After car sharing impacts were approximated and input into a regional travel demand model, slight reductions in VMT and emissions were found, though the study was conceptual in nature and only considered a limited car-sharing service connecting users to transit and employment centers (Kent, 2014).

According to the EPA's projections (EPA, 2008c), for every 15,000 miles reduction in VMT there is an emissions reduction and fuel saving for the following pollutants per day per vehicle for gasoline passenger cars:

- 34.2 lb VOC,
- 31.1 lb CO,
- 22.9 lb $NO_x$,
- 0.14 lb $PM_{10}$, and
- 0.14 lb $PM_{2.5}$.

**Links to Human Health Impacts**

As demonstrated, the literature indicates that car sharing may have a large impact on travel behavior and mode choice, resulting in a range of potential health outcomes mainly associated with a presumed reduction in vehicle ownership and VMT. Car sharing is hence expected to reduce emissions of pollutants considered harmful to human health; however, no studies were found specifically documenting the human health impacts of the emissions reductions associated with these projects.

Kent (2014) suggested that the encouragement of walking and bicycling by car sharing could result in a decreased risk of mortality from vehicle accidents, though yet there appears to be little evidence for this claim. An analysis of 2001 National Household Travel Survey data actually found that bicyclists and pedestrians suffered fatal injuries at a rate 2.3 and 1.5 times, respectively, greater than that of vehicle occupants (Beck et al., 2007). Pedestrians were less likely to be involved in non-fatal accidents than vehicle occupants, while cyclists were nearly twice as likely to be non-fatally injured. It appears that shifting from vehicle travel to active travel modes may lead to an increase in traffic fatalities, though more research is needed to determine what the specific effect of car sharing would be.

There is general agreement among empirical studies that car sharing results in increased usage of alternative transportation modes such as walking and cycling, leading to an improvement in physical activity and physical health. An analysis conducted by SGS (2012) on behalf of the Council of City of Sydney showed 62 additional minutes walking (per annum) for a car share member in Sydney compared to a non-member. The results of several other studies indicated an increase in walking and cycling among individuals who joined car share organizations (see, e.g., Lane, 2005; Shaheen et al., 2009; Martin and Shaheen, 2011a). This is attributable to an increase in the connectivity and accessibility of other modes, a reduction in vehicle ownership resulting in the partial replacement of vehicle trips with alternate modes, and car sharing vehicles typically being accessed by walking or through other nonvehicle means. In contrast, vehicle ownership itself has been linked to greater feelings of autonomy, status, comfort, and safety (Hiscock et al., 2002).

In addition to more observed benefits such as emissions reduction and congestion on the roadway, other key benefits were also identified due to car sharing, leading to improved transportation options, such as improved accessibility across lower-income residents and reduced time to find parking (SGS, 2012). Car sharing increases mobility for those without cars and can be an important transportation alternative for those unable to afford a private vehicle. Cost is a significant entry barrier for vehicle ownership, and car sharing provides a means of vehicle usage that is more economical than taxis or standard car rentals. This can allow access to necessary destinations, which may be impractical to reach via public transport or active transport modes, such as employment, medical facilities, essential services, and social or recreational trips. Surveys of car sharing participants have indicated that the majority of members come from households without access to a private vehicle (Burkhardt and Millard-Ball, 2006; Cervero et al., 2007; Martin and Shaheen, 2011a). Car sharing does not appear to have reached low-income or minority populations because members tend to be young, white, middle income, and highly educated (Burkhardt and Millard-Ball, 2006; Cervero et al., 2007; Lane, 2005; Martin et al., 2010; Shaheen and Rodier, 2005).

#### 6.2.6.5 Value/Congestion Pricing

Congestion pricing is a strategy that regulates travel demand and discourages travel during peak periods or in highly congested areas by charging fees to system users. This strategy provides the possibility of managing travel demand without adding roadway supply. In peak hours, the implementation and enforcement of congestion pricing lead to a reduction in travel in certain areas, or a shift in travel to other transportation modes or to off-peak periods. The revenues generated from this strategy can be reinvested in maintenance, roadway improvements, public transportation and other mode choice options that benefit users.

The four general types of pricing strategies are (Decorla-Souza, 2006):

- Variably priced lanes, such as express toll lanes and HOT lanes.
- Variable tolls on entire roadways, such as higher tolls during peak hours.
- Cordon charges, which are fees to enter a congested area.
- Area-wide charges, which are fees to enter high-traffic road segments during congested periods.

The United States has implemented many different congestion pricing projects, such as HOT lanes on I-15 in San Diego, California; State Route 91 Express Lanes in Orange County, California; bridge pricing in Lee County, Florida (Decorla-Souza 2006), 495 Express Lanes in Washington, D.C.; LBJ TEXpress Lanes on I-635 in Dallas, Texas; and I-85 Express Lanes in metropolitan Atlanta, Georgia. Previous research has shown that congestion pricing strategies reduce congestion, improve travel time, and shift automobile travel to other transportation alternatives.

### Links to Transportation/Emission Impacts

Implementation of value/congestion pricing strategies can impact driver behavior (i.e., choosing whether to pay for the service, drive another route, choose another mode, etc.), traffic volumes, transit ridership, and emission levels. Congestion pricing projects have seen a rise in carpooling, car sharing and transit ridership.

Various congestion pricing strategies have been successfully studied and applied to improve traffic operations. On the State Route 91 Express Lanes in Orange County, California, traffic speeds in managed lanes during peak hours were over 60 mph, while traffic speeds on the free adjacent lanes were about 15 mph. This speed difference means that an average 10-mile daily trip on these express lanes saves 30 minutes a day or 120 hours annually (Decorla-Souza, 2006). Holguin-Veras et al., (2006) discussed the impacts of the Port Authority of New York and New Jersey's time-of-day pricing on commercial carriers. The results from the study indicated that 15.3 percent of the carriers changed their behavior to use off-peak hours.

The application of pricing strategies in London, England, and Stockholm, Sweden, has led to a significant increase in transit mode share (Decorla-Souza, 2006). Because there were fewer vehicles, bus delays were reduced by 50 percent in central London from pre-pricing conditions, and the number of bus riders increased by 7 percent. In Stockholm, daily public transit usage was up by 40,000 riders during January 2006, a 9 percent increase compared to the same month in 2005.

Beevers et al. (2005) measured the air quality impact of the London congestion charging scheme. In their study in London, England, between 2002 and 2003, both total emissions of $NO_x$ and $PM_{10}$ were reduced by 12 percent. Using Delaware's household travel demand and highway traffic count data, Daniel and Bekka (2000) modeled significant reductions on emissions (including CO, HC, and $NO_x$) obtained through congestion pricing. Their model results indicated "as much as 10 percent in aggregate and 30 percent in highly congested areas. Benefits from reduced emissions are 15 to 30 percent of those from reduced congestion".

### Links to Human Health Impacts

While the literature presents a number of safety impacts of congestion/value pricing, few studies have examined this project type from the perspective of emissions, physical/mental health, or equity.

Abdelwahab (2002) discussed the highway safety impacts of toll plazas and electronic toll collection (ETC) systems in a case study in Florida. The model results showed that medium/heavy-duty trucks equipped with ETC devices or tags had a higher risk of being involved in crashes at toll plazas. The number of crashes upstream of the toll plaza was also higher. As the model results showed, ETC users, especially older drivers and female drivers, had a statistically higher risk of injury during an accident.

Since congestion pricing directly influences traffic congestion, the link between traffic congestion and traffic safety implies a safety impact from congestion pricing. Quddus et al. (2009) conducted a study to find the relationship between the level of congestion and the severity of traffic crashes by using disaggregated crash records from 2003 to 2006 on the M25 in London, England. The results suggested that the level of traffic congestion (measured by total delay or congestion index) does not affect the severity of road crashes.  However, the results also indicated that increased traffic flow reduces the severity of crashes.

Congestion pricing also has equity impacts.  Ecola (2009) addressed equity issues with congestion pricing pointing out that the impact of congestion pricing could be either regressive or progressive depending on how it is implemented.  Ecola continued that some individuals could be worse off even when the group benefit is positive from congestion pricing.

### 6.2.7 Other Project Types

#### 6.2.7.1 Pedestrian/Bicycle

Walking and bicycling are beneficial to health, the environment, and the transportation system.  Every state DOT has a bicycle and pedestrian coordinator used "to promote and facilitate the increased use of non-motorized transportation, including developing facilities for the use of pedestrians and bicyclists and public educational, promotional, and safety programs for using such facilities" (FHWA, 2014c).  Bicycle and pedestrian facilities include a variety of projects and amenities, such as a network of paths or trails, sidewalks and crosswalks, dedicated bicycle lanes, appropriate pavement markings in bicycle/pedestrian areas, secure storage for equipment, integration with transit, access to street-level shops and activity centers, and appropriate street design and infrastructure (EPA, 1992).

Numerous studies have identified the potential air quality benefits of walking and cycling along with impacts on human health.

**Links to Transportation/Emission Impacts**
Improving walking and cycling conditions can reduce automobile trip generation and traffic congestion.  Bicycling and walking can also provide alternative ways to access public transportation.  Replacing short trips can help reduce emissions from cold starts and vehicle idling.

Results from a national travel survey showed that nearly 40 percent of all trips are less than 2 miles—the equivalent of a 30-minute walk or 10-minute bicycle ride—which suggests that bicycling and walking can reduce VMT when used for short trips (Rails, 2008; Bedsworth et al., 2011; Pucher and Dijkstra, 2003; de Nazelle et al., 2010; Lindsay et al., 2011).  Short-distance trips often include those to work and school—trips the *Urban Mobility Report* says would be ideal to switch to walking or bicycling (Schrank, 2007; Rails, 2008).  Cyclists surveyed in Portland, Oregon reported their average bicycle trip was 3 miles, indicating that many short vehicle trips could potentially switch to bicycles (Dill, 2009).  The Rails to Trails Conservancy asserts that even moderate shifts in short trips to bicycling and walking could reduce 49 billion vehicle miles driven annually in the United States (Rails, 2008).

Several researchers noted that congestion is reduced when motorists shift from car trips to bicycling (Litman, 2013c; Garrett-Peltier, 2011; Borjesson and Eliasson, 2012; Rabl and de Nazelle, 2011; Davis, 2010).  An analysis of the relationship between land use and traffic in Phoenix, Arizona, found less congestion in areas with more options for bicycling and walking, such as higher density, mixed land uses, and a connected street grid (Kuzmyak, 2012).  According to research by Litman (2013c), the impacts walking and cycling have on congestion are most noticeable in areas where short trips typically begin and end, such as commercial districts, near schools, and near recreational centers.

Furthermore, walking and cycling improve air quality because they do not directly produce pollution. These modes of active transportation can also reduce criteria pollutants (Bedworth et al., 2011; WHO, 2011; Lindsay et al., 2011; Grabow et al., 2012). De Nazelle et al. (2010) examined the potential emissions savings across the US from converting short vehicle trips to cycling or walking using data from a national transportation survey. The study estimated that converting 35 percent of trips less than 0.5 miles would amount to reducing approximately 30 tons of VOCs, 400 tons of CO, and 15 tons of $NO_x$ per day.

The California Air Resources Board (CARB, 2008) estimated that if Californians were to replace an additional 1 percent of car and light truck trips (average trip length 1.8 miles) with bicycle trips by 2010 they would achieve statewide reductions of:

- 2,656,035 VMT,
- 3.58 tons/day ROG and NOx,
- 0.65 tons/day $PM_{10}$ (includes tire and brake wear), and
- 20.11 ton/day CO (CARB, 2008).

**Links to Human Health Impacts**

There is a considerable amount of literature demonstrating numerous health impacts from bicycling and pedestrian activities. De Hartog et al. (2010) conducted studies in the Netherlands that quantified the impact on all-cause mortality in terms of mortality impacts in life-years gained or lost when 500,000 people would choose bicycles for short trips over cars on a daily basis. They found that the “estimated beneficial effects of increased physical activity are substantially larger (3 to 14 months gained) than the potential mortality effect of increased inhaled air pollution doses (0.8 to 40 days lost) and the increase in traffic accidents (5 to 9 days lost).”

AA recent study conducted by UBC (2014) investigated the relationship between traffic-related air pollution exposure and respiratory and cardiovascular health impacts in commuting cyclists to determine commuting cyclists’ exposure to traffic-related air pollutants ($PM_{2.5}$, $PM_{10}$, ultrafine particulate). Comparisons of health indicators after cycling in urban (downtown) versus residential routes showed cyclists had decreased endothelial function 1 hour after cycling on the more polluted urban route due to levels of ultra-fine particulates ~ 60 percent higher than the residential route. “The implications of the study suggest that while exercise is promoted as healthy behavior, cyclists may experience high doses of air pollution due to their elevated breathing rates and cycling in proximity to traffic, especially during periods of elevated air pollution.” Public outreach could provide advice to the public regarding where and when to cycle in order to minimizing potential adverse impacts related to air pollution exposure (UBC, 2014).

Many public transportation trips include walking with most of those initial walking trips found to be usually less than 10 minutes (Rails-to-Trails Conservancy, 2008), especially in areas with adequate walking conditions. The Transit Cooperative Research Program suggests that 400 meters (0.25 miles) to bus stations and 800 meters (0.5 miles) to rail stations are the most common distances that pedestrians will be willing to walk (TCRP, 2003). In fact, many studies suggest 12 to 15 minutes of daily reported walking due to transit use, which covers almost half of the daily recommended level of physical activity for adults (Saelens et al., 2014; Rissel et al., 2012). Besser and Dannenberg (2005) analyzed walking times associated with transit use and determined that, in the United States, transit users spend 19 minutes walking to and from transit per day, on average.

Safety impacts are one other essential health impact emerging from pedestrian/bicycle project types. The National Highway Traffic Safety Administrations' 2012 statistics state that there were 726 fatalities with over 49,000 people injured in vehicle related bicycle crashes and 4,743 pedestrian deaths with over 76,000 reported pedestrian injuries (NHTSA, 2012). Several proven strategies can increase pedestrian and cyclist safety, according to a study by Pucher and Dijkstra (2003). These include strategies such as providing better facilities and infrastructure and traffic-calming mechanisms (Pucher and Dijkstra, 2003). In a meta-analysis of 33 studies, Elvik (2001) evaluated how traffic-calming affected road safety schemes. The analysis found that when traffic-calming devices were implemented, injury accidents were reduced by 15 percent, with the largest reduction on residential streets. Ewing and Dumbaugh (2009) and Bunn et al. (2009) also concluded that traffic-calming mechanisms and favorable urban design techniques can improve the safety of a roadway for pedestrians and cyclists.

Roadway improvements to provide bicycling and pedestrian facilities are important to promote active transportation and public physical activities from a health perspective. Lightman et al. (2012) illustrated the relationship between road improvement and health in a study in Toronto, Ontario, Canada. The researchers studied active transportation for the purpose of improving health and quality of life, and walking and cycling benefits by adding new infrastructures, such as bike lanes, in the city. An estimated 120 deaths were prevented by improving the walking and cycling level in 2006 in Toronto.

Akar and Clifton (2009) conducted a campus-based analysis with data from the Campus Transportation Survey at the University of Maryland. The collected responses indicated that the most important factor that prevented biking was the lack of bike lanes and bike parking facilities. The importance of a bikeway facility (e.g., width of the bike lane or facility continuity) and presence of on-street parking was also noted by Sener et al., (2009). Their results showed the importance of a continuous bicycle facility as well as the absence of parking on the route in encouraging bicycling.

Facilities and infrastructure for bicycles and pedestrians, such as sidewalks and interconnected trails, often encourage active lifestyles and increase walking and cycling (Wang et al., 2004; Jacobsen et al., 2009; de Nazelle et al., 2011; Dill, 2009; Aultman-Hall et al., 1997; Sener et al., 2009). A survey by Aultman-Hall et al., (1997) in Guelph, Ontario, Canada, found that 93 percent of cyclists surveyed used good- or average-quality off-road road paths, compared to 7 percent who used poor-quality paths, indicating well-maintained, accessible paths are used significantly more than those that are not. This type of infrastructure can also stimulate mixed-use development and higher densities, which have been found to increase bicycling and walking (Jackson, 2002; Berman, 1996; Cervero, 1996; Rails, 2008). On the other hand, areas without these facilitates can create an unpleasant and hazardous environment for cyclists and pedestrians (Wang et al., 2005; Pucher and Dijkstra, 2003).

#### 6.2.7.2 Dust Mitigation

Both paved and unpaved roads contribute to fugitive dust emissions. Typical dust mitigation projects (usually for $PM_{10}$) include paving shoulders, curbs and gutters, roads, and access points. Street sweeping on paved roads removes sand and/or other de-icing materials, and the deposition of other particulates on roads.

The Alaska Department of Environmental Conservation (ADEC, 2011) outlines the top 10 dust control techniques as follows:

- Reduce Traffic - Reducing the number of vehicles can reduce dust. Traffic can be reduced by restricting vehicle weight or type, or by limiting motor vehicle access to dirt roads.
- Reduce Speed - Studies show that $PM_{10}$ quantities increase with vehicle speed. Reducing speed from 40 miles per hour (mph) to 20 mph reduces dust emissions by 65 percent.
- Improve Road Design - Good road drainage can reduce dust.
- Water the Road - Moisture in the surface of dirt roads causes particles to stick together.
- Cover Unpaved Roads with Gravel - Applying gravel to a dirt road surface can reduce dust.
- Increase Moisture Content of the Road Surface - Moisture in the surface of dirt roads causes particles to stick together. The moisture content of dirt roads can be increased either through spreading water or by application of deliquescent salts like calcium chloride or magnesium chloride that absorb water from the air.
- Bind Particles Together (Palliative 3) – Apply chemicals, such as petroleum-based, organic nonpetroleum, electrochemical stabilizers, and synthetic polymers which bind fine particles together or onto larger particles.
- Pave Unpaved Roads - Paving is the most effective, and most expensive, method to control dust from unpaved roads.
- Reduce Exposed Ground - Covered ground doesn't blow away and create dust.
- Use Wind Breaks - Windbreaks are barriers designed to slow the speed and redirect the flow of wind (ADEC, 2100).

**Links to Transportation/Emission Impacts**
The quantity of dust emissions from a given segment of road depends on various factors such as whether it is paved or unpaved, precipitation levels, and traffic volumes. Emissions reductions reported by project sponsors at the local level indicated a range of daily $PM_{10}$ emissions reductions from 143.0 to 6,292.2 kg (Grant et al., 2008). These strategies have limited impact on congestion levels, though some benefits may be observed through speed improvements on previously unpaved or icy roads.

A traffic-generated dust plume commonly includes PM with a gaseous pollutant mixture of nitrogen oxides ($NO_x$), CO, and VOCs (e.g., benzene). These plumes, or particle complexes, have been demonstrated to elicit an exposure-response relationship with short-term human health effects (premature death and hospital admissions) and long-term human health effects (morbidity, lung cancer, and cardiovascular and cardiopulmonary diseases) (Cassee et al., 2013). Fifty percent of $PM_{10}$ emissions and 19 percent of $PM_{2.5}$ emissions are due to traffic-generated dust (Cassee et al., 2013).

A review of the research literature on traffic-generated dust includes the development of predictive models, a direct measurement tool, and control techniques and products. Strategies such as sweeping and water flushing are often implemented to reduce non-exhaust emissions; however, there is no evidence supporting the effectiveness of these methods (Peltier et al., 2011; Keuken et al., 2011; Amato et al., 2010). Research on cost-saving chemical suppressants (e.g., hygroscopic salts) used to remove and/or bind dust (e.g., organic non-bituminous binders) demonstrated that their effectiveness is short lived, but these suppressants are a viable option for resource-limited entities (Greening, 2011). The most effective method of reducing traffic-generated dust is to seal the road surface with asphalt or concrete. Although this is an expensive strategy, it is the most economically efficient and sustainable with regard to long-term life-cycle costs (Greening, 2011). When estimating human exposure response to traffic-generated dust, it is important to consider a diverse road user mix and geographic location. For example, pedestrians and cyclists might not be influenced by the adverse effects of non-exhaust emissions because they do not usually use unpaved roads (Greening, 2011).

The City of Maricopa, Arizona estimated that paving 1.5 miles of an unpaved road with an ADT of 150 vehicles/day can reduce $PM_{10}$ by 47 tons/year and $PM_{2.5}$ by 12 tons/year. The city also proposed using a $PM_{10}$ efficient street sweeper for non-freeway streets with an ADT per through lane of 5,000 vehicles a day. With a street sweep cycle of 7 days they expect to see reductions in $PM_{10}$ of 150 tons/year (FHWA, 2011a).

Road traffic emissions are not confined to the tailpipe of a vehicle. They can also be the result of frictional processes from tire, rotor, and brake pad wear in addition to re-suspended road dust (Thorpe and Harrison, 2008). Although organic dust is ubiquitous to the atmosphere, it tends to be more pronounced in dry and drought-sensitive areas where vegetation is sparse (Greening, 2011). Elements ranging from transition metals, ions, organic compounds, stable radicals of carbonaceous material, minerals, reactive gases, and organic matter are causally associated with human health conditions (Valavanidis, 2008). In spite of the known adverse consequences of traffic-generated dust on human health, road safety, and the environment, quantitative data continue to be limited (Greening, 2011).

The Arizona Department of Transportation (ADOT, 2013) tested two dust mitigation surface treatments for unpaved roads using field measurements of $PM_{10}$ emission rates. The segment using Envirotac II Acrylic copolymer reduced $PM_{10}$ emissions by a factor of 5 after 5 months. The other road segment was treated with CRS II Emulsified liquid and other treatments that reduced $PM_{10}$ emissions by a factor of sixty after 1 year (ADOT, 2013).

**Links to Human Health Impacts**

Dust mitigation is expected to reduce emissions of pollutants considered harmful to human health However, there is limited evidence and very few examples in published literature regarding the health benefit impacts of dust mitigation projects. Traffic-generated road dust contains over 20 different species of allergens and other substances such as particles from normal vehicle wear of tires, brake pads, and rotors (Greening, 2011; Thorpe et al., 2008).

Children, the elderly, and individuals with a pre-existing condition such as asthma tend to be the most susceptible to traffic-generated dust. Slow-moving cyclists and pedestrian road users are subjected to direct exposure from traffic-generated dust. Through the normal process of inhalation, $PM_{2.5}$ airborne dust enters the human respiratory system by way of the nose and throat and then goes into the lungs (Valavanidis et al., 2008). Epidemiology and toxicology studies on re-suspended and inhaled PM demonstrate that the human body goes through a chronic inflammatory response following cumulative exposure. The body's natural defense against foreign PM is reflected in reversible airway disease such as acute asthma exacerbation, all the way to irreversible end organ disease such as COPD, cancer, and cardiovascular anomalies.

Reduced visibility from dust plumes and/or storms has been cited as a reason for road crashes worldwide; however, little epidemiologic data are available due to a lack of police reporting at the scene (Greening, 2011; GRSF, 2014). Individual states are addressing dust-related traffic safety issues.

#### 6.2.7.3 Freight/Intermodal

Intermodal freight is defined as goods and products transported using more than one mode of travel and includes points of connections (e.g., ports and warehouses) and the links between them (e.g., roads and rail lines). As international trade grows around the world, freight movement will also increase along railways, roadways, and seaports. Past examples of CMAQ funded freight/intermodal projects range from improvements to rail tracks, construction of intermodal facilities or other infrastructure including bridges, and access improvements (FHWA, 2014d).

**Link to Transportation/Emission Impacts**

Intermodal freight is a major component of the transportation system within the United States. The movement of freight along multiple transportation modes impacts the transportation sector in surface congestion and on-road mobile source emissions. Many of these facilities link various travel modes, most of which utilize large vehicle transport methods such as trucks, rail, and ships.

It is estimated that 2.2 billion tons of commodities are moved by freight every year in the United States and cargo is estimated to increase by 92 percent in the next 30 years (DiJohn, 2010). This increase in freight can have a huge impact on the transportation system. Intermodal freight can impact congestion along roadways and rail lines, especially in urban areas where rail and port terminals are usually located. For example, in Southern California, once cargo arrives at ports in Los Angeles or Long Beach, the cargo is transferred to its final destination by rail or truck (Lowe, 2005). Freight trains in many urban areas such as Chicago, Illinois, use the same rail tracks as the commuter lines. According to Metra (2007), 312 incidents of commuter train delays were caused by freight interference and represent 17.3 percent of all delays. Areas along the National Highway System that carry more than 10,000 trucks per day, including freight trucks traveling locally and across the country, have highly congested segments with stop-and-go conditions (FHWA, 2007). According to VECTOR (2009), the increased freight forecast will exacerbate congestion throughout the transportation system, especially at ports, border crossings, locks, and major domestic terminals and transfer points.

Freight transportation is a major contributor to emissions. Nationally, freight accounts for 1/2 of all $NO_x$ emissions from mobile sources and 27 percent of $NO_x$ emissions from ships and locomotives (Schmitt et al., 2008). Shifting between transportation modes impacts the amount of emissions attributed to intermodal freight. Based on the results obtained from a truck-to-rail freight modal shifts analysis in the Midwest by Bickford (2012), if 12 million to 530 million tons of freight is shifted from truck to rail, the removal of 40 percent of daily freight truck VMT will result in a 26 percent net reduction in $NO_x$. However, the increased freight tonnage predicted will likely make shifting freight cargo from truck to rail difficult. The Energy Information Administration Annual Energy Outlook 2012 projects that between 2010 and 2035, the rate for freight truck VMT growth will be 1.6 percent compared to

1.2 percent for passenger VMT (EIA, 2011).  If this occurs, freight transportation will be a growing contributor to U.S. emissions sources.

**Link to Human Health Impacts**

The California Air Resources Board (2006) conducted a health risk assessment on intermodal freight yards and found in the 18 rail yards studied, there were 210 tons of diesel emissions a year and an increased cancer risk for 3 million people living near the facilities.  Estimates were that 4 of the facilities posed an excessive cancer risk of 500 to 3,300 chances per million.  A health assessment study near the Hobart rail yard in California indicated that communities living near an intermodal yard are exposed to an increased risk of developing cancer (Li, 2007).  In particular,  Li (2007) indicated that "the area with the greatest impact has an estimated potential cancer risk of over 1000 chances in a million, occurring in the area right next to the boundaries of the rail yard fence line," noting that the land use of this area is industrial.  Furthermore, "the estimated cancer risks decrease to about 250 in a million at approximately a half mile (up to 1 mile in the northeast) from the rail yard boundaries" (Li, 2007).  Finally, the study estimated around 552,000 people are exposed to a cancer risk of 10 to 25 chances in a million due to diesel PM emissions from the BNSF Hobart rail yard.

## 6.3 Summary and Conclusions

The link between transportation and human health has attracted the attention of many researchers, practitioners, and policy makers, as solutions are sought to address concurrently the issues of congestion mitigation, improved air quality, and improved human health.

Under the CMAQ program, various projects have been developed with the objective of reducing vehicle emission and traffic congestion.  These projects can be categorized under several groups including innovative vehicle/fuel technologies, vehicle activity programs, traffic flow improvements, ITS, improved public transportation, transportation demand managements, and other types of projects such as bicycle/pedestrian improvements.  Along with their environmental impacts, these projects can either directly or indirectly impact human health through air quality, injury prevention, physical and mental health, or access equity.  The objective of this effort was an assessment of the transportation and human health impacts associated with actions funded under the CMAQ program.

This human health impacts assessment was completed through a thorough literature review based on published literature (scientific articles, reports, etc.) on transportation and health effects.  A total of 21 project types were examined.  Each project type was observed to have unique links to transportation and health impacts at varying quantitative and qualitative levels.

Many CMAQ projects were shown to impact the transportation system through reduction or elimination of vehicle trips, changes when travel occurs, or improvements in vehicle operating speeds in order to alleviate traffic congestion.  These transportation changes can impact the amount of vehicle emissions generated.  The reduction or elimination of vehicle trips may lessen the amount of vehicle emissions generated from the trip.  When vehicle speeds are increased away from congested conditions, vehicle emission rates generally improve so that fewer emissions are generated.  Shifting vehicle travel to less congested times when more roadway capacity is available, also known as peak spreading, can result in improved travel speeds for those shifting their trip and may also improve peak period travel speeds because of the lessened demand.

Some CMAQ projects do not impact the operations of the transportation system. These CMAQ projects either limit certain vehicle engine activity off the roadway or they improve the performance of the vehicle’s engine, catalytic system, and fuel performance. When vehicle idling is limited, typically through local regulations, those vehicle emissions generated from idling are reduced. Vehicle technology improvements directly impact the emissions generated from the vehicle.

One of the issues when considering human health impacts in the context of transportation air quality analysis is current emission reduction analyses performed by agencies address only mass estimates (kilograms/day) of pollutant reductions from these types of projects. These mass emissions estimates are generally not extrapolated by the transportation field into changes in either pollutant concentrations or exposure resulting from the project. Regional pollutant concentrations are estimated in a more complex process of air dispersion modeling typically performed by the state environmental agency. Human health impact studies require the more focused pollutant concentrations and exposures instead of regional mass estimates to form linkages between projects and health effects.

Quantification of the link between a reduction in emissions of harmful pollutants from an emissions reduction project such those funded under CMAQ and the corresponding change in the human health impact have limited evidence and very few examples in published literature. There are various uncertainties in quantifying this link since the process might be influenced by various factors, such as changes in fuels or technology or land use, that make discerning a single project’s impacts to adjacent or nearby populations extremely difficult and challenging.

Transportation-related pollutants are reduced when traffic congestion is reduced or when alternative fuels or engine retrofits are used to lower the rate of transportation-related pollutants produced. The main form of reporting these outcomes in the transportation literature is through activity changes (i.e., changes in vehicle speeds, reduction in stops or idling, or reduced VMT). The review of the literature indicated few studies report directly measured pollutant changes from CMAQ-funded projects, strategies, or programs. Where estimates of pollutant changes are reported, these studies rely on the modeled translation of measured activity changes using pollutant rates or emission factors to mass (regional) estimates of pollutant changes and not directly measured emissions.

Some CMAQ project types improve air quality by directly reducing vehicle emissions through innovative technologies or regulatory measures. Examples of these project types are alternative fuel vehicles, diesel retrofits, idle reduction, and extreme-low temperature cold start programs. These project types do not alter on-road vehicle activity. Idle reduction programs do seek to limit idling activity of vehicles which are associated with higher vehicle emission rates.

Other CMAQ project types mitigate traffic congestion through reducing vehicle use or by improving transportation system efficiency. Examples of these project types include ridesharing, TDM, public education, and improved public transportation. The primary goal of these project types is to provide travelers with options to eliminate all or some of their vehicle trips. Eliminating vehicle trips from the transportation system has 2 primary air quality impacts; first, pollutants prevented from the eliminated trips, and second, reduction of vehicle demand on the transportation system resulting in positive operational effects, i.e., increases in vehicle operating speeds, travel time reduction, and decreases in idling.

Various CMAQ efforts are focused more on decreasing traffic congestion by reducing vehicle usage or improving transportation system efficiency. Decades of urban sprawl (indicative of lower population density, longer commutes, and heavy reliance on automobiles for travel) and continuing growth of city populations have resulted in congestion becoming a critical issue. Traffic congestion directly affects regional air quality through increased vehicle emissions, economic losses, energy dependency, lost time, and greater stress level and frustration for motor vehicle users. Examples of established techniques to improve transportation system efficiency and mobility include signal re-timing, roadway and intersection improvements, roundabouts, HOV and managed lanes, congestion pricing, and intermodal freight facilities. These project types target traffic flow improvements on facilities by removing or mitigating causes of vehicle delay, such as poorly timed or uncoordinated traffic signals, reduction of vehicle conflicts at driveways and intersections, and attracting some amount of traffic to parallel lanes where access is managed through vehicle occupancy requirements or toll rates. Public education and outreach efforts can also bring important benefits in reducing congestion and resultant emissions. Effective campaigns improving travel behavior and increasing safety awareness or reducing risky driving behavior are simple but useful ways to attract public's attention to transportation and air quality issues.

The health effects from reduced vehicle emissions generally relate to changes in regional air quality that impact respiratory illnesses. However, limited evidence and very few examples exist in the published literature that quantify the link between a reduction in emissions of harmful pollutants from an emissions reduction project such as those funded under CMAQ and the corresponding change in the human health impact. Projects can impact the physical and mental health of individuals in ways not limited to disease, but also can impact their general well-being and quality of life. Injury prevention can also be a benefit received when the risk of vehicle crashes or injury severity is reduced. Finally, access equity is another potential pathway to human health impacts. Access equity refers to project impacts that provide improved access to healthcare, education, jobs, nutritional food, and safe recreational areas, providing equitable benefits to all residents.

The link between air quality and human health has been well-documented in the public health field, with a substantial body of evidence documenting the adverse impacts of pollutant emissions on human health. The public health field has associated diesel emissions with numerous health risks, including respiratory ailments, lung cancer, headaches, bronchitis, pneumonia, exacerbation of asthma symptoms, birth defects, and increased mortality among people with cardiopulmonary disease. The reviewed literature has also revealed links between high ambient PM levels and increased hospital admissions, emergency room visits, and premature deaths among individuals suffering from acute and chronic respiratory conditions.

EPA, via statutory authority of the Clean Air Act, investigates this linkage and promulgates national ambient air quality standards to protect human health and the environment. Large amounts of documentation exist through this standard-setting process on the harmful effects of the criteria pollutants.  Other EPA regulations, such as the heavy-duty diesel engine and mobile source air toxics rules, document the harmful effects of diesel exhaust and other mobile source air toxics.

Traffic congestion mitigated through the promotion of alternative transportation options, such as public transportation, walking, bicycling, and car sharing can lead to a number of positive health benefits in the areas of physical and mental health.  Health outcomes have been studied in the areas of active transport and public transportation, project types with significant CMAQ funding, where the use of these alternative modes has been tied to increased levels of physical activity in addition to the benefits associated with decreased emissions and vehicle usage.  Walking and bicycling have been linked with decreased levels of illnesses and health issues, such as obesity, type II diabetes, cardiovascular diseases, and depression.  Walkable environments were shown to be directly related to improved mental health of their residents, and walking was shown to reduce risk of cognitive impairment.  Research also showed important relationships between transit use and increased walking due to potential additional walking time to access transit across transit users.  Traveler stress levels have been shown to be reduced, for example, as a result of decreased traffic-related noise and improved travel times.

By improving traffic flow and system efficiency, congestion reduction can also lower vehicle crash and injury risk.  Use of technology is an important component of these benefits.  Technologies effectively managing traffic flow, either through improved systems (as in the case of real-time freeway monitoring) or advanced traveler information systems, help mitigate traffic safety problems in addition to improvements to congestion and mobility, as shown by numerous studies in the literature.  For example, innovative intersection design for left-turns has demonstrated reductions in vehicle crashes.  Similar crash reductions can also be obtained with effective roadway improvements.  Freeway management systems have created benefits to human health from a reduction in vehicle crashes.  Conventional bus replacement projects provide ancillary benefits since new buses are equipped with improved technologies (e.g., collision warning and avoidance systems and driver assistance) providing a safer riding experience.

Access equity is another component in the linkage between transportation projects and human health impacts and is affected by most of the CMAQ strategies.  The literature review revealed several aspects of equity considerations such as traffic signalization (e.g., accessible pedestrian signals), and the use of managed lanes (e.g., financial limitations for lower income drivers).  Equity considerations in TDM (such as improved walking/cycling conditions and rideshare services) and congestion pricing strategies were shown to vary across different demographic groups and based on local conditions.  Public transportation has also been shown to improve access to essential services, resulting in equity benefits for vulnerable communities.

# Appendix A – CMAQ Study Major Project Types and Trends

The CMAQ projects were analyzed by major project type to understand the distribution by project type and funding. The subcategories in each major project type are described in the following sections.

## A.1 Vehicle/Fuel Technology

This CMAQ study project type contains the three subcategories described below.

- Alternative Fuel Vehicles/Fueling Facilities: includes projects with a range of alternative fuels—such as compressed natural gas (CNG), hybrid gas/electric, all electric, biodiesel, ethanol blended gasoline (e.g., E85), and LPG. Approximately half of the over 400 projects in this subcategory involved either the purchase of CNG fueled vehicles or the installation/upgrade of CNG handling infrastructure or fueling stations. The projects within this subcategory generally involve either: a) the installation/upgrade of alternative fuel facilities; b) the purchase of alternative fuel vehicles; or c) in some limited situations, the purchase of alternative fuels.
- Conventional Bus and Paratransit Replacements: this subcategory encompasses projects that involve engine retrofits of existing buses, and the replacement of transit bus and paratransit vehicles to expand the existing fleet or to replace aging vehicles within the fleet with cleaner, lower emitting vehicles.
- Diesel Engine Retrofits: SAFETEA-LU placed an emphasis on funding projects involving diesel engine retrofits and other advanced truck technologies. The MAP-21 continues this emphasis and expands the focus to specifically identify diesel retrofits as eligible projects. The majority of the diesel retrofit projects funded since FY 2006 have included the installation of diesel particulate filters. The projects within this subcategory typically include either: (a) the purchase and installation of after-treatment hardware; (b) repowering; (c) engine rebuilding; or (d) other emission reducing technologies.

As shown previously in Figure 7, the Vehicle/Fuel Technology project type ranks fourth highest in funding and fourth highest in total projects obligated. Figure A-1 shows the total CMAQ funding and the number of projects obligated for the Vehicle/Fuel Technology project type during the 2006-2012 timeframe. Total funding generally ranged between $100 million and $200 million per year, with a spike of $350 million in 2007. The number of projects varied between 86 and 126, with a separate spike of 211 projects in 2009.

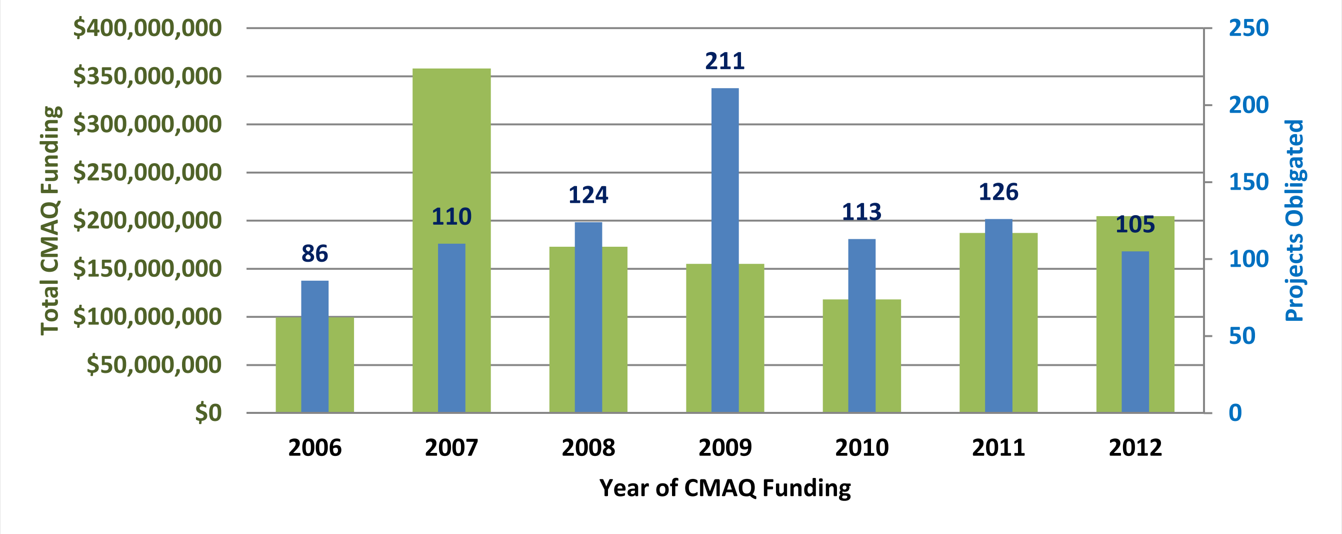

**Figure A-1. Funding and Number of CMAQ Projects per year in Vehicle/Fuel Technology Project Type**

## A.2 Vehicle Activity Programs

This CMAQ study project type contains the two subcategories described below.

- Idle Reduction: these projects typically apply to heavy duty trucks and may include truck stop electrification efforts or on-board devices like auxiliary power units or direct fired heaters. The projects within this subcategory generally involve either: a) on-board idle reduction devices on vehicles that will primarily benefit the nonattainment or maintenance area; or b) off-board idle reduction facilities within nonattainment or maintenance areas.
- Extreme Low-Temperature Cold Start Programs: these projects are intended to reduce emissions from extreme cold-start conditions and include retrofitting vehicles and fleets with water and oil heaters and installing electrical outlets and equipment in publicly owned garages or fleet storage facilities.

As shown previously in Figure 7, with just the two small subcategories, the Vehicle Activity Programs project type ranks the lowest both in funding and total number of projects among the seven major project types. Figure A-2 shows the total CMAQ funding and the number of projects obligated for the Vehicle Activity Programs project type during the 2006-2012 timeframe.

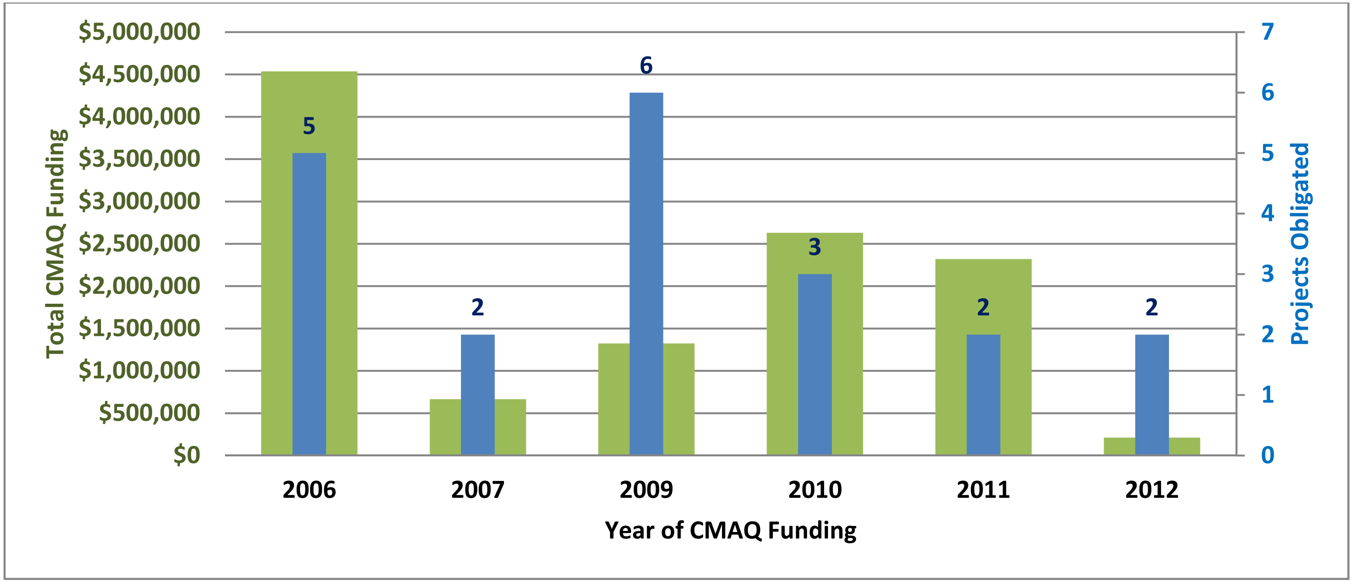

**Figure A-2. Funding and Number of CMAQ Projects per year in Vehicle Activity Project Type**

## A.3 Traffic Flow Improvements

This CMAQ study project type contains the five subcategories described below.

- Traffic Signalization: projects typically involve one or more of the following: (a) outfitting an intersection with traffic signals; (b) traffic signal synchronization in a network; and/or (c) traffic signal timing projects.
- Traffic Engineering (Roadway Improvements): projects typically involve one or more of the following: (a) shoulder paving; (b) pavement rehabilitation/resurfacing; (c) grade separations; (d) bridge/overpass construction; (e) turn lane extensions; and/or (f) ramp improvements. In general, this subcategory included the projects that could not readily or singularly be identified as one of the other traffic flow improvement subcategories. Also note that some projects in this type may include STP projects not subject to eligibility criteria.
- Intersection Improvements: projects within this subcategory generally involve one or more of the following: (a) construction of curbs or medians; (b) signalization; and/or (c) geometric improvements.
- High-Occupancy Vehicle and Managed Lanes: these projects attempt to encourage carpooling/ridesharing to reduce the number of vehicles on the freeways. Managed lanes have the ability to add capacity to freeways to reduce congestion and delay during peak hours. Examples of these types of programs include HOV facilities, dynamic shoulder lanes, and bus-on-shoulder programs.
- Roundabouts: the projects within this subcategory involve the construction of roundabouts to improve traffic flow at existing intersections.

The Traffic Flow Improvement project type ranks highest in funding and highest in total projects obligated as shown previously in Figure 7. Figure A-3 shows the total CMAQ funding and the number of projects obligated for the Traffic Flow Improvement project type during the 2006-2012 timeframe. Total funding generally ranged between $380 million and a high of $640 million per year, which occurred in 2011. The number of projects varied between 291 and a high of 423, which also occurred in 2011.

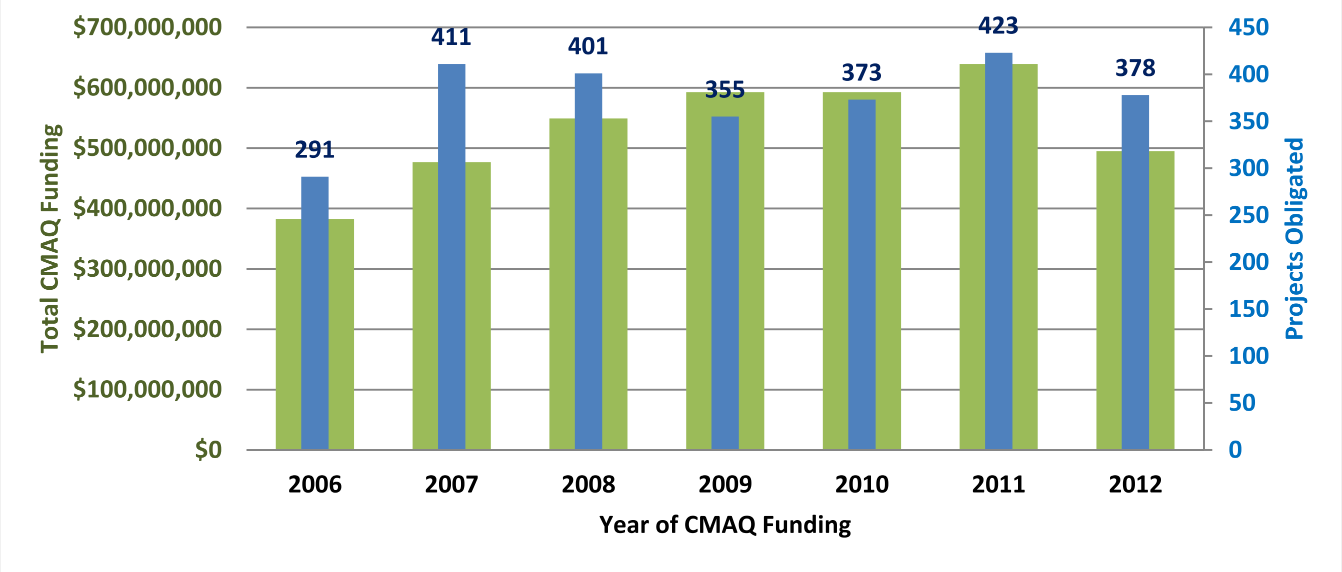

**Figure A-3. Funding and Number of CMAQ Projects per year in Traffic Flow Improvement Project Type**

## A.4 Intelligent Transportation Systems

This CMAQ study project type contains the three subcategories described below.

- General ITS: these projects integrate advanced technologies into the transportation infrastructure and vehicles to gather and relay real-time data to better coordinate and manage traffic. Examples of typical ITS projects include dynamic message signs, motorist assistance programs, traffic management centers, and incident response programs. The ITS also includes many other related improvement projects such as traffic signalization and freeway management systems. Specifically, these two ITS areas have had a significant number of projects with CMAQ funding. Therefore, the study team made the decision to separate traffic signalization and freeway management systems into subcategories of their own and to group other ITS-related projects into a general ITS subcategory.
- Freeway Management Systems: these projects are identified as a subcategory of the ITS project type that include physical assets, technologies, and strategies that are implemented to monitor and manage freeway traffic. Typical strategies, programs, and system components include, but are not limited to, ramp metering, incident management teams, safety patrols, dynamic signage, traffic management centers, and communication, detection and surveillance

devices. A large portion of projects in this subcategory are receiving funding to aid in the construction and/or operation of traffic management centers.

- Traveler Information Systems: projects within this subcategory focus on physical assets or services that provide real-time information on network performance to support better decision making by travelers choosing modes, times, routes, and locations. Much of the funds dedicated to projects in this subcategory involve either: (a) ITS infrastructure including utility, power, and communications systems; (b) interactive traveler services including radio, phone and Web site applications; or (c) expansion of commuter programs.

As shown previously in Figure 7, the ITS project type ranks fifth in funding and fifth in total projects obligated. Figure A-4 shows the total CMAQ funding and the number of projects obligated for the ITS project type during the 2006-2012 timeframe. Total funding fluctuated between $95 million and approximately double that amount, at $200 million per year, which occurred in 2008. The number of projects closely matched the funding fluctuation, with a low of 67, which was evenly doubled to a high of 134, which also occurred in 2008.

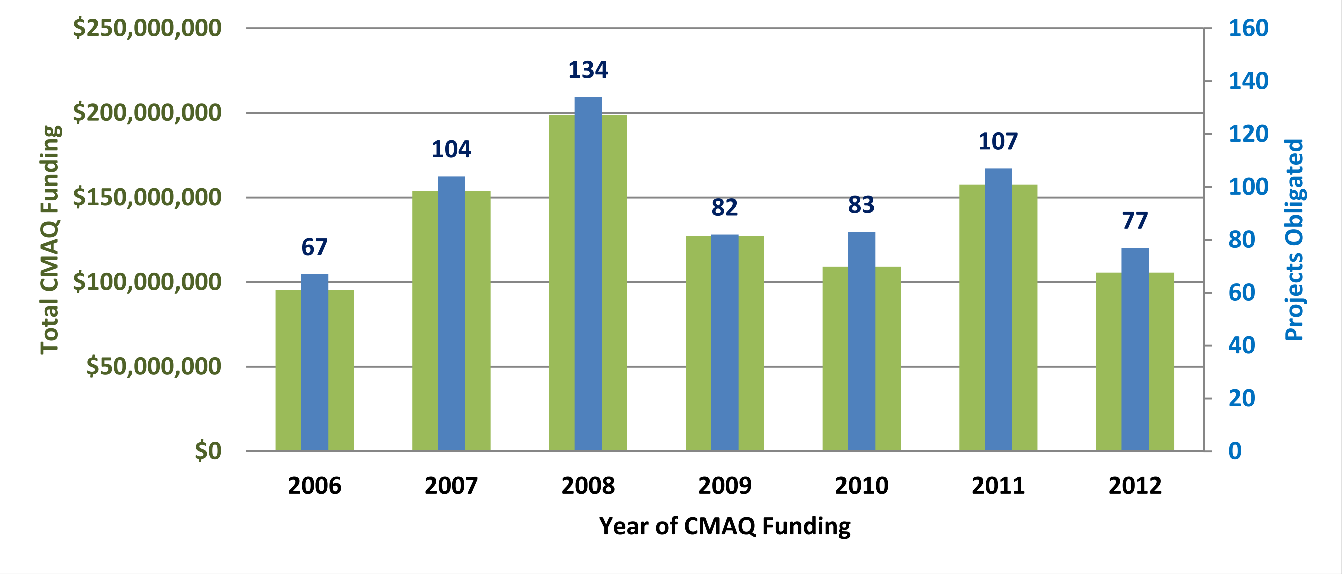

**Figure A-4. Funding and Number of CMAQ Projects per year in Intelligent Transportation Systems Project Type**

## A.5 Improved Public Transit

This CMAQ study project type contains the three subcategories described below.

- Transit Facilities, Systems, and Services: this subcategory includes projects associated with new or enhanced public transit. Since the Federal Transit Administration (FTA) administers most transit projects, some projects under this subcategory are managed by the FTA. The funds are transferred, or "flexed" from FHWA to FTA upon eligibility approval by the FTA. Typical projects in this subcategory tend to include: (a) transit fare collection systems; (b) new bus or rail equipment to increase capacity; (c) new or expanded transit infrastructure such as stations, shelters, platforms or bridges; or (d) station or commuter lot parking facilities. New transit service routes are also considered eligible for CMAQ funding; however, due to the number of and amount of CMAQ funding dedicated to these types of projects, the study team determined that a distinction should be made. Thus, these projects are included in separate subcategories for new bus services and new rail services.

- New Bus Services: projects within this subcategory focus on increasing bus transit capacity—through either implementation assistance or operating assistance for new bus service routes—with the end result being a likely increase in transit ridership ultimately reducing congestion and reducing emissions.
- New Rail Services: projects within this subcategory focus on increasing rail transit capacity—through either implementation assistance or operating assistance for new rail service routes—with the end result being a likely increase in transit ridership ultimately reducing congestion and reducing emissions.

The Improved Public Transit project type ranks second from the highest in funding and second from the lowest total projects obligated as shown previously in Figure 7. This dichotomy is not unexpected given the high capital cost of bus and rail transit projects. Figure A-5 shows the total CMAQ funding and the number of projects obligated for the Improved Public Transit project type during the 2006-2012 timeframe. Total funding per year varied between $135 million in 2006 and a high of $423 million in 2012. The number of projects varied between 69 and a high of 100, which occurred in 2007.

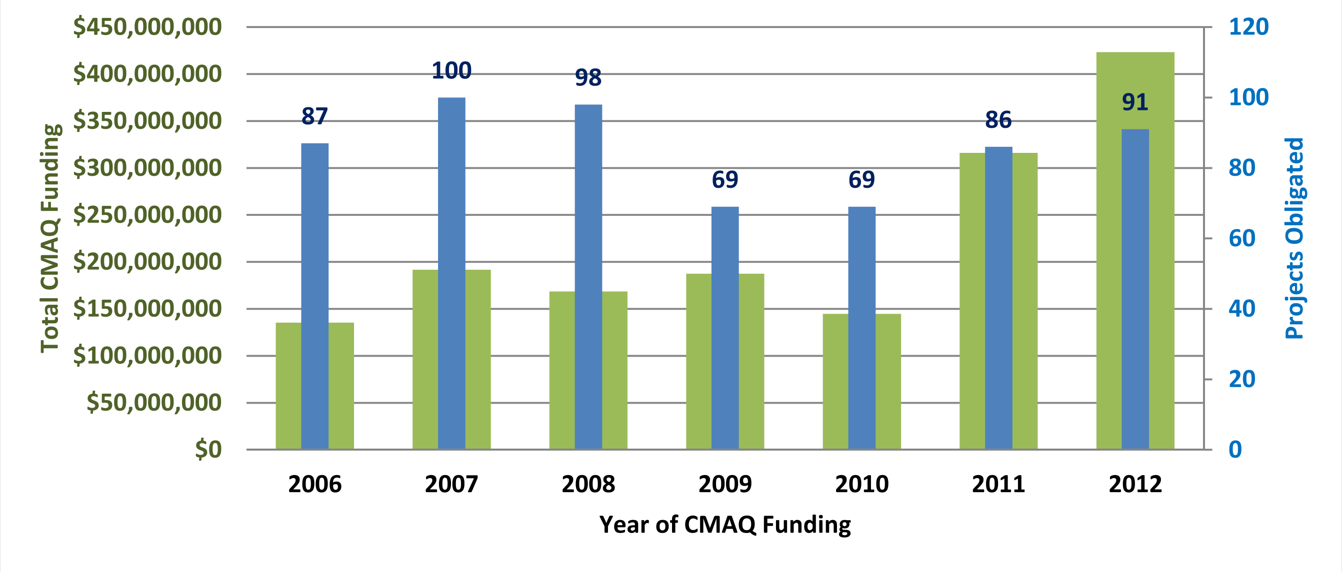

**Figure A-5. Funding and Number of CMAQ Projects per year in Improved Public Transit Project Type**

## A.6 Transportation Demand Management

This CMAQ study project type contains the five subcategories described below.

- Public Education/Outreach: These projects seek to educate the public, community leaders, and potential project sponsors about trip making and transportation mode choices, traffic congestion, and air quality. These efforts are geared toward helping communities reduce emissions and congestion by inducing drivers to change their transportation choices. These programs may include: (a) activities to promote new or existing transportation services; (b) development, placement, and evaluation of messages and advertising materials (including market research, focus groups, and creative); (c) technical assistance; (d) programs that promote commuter benefits; and e) transit “store” operations.
- TDM: this subcategory includes a broad range of projects to reduce SOV use. Similar to other subcategories, TDM projects aim to optimize the performance of the existing local and regional transportation networks, thereby reducing emissions. Separate subcategories within this study include TDM-related projects related to park and ride facilities, car sharing, public education and outreach, and value/congestion pricing. The projects detailed in this subcategory are intended to represent other similar types of TDM activities, which do not readily fit the aforementioned subcategories. Overall the projects within this subcategory can involve the following strategies:
    - Fringe parking
    - Traveler Information Services
    - Shuttle services
    - Guaranteed ride home programs
    - Carpools, vanpools
    - Traffic calming measures
    - Parking pricing
    - Variable road pricing
    - Telecommuting/Teleworking
    - Employer-based commuter choice programs
- Park and Ride Facilities: projects within this subcategory cover a wide variety of programs to encourage higher-occupancy modes and shared rides, reduce trips, and limit car travel. In particular, this subcategory includes fringe and transportation corridor parking facilities serving multiple-occupancy vehicle programs or transit service.
- Car Sharing: projects within this subcategory involve the pooling of vehicles for shared use by users who have an occasional as opposed to a daily need for vehicle travel. Car sharing programs must be able to demonstrate an emissions reduction in order to qualify for CMAQ funding under this subcategory.
- Value/Congestion Pricing: overall the projects within this subcategory could involve:
    - HOT lanes on which variable tolls are charged to drivers of low-occupancy vehicles using HOV lanes;
    - New variably tolled express lanes on existing toll-free facilities;
    - Variable tolls on existing or new toll roads;
    - Network-wide or cordon pricing;
    - Usage-based vehicle pricing, such as mileage-based vehicle taxation; and
    - Parking pricing with time-of-day variations reflecting congested conditions.

As shown previously in Figure 7, the TDM project type ranks sixth in funding, but third highest in total projects obligated. This is due to the fact that projects in this subcategory are often of lower costs. Figure A-6 shows the total CMAQ funding and the number of projects obligated for the TDM project type during the 2006-2012 timeframe. Total funding varied between approximately $60 million in 2006 and $160 million in 2010. The number of projects varied as well, with lows of 123 in 2010 and 2012, and a high of 186 in 2007.

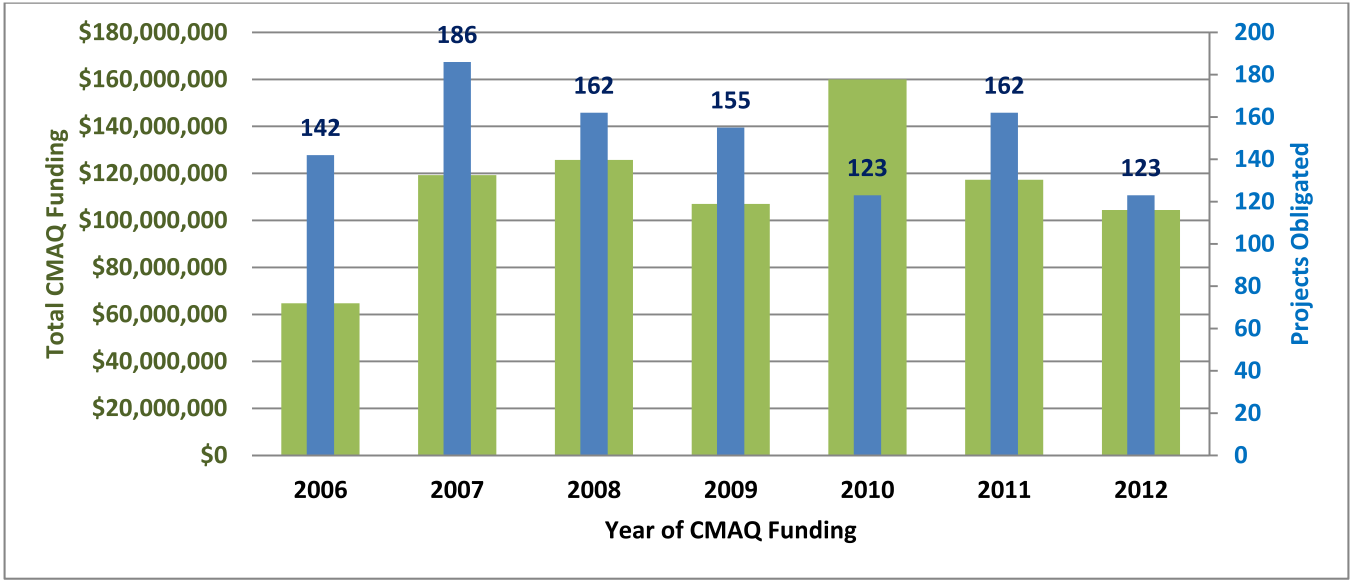

**Figure A-6. Funding and Number of CMAQ Projects per year in Transportation Demand Management Project Type**

## A.7 Other

This CMAQ study project type contains the five subcategories described below. These subcategories were grouped together because they did not readily fit one of the other major project types. There is little to no similarity among the subcategories themselves.

- Pedestrian/Bicycle: these projects and programs are designed to encourage and facilitate the use of non-motorized modes of transportation. These projects typically include:
    - The construction of pedestrian and bicycle lanes and paths;
    - Installation of bike racks, bike lockers, and support facilities;
    - Non-construction outreach related to safe bicycle use;
    - Establishing coordinator positions for marketing, public education, and safety programs.
- Dust Mitigation: the projects designed to mitigate dust are not explicitly identified as 1 of the 17 project types within the CMAQ funding eligibility guidance. However, a substantial number of projects within the CMAQ database (168, or 2 percent of the total) were identified as having a focus on dust mitigation. The majority of projects within this subcategory involve paving of unpaved surfaces (e.g., dirt roads, parking lots, shoulders), or the purchase of street

sweepers.  Other projects involve the use of dust suppressants (e.g., $MgCl_2$, $CaCl_2$) to treat unpaved roads.  These projects focused the emission reduction estimates on $PM_{10}$ (dust)—with 70 percent of the projects estimating improvements for that pollutant type.

- Freight/Intermodal:  the projects in this subcategory cover a wide range of technical areas from improvements to port facilities (i.e., shore power, rail improvements) and port operations (i.e., truck traffic reduction).  The MAP-21 CMAQ Interim program guidance explains that these emissions reduction projects fall generally into 2 categories:  primary efforts that target emissions directly or secondary projects that reduce net emissions.  Successful primary projects could include new diesel engine technology or retrofits of vehicles or engines. Secondary projects reduce emissions through modifications or additions to infrastructure and the ensuing modal shift.
- Innovative Projects:  this subcategory includes experimental type projects that seek to incorporate new strategies that better meet travel needs and also may show promise in reducing emissions, but do not yet have supporting data.  The FHWA has supported and funded some of these projects as demonstrations to determine their benefits and costs.  Such innovative strategies are not intended to bypass the definition of basic project eligibility, but seek to better define the projects' future role in strategies to reduce emissions.  An innovative project is expected to reduce emissions by decreasing VMT, fuel consumption, congestion, or by other factors.  Agencies are encouraged to creatively address their air quality problems and to consider new services, innovative financing arrangements, public-private partnerships, and complementary approaches that use transportation strategies to reach clean air goals.
- Other:  projects in this subcategory comprise those projects where a subcategory could not be definitively identified by the project description in the CMAQ database.  As such, the projects in this project type cover a wide variety of programs that span the entirety of the CMAQ program.

The projects listed as 'Other' type rank fourth in total funding, but second highest in total projects obligated as shown previously in Figure 7.  This difference is primarily due to the high number of lower cost pedestrian and bicycle projects.  Figure A-7 shows the total CMAQ funding and the number of projects obligated for the other project type during the 2006-2012 timeframe.  Total funding per year steadily increased from $92 million in 2006 to a high of $355 million in 2012.  The number of projects followed roughly the same strong upward trajectory from 160 projects in 2006 to a peak of 372 projects in 2011.

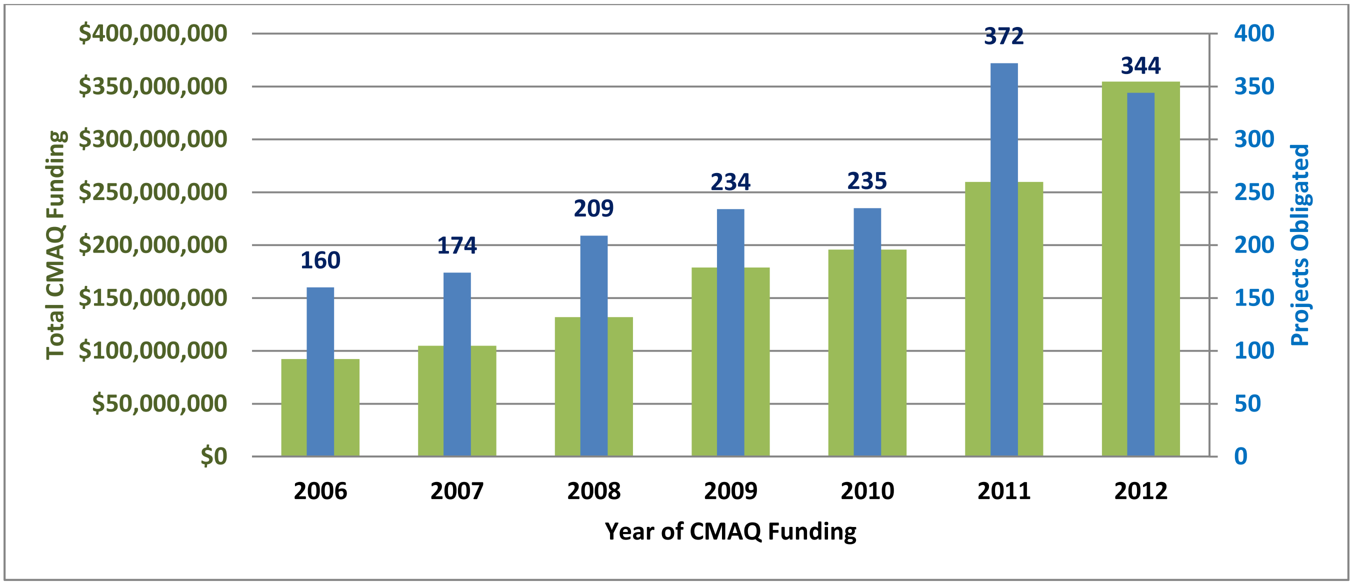

**Figure A-7. Funding and Number of CMAQ Projects per year in Other Project Type**

# Appendix B – Detailed Case Study Findings on CMAQ Project Outcomes

Additional information on the Case Study projects are included in this section, which includes an overview of projects in each subcategory, the geographic distribution of projects, the number and size of projects by year, and information about the estimated impacts. Note that there is considerable overlap between the categories and many projects could be classified into more than one category. For example, many of the projects included in the Conventional Bus and Paratransit Replacement category involve the purchase of alternative fuel vehicles (e.g., hybrid, CNG) but were not included in the Alternative Fuel Vehicles/Fueling Facilities category.

## B.1 Vehicle/Fuel Technology

### B.1.1 Alternative Fuel Vehicles/Fueling Facilities

#### B.1.1.1 Overview of Projects

Projects covering alternative fuel vehicles are explicitly identified as 1 of the 17 categories of projects eligible for funding under the CMAQ program. Overall the projects within this category generally involve either:

- the installation/upgrade of alternative fuel facilities;
- the purchase of alternative fuel vehicles; or in some limited situations,
- the purchase of alternative fuels.

The range of alternative fuels employed in these projects includes CNG, hybrid gas/electric, all electric, biodiesel, ethanol blended gasoline (e.g., E85), and liquefied petroleum gas (LPG). Approximately half of the over 400 projects in this category involved either the purchase of CNG fueled vehicles or the installation/upgrade of CNG handling infrastructure or fueling stations.

#### B.1.1.2 Distribution of Projects

Figure B-1 shows the distribution of the projects within the Alternative Fuel Vehicles/Fueling Facilities subcategory by State. The shading in each State shows the cumulative level of CMAQ funding obligated to projects in the subcategory between FY 2006 and FY 2012. The number of Alternative Fuel Vehicles/Fueling Facilities projects funded during this period is shown for each State. This figure shows alternative fuel projects were funded across much of the country, with relatively high funding levels on both coasts as well as in the Great Lakes region and in Texas.

Figure B-2 shows the number of projects started and the CMAQ funding for these projects for year during this timeframe. In general, projects in this category have been initiated at a relatively steady rate with the exception of a spike during FY 2009. The CMAQ funding during this period has been

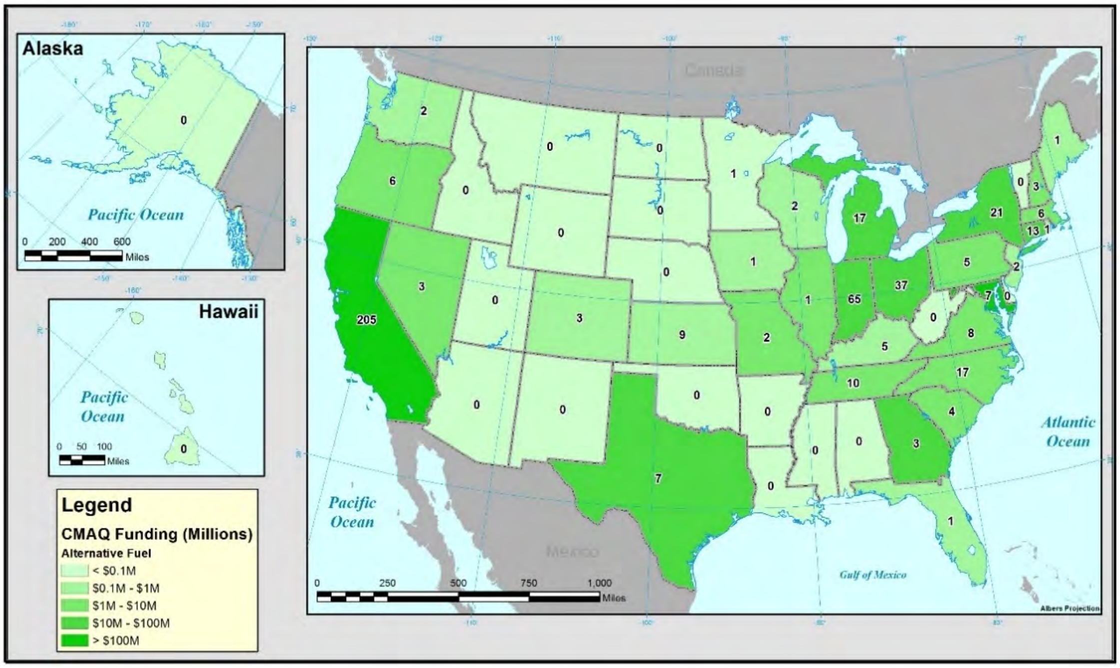

Figure B-1. Distribution of Projects and Funding for Alternative Fuel Vehicles/Fueling Facilities by State

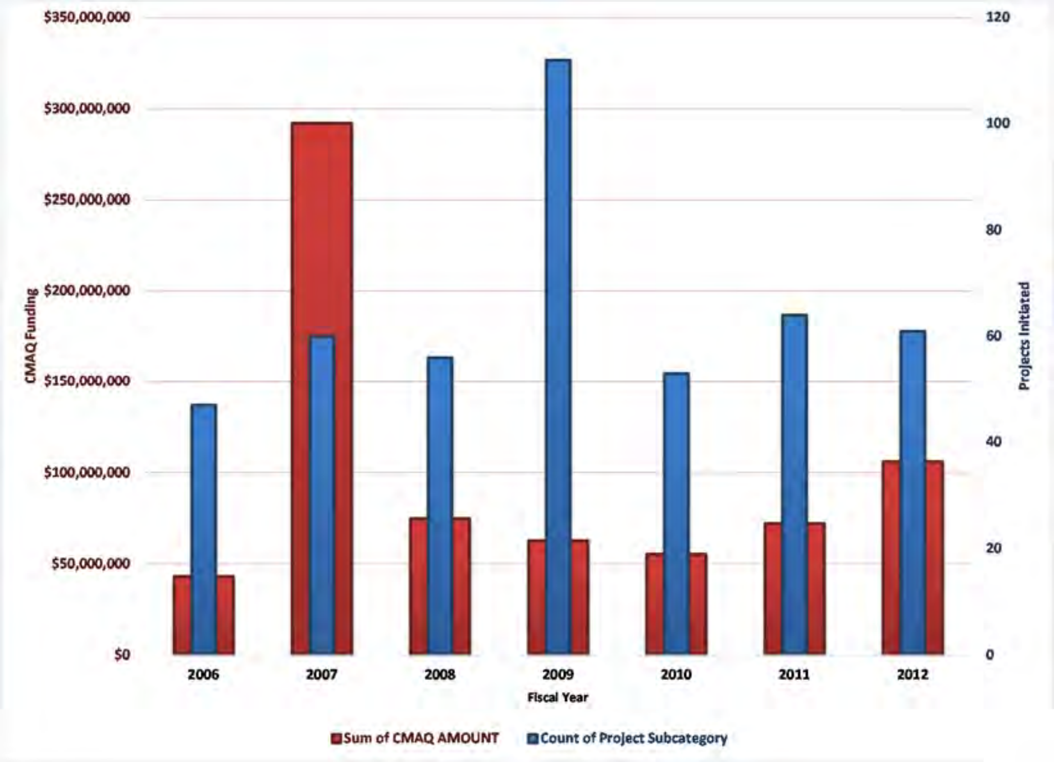

Figure B-2. Number of Alternative Fuel Vehicles/Fueling Facilities Projects Initiated Per Year generally increasing. The spike in the funding that occurred during FY 2007 is largely attributed to three large bus replacement projects, which collectively accounted for approximately $200 million.

### B.1.1.3 Impacts of Case Study Projects

Table B-1 summarizes the five case studies that were analyzed for this subcategory. The projects represent a good cross section of project types in this category—including three projects for the purchase of CNG buses, one project for the purchase of hybrid fleet vehicles, and one project for the purchase of alternative fuel.

**Table B-1. Summary of Alternative Fuel Vehicles/Fueling Facilities Case Studies**

| CMAQ ID | State | CMAQ Funding | Total Funding | Description |
|---|---|---|---|---|
| CA20060085 | California | $1,600,000 | $1,808,000 | B-Line CNG Bus Purchase (4) |
| CA20070042 | California | $1,584,700 | $3,132,700 | Clovis Unified CNG School Buses (10) |
| CA20070201 | California | $29,704,536 | $38,850,025 | Purchase CNG Refuse Trucks (14) |
| IN20090052 | Indiana | $754,000 | $754,000 | Gary Hybrid Small SUV's (26) |
| OH20090147 | Ohio | $1,109,419 | $1,109,419 | LUC TARTA Biodiesel Fuel Purchase |

#### Traffic/Congestion Mitigation Impacts

Since the projects in this category largely involve the replacement of aging vehicles or the addition of new vehicles to the fleet, they are unlikely to significantly impact general traffic patterns or mitigate congestion, except to the extent that new transit vehicles encourage additional ridership. Similarly, the alternative fuel purchase would not have travel impacts.

Accordingly, in all five case studies there were no impacts on traffic/congestion mitigation indicated.

#### Emissions/Air Quality Impacts

Emission reductions estimates in this category typically are based on the lower emission rates of the alternative fuel vehicles relative to the vehicles being replaced and not on changes in ridership or diversion from private vehicles. The reduction in emissions can be estimated for a given project using appropriate emission factors for the traditional fuels and the alternative fuels.

Table B-2 presents the estimated emissions reductions for VOCs, CO, NOx, $PM_{10}$ and $PM_{2.5}$ for each of the Alternative Fuel Vehicles/Fueling Facilities case studies.

Analysis of these five case studies indicated that these individual projects were likely to have the following impacts on vehicle emissions and air quality:

- All projects predicted reductions in at least one pollutant—two estimated reductions for two pollutants and two estimated for four pollutants.
- Four of the five projects predicted significant reduction in NOx emissions.

### Table B-2. Estimated Emissions Reductions for Alternative Fuel Vehicles/Fueling Facilities Case Studies

| CMAQ ID | Year(s) | Estimated Emissions Reductions (kg/day) | | | | |
|---|---|---|---|---|---|---|
| | | VOC | CO | NOx | $PM_{10}$ | $PM_{2.5}$ |
| CA20060085 | 2006 | NR | NR | 26.0 | 0.27 | NR |
| CA20070042 | 2007 | NR | NR | 8.72 | 0.48 | NR |
| CA20070201 | 2007 | NR | NR | 2.19 | 0.00 | NR |
| IN20090052 | 2009 | 0.26 | 0.37 | 0.00 | NR | 6.44 |
| OH20090147 | 2009 | 0.58 | 4.90 | 1.03 | 0.44 | NR |

NR - Not reported

**Human Health Impacts**

Of the five alternative fuel case studies evaluated, none reported human health impacts in the selection process.

## B.1.2 Conventional Bus and Paratransit Replacements

### B.1.2.1 Overview of Projects

The replacement of conventional buses and paratransit vehicles fall under the Transit Improvement category of projects eligible for CMAQ funding. However, because of the relatively high number of bus/paratransit replacement projects and the amount of CMAQ funding obligated to these projects, the project team has included these projects as a standalone category to be assessed. This category encompasses projects that involve engine retrofits of existing school buses and the replacement of transit bus and paratransit vehicles to expand the existing fleet or to replace aging vehicles within the fleet with cleaner, lower emitting vehicles.

### B.1.2.2 Distribution of Projects

Figure B-3 shows the distribution of the projects within the Conventional Bus and Paratransit Replacements subcategory by State. The shading in each State shows the cumulative level of CMAQ funding obligated to projects in the subcategory between FY 2006 and FY 2012, which totaled over $538 million. All 353 Conventional Bus and Paratransit Replacement projects funded during this period is shown for each State. This figure shows Conventional Bus and Paratransit Replacement projects were funded across much of the country, with particularly high numbers in the Great Lakes region. The highest funding levels were in Ohio and Pennsylvania, and nearly 30 percent of the projects during this period were in Michigan.

Figure B-4 shows the number of projects started and the CMAQ funding for these projects for each year during this timeframe. In general, projects in this subcategory have been initiated at a relatively steady rate of approximately 40 projects per year with the exception of a spike during FY 2008 and FY 2009. The CMAQ funding for these projects shows a generally increasing trend during this period from $55 million in FY 2006 to a high of over $100 million in FY 2011, with the exception of a dip in funding under $54 million during FY 2010.

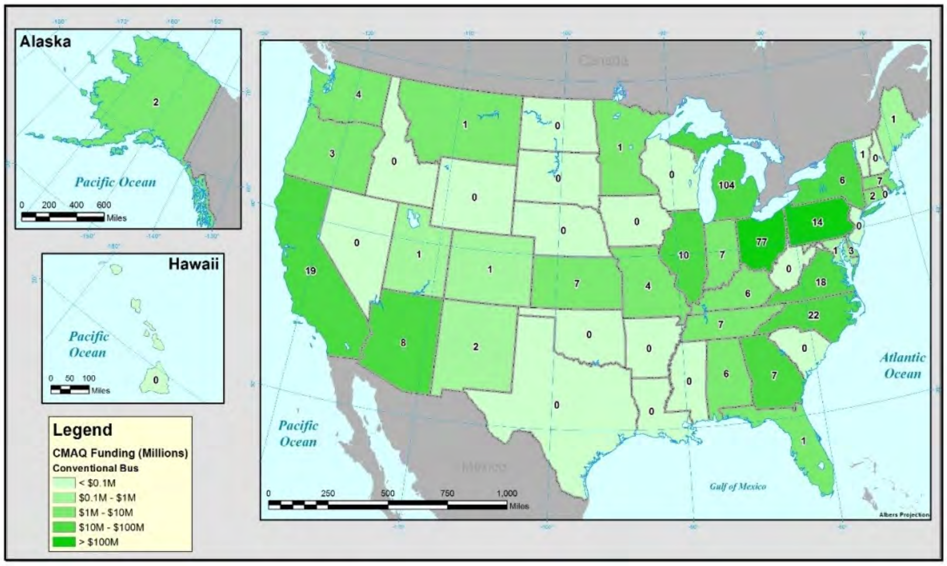

Figure B-3. Distribution of Projects and Funding for Conventional Bus and Paratransit Replacements by State

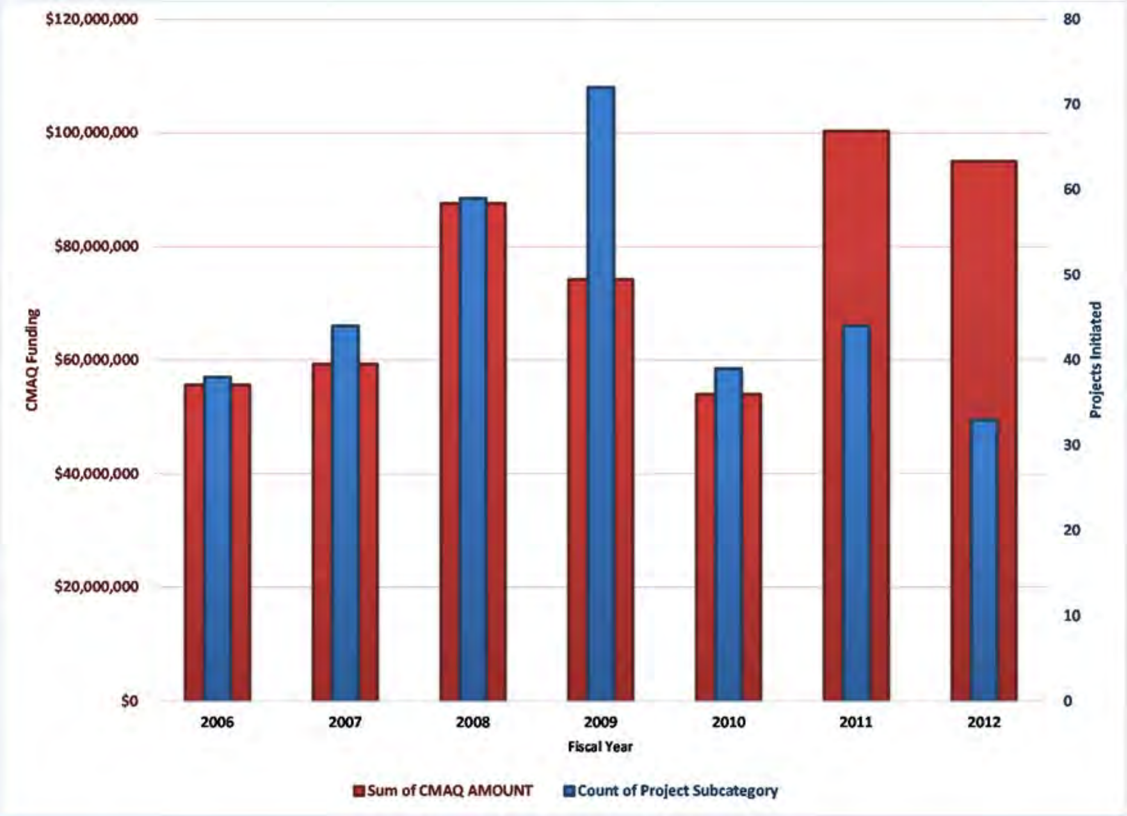

Figure B-4. Number of Conventional Bus and Paratransit Replacement Projects Initiated Per Year

### B.1.2.3 Impacts of Case Study Projects

Table B-3 summarizes the case studies that were analyzed for this subcategory.

**Table B-3. Summary of Conventional Bus and Paratransit Replacement Case Studies**

| CMAQ ID | State | CMAQ Funding | Total Funding | Description |
|---|---|---|---|---|
| IL20120183 | Illinois | $1,218,000 | $1,522,500 | Purchase seven biodiesel buses to replace older buses with cleaner burning, fuel saving, and reduced emissions vehicles. |
| MI20070111 | Michigan | $823,062 | $1,043,518 | Purchase up to eight CNG buses for the replacement of older, conventional buses. |
| TN20120006 | Tennessee | $3,600,000 | $3,600,000 | Purchase six diesel hybrid electric buses with 30% better fuel efficiency than older buses that will be replaced |

**Traffic/Congestion Mitigation Impacts**

As with the alternative fuel projects, the projects in this subcategory involve the replacement of aging vehicles or the addition of new vehicles to the fleet so they are unlikely to significantly impact general traffic patterns or mitigate congestion, except to the extent that new transit vehicles encourage additional ridership.

Of the three case studies examined, no changes were expected from two projects, where the sponsors noted that funds were used to replace existing buses that were operating on existing routes. Tennessee noted that a 7 percent increase in unlinked transit trips were expected versus the previous year; however, this value is not likely to be directly attributable to the case study project. Illinois also indicated that the new biodiesel buses provide increased capacity and comfort amenities that could potentially increase transit ridership and reduce vehicle trips and VMT.

**Emissions/Air Quality Impacts**

Emission reductions estimates in this subcategory typically are based on the lower emission rates of the alternative fuel vehicles relative to the vehicles being replaced and not on changes in ridership or diversion from private vehicles. The reduction in emissions can be estimated for a given project using appropriate emission factors for the traditional vehicles and the alternative fuel or hybrid vehicles.

Table B-4 presents the estimated emissions reductions for VOCs, CO, NOx, $PM_{10}$ and $PM_{2.5}$ for the Conventional Bus and Paratransit Replacement case studies.

### Table B-4. Estimated Emissions Reductions for Conventional Bus and Paratransit Replacement Case Studies

| CMAQ ID | Year(s) | Estimated Emissions Reductions (kg/day) | | | | |
|---|---|---|---|---|---|---|
| | | VOC | CO | NOx | $PM_{10}$ | $PM_{2.5}$ |
| IL20120183 | 2006 | 0.0014 | NR | 0.065 | NR | NR |
| MI20070111 | 2008-2013 | 0.10 | 1.17 | 6.46 | NR | 0.06 |
| TN20120006 | 2006 | NR | QA | QA | NR | QA |

NR - Not reported
QA – Qualitative estimate

All three projects estimated a reduction in pollutants for which calculations were conducted. Analysis of these case studies indicated that these individual projects were likely to have the following impacts on vehicle emissions and air quality:

- The Illinois project used a local East-West Gateway model to estimate a 10 percent reduction in VOCs and 4 percent reduction of NOx based on emissions generated from the old versus the replacement bus.
- The Michigan project estimated over 90 percent reductions in four emissions based on calculations using the Mobile 6 spreadsheet for the 697,043 miles traveled by the new CNG vehicles from 2008-2013 versus the emissions from diesel vehicles for the same mileage.
- The Tennessee project estimated 90 percent reductions in $PM_{2.5}$ and 50 percent reductions in NOx and CO based on industry literature on diesel hybrid electric buses versus the traditional diesel buses that were replaced. The new buses have 30 percent better fuel efficiency.

#### Human Health Impacts

Of the three case studies evaluated, only one reported human health impacts in the selection process. The Tennessee project expected an increase in transit ridership, which would promote a safer travel mode than car travel with fewer injuries and property damage and improved air quality associated with both reduced car trips and cleaner bus technology. Additionally, the project application noted that cleaner air and walking to the bus stop improves overall physical health of the local population and that transit promotes access equity for an area by expanding general mobility.

### B.1.3 Diesel Engine Retrofits

#### B.1.3.1 Overview of Projects

SAFETEA-LU placed an emphasis on funding projects involving diesel engine retrofits and other advanced truck technologies. MAP-21 continues this emphasis and expands the focus to specifically identify diesel retrofits as eligible projects. The projects within this category, which falls under alternate fuels and vehicles, typically include:

- The purchase and installation of after-treatment hardware (e.g., diesel particulate filters, oxidation catalysts, etc.),
- Repowering,

- Engine rebuilding, and
- Other emission reducing technologies.

The majority of the diesel retrofit projects funded since FY 2006 have included the installation of diesel particulate filters.

### B.1.3.2 Distribution of Projects

Figure B-5 shows the distribution of the projects within the Diesel Engine Retrofits subcategory by State. The shading in each State shows the cumulative level of CMAQ funding obligated to projects in the category between FY 2006 and FY 2012. The 97 Diesel Engine Retrofits projects funded during this period is shown for each State. This figure shows alternative fuel projects were funded across the country, with the highest number of projects in California and Oregon on the west coast, Michigan and Ohio in the Great Lakes region, and Georgia on the east coast. California, Massachusetts, and Georgia received relatively high funding levels.

Figure B-6 shows the number of projects started and the CMAQ funding for these projects for year during this timeframe. In general, projects increased to a peak of 27 projects funded at over $18 million in FY 2009 from a single project funded at $640,000. Since FY 2009, the number of projects and funding levels have tended to decrease, with 11 projects funded at $3.6 million in FY 2012.

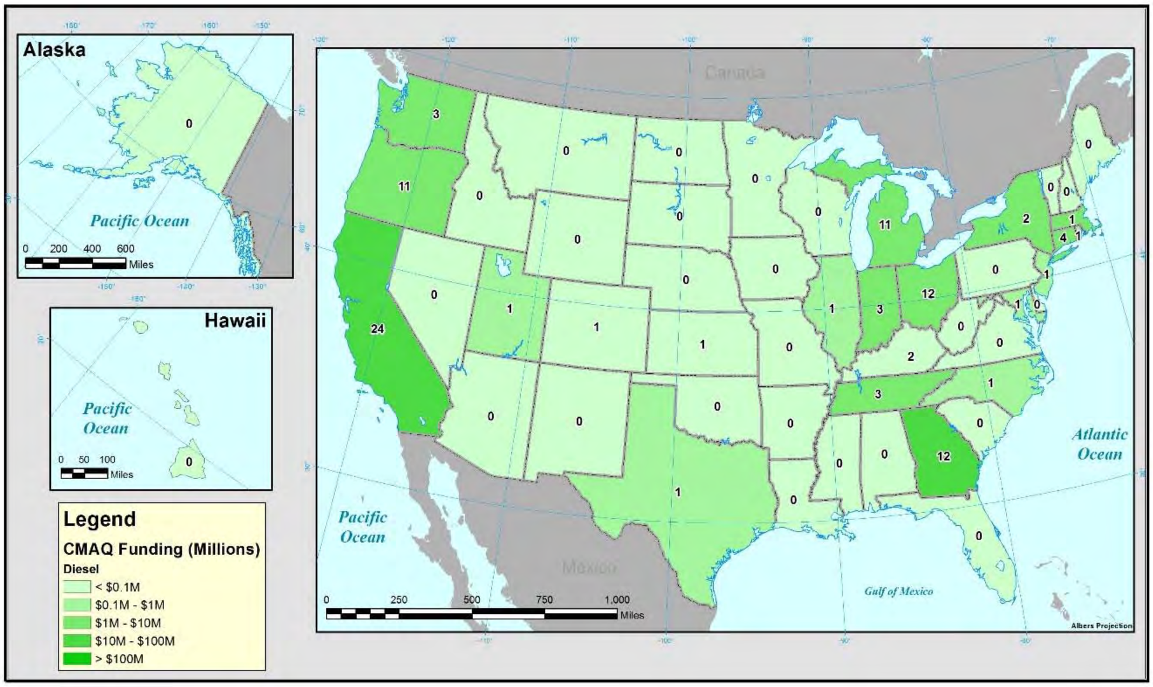

**Figure B-5. Distribution of Projects and Funding for Diesel Engine Retrofit by State**

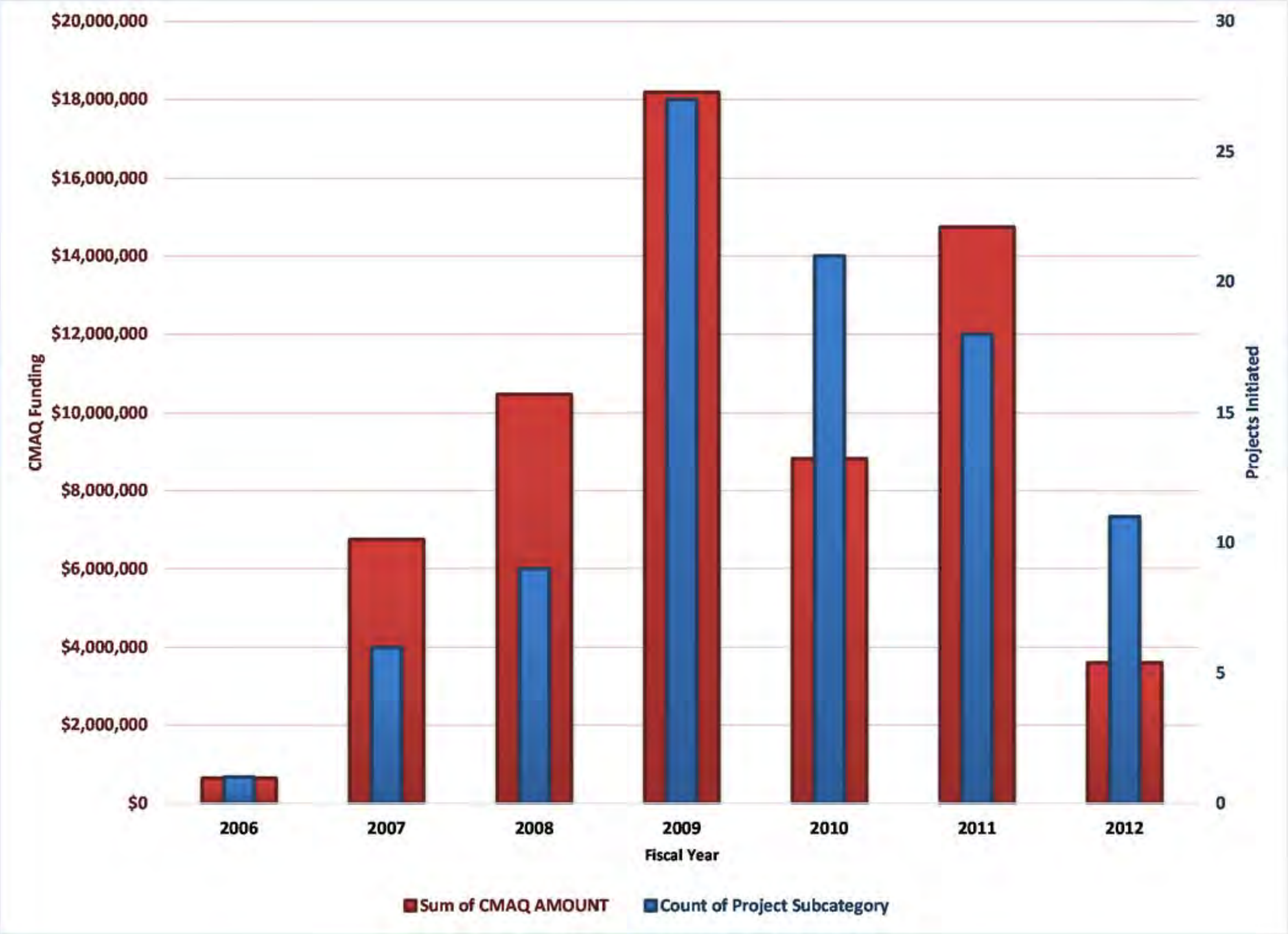

Figure B-6. Number of Diesel Engine Retrofit Projects Initiated Per Year

### B.1.3.3 Impacts of Case Study Project

Table B-5 summarizes the case study that was analyzed for this category.

**Table B-5. Summary of Diesel Engine Retrofit Case Study**

| CMAQ ID | State | CMAQ Funding | Total Funding | Description |
|---|---|---|---|---|
| NC20060043 | North Carolina | $640,000 | $800,000 | Charlotte Mecklenburg City Install particulate filters on 90 buses |

### Traffic/Congestion Mitigation Impacts

Since the projects in this category involve the retrofitting of filters on existing vehicles, they are unlikely to significantly impact general traffic patterns or mitigate congestion.

No traffic/congestion impacts were considered in the selection process for the case study project.

**Emissions/Air Quality Impacts**

Emission reductions estimates in this category typically are based on the lower emission rates of the vehicles with filters relative to the vehicles not experiencing any changes. The reduction in emissions can be estimated for a given project using modeling emissions from typical conditions versus the modified condition.

The Diesel Engine Retrofit project reported an estimated reduction in emissions for all pollutants.

Table B-6 presents the estimated emissions reductions for VOCs, CO, and $PM_{2.5}$ for the Diesel Engine Retrofit case study.

**Table B-6. Estimated Emissions Reductions for the Diesel Engine Retrofit Case Study**

| CMAQ ID | Year(s) | Estimated Emissions Reductions (kg/day) | | | | |
|---|---|---|---|---|---|---|
| | | VOC | CO | NOx | $PM_{10}$ | $PM_{2.5}$ |
| NC20060043 | 2004 | 2.64 | 27.15 | 0 | 0 | 12.1 |

Analysis of this case study indicated that this individual project was likely to have the following impacts on vehicle emissions and air quality:

- The EPA MOBILE 6 model showed reductions in VOC, CO, and $PM_{2.5}$ based on an average vehicle mileage of 50,000 miles per bus for 90 buses. NOx is assumed to be unaffected by the particulate filters.

**Human Health Impacts**

No human health impacts were reported in the selection process for the case study project.

## B.2 Vehicle Activity Programs

### B.2.1 Idle Reduction

### B.2.1.1 Overview of Projects

Projects covering idle reduction are explicitly identified as 1 of the 17 categories of projects eligible for funding under the CMAQ program. Overall the projects within this category generally involve either:

- On-board idle reduction devices on vehicles that will primarily the nonattainment or maintenance area;
- Off-board idle reduction facilities within nonattainment or maintenance areas.

These projects typically apply to heavy-duty trucks and may include truck stop electrification efforts or on-board devices such as auxiliary power units or direct fired heaters.

### B.2.1.2 Distribution of Projects

Figure B-7 shows the distribution of the projects within the Idle Reduction category by State. The shading in each State shows the cumulative level of CMAQ funding obligated to projects in the category between FY 2006 and FY 2012. The 13 Idle Reduction projects funded during this period is shown for each State. This figure shows Idle Reduction projects were funded across the country, with relatively high funding levels for Georgia, Maryland, and Texas.

Figure B-8 shows the number of projects started and the CMAQ funding for these projects for year during this timeframe. In general, projects in this category have been decreasing, with four projects initiated in FY 2006 to only a single project initiated each in FY 2011 and FY 2012. The CMAQ funding during this period has been generally decreasing from over $4.4 million in FY 2006 to only $200,000 in FY 2012.

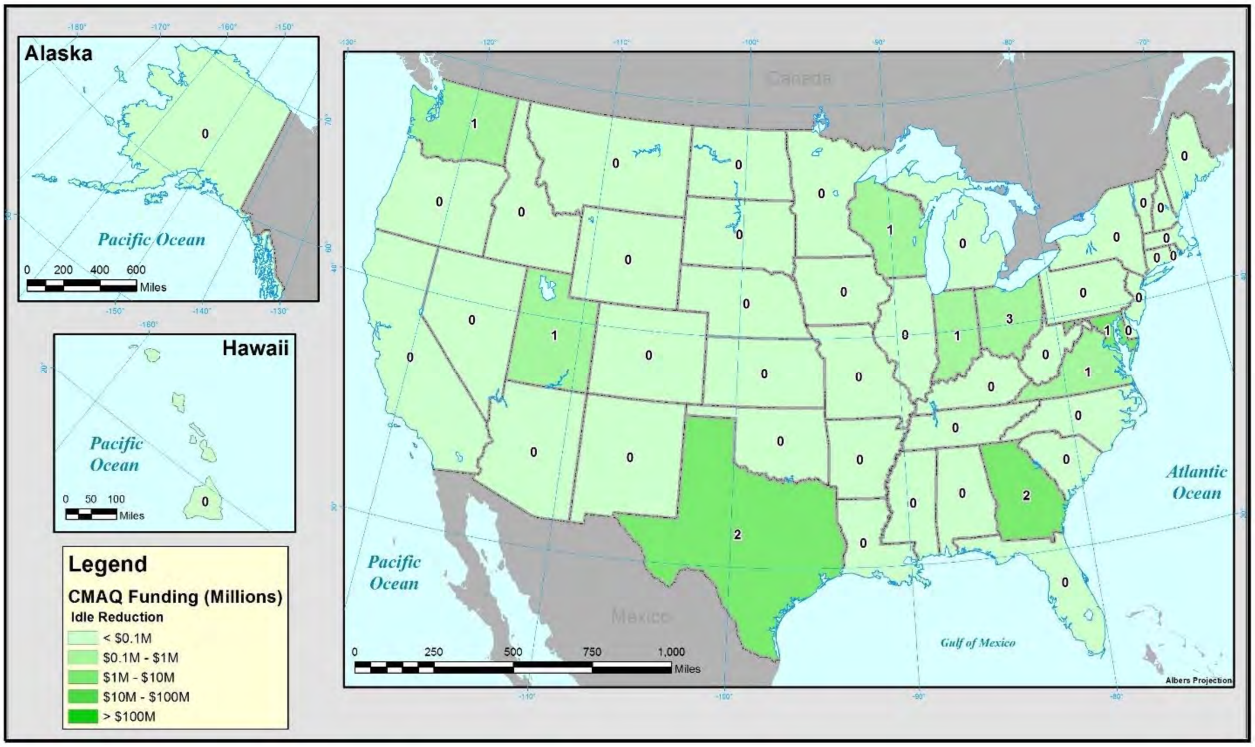

**Figure B-7. Distribution of Projects and Funding for Idle Reduction by State**

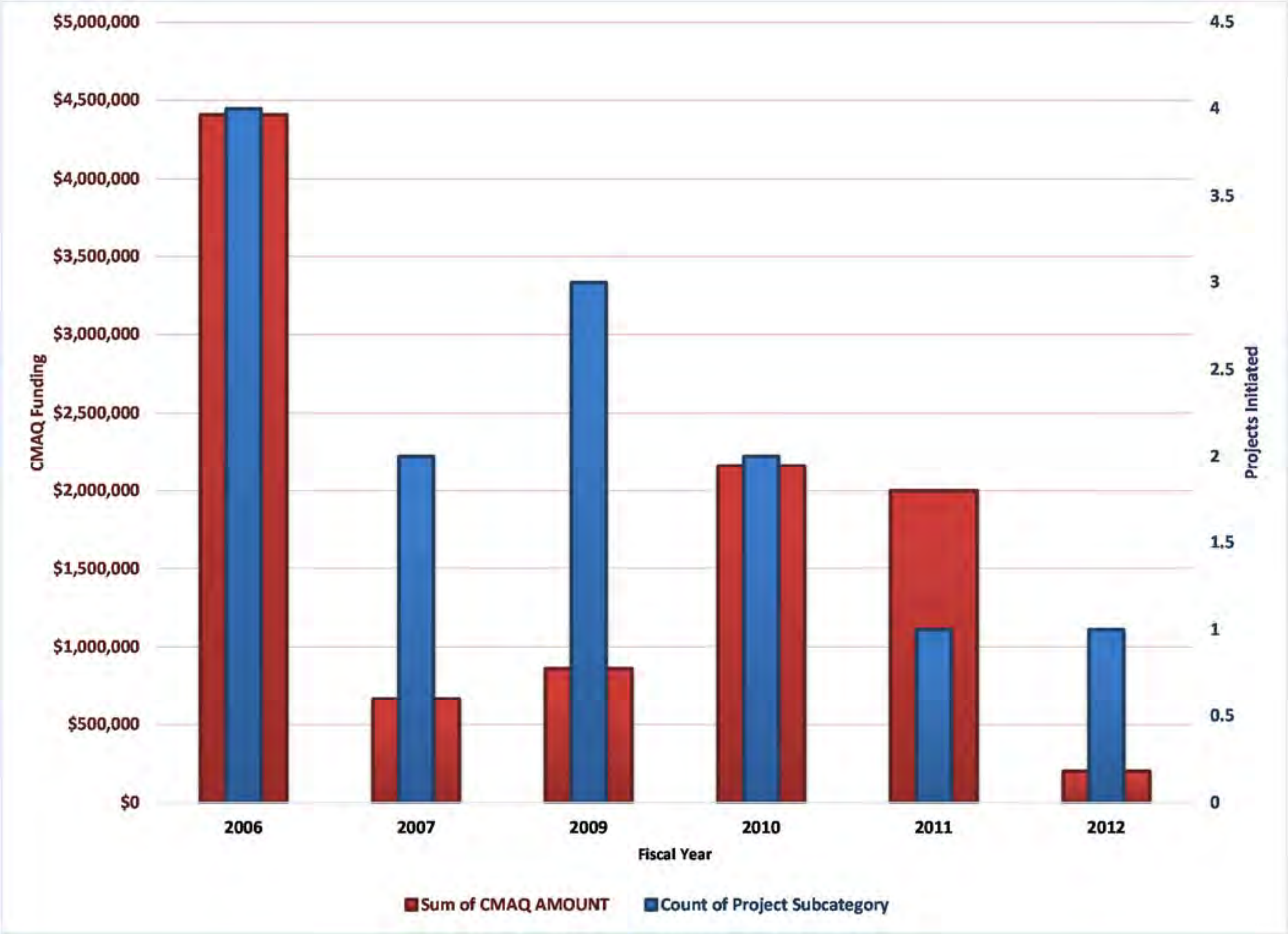

Figure B-8. Number of Idle Reduction Projects Initiated Per Year

### B.2.1.3 Impacts of Case Study Project

Table B-7 summarizes the case study that was analyzed for this category.

**Table B-7. Summary of Idle Reduction Case Study**

| CMAQ ID | State | CMAQ Funding | Total Funding | Description |
|---|---|---|---|---|
| OH20090131 | Ohio | $86,720 | $108,400 | Retrofit of 30 existing vehicles with 19 Engine and Hydraulic System Heaters and 11 Engine Pre-Heaters |

#### Traffic/Congestion Mitigation Impacts

Since the projects in this category largely involve the reduction of idling on existing vehicles, they are unlikely to significantly impact general traffic patterns or mitigate congestion.

No traffic/congestion impacts were considered in the selection process for the case study project.

**Emissions/Air Quality Impacts**

Emission reductions estimates in this category typically are based on the lower emission rates of the vehicles relative to the vehicles not experiencing any changes to reduce idling. The reduction in emissions can be estimated for a given project using modeling emissions from typical conditions versus the modified, anti-idling condition.

The idle reduction project reported an estimated reduction in emissions for two pollutants.

Table B-8 presents the estimated emissions reductions for VOCs, CO, NOx, $PM_{10}$ and $PM_{2.5}$ for the Idle Reduction case study.

**Table B-8. Estimated Emissions Reductions for the Idle Reduction Case Study**

| CMAQ ID | Year(s) | Estimated Emissions Reductions (kg/day) | | | | |
|---|---|---|---|---|---|---|
| | | VOC | CO | NOx | $PM_{10}$ | $PM_{2.5}$ |
| OH20090131 | 2008 | NR | NR | 3.252 | NR | 0.086 |

NR - Not reported

Analysis of this case study indicated that this individual project was likely to have the following impacts on vehicle emissions and air quality:

- Reductions in both NOx and $PM_{2.5}$ when modeling emissions from typical vehicles versus vehicles with anti-idling devices.

**Human Health Impacts**

The case study that was evaluated did not report human health impacts in the selection process.

## B.2.2 Extreme Low-Temperature Cold Start Programs

### B.2.2.1 Overview of Projects

Projects covering idle reduction are explicitly identified as 1 of the 17 categories of projects eligible for funding under the CMAQ program. These projects are intended to reduce emissions from extreme cold-start conditions and include retrofitting vehicles and fleets with water and oil heaters and installing electrical outlets and equipment in publicly-owned garages or fleet storage facilities.

### B.2.2.2 Distribution of Projects

Figure B-9 shows the distribution of the projects within the Extreme Low-Temperature Cold Start category by State. The shading in each State shows the cumulative level of CMAQ funding obligated to projects in the category between FY 2006 and FY 2012. The eight Extreme Low-Temperature Cold

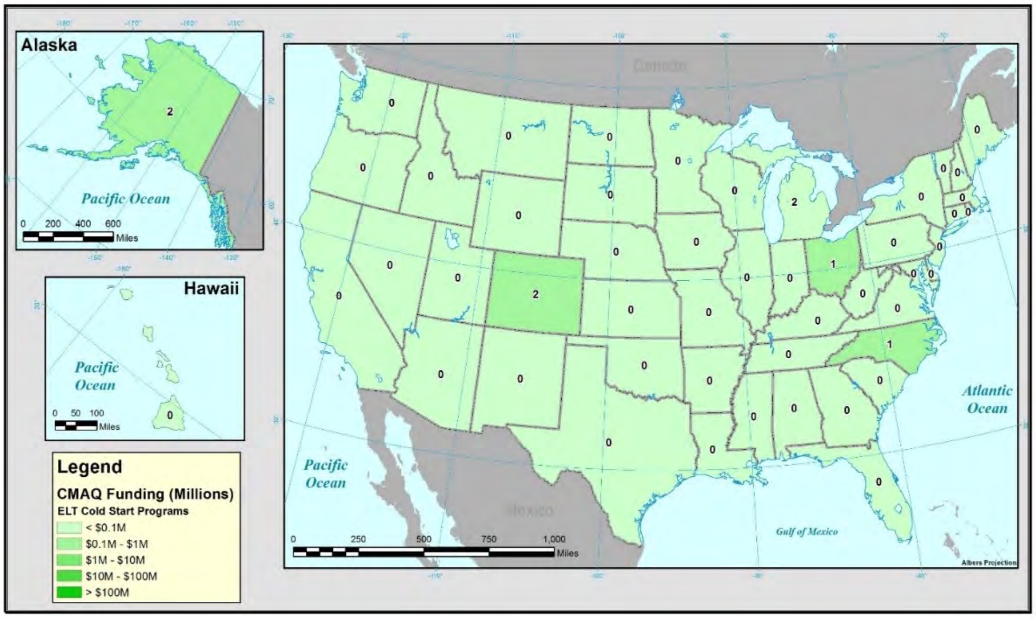

**Figure B-9. Distribution of Projects and Funding for Extreme Low-Temperature Cold Start by State**

Start projects funded during this period is shown for five States. This figure shows these projects were funded across the country, with relatively high funding levels for Alaska.

Figure B-10 shows the number of projects started and the CMAQ funding for these projects for year during this timeframe. In general, in years where projects are initiated, one to three projects have been initiated with funding amounts that have ranged from just over $12,000 to over $470,000. No projects were initiated in FY 2007 and FY 2008.

### B.2.2.3 Impacts of Case Study Project

Table B-9 summarizes the case study that was analyzed for this category.

**Traffic/Congestion Mitigation Impacts**

Since the projects in this category largely involve the reduction of starting existing vehicles, they are unlikely to significantly impact general traffic patterns or mitigate congestion.

No traffic/congestion impacts were considered in the selection process for the case study project.

**Emissions/Air Quality Impacts**

Emission reductions estimates in this category typically are based on the lower emission rates of the vehicles relative to the vehicles not experiencing any changes to reduce idling. The reduction in emissions can be estimated for a given project using modeling emissions from typical conditions versus the modified, anti-idling condition.

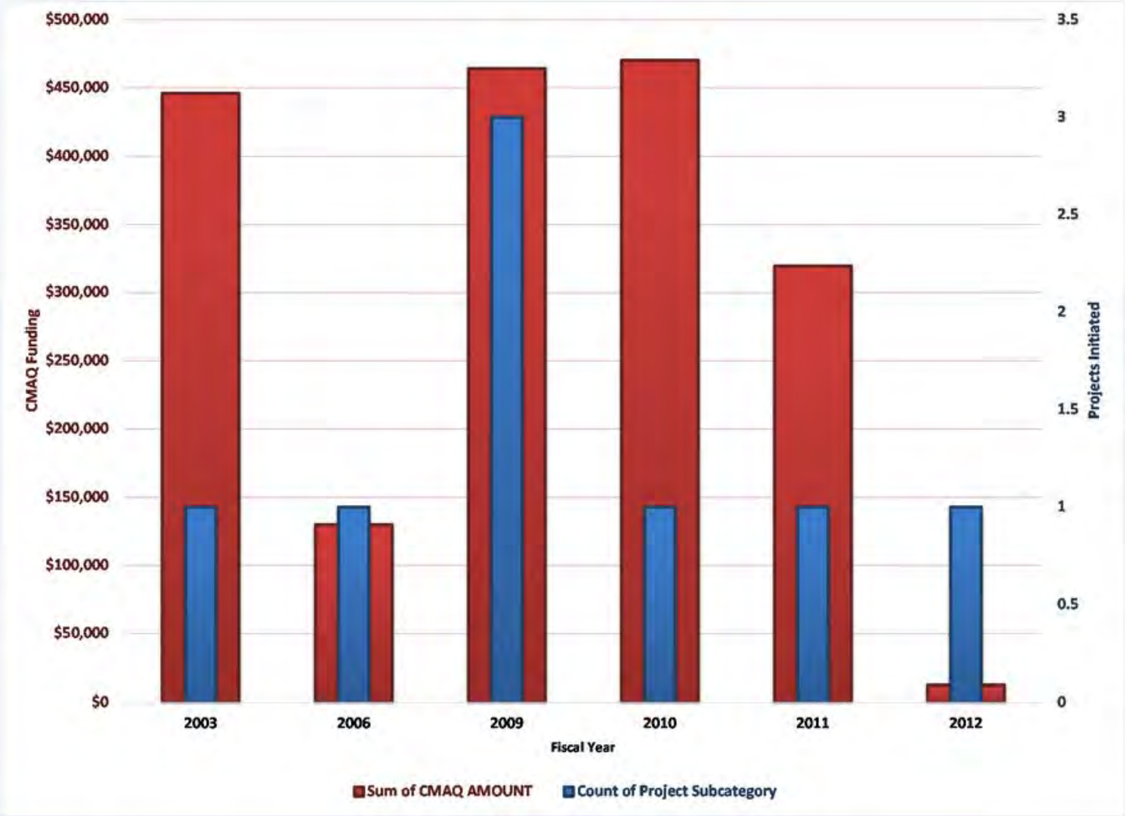

**Figure B-10. Number of Extreme Low-Temperature Cold Start Projects Initiated Per Year**

**Table B-9. Summary of Extreme Low-Temperature Cold Start Case Study**

| CMAQ ID | State | CMAQ Funding | Total Funding | Description |
|---|---|---|---|---|
| AK20030003 | Alaska | $481,371 | $481,371 | Retrofit of 30 existing vehicles with 19 Engine and Hydraulic System Heaters and 11 Engine Pre-Heaters |

The Extreme Low-Temperature Cold Start project reported an estimated reduction in emissions for two pollutants.

Table B-10 presents the estimated emissions reductions for VOCs, CO, NOx, $PM_{10}$ and $PM_{2.5}$ for the Extreme Low-Temperature Cold Start case study.

**Table B-10. Estimated Emissions Reductions for the Extreme Low-Temperature Cold Start Case Study**

| CMAQ ID | Year(s) | Estimated Emissions Reductions (kg/day) | | | | |
|---|---|---|---|---|---|---|
| | | VOC | CO | NOx | $PM_{10}$ | $PM_{2.5}$ |
| AK20030003 | 2006 | NR | 998 | NR | NR | NR |

NR - Not reported

Analysis of this case study indicated that this individual project was likely to have the following impacts on vehicle emissions and air quality:

- Estimated reductions of CO amounted to 2204 pounds of CO reduction per winter day due to the number of installations and estimated heater usage, which includes the benefit of installations performed over three years. Reduction of overall CO is less than 1%, but this improvement is a reduction of 4.3% for warm-up idle emissions only. Modeling indicates that warm-up idling accounts for over 50% of CO in some locales, so benefits occur where they are desired.

**Human Health Impacts**

The case study project reported environmental, physical and mental health, and equity impacts. Specifically, the case study examined the added costs for electricity for block heater use, which would be offset by improvements in fuel economy. Programmable timers were sometimes distributed with the heaters to increase convenience and minimize electrical costs. The block heaters were recommended to families who were new to the area, especially spouses of military personnel. For most installations, the cost to the car owners to install the heaters was $25 each.

## B.3 Traffic Flow Improvements

### B.3.1 Traffic Signalization

#### B.3.1.1 Overview of Projects

Projects covering traffic signalization fall under the subcategory of ITS of the CMAQ program category, Congestion Reduction and Traffic Flow Improvements. However, due to the high number of projects and the amount of CMAQ funding received for projects of this nature, the project team has identified traffic signalization as a stand along category for evaluation. Traffic signalization projects typically involve one or more of the following:

- Outfitting of an intersection with traffic signals,
- Traffic signal synchronization in a network,
- Traffic signal timing projects.

#### B.3.1.2 Distribution of Projects

Figure B-11 shows the distribution of the projects within the Traffic Signalization subcategory by State. The shading in each State shows the cumulative level of CMAQ funding obligated to projects in the subcategory between FY 2006 and FY 2012. The number of traffic signalization projects funded during this period is shown for each State, with the highest number of projects in California and Michigan. This figure shows traffic signalization projects were funded across much of the country, with the highest funding levels in Pennsylvania.

Figure B-12 shows the number of projects started and the CMAQ funding for these projects for year during this timeframe. In general, projects in this subcategory have been initiated at a relatively steady rate, averaging 178 projects per year. Aside from a slight decrease in FY 2011, the CMAQ funding for traffic signalization projects during this period also has remained fairly steady.

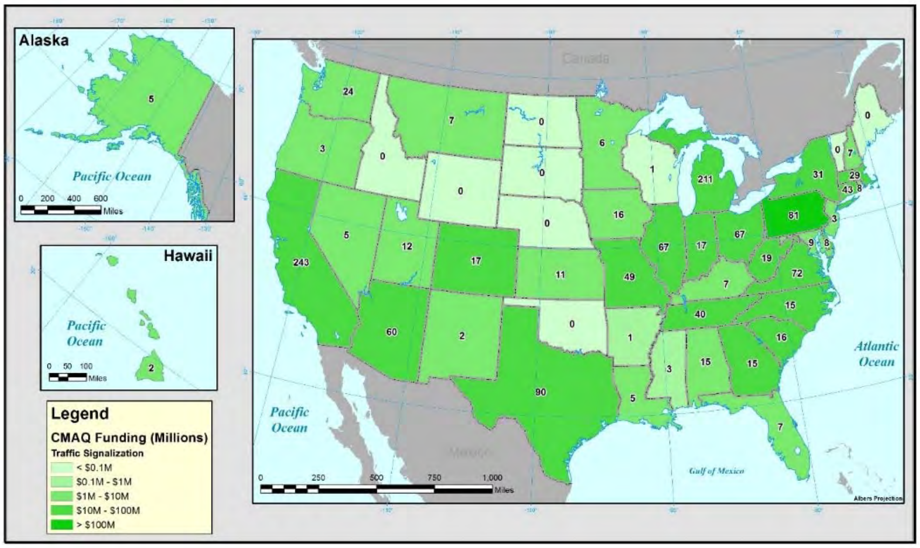

**Figure B-11. Distribution of Projects and Funding for Traffic Signalization by State**

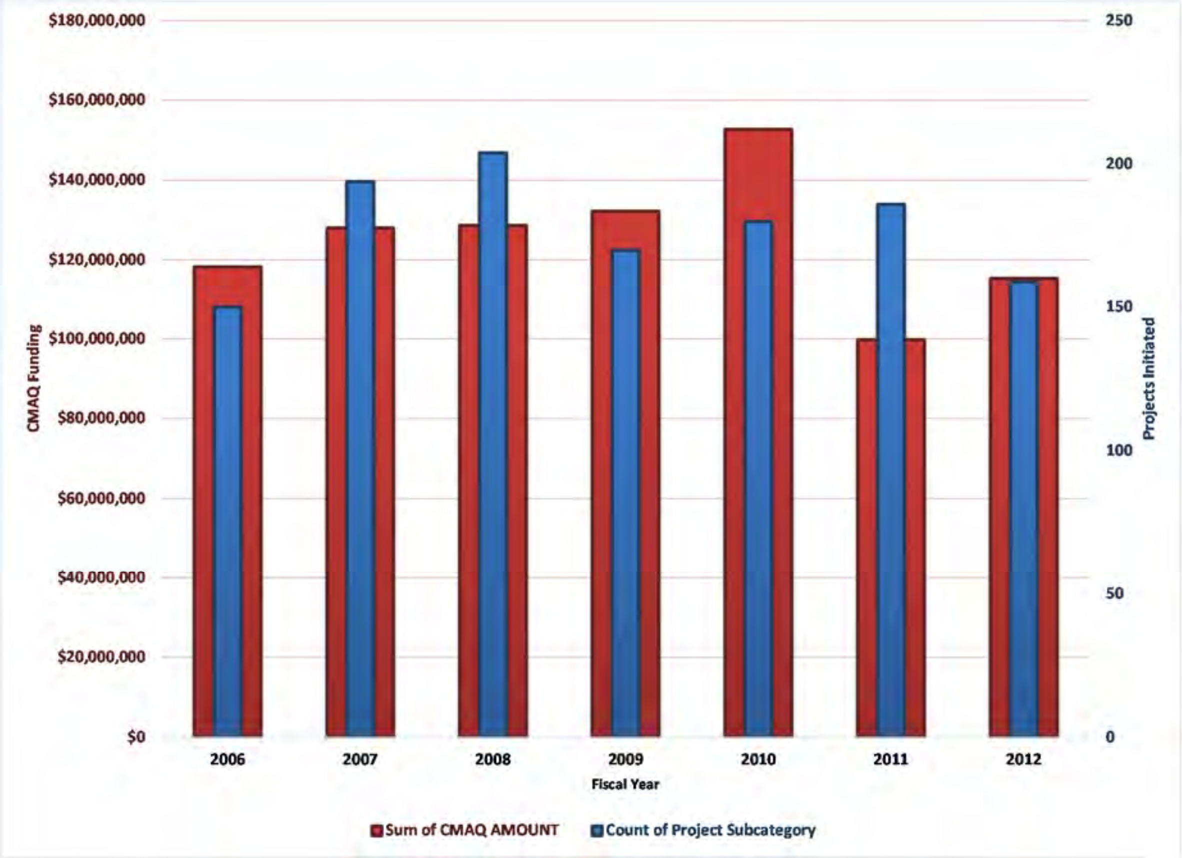

**Figure B-12. Number of Traffic Signalization Projects Initiated Per Year**

### B.3.1.3 Impacts of Case Study Projects

Table B-11 summarizes the nine case studies that were analyzed for this subcategory. The projects represent a good representation of the majority of traffic signalization projects.

**Traffic/Congestion Mitigation Impacts**

Since the projects in this subcategory largely involve the installation and/or synchronization of traffic signals to improve traffic flow, a decrease in traffic congestion and delay can be expected.

An analysis of the nine case studies indicated the following expected impacts on traffic/congestion:

- Reduction of 45,000 vehicle trips per day and a speed increase of 3 mph in California
- An increase of 2 mph in peak period speed (MI20060068)
- An increase of 3.5 mph in speed (MI20070075)
- An increase of 0.5 mph in speed (MI20080056)
- The Illinois project expected to see an increase in speed of 3.75 mph
- Arizona indicated an expected increase in speed of 25%.

### Table B-11. Summary of Traffic Signalization Case Studies

| CMAQ ID | State | CMAQ Funding | Total Funding | Description |
|---|---|---|---|---|
| TX20100052 | Texas | $619,172 | $773,965 | Upgrade traffic signals and synchronization |
| CA20120055 | California | $556,285 | $628,360 | Signal interconnect and monitoring cameras |
| MI20060068 | Michigan | $380,000 | $380,000 | Upgrade and interconnection of traffic signals |
| MI20070075 | Michigan | $900,200 | $900,200 | Traffic signal upgrades |
| MI20080056 | Michigan | $450,000 | $450,000 | Wireless communications system installation for traffic signalization |
| MO20070013 | Missouri | $656,000 | $902,000 | Signal upgrades |
| IL20080074 | Illinois | $3,449,757 | $4,312,197 | Signal interconnect, updates in video detection and transit priority emitters and emergency vehicle pre-emption systems |
| PA20110110 | Pennsylvania | $940,270 | $1,021,270 | Traffic signal replacement and upgrades |
| AZ20120034 | Arizona | $900,000 | $923,167 | Traffic signal interconnect, CCTV cameras, DMS and ITS fiber backbone |

The evaluation of the expected travel impacts for the case studies indicate that most traffic/congestion mitigation impacts are expected as a result of increased speed due to improved traffic flow.

## Emissions/Air Quality Impacts

Table B-12 presents the estimated emissions reductions for VOCs, CO, NOx, $PM_{10}$ and $PM_{2.5}$ for each of the traffic signalization case studies.

### Table B-12. Estimated Emissions Reductions for Traffic Signalization Case Studies

| CMAQ ID | Year(s) | Estimated Emissions Reductions (kg/day) | | | | |
|---|---|---|---|---|---|---|
| | | VOC | CO | NOx | $PM_{10}$ | $PM_{2.5}$ |
| TX20100052 | 2007 | 3.440 | 23.070 | 7.580 | NR | NR |
| CA20120055 | 2017 | 0.58 | 5.04 | NR | 0.58 | NR |
| MI20060068 | 2006 | 0.949 | NR | 0.067 | NR | NR |
| MI20070075 | 2015 | 873.6 | NR | 601.2 | NR | NR |
| MI20080056 | 2015 | 340.0 | NR | 377.79 | NR | NR |
| MO20070013 | 2007 | 0.004476 | NR | 0.003777 | NR | NR |
| IL20080074 | 20 years | 0.9504 | NR | 2.2558 | NR | NR |
| PA20110110 | 2010 | 2.22 | 10.22 | 0.68 | NR | 0.01 |
| AZ20120034 | 2012 | 1.29 | 10.61 | 5.10 | 0.41 | NR |

NR - Not reported

Analysis of these nine case studies indicated that most of these individual projects were likely to have a reduction in VOCs and $NO_x$. Very few of these projects expect to see a reduction in $PM_{10}$ or $PM_{2.5}$.

**Human Health Impacts**

From the nine traffic signalization case studies evaluated, the following human health impact was identified:

- Motor vehicles create the majority of their pollution when idling or accelerating from a stop. By linking individual traffic signals together, they can be programmed to work as one cohesive unit along a specific corridor. This coordination timing allows for fewer stops along the specified corridor. By allowing more vehicles to travel at a consistent speed with less stopping, idling, or accelerating, less air pollution is expelled into the air, thereby improving overall air quality in the City of Bakersfield.

## B.3.2 Traffic Engineering (Roadway Improvements)

### B.3.2.1 Overview of Projects

Projects covering traffic engineering fall under the Congestion Reduction and Traffic Flow Improvements category of the CMAQ Program. Although this was not originally a subcategory, a high number of projects receiving CMAQ funds described a number of roadway improvement efforts that did not meet the standards of traditional traffic flow improvements. Therefore, the project team identified these projects as a standalone category to be evaluated as Traffic Engineering. These projects typically involve one or more of the following activities garnered from the descriptions in the CMAQ database:

- Shoulder paving
- Pavement rehabilitation/resurfacing
- Grade separations
- Bridge/overpass construction
- Road widening
- Turn lane extensions
- Ramp improvements

### B.3.2.2 Distribution of Projects

Figure B-13 shows the distribution of the projects within the Traffic Engineering subcategory by State. The shading in each State shows the cumulative level of CMAQ funding obligated to projects in the subcategory between FY 2006 and FY 2012. The number of traffic engineering projects funded during this period is shown for each State, with the highest number of projects in Michigan. This figure shows traffic engineering projects were funded across much of the country, with the highest funding levels in California, Texas, Ohio and Pennsylvania.

Figure B-14 shows the number of projects started and the CMAQ funding for these projects for each year during this timeframe. FY 2006 had the fewest number of initiated projects in this subcategory. Between FY 2007 and FY 2012, the average number of projects initiated per year was 137. CMAQ funding for these projects vary from year to year with a low of $57.5 million in FY 2006 and a peak of $337 million in FY 2011. FY 2009 also saw a significant increase in funding due to a California interchange reconstruction project. The peak funding in 2011 can be attributed to several major construction/reconstruction projects with funding amounts over $20 million.

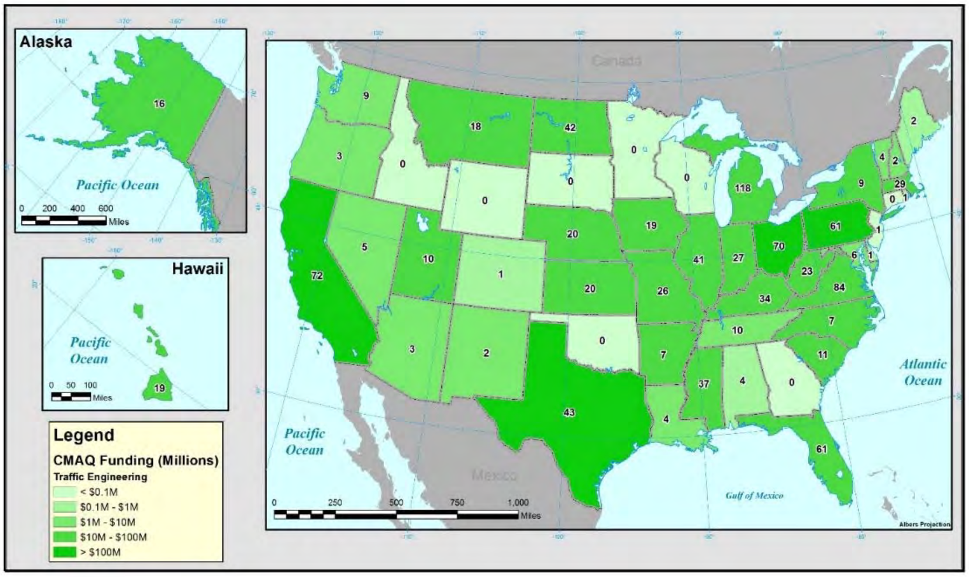

**Figure B-13. Distribution of Projects and Funding for Traffic Engineering by State**

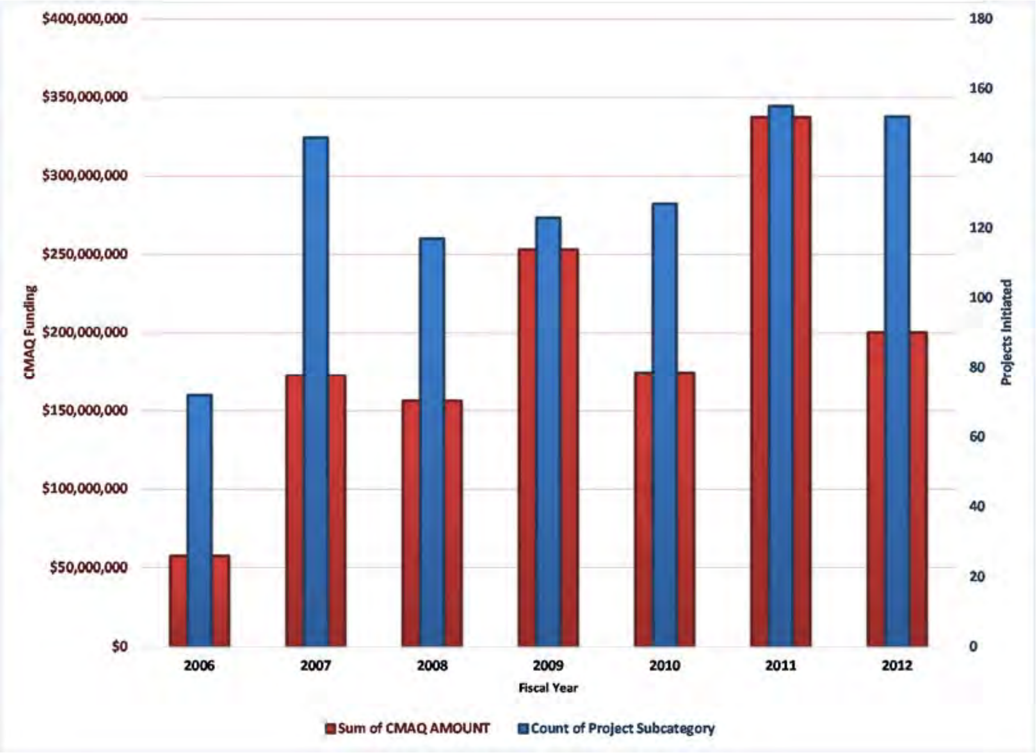

**Figure B-14. Number of Traffic Engineering Projects Initiated Per Year**

### B.3.2.3 Impacts of Case Study Projects

Table B-13 summarizes the nine case studies that were analyzed for this subcategory.

**Traffic/Congestion Mitigation Impacts**

The projects in this subcategory largely involve the installation of additional turn lanes and other geometric improvements to roadways such as lane widening. These types of improvements are expected to have an impact on the overall traffic patterns in an area and likely would increase throughput and reduce delay.

An analysis of the nine case studies indicated the following expected impacts on traffic/congestion:

- Increase of 7 mph for improvements to the Roslyn area in NY.
- The new grade separation project in Coachella, CA expects to result in an decrease of 55.2 vehicle hours of delay per day
- Roadway improvements to a congested location are expected to increase level of service at an intersection by reducing delay by 133.65 hours per year.
- Franklin County, MO expected to see an increase of 8 mph in speed and a reduction in delay of 41.2 seconds for improvements to Rte. 47.
- Improvements in Watertown, MA are expected to reduce daily delay by 398.5 hours.

### Table B-13. Summary of Traffic Engineering Case Studies

| CMAQ ID | State | CMAQ Funding | Total Funding | Description |
|---|---|---|---|---|
| NY20070021 | New York | $3,247,200 | $4,120,000 | Lane rehabilitation/left turn lane installation/traffic signalization in area surrounding Roslyn Heights Long Island Rail Road Station and Roslyn HS. |
| PA20100083 | Pennsylvania | $440,000 | $550,000 | Improve turning radius and signals |
| CA20100244 | California | $10,030,500 | $20,410,500 | New grade separation overheard structure in Coachella, CA – improvements include bike lanes, sidewalks, retaining walls, reconstruct traffic signals/driveways |
| OH20080027 | Ohio | $599,200 | $749,000 | Construction of right turn lane, road widening, signal timing, curb and gutter storm drainage system in Batavia, OH |
| CA20120117 | California | $708,000 | $937,041 | Petaluma Blvd reconfigured lanes from four through lanes to two through lanes and one 2-way left turn lane. Other improvements include bike markings, signage, audible pedestrian crossings, replace existing traffic loops, etc. |
| MO20090019 | Missouri | $960,000 | $1,200,000 | Franklin County Rte. 47 improvements – widen to five lanes, channelization, turn lanes and signal. |
| MA20090061 | Massachusetts | $1,431,296 | $1,789,120 | Watertown, MA – improvements include four-way stop control, roadway realignment, roadway resurfacing. |
| VA20070115 | Virginia | $2,070,977 | $2,588,721 | Add center left turn lane on U.S. Route 1 for a distance of 0.18 miles in Colonial Heights, VA |
| OH20070031 | Ohio | $711,678 | $864,035 | Addition of a SB left turn lane in Newark, OH |

- Virginia expected to see a reduction in delay of 205 seconds per vehicle after adding a center left turn lane.
- In Newark, OH, addition of a left turn lane expects to result in an 8 second reduction in delay per vehicle during PM peak hours.

The evaluation of the expected travel impacts for the case studies indicates that projects in this subcategory can expect to see increased level of services resulting in decreased delay.

### Emissions/Air Quality Impacts

Emission reductions estimates in this subcategory typically are based on the decrease in delay as a result of the increased level of service.

Table B-14 presents the estimated emissions reductions for VOCs, CO, NOx, $PM_{10}$ and $PM_{2.5}$ for each of the Traffic Engineering case studies.

**Table B-14. Estimated Emissions Reductions for Traffic Engineering Case Studies**

| CMAQ ID | Year(s) | Estimated Emissions Reductions (kg/day) | | | | |
|---|---|---|---|---|---|---|
| | | VOC | CO | NOx | $PM_{10}$ | $PM_{2.5}$ |
| NY20070021 | 2008 | 108.47 | 235.59 | 68.65 | 0.26 | 0.49 |
| PA20100083 | 2011 | 0.31 | 3.42 | 0.10 | NR | 0.01 |
| CA20100244 | 2030 | 0.099 | 1.091 | 0.159 | 0.004 | 0.004 |
| OH20080027 | 2006 | 1.049 | 7.01 | 0.14 | NR | NR |
| CA20120117 | 2009-2011 | 0.34 | 373 | 0.45 | 0.06 | NR |
| MO20090019 | 2009 | 6.148 | NR | 9.452 | NR | NR |
| MA20090061 | 2010 | 2.68 | 22.53 | 1.73 | NR | NR |
| VA20070115 | 2011 | 0.60 | 15.7 | 0.79 | NR | NR |
| OH20070031 | 2008 | 3.77 | 50.67 | 0.34 | NR | NR |

NR - Not reported

Analysis of these nine case studies indicated that projects in this subcategory are likely to have a reduction in VOCs, CO and $NO_x$.

### Human Health Impacts

From the nine traffic engineering case studies evaluated, the following human health impacts were identified:

- (CA20100244) After the project is completed, safety will improve because the vehicular traffic and pedestrian traffic will be separated from the freight trains. Additionally, pedestrian and bicycle facilities are being built in conjunction with the project to provide a safer path for active transportation users.
- Per the emission calculations included above, once the project is completed, the air quality will improve significantly by eliminating the light-duty automobile and heavy-duty truck idle time associated with the crossing of the freight trains.
- By grade separating vehicle and pedestrian traffic from freight, the air quality will improve and consequently the overall health will improve in the area. The pedestrian improvements combined with the grade separation project will encourage more people to engage in physical activity that has been proven to improve the overall health of individuals.
- Maintaining access to affected properties and local communities will receive special consideration during the construction stages of the project. After the project is built, access to local schools, stores, gas stations, employment centers, healthcare providers, city hall,

downtown amenities, and recreational facilities will improve.  Property values will most likely increase.  The area may also be more attractive to potential employers who can hire local residents.

- (CA20120117) Reduction in vehicle crashes and potential accidents to bicyclists and pedestrians.  The previous road diet section immediately north of this section reduced crashes by 50%.
- The assumption is that traffic will not be as congested during non-peak hours, therefore air quality will be improved.
- In general, road diets generate benefits to users of all modes of transportation, including bicyclists and pedestrians.  With improved mobility and access and improved livability and quality of life one would anticipate improved physical and mental health.  On this particular project additional bike racks and benches within the corridor were included.
- Several curb ramps were upgraded to meet Americans with Disabilities Act (ADA) compliance to improve accessibility around downtown.
- (OH20070031) .66 crash modification factor compared to 2012.

### B.3.3 Intersection Improvements

#### B.3.3.1 Overview of Projects

Intersection improvement projects fall under the Traditional Improvements subcategory of the projects eligible for CMAQ funding in the overall category of Congestion Reduction and Traffic Flow Improvements.  Although intersection improvements are not 1 of the 17 original categories identified as eligible for CMAQ funding, the project team has included these projects as a standalone category to be assessed due to the relatively high number of projects and the amount of CMAQ funding obligated to these projects.  Overall the projects within this subcategory generally involve either:

- Construction of curbs, medians;
- Signalization,
- Geometric improvements.

#### B.3.3.2 Distribution of Projects

Figure B-15 shows the distribution of the projects within the intersection improvements subcategory by State.  The shading in each State shows the cumulative level of CMAQ funding obligated to projects in the subcategory between FY 2006 and FY 2012.  The number of intersection improvement projects funded during this period is shown for each State.  This figure shows intersection improvement projects were funded across much of the country, with approximately 2/3 of funding toward the east coast.  Intersection improvement projects in Texas account for approximately 1/3 of the number of projects and 1/4 of overall CMAQ funding for intersection improvements.

Figure B-16 shows the number of projects started and the CMAQ funding for these projects for each year during this timeframe.  In general, projects in this subcategory have been initiated at a relatively steady rate.  The CMAQ funding during this period averages approximately $45 million.

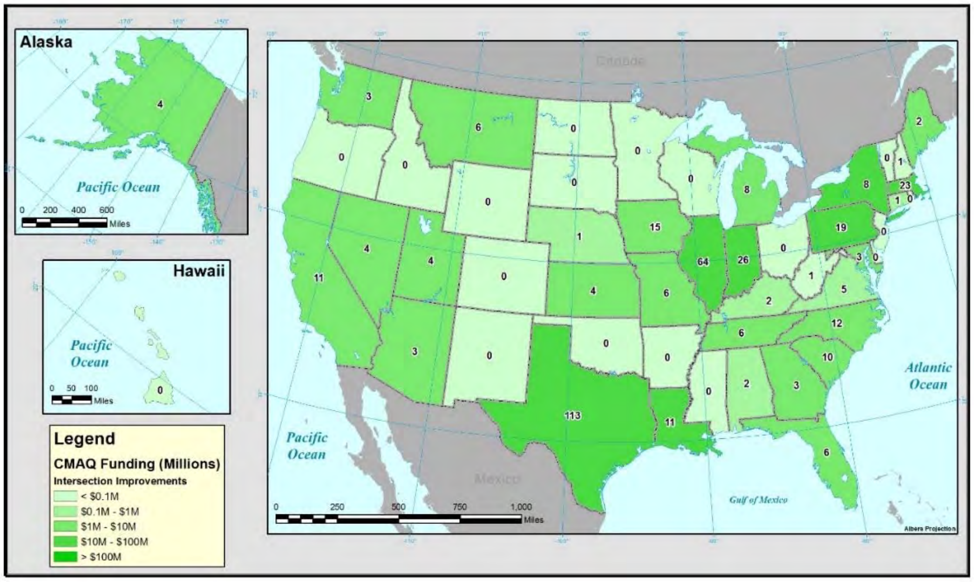

Figure B-15. Distribution of Projects and Funding for Intersection Improvement Projects by State

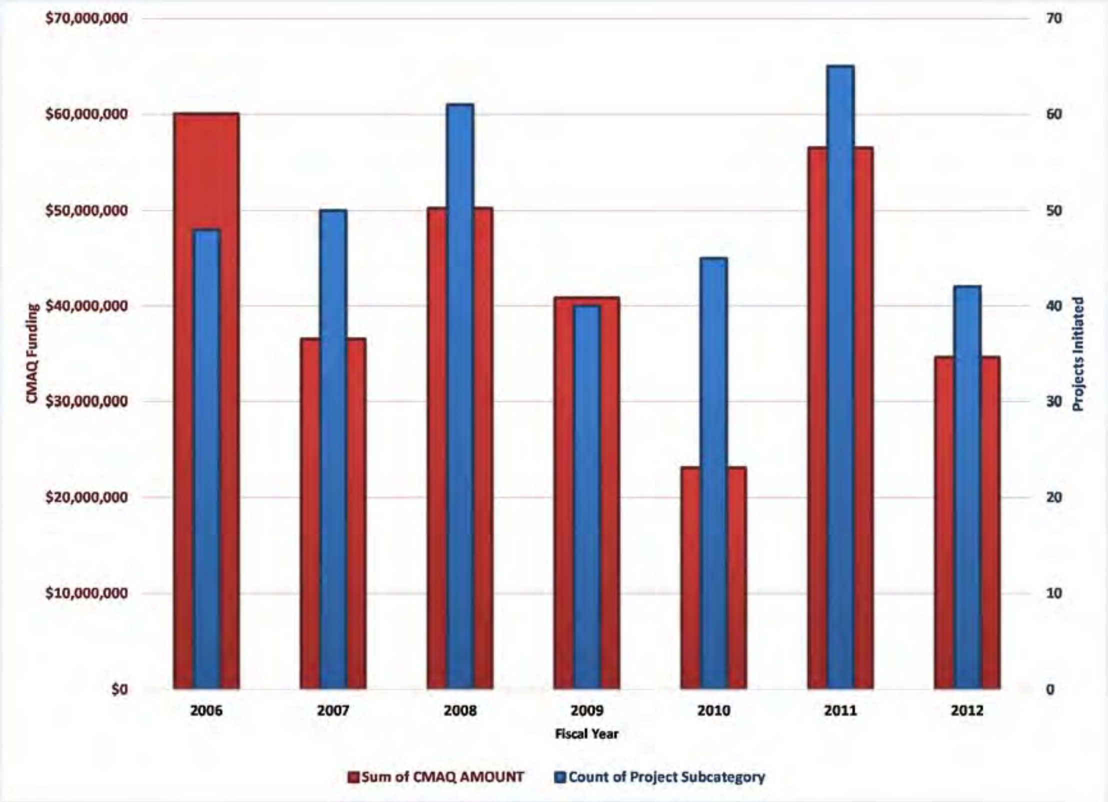

Figure B-16. Number of Intersection Improvement Projects Initiated Per Year

### B.3.3.3 Impacts of Case Study Projects

Table B-15 summarizes the 2 case studies that were analyzed for this subcategory.

**Table B-15. Summary of Alternative Intersection Improvements Case Studies**

| CMAQ ID | State | CMAQ Funding | Total Funding | Description |
|---|---|---|---|---|
| AZ20080035 | Arizona | \$656,000 | \$1,250,000 | Widen intersection at 10th Ave and Thunderbird Rd. |
| TX20090046 | Texas | \$541,020 | NR | WB Right turn at FM2499 and Gerault, Level 8 improvement |

NR - Not reported

**Traffic/Congestion Mitigation Impacts**

Since the projects in this subcategory involve the improvement of capacity and coordination of traffic flow, the potential to reduce congestion and delay are increased.

Only one of the two case studies examined identified possible travel impacts. Analysis of that case study indicated that it was likely to have the following impacts on traffic/congestion mitigation:

- Intersection improvement adding right turn lanes and reduced vehicle delay by an estimated 10.87 hours per weekday.

**Emissions/Air Quality Impacts**

Emission reductions estimates in this subcategory typically are based on the decreased congestion and delay due to improved traffic flow at intersections.

Table B-16 presents the estimated emissions reductions for VOCs, CO, NOx, $PM_{10}$ and $PM_{2.5}$ for each of the Intersection Improvements case studies.

**Table B-16. Estimated Emissions Reductions for Intersection Improvements Case Studies**

| CMAQ ID | Year(s) | Estimated Emissions Reductions (kg/day) | | | | |
|---|---|---|---|---|---|---|
| | | VOC | CO | NOx | $PM_{10}$ | $PM_{2.5}$ |
| AZ20080035 | 2008 | 0.13 | 0.55 | 0.06 | 0.0010 | NR |
| TX20090046 | 2013 | 2.62 | NR | 4.60 | NR | NR |

NR - Not reported

**Human Health Impacts**

Neither of the intersection improvement case studies reported human health impacts in the selection process.

## B.3.4 High-Occupancy Vehicle and Managed Lanes

### B.3.4.1 Overview of Projects

High-occupancy vehicle (HOV) lanes and managed lanes attempt to encourage carpooling/ridesharing to reduce the number of vehicles on the freeways. Managed lanes have the ability to add capacity to freeways to reduce congestion and delay during peak hours. These types of projects fall into the Congestion Reduction and Traffic Flow Improvements category of the CMAQ program. Examples of these types of programs include HOV facilities, dynamic shoulder lanes, and bus-on-shoulder programs.

### B.3.4.2 Distribution of Projects

Figure B-17 shows the distribution of the projects within the HOV and Managed Lanes Subcategory by State. The shading in each State shows the cumulative level of CMAQ funding obligated to projects in the subcategory between FY 2006 and FY 2012. During this time period, eight states have received CMAQ funding for projects in this subcategory: California, Florida, Kentucky, Maryland, Massachusetts, Texas, Virginia, and Washington. Of these, California and Texas have received over $1 billion combined, with the majority of that funding going to projects in California.

Figure B-18 shows the number of projects started and the CMAQ funding for these projects for year during this timeframe. In general, projects in this subcategory have been initiated at a relatively steady rate. The CMAQ funding during this period has also been relatively steady aside from increases in FY 2008 and FY 2010. The spike in these 2 years can be attributed to three projects in California that were each over $50 million apiece.

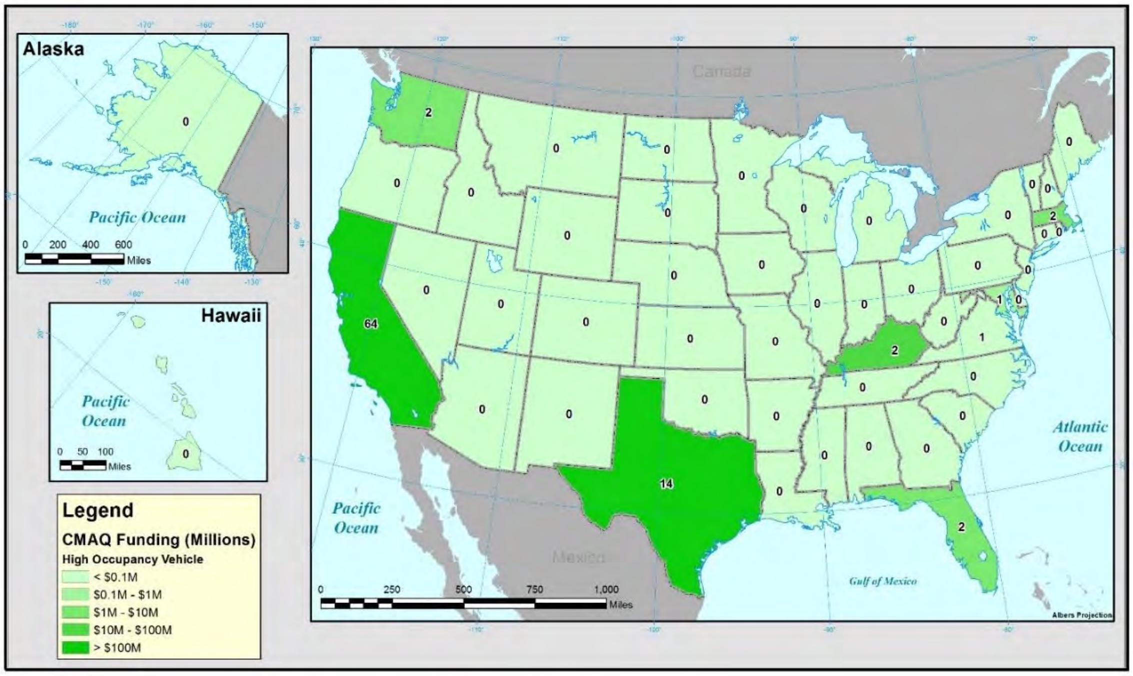

Figure B-17. Distribution of Projects and Funding for HOV and Managed Lanes by State

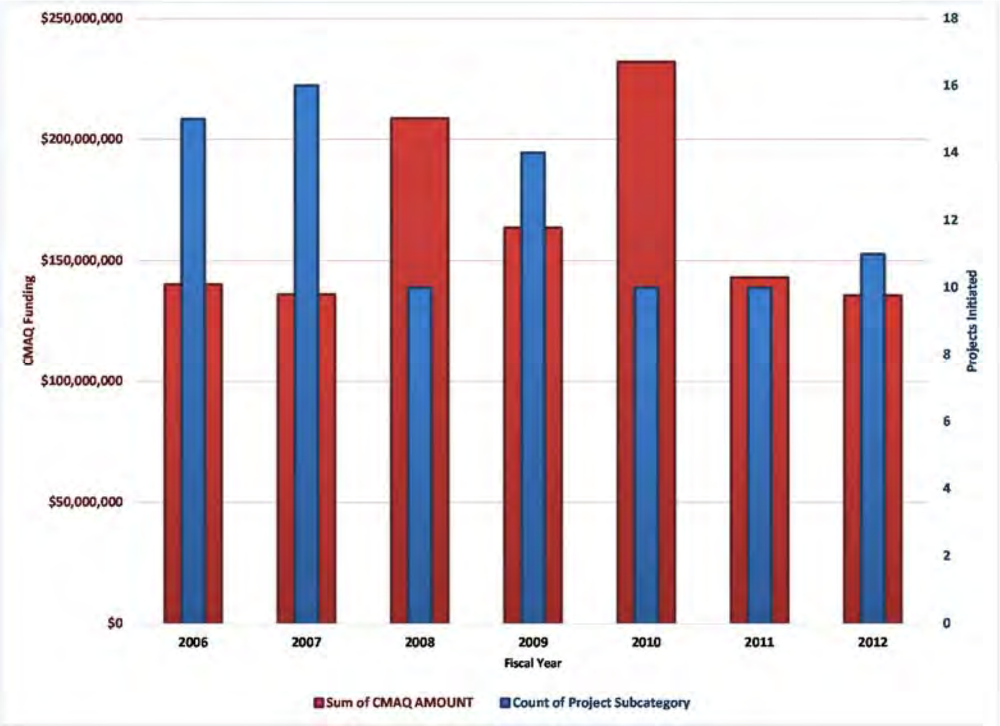

**Figure B-18. Number of HOV and Managed Lanes Projects Initiated Per Year**

### B.3.4.3 Impacts of Case Study Projects

Table B-17 summarizes the four case studies that were analyzed for this subcategory.

**Table B-17. Summary of HOV and Managed Lanes Case Studies**

| CMAQ ID | State | CMAQ Funding | Total Funding | Description |
|---|---|---|---|---|
| CA20080095 | California | $7,780,000 | $106,494,000 | HOV lane implementations on various freeways in San Leandro and Oakland, CA |
| CA20070140 | California | $225,000 | $102,482,000 | Widened Route 101 in Sonoma County for HOV lane |
| KY20120009 | Kentucky | $21,400,000 | $53,400,000 | Bus-on-Shoulder Lane (part of I-471 pavement reconstruction) |
| TX20090099 | Texas | $12,472,000 | $17,400,400 | HOV from I-30 in Ft. Worth to Dallas County line |

**Traffic/Congestion Mitigation Impacts**

The projects in this subcategory are expected to decrease congestion by encouraging ridesharing modes such as carpools, vanpools, commuter buses, etc. The increase in these types of travel options to utilize these lanes is expected to decrease congestion by reducing the number of vehicles on the roadways. In the four case studies selected, the following traffic/congestion impacts were identified:

- Travel time for HOV lane users is expected to be reduced by 68% and 63% for the freeways impacted by the improvements in San Leandro and Oakland, CA.
- The Bus-on-Shoulder project in Kentucky expects for bus speeds to increase by 15 mph when using the bus shoulder lane.

### Emissions/Air Quality Impacts

Emission reductions estimates in this subcategory typically are based on reduction of vehicle trips as a result of increased ride sharing.

Table B-18 presents the estimated emissions reductions for VOCs, CO, NOx, $PM_{10}$ and $PM_{2.5}$ for each of the HOV and Managed Lanes case studies.

**Table B-18. Estimated Emissions Reductions for HOV and Managed Lanes Case Studies**

| CMAQ ID | Year(s) | Estimated Emissions Reductions (kg/day) | | | | |
|---|---|---|---|---|---|---|
| | | VOC | CO | NOx | $PM_{10}$ | $PM_{2.5}$ |
| CA20080095 | 2016 | 34.21 | 259.40 | 40.81 | 2.23 | 1.57 |
| CA20070140 | 2009 | 53.01 | 372.57 | 54.73 | 3.21 | NR |
| KY20120009 | 2011 | 7.64 | 8.49 | 65.6 | NR | 4.92 |
| TX20090099 | 2013 | 12.10 | NR | 35.13 | NR | NR |

NR - Not reported

Analysis of these four case studies indicated that these individual projects were likely to have the following impacts on vehicle emissions and air quality:

- All projects predicted reductions in at least two pollutants—two estimated reductions for four pollutants and one estimated for all five pollutants examined.

### Human Health Impacts

From the four HOV and Managed Lanes projects evaluated, the following human health impact was identified:

- Operational Improvements at Davis and Marina Interchange will improve local traffic circulation, better accessibility to public facilities such as hospitals, schools, etc.

## B.3.5 Roundabouts

### B.3.5.1 Overview of Projects

Roundabout projects fall under the subcategory of Intersection Improvements of the Congestion Reduction and Traffic Flow Improvements category of projects eligible for CMAQ funding. However, due to the number of roundabout projects and the amount of CMAQ funding obligated to these projects, the project team has included these projects as a standalone category to be assessed. Overall the projects within this subcategory involve the construction of roundabouts to improve traffic flow at existing intersections.

### B.3.5.2 Distribution of Projects

Figure B-19 shows the distribution of the projects within the Roundabouts subcategory by State. The shading in each State shows the cumulative level of CMAQ funding obligated to projects in the subcategory between FY 2006 and FY 2012. Fifteen states have received CMAQ funding for projects involving roundabouts. California and Illinois have the highest number of roundabout projects, while Michigan received the highest funding for roundabout projects.

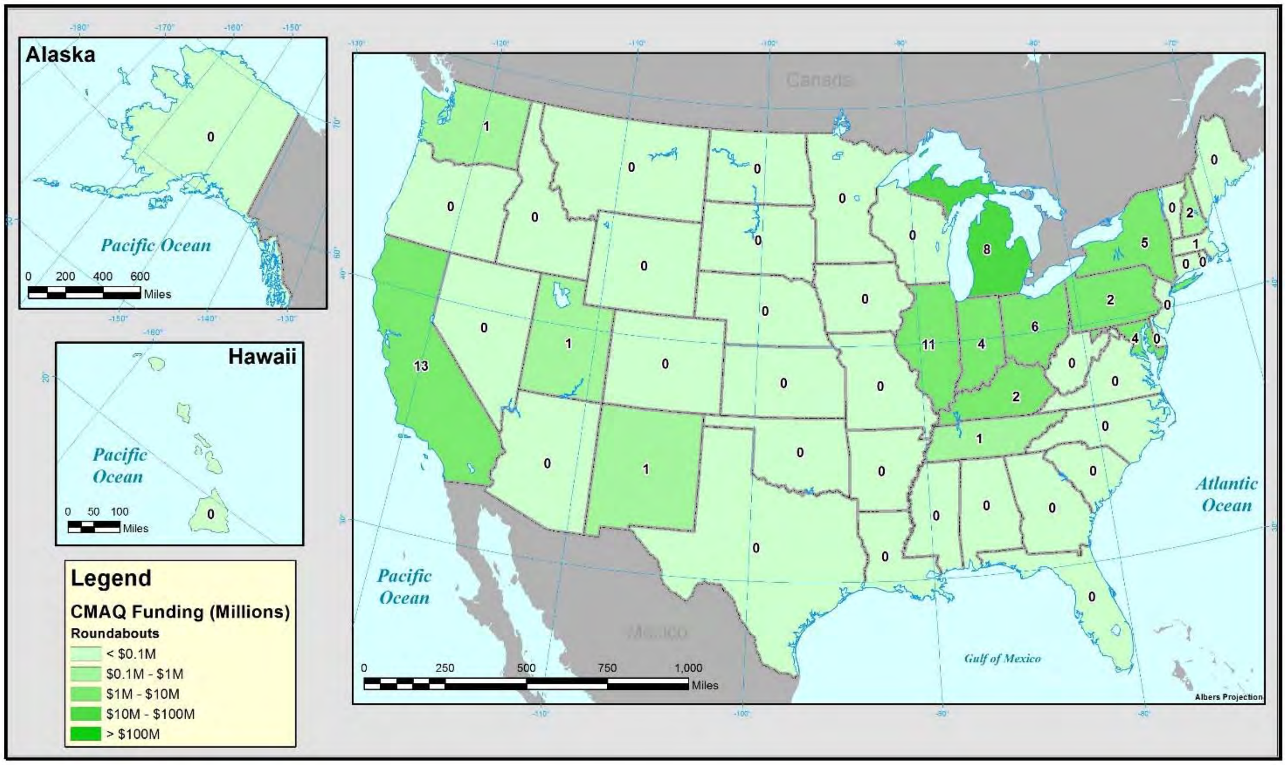

**Figure B-19. Distribution of Projects and Funding for Roundabouts by State**

Figure B-20 shows the number of projects started and the CMAQ funding for these projects for year during this timeframe. In general, projects in this subcategory have been initiated at a relatively steady rate with the highest number of roundabout projects initiated in FY 2012. The CMAQ funding during this period varied from year to year but peaked in FY 2010 and FY 2012, likely due to an increase in the number of projects.

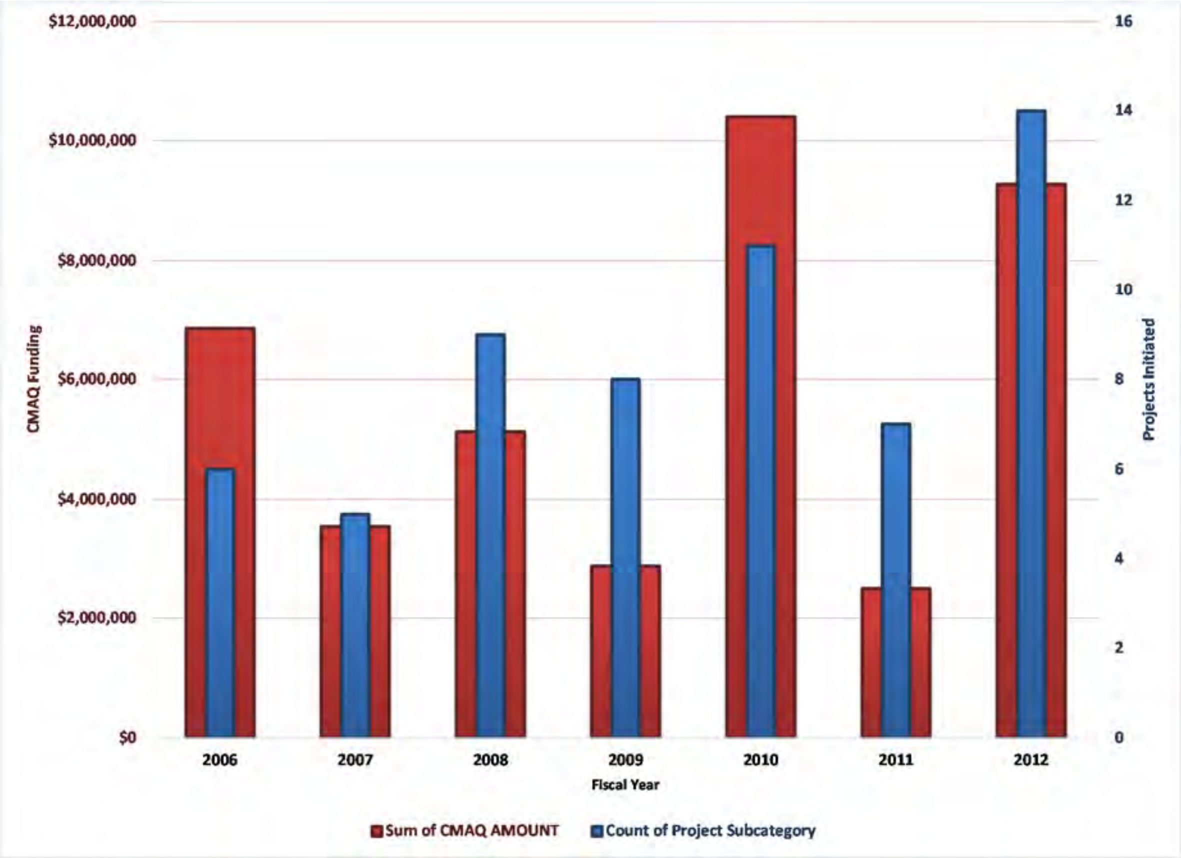

**Figure B-20. Number of Roundabout Projects Initiated Per Year**

### B.3.5.3 Impacts of Case Study Projects

Table B-19 summarizes the case study that was analyzed for this subcategory.

**Table B-19. Summary of Roundabout Case Study**

| CMAQ ID | State | CMAQ Funding | Total Funding | Description |
|---|---|---|---|---|
| PA20110083 | Pennsylvania | $2,712,000 | $2,752,000 | Intersection Upgrades – replacing signal with a roundabout |

**Traffic/Congestion Mitigation Impacts**

The projects in this subcategory involve the construction of roundabouts to replace existing intersections. This can significantly impact general traffic patterns and mitigate congestion by improving traffic flow.

Analysis of this case study indicated that this individual project was likely to have the following impacts on traffic/congestion mitigation:

- Reduction of VMT and an increase in speed.

**Emissions/Air Quality Impacts**

Emission reductions estimates in this subcategory typically are based on the improved traffic flow and resulting reduction in delay that would benefit local air quality through reductions in unnecessary vehicle idling.

Table B-20 presents the estimated emissions reductions for VOCs, CO, NOx, $PM_{10}$ and $PM_{2.5}$ for the Roundabout case study.

**Table B-20. Estimated Emissions Reductions for Roundabout Case Study**

| | | Estimated Emissions Reductions (kg/day) | | | | |
|---|---|---|---|---|---|---|
| CMAQ ID | Year(s) | VOC | CO | NOx | $PM_{10}$ | $PM_{2.5}$ |
| PA20110083 | 2015 | 9.07 | NR | NR | NR | NR |

NR - Not reported

**Human Health Impacts**

For the roundabout case study evaluated, human health impacts include reduced crash risk and reduced emergency response times.

## B.4 Intelligent Transportation Systems

### B.4.1 General ITS

### B.4.1.1 Overview of Projects

ITS projects are a subcategory of the Congestion Reduction and Traffic Flow Improvements category eligible for CMAQ funding. These projects integrate advanced technologies into the transportation infrastructure and vehicles to gather and relay real-time data to better coordinate and manage traffic. Examples of typical ITS projects include dynamic message signs, motorist assistance programs, traffic management centers, and incident response programs. ITS also includes many other related improvement projects such as traffic signalization and freeway management systems. Specifically, these two ITS areas have had a significant number of projects with CMAQ funding. Therefore, the study team made the decision to separate traffic signalization and freeway management systems into subcategories of their own and to group other ITS-related projects into a general ITS subcategory.

### B.4.1.2 Distribution of Projects

Figure B-21 shows the distribution of the projects within the general ITS subcategory by State. The shading in each State shows the cumulative level of CMAQ funding obligated to projects in the subcategory between FY 2006 and FY 2012. The number of general ITS projects funded during this period is shown for each State. This figure shows that CMAQ funding for general ITS projects has been distributed across the United States with Texas having the most projects during this time period.

Figure B-22 shows the number of projects started and the CMAQ funding for these projects for each year during this timeframe. In general, projects in this subcategory have been initiated at a relatively steady rate with the exception of a spike during FY 2008 and a lower start for FY 2006. The CMAQ funding during this period has risen dramatically from FY 2006 to FY 2007. After FY 2007, CMAQ funding decreased steadily aside from a peak in FY 2011.

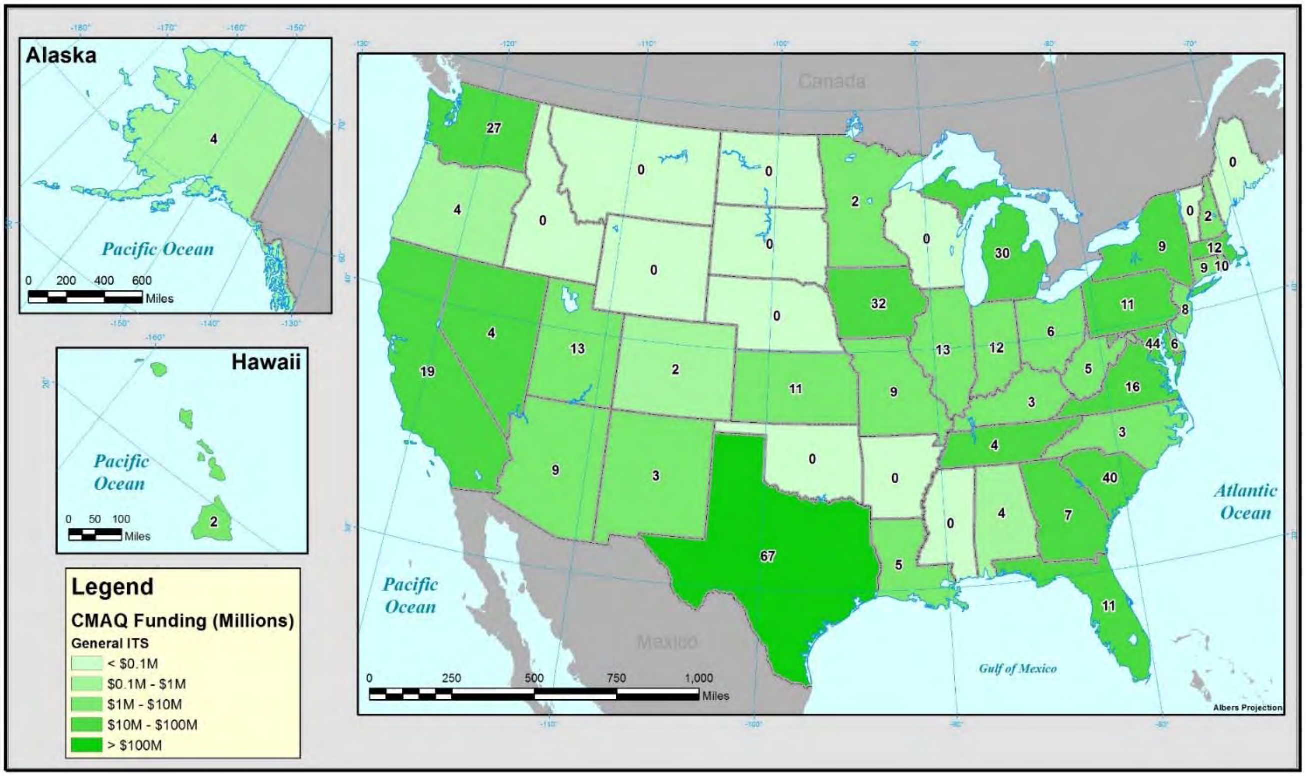

**Figure B-21. Distribution of Projects and Funding for General ITS by State**

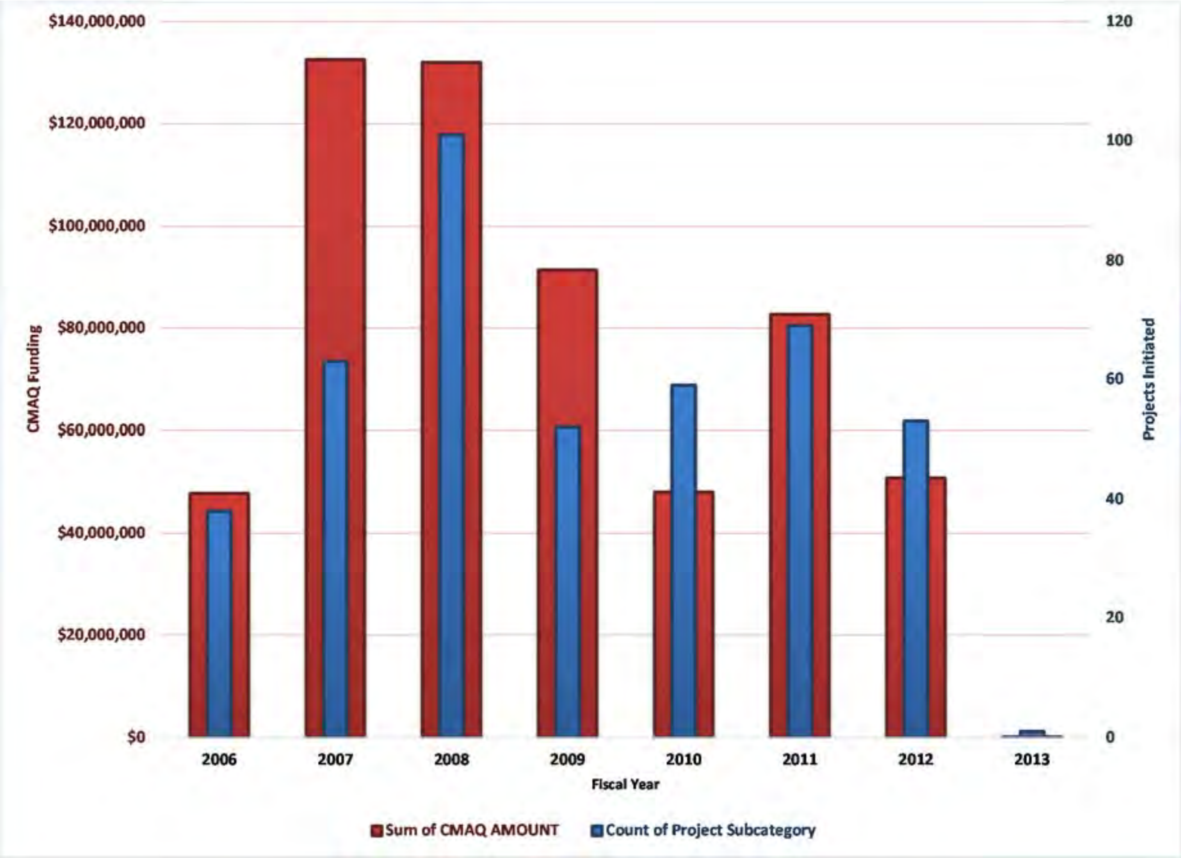

**Figure B-22. Number of General ITS Projects initiated per year.**

### B.4.1.3 Impacts of Case Study Projects

Table B-21 summarizes the three case studies that were analyzed for this subcategory.

**Table B-21. Summary of General ITS Project Case Studies**

| CMAQ ID | State | CMAQ Funding | Total Funding | Description |
|---|---|---|---|---|
| NY20120023 | New York | $732,000 | $915,000 | Integrated Incident Management System |
| WA20110036 | Washington | $50,000 | $65,000 | Traffic signal optimization |
| MO20110021 | Missouri | $98,337 | $142,557 | Install CCTV cameras, static incident bypass route signs, minor geometric improvements |

### Traffic/Congestion Mitigation Impacts

Projects in this subcategory involve the installation and/or implementation and support of physical assets and programs or services that are designed specifically to assist in traffic/congestion mitigation. Therefore, the impacts are direct and can be significant depending on the strategy and situation.

Analysis of the four case studies indicated that these individual projects were likely to have or had the following impacts on traffic/congestion mitigation:

- Expected improvements include an increase in speed increase of 7.5 mph (30%). (MO20110021)
- Integrated Incident Management is expected to improve speed from 20 mph to 24 mph along large stretches of freeways/expressways in the 5 borough of NYC on weekdays. (NY20120023)

Based on an analysis of the case studies selected, the expected travel impacts from general ITS typically involve an improvement in speed along the project corridor.

### Emissions/Air Quality Impacts

Emission reductions estimates in this subcategory typically are based on overall congestion reduction due to improved speeds along the corridor.

Table B-22 presents the estimated emissions reductions for VOCs, CO, NOx, $PM_{10}$ and $PM_{2.5}$ for each of the general ITS case studies.

**Table B-22. Estimated Emissions Reductions for General ITS Case Studies**

| CMAQ ID | Year(s) | Estimated Emissions Reductions (kg/day) | | | | |
|---|---|---|---|---|---|---|
| | | VOC | CO | NOx | $PM_{10}$ | $PM_{2.5}$ |
| NY20120023 | 2012 | 10.16 | 100.77 | 14.06 | 0 | 0 |
| WA20110036 | 2013 | -2.986 | -29.045 | 6.750 | NR | NR |
| MO20110021 | 2012 | 0.342 | NR | 0.275 | NR | NR |

NR - Not reported

Analysis of these three case studies indicated that these individual projects were likely to have the following impacts on vehicle emissions and air quality:

- All examined general ITS projects had a decrease in VOCs and $NO_x$ in varying ranges.
- These general ITS projects were not expected to have a reduction in $PM_{10}$ or $PM_{2.5}$.

**Human Health Impacts**

Of the three general ITS case studies evaluated, none reported human health impacts.

## B.4.2 Freeway Management Systems

### B.4.2.1 Overview of Projects

Freeway management systems are identified as a subcategory of the Intelligent Transportation Systems that are eligible for CMAQ funding as part of the Congestion Reduction and Traffic Flow Improvement category.  Freeway management systems include physical assets, technologies and strategies that are implemented to monitor and manage freeway traffic.  Typical strategies, programs and system components include, but are not limited to, ramp metering, incident management teams, safety patrols, dynamic signage, traffic management centers, and communication, detection and surveillance devices. A large portion of projects in this subcategory are receiving funding to aid in the construction and/or operation of traffic management centers.

### B.4.2.2 Distribution of Projects

Figure B-23 shows the distribution of the projects within the Freeway Management Systems subcategory by State.  The shading in each State shows the cumulative level of CMAQ funding obligated to projects in the subcategory between FY 2006 and FY 2012.  The number of Freeway Management Systems projects funded during this period is shown for each State.  This figure shows freeway management systems projects were funded across much of the country.  California had over $100 million in funding, which accounts for approximately 44% of all funds distributed for freeway management systems projects.  Another 23% of funding went to Michigan with the rest distributed throughout the remaining 25 states with a slightly higher concentration toward the east coast.

Figure B-24 shows the number of projects started and the CMAQ funding for these projects for year during this timeframe.  In general during this timeframe, projects initiated per year fell right around 20 aside from a spike in FY 2007 and a decline in FY 2010.  The CMAQ funding during this period has averaged around $34 million.  Although the peak year for project initiation occurred in FY 2007 with 32 projects, the funding for that particular year was the lowest during this time period.  The highest amount of funding occurred in FY 2011 with a total of over $58 million.  This spike in funding can be attributed to an increase in funding in California projects during that year for the Freeway Performance Initiative (FPI), which amounted to $20 million.

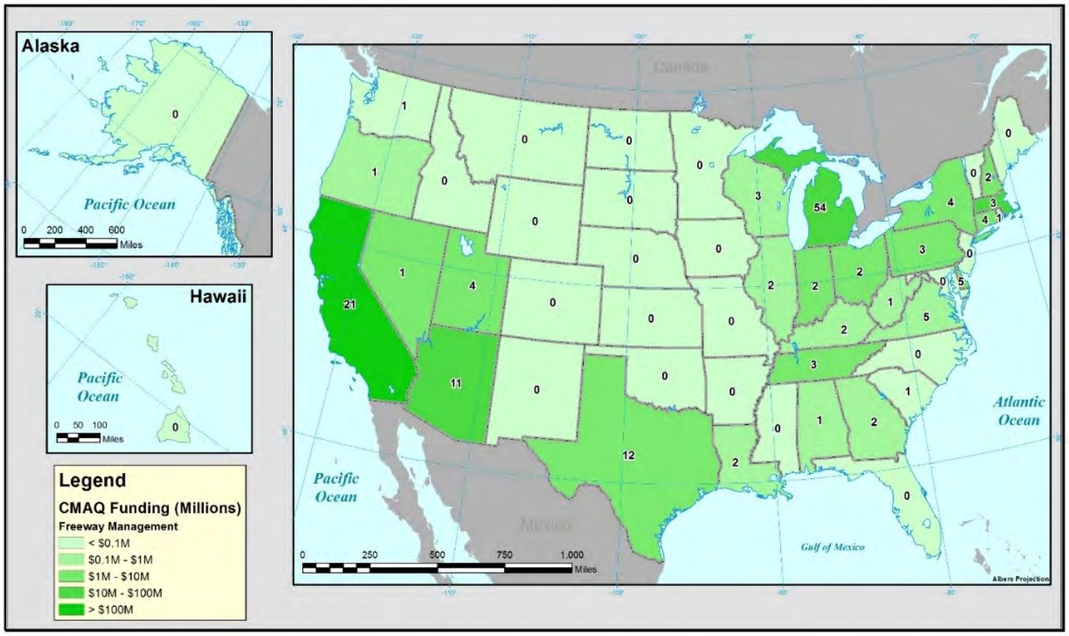

Figure B-23. Distribution of Projects and Funding for Freeway Management Systems by State

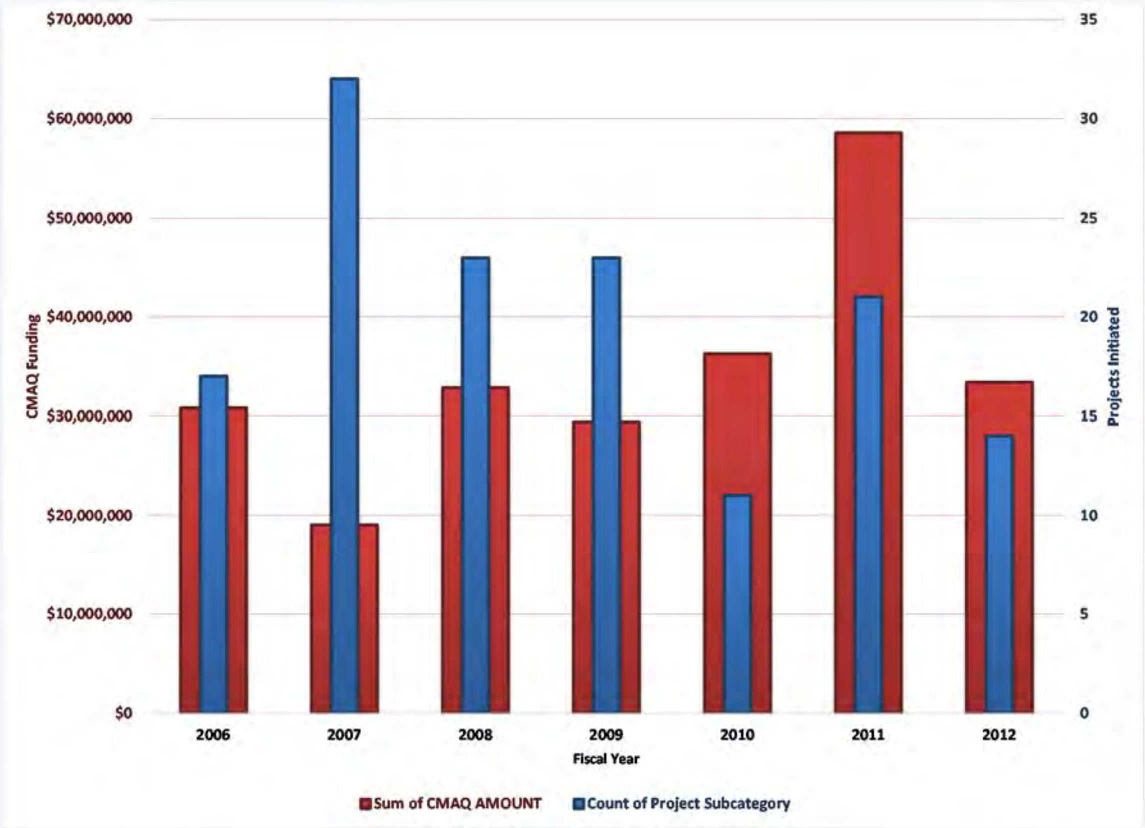

Figure B-24. Number of Freeway Management Systems Projects Initiated Per Year

### B.4.2.3 Impacts of Case Study Projects

Table B-23 summarizes the case study that was analyzed for this subcategory.

**Table B-23. Summary of Freeway Management System Case Study**

| CMAQ ID | State | CMAQ Funding | Total Funding | Description |
|---|---|---|---|---|
| CA20060168 | California | $1,000,000 | $15,386,426 | Fiber optic communication lines/CMS/ramp metering systems |

**Traffic/Congestion Mitigation Impacts**

Since the projects in this subcategory directly involve strategies, technologies and physical assets to monitor and manage traffic, they are likely to have a notable impact on general traffic patterns and congestion mitigation.

Analysis of the freeway management systems case study indicated that this individual project is likely to have the following impacts on traffic/congestion mitigation:

- Reduction of 225,000 vehicle trips
- Reduction of 1,000 vehicle hours per year

**Emissions/Air Quality Impacts**

Emission reductions estimates in this subcategory typically are based on a reduction of delay due to congestion as well as vehicle trips.

Table B-24 presents the estimated emissions reductions for VOCs, CO, NOx, $PM_{10}$ and $PM_{2.5}$ for the Freeway Management Systems case study.

**Table B-24. Estimated Emissions Reductions for Freeway Management Systems Case Study**

| CMAQ ID | Year(s) | Estimated Emissions Reductions (kg/day) | | | | |
|---|---|---|---|---|---|---|
| | | VOC | CO | NOx | $PM_{10}$ | $PM_{2.5}$ |
| CA20060168 | 2009 | 115.73 | 373.30 | 15.99 | 13.45 | NR |

NR - Not reported

**Human Health Impacts**

The evaluated freeway management systems case study did not report human health impacts in the selection process.

## B.4.3 Traveler Information Systems

### B.4.3.1 Overview of Projects

Projects covering traveler information systems fall under the Traffic Flow Improvements and TDM categories of projects eligible for funding under the CMAQ program. Due to the number of projects labeled as Traveler Information Services and the amount of CMAQ funding obligated to these projects, the project team has included these projects as a standalone category to be assessed. Projects within this subcategory focus on physical assets or services that provide real-time information on network performance to support better decision making by travelers choosing modes, times, routes, and locations. Much of the funds dedicated to projects in this subcategory involve either:

- ITS infrastructure including utility, power, and communications systems
- Interactive traveler services including radio, phone and Web site applications
- Expansion of commuter programs

### B.4.3.2 Distribution of Projects

Figure B-25 shows the distribution of the projects within the Traveler Information Systems subcategory by State. The shading in each State shows the cumulative level of CMAQ funding obligated to projects in the subcategory between FY 2006 and FY 2012. The number of traveler information systems projects funded during this period is shown for each State, with Utah having the highest number of projects. This figure shows traveler information systems projects were funded across much of the country, with relatively higher funding in California.

Figure B-26 shows the number of projects started and the CMAQ funding for these projects for each year during this timeframe. In general, projects in this subcategory have been initiated at a relatively steady rate with a slightly higher number of project initiated in FY 2011. The CMAQ funding during this period varies significantly from year to year. Funding for traveler information systems projects ranged as low as $2,368,291 in FY 2007 and as high as $33,833,134 in FY 2008.

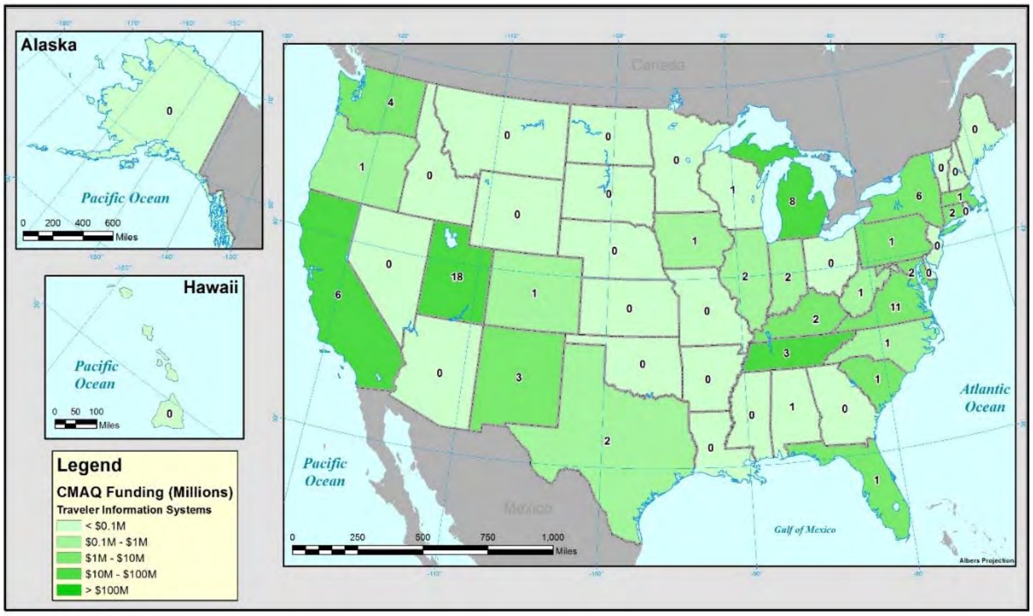

Figure B-25. Distribution of Projects and Funding for Traveler Information Systems by State

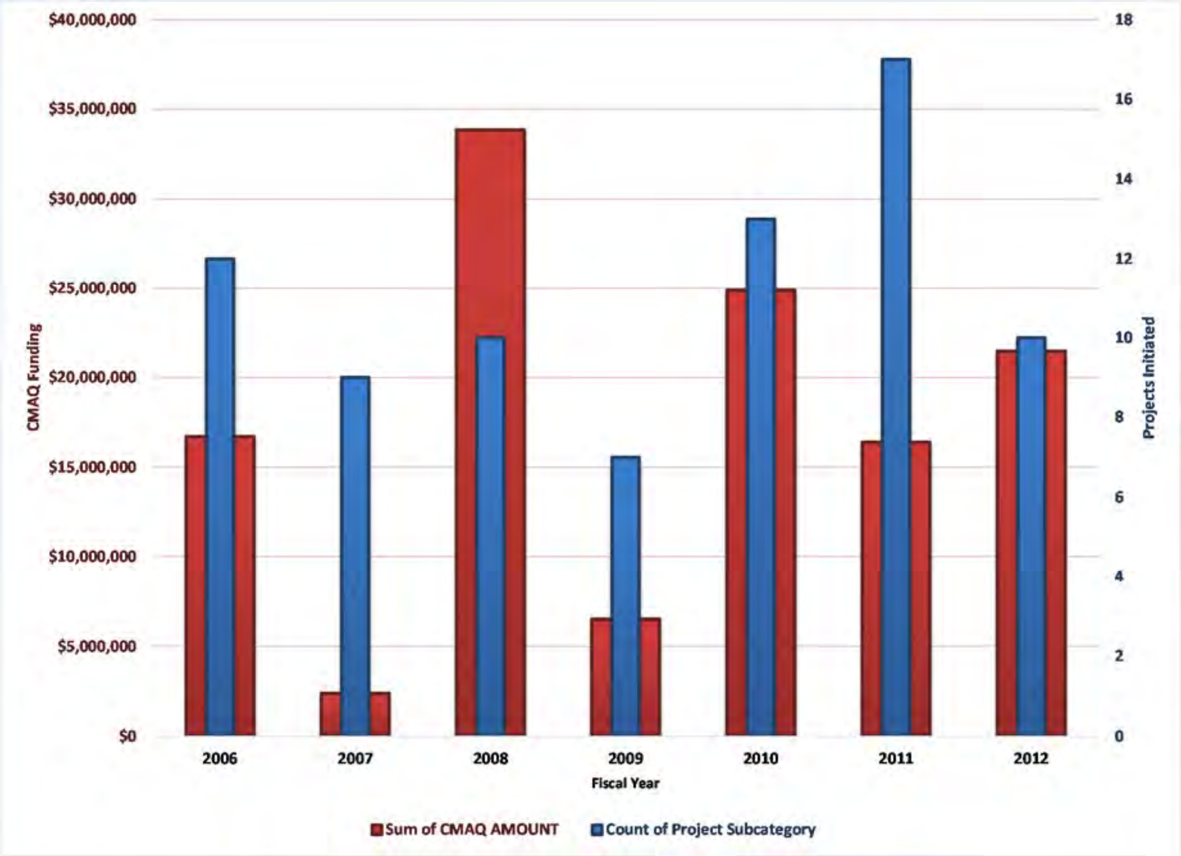

Figure B-26. Number of Traveler Information Systems Projects Initiated Per Year

### B.4.3.3 Impacts of Case Study Projects

Table B-25 summarizes the single case study that was analyzed for this subcategory.

**Table B-25. Summary of Traveler Information Systems Case Study**

| CMAQ ID | State | CMAQ Funding | Total Funding | Description |
|---|---|---|---|---|
| MI20100022 | Michigan | $3,120,000 | $3,900,000 | DMS removal, installation and upgrade; microwave vehicle detection system installation |

**Traffic/Congestion Mitigation Impacts**

Traveler Information Systems projects involve those that focus physical assets and services to provide travelers with real-time information to support better decision making regarding mode, time and routes traveled. Providing this information to travelers beforehand and during a trip can potentially have a significant impact on general traffic patterns to mitigate congestion. An informed traveler can choose to change their route or use HOV/HOT lanes, change their mode to public transportation or even postpone their trip to a later time.

Analysis of the case study indicated that this individual project was likely to have the following impacts on traffic/congestion mitigation:

- A decrease of 297,916 VMT per day.

**Emissions/Air Quality Impacts**

Emission reductions estimates in this subcategory typically are based on a decrease in traffic delay and VMT.

Table B-26 presents the estimated emissions reductions for VOCs, CO, NOx, $PM_{10}$ and $PM_{2.5}$ for the Traveler Information Systems case study.

**Table B-26. Estimated Emissions Reductions for the Traveler Information Systems Case Study**

| CMAQ ID | Year(s) | Estimated Emissions Reductions (kg/day) | | | | |
|---|---|---|---|---|---|---|
| | | VOC | CO | NOx | $PM_{10}$ | $PM_{2.5}$ |
| MI20100022 | 2010 | 143.3 | NR | 65.5 | NR | NR |

NR - Not reported

**Human Health Impacts**

The traveler information systems case study identified human health impacts to include reduced crash risk due to congestion mitigation.

# B.5 Improved Public Transit

## B.5.1 Transit Facilities, Systems, and Services

### B.5.1.1 Overview of Projects

Projects covering Transit Facilities, Systems and Services fall under the overall CMAQ category, Transit Improvements. Projects supporting transit facilities, systems and services are only eligible for CMAQ funding if they are associated with new or enhanced public transit. Since the FTA administers most transit projects, some projects under this category are managed by the FTA. The funds are transferred, or “flexed” from FHWA to FTA upon eligibility approval by the FTA. Typical projects in this subcategory tend to include:

- Transit fare collection systems
- New bus or rail equipment to increase capacity
- New or expanded transit infrastructure such as stations, shelters, platforms or bridges
- Station or commuter lot parking facilities

New service routes are also considered eligible for CMAQ funding; however, due to the number of and amount of CMAQ funding dedicated to these types of projects, the study team determined that a distinction should be made. Thus, these projects are included in New Bus Services and New Rail Services.

### B.5.1.2 Distribution of Projects

Figure B-27 shows the distribution of the projects within the transit facilities, systems and services subcategory by State. The shading in each State shows the cumulative level of CMAQ funding obligated to projects in the subcategory between FY 2006 and FY 2012. The number of these projects funded during this period is shown for each State, with California having the highest number of projects. This figure shows projects in this subcategory were distributed nationally with high funding amounts in California, Illinois, and New York.

Figure B-28 shows the number of projects started and the CMAQ funding for these projects for year during this timeframe. In general, projects in this subcategory have been initiated at a relatively steady rate. FY 2007 saw a slightly higher number of project initiated. The CMAQ funding during this period has been generally increasing with a significant increase in FY 2012 that included almost $100 million more than the prior year.

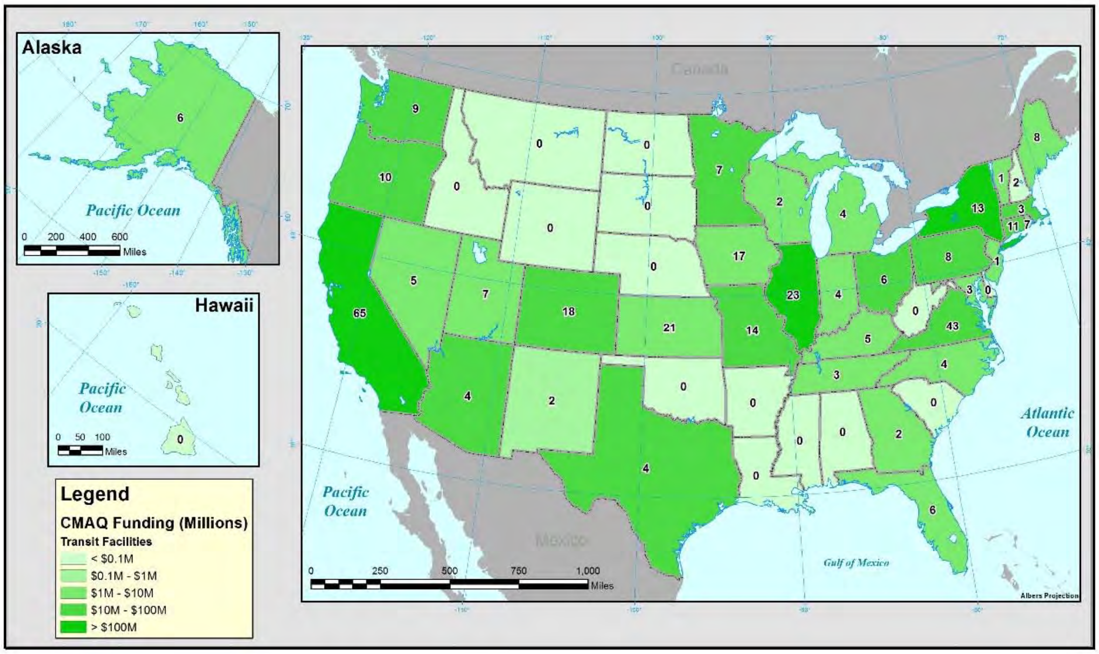

Figure B-27. Distribution of Projects and Funding for Transit Facilities, Systems and Services by State

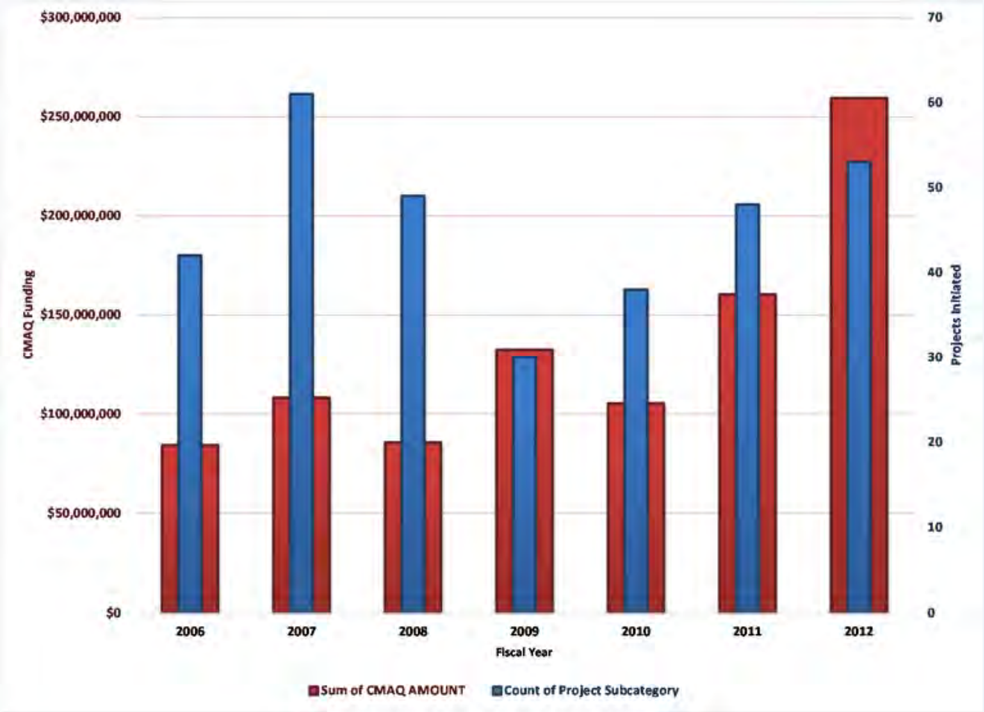

Figure B-28. Number of Transit Facilities, Systems and Services Projects Initiated Per Year

### B.5.1.3 Impacts of Case Study Projects

Table B-27 summarizes the four case studies that were analyzed for this subcategory.

**Table B-27. Summary of Transit Facilities, Systems and Services Case Studies**

| CMAQ ID | State | CMAQ Funding | Total Funding | Description |
|---|---|---|---|---|
| VA20110049 | Virginia | $149,910 | $187,387 | 11 bus shelters for existing bus stops |
| KS20070016 | Kansas | $600,000 | $750,000 | Student and commuter transit services along K-10 corridor |
| MO20110003 | Missouri | $938,400 | $938,400 | Operating funds for increased transit service (Troost MAX) |
| OR20060006 | Oregon | $325,720 | $363,000 | AVL/ASA equipment for bus fleet |

**Traffic/Congestion Mitigation Impacts**

Projects relating to improvements to transit facilities, systems and services generally involve an increase in the capacity, frequency and/or reliability of services for transit riders. These actions can have a significant impact on traffic/congestion mitigation by offering an alternative transportation mode and reducing the number of vehicles on the road.

Analysis of the four case studies indicated that these individual projects were likely to have the following impacts on traffic/congestion mitigation:

- In Virginia, improvements were expected to reduce vehicle trips by 36 per day and VMT by 361 trips per day. Transit was expected to see an increase of 41 boardings per day.
- Increase in transit services in Kansas expected a reduction of 1,425,000 VMT for the duration of the project. Transit was expected to see an increase of 50 riders/day.
- The Missouri deployment of the Troost MAX line expects to see an increase in demand. VMT are expected to decrease by 9,360,000 and an increase of 2000 transit new riders are expected.
- The passenger information system program in Oregon expects to be able to reduce VMT by 605,800 and increase transit trips by 165,000.

Common expected travel impacts between these case studies include reduction of vehicle trips, VMT and an increase in transit trips.

**Emissions/Air Quality Impacts**

Emission reductions estimates in this subcategory typically are based on reduction of vehicle trips and VMT.

Table B-28 presents the estimated emissions reductions for VOCs, CO, NOx, $PM_{10}$ and $PM_{2.5}$ for each of the transit facilities, systems and services case studies.

**Table B-28. Estimated Emissions Reductions for Transit Facilities, Systems and Services Case Studies**

| CMAQ ID | Year(s) | Estimated Emissions Reductions (kg/day) | | | | |
|---|---|---|---|---|---|---|
| | | VOC | CO | NOx | $PM_{10}$ | $PM_{2.5}$ |
| VA20110049 | 2011 | 0.24 | NR | 0.23 | NR | NR |
| KS20070016 | 2006-2008 | 0.59 | NR | 0.53 | NR | NR |
| MO20110003 | 2010 | 4.1 | NR | 6.5 | NR | NR |
| OR20060006 | 2010-2013 | NR | 22.85 | NR | 0.29 | NR |

NR - Not reported

Based on the case studies evaluated, projects within this subcategory typically estimate a reduction in VOC and $NO_x$ emissions.

**Human Health Impacts**

Two of the case studies evaluated identified the following human health impacts:

- Provides connections to educational opportunities at the University of Kansas, Haskell Indian Nations University, and Johnson County Community College. Also provides transit opportunities for commuters in Johnson and Douglas Counties in Kansas.
- Enhanced accessibility for those in the urban core to jobs, education, shopping, health services, trails and other recreational opportunities, etc. Improved access to University of Missouri - Kansas City Volker Campus and its Medical Center Campus at Hospital Hill.
- The Oregon project will improve access for visually-impaired individuals who require stop announcement assistance to use public transportation.

## B.5.2 New Bus Services

### B.5.2.1 Overview of Projects

Projects covering New Bus Services fall under the Transit Improvements category of projects eligible for funding under the CMAQ program. Due to the number of projects labeled as New Bus Services and the amount of CMAQ funding obligated to these projects, the project team has included these projects as a standalone category to be assessed. Projects within this subcategory focus on increasing transit capacity with the end result being a likely increase in transit ridership ultimately reducing congestion.

### B.5.2.2 Distribution of Projects

Figure B-29 shows the distribution of the projects within the new bus services subcategory by State. The shading in each State shows the cumulative level of CMAQ funding obligated to projects in the subcategory between FY 2006 and FY 2012. The number of new bus service projects funded during this period is shown for each State. This figure shows new bus service projects were funded across much of the country, with relatively higher funding levels in California and on the east coast, particularly in Connecticut.

Figure B-30 shows the number of projects started and the CMAQ funding for these projects for year during this timeframe. In general, projects in this subcategory have been initiated at a relatively steady rate. The CMAQ funding during this period has been generally steady as well with a significant spike in 2012. The spike in the funding that occurred during FY 2012 is attributable to a Bus Rapid Transit project in Connecticut which accounted for $47 million.

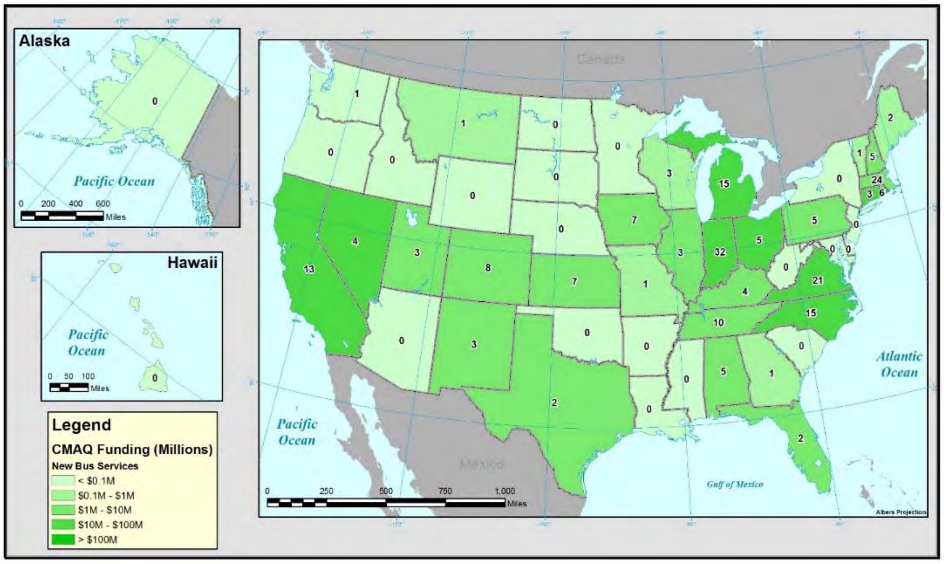

Figure B-29. Distribution of Projects and Funding for New Bus Services by State

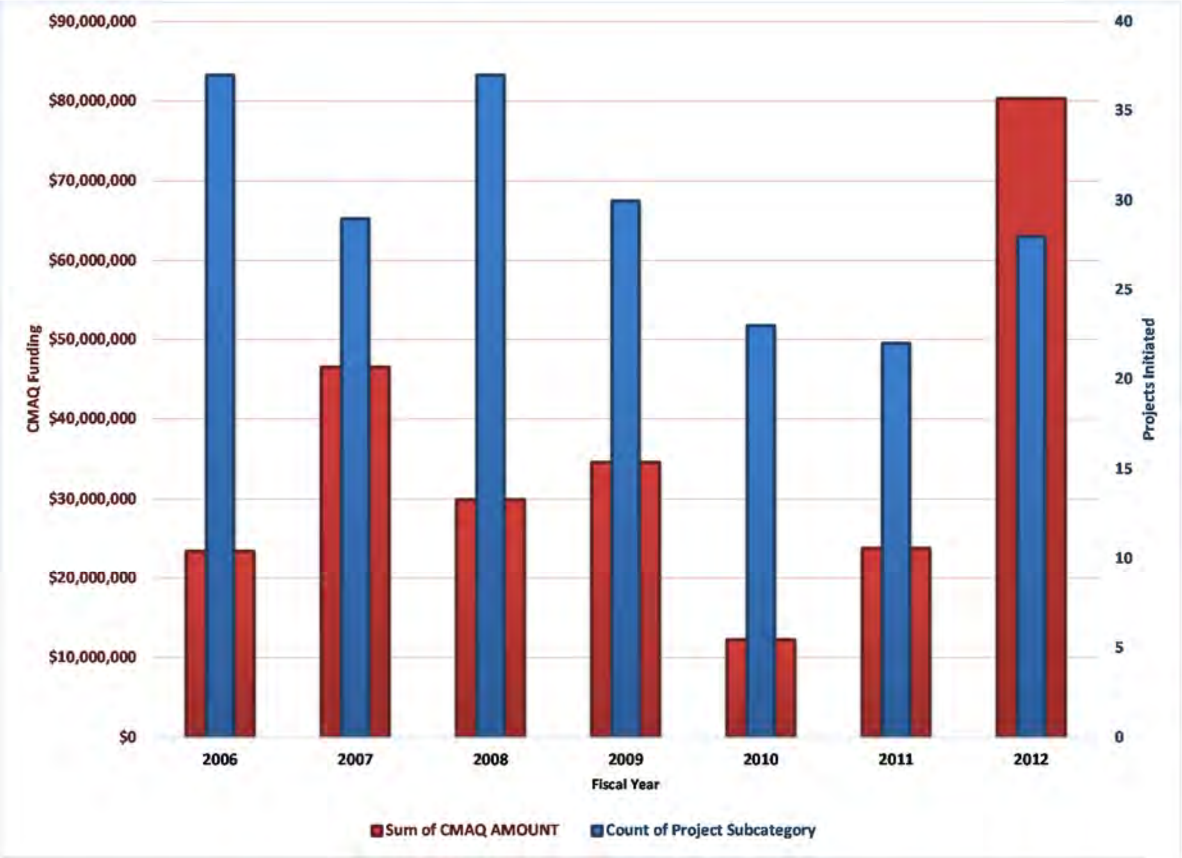

**Figure B-30. Number of New Bus Services Projects Initiated Per Year**

### B.5.2.3 Impacts of Case Study Projects

Table B-29 summarizes the two case studies that were analyzed for this subcategory.

**Table B-29. Summary of New Bus Services Case Studies**

| CMAQ ID | State | CMAQ Funding | Total Funding | Description |
|---|---|---|---|---|
| MI20100071 | Michigan | $1,662,128 | $2,077,660 | Operating assistance for bus routes, route extensions |
| KY20100005 | Kentucky | $1,019,200 | $1,274,000 | Increase frequency of TARC bus service along highway corridors |

**Traffic/Congestion Mitigation Impacts**

Projects in this subcategory involve the implementation of new bus services to increase transit capacity. By increasing transit capacity, transit ridership is expected to increase, resulting in a decrease in traffic congestion.

Analysis of the two case studies indicated that these individual projects were likely to have the following impacts on traffic/congestion mitigation:

- In Kentucky, a decrease of 729,000 annual vehicle trips; 7,498,000 annual VMT; and an increase of 1,460,000 annual transit trips was expected due to the new bus services.
- For Michigan, the case study indicated an expected increase of 173 transit trips, but did not specify a timeframe in which this increase would occur (i.e., hourly, daily, weekly, etc.).

An analysis of the expected traffic/congestion impacts shows that expected traffic impact for new bus services will typically be an increase in transit trips resulting in a reduction in vehicle trips and VMT.

**Emissions/Air Quality Impacts**

Emission reductions estimates in this subcategory typically are expected to show a reduction in emissions due to a decrease in vehicle trips and VMT.

Table B-30 presents the estimated emissions reductions for VOCs, CO, NOx, $PM_{10}$ and $PM_{2.5}$ for each of the new bus services case studies.

Analysis of these case studies indicated that new bus services can be expected to cause emissions reductions for VOCs, CO, NOx, $PM_{10}$ and $PM_{2.5}$.

**Table B-30. Estimated Emissions Reductions for New Bus Services Case Studies**

| CMAQ ID | Year(s) | Estimated Emissions Reductions (kg/day) | | | | |
|---|---|---|---|---|---|---|
| | | VOC | CO | NOx | $PM_{10}$ | $PM_{2.5}$ |
| MI20100071 | 2010 | 3.775 | 62.395 | 2.756 | NR | 0.063 |
| KY20100005 | 2006 | 41.11 | 496.8 | 42.92 | 1.14 | NR |

NR - Not reported

**Human Health Impacts**

Neither of the new bus services case studies reported human health impacts to the research team.

## B.5.3 New Rail Services

### B.5.3.1 Overview of Projects

Projects covering New Rail Services fall under the Transit Improvements category of projects eligible for funding under the CMAQ program. Due to the number of projects labeled as New Rail Services and the amount of CMAQ funding obligated to these projects, the project team has included these projects as a standalone category to be assessed. Projects within this subcategory focus on increasing transit capacity with the end result being a likely increase in transit ridership ultimately reducing congestion.

### B.5.3.2 Distribution of Projects

Figure B-31 shows the distribution of the projects within the New Rail Services subcategory by State. The shading in each State shows the cumulative level of CMAQ funding obligated to projects in the subcategory between FY 2006 and FY 2012. The number of new rail service projects funded during this period is shown for each State. This figure shows new rail service projects were funded across much of the country with California being the highest funding recipient.

Figure B-32 shows the number of projects started and the CMAQ funding for these projects for year during this timeframe. In general, projects in this subcategory have been initiated at a relatively steady rate with a slight increase in FY 2011. The CMAQ funding during this period averaged approximately $33 million between FY 2006 and FY 2010. In FY 2011, CMAQ funding for new rail service projects increased almost 5 times from the year before. The spike in the funding can largely be attributed to two projects in California and one in Massachusetts that totaled approximately $79 million of the funds for that year.

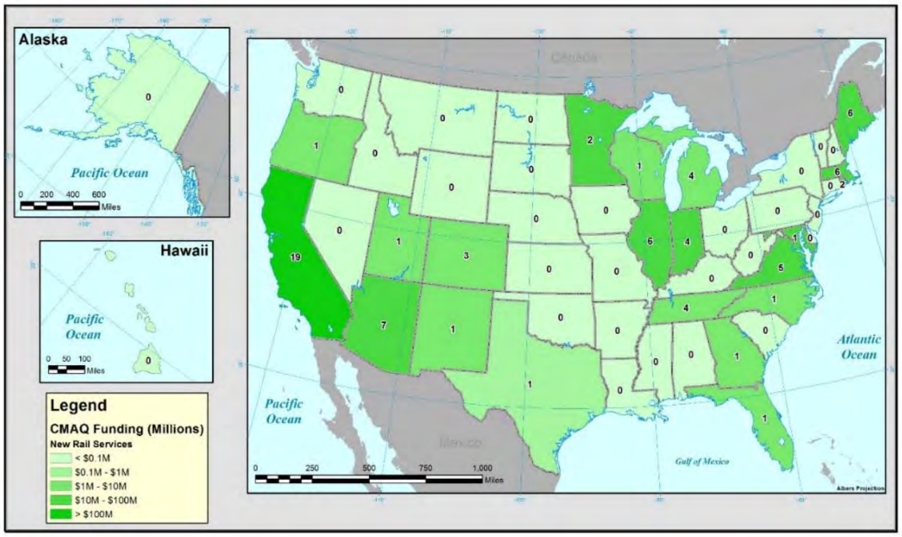

**Figure B-31. Distribution of Projects and Funding for New Rail Services by State**

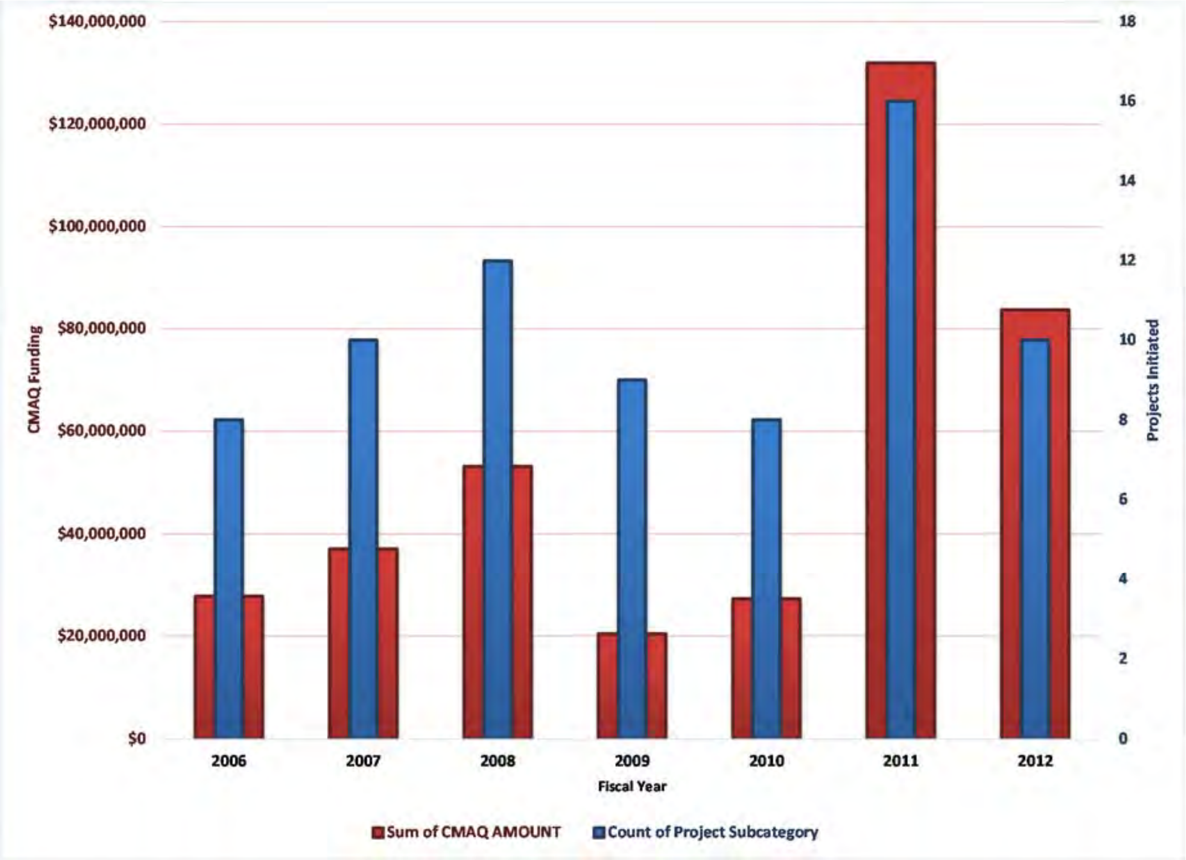

**Figure B-32. Number of New Rail Service Projects Initiated Per Year**

### B.5.3.3 Impacts of Case Study Projects

Table B-31 summarizes the 2 case studies that were analyzed for this subcategory.

**Table B-31. Summary of New Rail Service Case Studies**

| CMAQ ID | State | CMAQ Funding | Total Funding | Description |
|---|---|---|---|---|
| CA20110388 | California | $215,000,000 | $998,900,000 | Construction of 8.6 mile Metro Exposition Line (LRT) |
| ME20100001 | Maine | $5,268,036 | $6,585,036 | Commuter rail service - operations |

**Traffic/Congestion Mitigation Impacts**

New Rail Service projects involve the acquisition, rehabilitation, expansion or modification of rail assets, facilities or services with the expectation that such actions will increase rail capacity and thereby ridership. These actions can have a significant impact on traffic/congestion mitigation by offering an alternative transportation mode and reducing the number of vehicles on the road.

Analysis of the two case studies indicated that these individual projects were likely to have the following impacts on traffic/congestion mitigation:

- The new light rail case study was expected to see a reduction of 10,651 vehicle trips per day in LA County; a reduction of 66,618 VMT per day and an increase in speed of 0.05 mph in the study area. In addition, it was expected that transit trips would be increased by 22,189 and bike/walk trip would increase by 19,041; however, the time period and location for these trips were not specified.
- In Maine, the commuter rail service was expected to decrease vehicle trips by 173 per day and VMT by 14,318 per day.

In both case studies, new rail service was expected to decrease both vehicle trips and VMT.

### Emissions/Air Quality Impacts

Emission reductions estimates in this subcategory typically are based on reduction of VMT and reduced highway and parking congestion.

Table B-32 presents the estimated emissions reductions for VOCs, CO, NOx, $PM_{10}$ and $PM_{2.5}$ for each of the new rail service case studies. The higher VOC and NOx emissions reductions estimated for CA20110388 may suggest a larger project scope compared to the Maine new rail services project; it is not clear why reductions in CO and $PM_{10}$ were not also reported.

**Table B-32. Estimated Emissions Reductions for New Rail Service Case Studies**

| CMAQ ID | Year(s) | Estimated Emissions Reductions (kg/day) | | | | |
|---|---|---|---|---|---|---|
| | | VOC | CO | NOx | $PM_{10}$ | $PM_{2.5}$ |
| CA20110388 | 2011 | 17.40 | 367.84 | 7.46 | 7.46 | NR |
| ME20100001 | 2006 | 7.79 | NR | 4.62 | NR | NR |

NR - Not reported

### Human Health Impacts

The case study for the new light rail line in California expected the following human health impacts:

- SAFETY and SECURITY: Bus and rail facilities (including vehicles, stations, parking lots, etc.) are designed to provide a safe, secure, and comfortable transit system.
- No impacts to groundwater resources were identified. The project does not significantly encroach on a flood plain and was built in accordance with all state and local flood plain protection standards. The project does not affect wildlife corridors nor does it interfere with a Habitat Conservation Plan. It does not result in any significant impacts on biological resources, including sensitive natural communities or wetlands.
- Energy Consumption: The project results in less passenger vehicle VMT and higher bus and light/heavy rail VMT and slightly less oil consumption than the baseline condition.

- Noise Impacts: Noise impacts from trains were mitigated through soundwalls and adjustments to crossing gates, horns and bells to meet FTA noise impact threshold criteria.
- An independent, before and after study conducted found that the opening of Expo Phase 1 was associated with increases in physical activity among approximately the 40 percent of experimental subjects (living closest to the line) who had the lowest physical activity levels before the line opened.  For further information on this Study, refer to: http://priceschool.usc.edu/expo-line-study/.
- The study area population is comprised of a primarily minority and low-income demographic. Low-income residents benefit from increased access to mass transit and, subsequently, increased access to employment opportunities and regional centers, including Downtown Los Angeles and Culver City.

## B.6 Transportation Demand Management

### B.6.1 Public Education/Outreach

#### B.6.1.1 Overview of Projects

Projects covering public education and outreach activities are explicitly identified as 1 of the 17 categories of projects eligible for funding under the CMAQ program.  These projects seek to educate the public, community leaders, and potential project sponsors about trip making and transportation mode choices, traffic congestion, and air quality.  These efforts are geared toward helping communities reduce emissions and congestion by inducing drivers to change their transportation choices.  These programs may include:

- Activities to promote new or existing transportation services
- Development, placement, and evaluation of messages and advertising materials (including market research, focus groups, and creative)
- Technical assistance
- Programs that promote commute benefits
- Transit “store” operations.

#### B.6.1.2 Distribution of Projects

Figure B-33 shows the distribution of the projects within the public education and outreach activities category by State.  The shading in each State shows the cumulative level of CMAQ funding obligated to projects in the category between FY 2006 and FY 2012.  The number of public education and outreach activity projects funded during this period is shown for each State.  This figure shows public education and outreach activity projects that were funded across much of the country, with particularly high funding levels in Georgia, and relatively high levels in Connecticut, New York, and Virginia on the east coast, Indian and Ohio in the Great Lakes region, and California on the west coast.

Figure B-34 shows the number of projects started and the CMAQ funding for these projects for year during this timeframe.  In general, the issuance of projects in this category have fluctuated between 35 and 50 projects annually with the exception of a spike of 60 projects during FY 2007.  The CMAQ funding has also fluctuated significantly during this period, ranging from approximately $25 million to $60 million dollars per year.

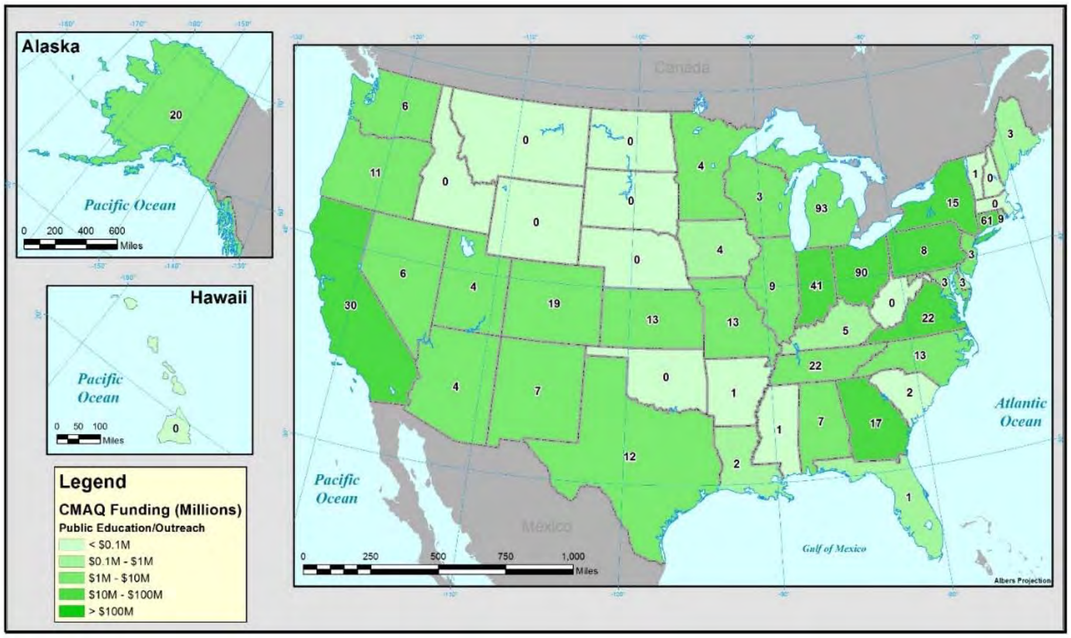

Figure B-33. Distribution of Projects and Funding for Public Education and Outreach Activities by State

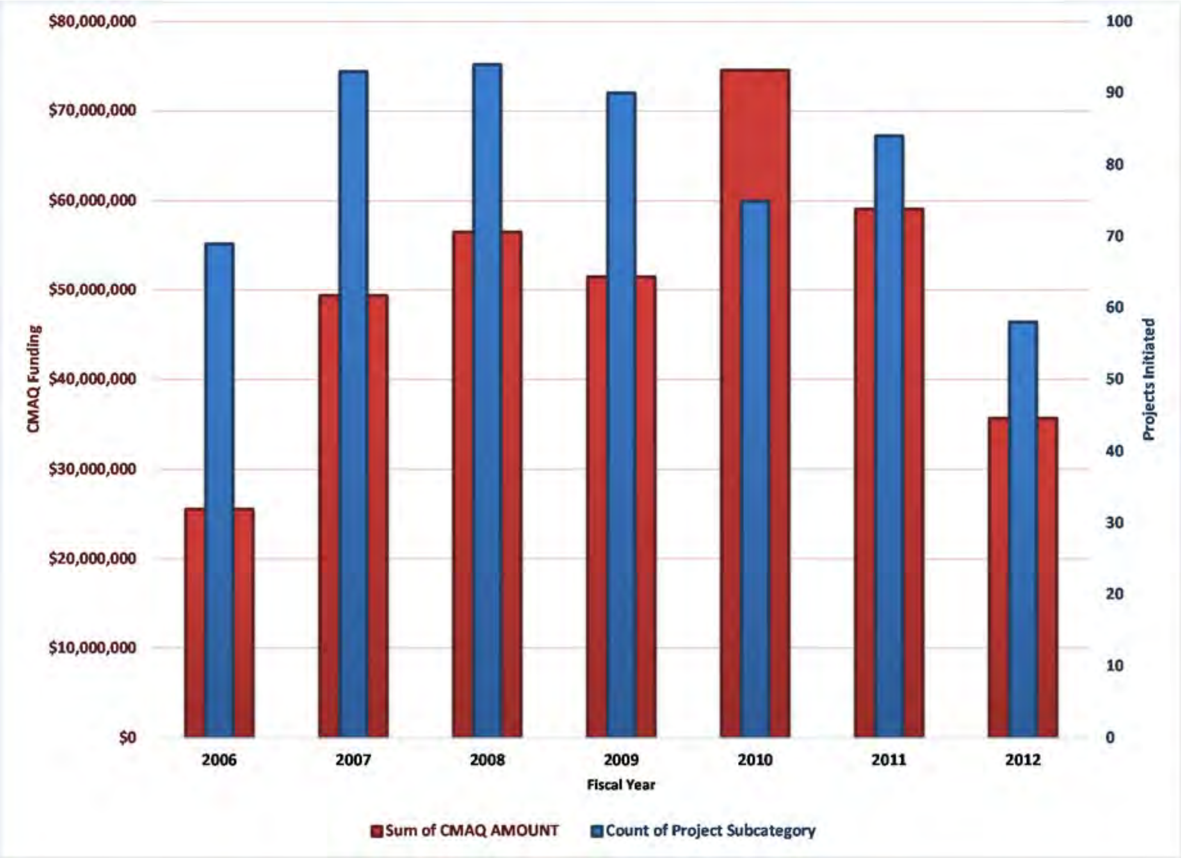

**Figure B-34. Number of Public Education and Outreach Activities Projects Initiated Per Year**

### B.6.1.3 Impacts of Case Study Projects

Table B-33 summarizes the case studies that were analyzed for this category.

**Table B-33. Summary of Public Education and Outreach Activities Case Studies**

| CMAQ ID | State | CMAQ Funding | Total Funding | Description |
|---|---|---|---|---|
| CO20090015 | Colorado | $861,215 | $1,016,215 | Summer ozone education and outreach program |
| KS20090009 | Kansas | $43,000 | $53,750 | Ozone Alert Day reduced transit fare program |
| MI20090002 | Michigan | $75,200 | $94,000 | Ozone Action public education program |

#### Traffic/Congestion Mitigation Impacts

Projects in this category involve public outreach and education to audiences that not always followed to examine any changes in their behavior. In some cases, these behavior changes must be assumed or estimated. The public outreach and education programs in this category may cover a wide variety of topics, but are typically associated with encouraging the reduction of trips and/or VMT, by switching to transit, bicycling, pedestrian, carpool, or vanpool modes.

Analysis of the three case studies indicated that these individual projects were likely to have the following impacts on traffic/congestion mitigation:

- The Colorado case study estimated trip reduction had taken place as a result of their outreach campaign.
- The Kansas case study expected 4500 people to modify their travel behavior only on ozone action days, with a reduction of 600 trips resulting in a reduction of 45,989 VMT on those days.
- The Michigan case study estimated VMT reduction of approximately 14.9 million VMT per year as a result of travelers using vanpools, carpools, transit, and telework options.

Unlike other potential public education and outreach programs, all three case studies examined focused solely on specific days of the year for travelers to modify their behavior.  While other projects may directly encourage transit usage or carpooling as part of a daily commute, for example, these three projects focus only on specific days.  Regardless, all three case studies expect a significant reduction in VMT and trips.

### Emissions/Air Quality Impacts

Emission reductions estimates in this category typically are based on the lessened emissions that result from reduced VMT and fewer trips.  Encouraging changes to other non-travel behavior can also reduce emissions, such as properly maintaining vehicles, mowing in the evening or with earth-friendly equipment, and modifying refueling practices.  The reduction in emissions can be estimated for a given project using appropriate emission factors for vehicles for estimated trip or VMT reductions.  All three case studies estimated reductions for VOC pollutants, and two estimated reductions for NOx pollutants.

Table B-34 presents available estimated emissions reductions for VOCs, CO, NOx, $PM_{10}$ and $PM_{2.5}$ for each of the public education and outreach projects case studies.

**Table B-34.  Estimated Emissions Reductions for Public Education and Outreach Activities Case Studies**

| CMAQ ID | Year(s) | Estimated Emissions Reductions (kg/day) | | | | |
|---|---|---|---|---|---|---|
| | | VOC | CO | NOx | $PM_{10}$ | $PM_{2.5}$ |
| CO20090015 | 2006 | QA | NR | NR | NR | NR |
| KS20090009 | 2010 | 13.6 | NR | 13.6 | NR | NR |
| MI20090002 | 2009 | 23.855 | NR | 18.765 | NR | NR |

NR - Not reported
QA – Qualitative estimate

Analysis of these three case studies indicated that these individual projects were likely to have the following impacts on vehicle emissions and air quality:

- The Colorado case study estimates potential VOC reductions of up to 2836 kg per day, that could occur if all participants followed through on activities that were encouraged as part of the program, which include trip reduction, vehicle maintenance, refueling practices, and mowing reduction.
- The Kansas case study used the Mobile Model to estimate reductions of 13.6 kg per day for each VOC and NOx pollutants.
- The Michigan case study calculated VOC and NOx pollutant reductions resulting from reduced VMT caused by mode shift to transit, carpooling, and teleworking.

**Human Health Impacts**

Of the three public education and outreach case studies evaluated, only one reported human health impacts in the selection process. The Colorado case study included discussion of the negative health impacts incurred on high ozone days, encouraging individuals to reduce exposure and modify their travel and household behavior to lessen pollutants on these days.

## B.6.2 Travel Demand Management

### B.6.2.1 Overview of Projects

Projects covering TDM are explicitly identified as 1 of the 17 categories of projects eligible for funding under the CMAQ program. Overall the projects within this category can involve:

- Fringe parking
- Traveler Information Services
- Shuttle services
- Guaranteed ride home programs
- Carpools, vanpools
- Traffic calming measures
- Parking pricing
- Variable road pricing
- Telecommuting/Teleworking
- Employer-based commuter choice programs

The broad range of TDM projects is a testament to the many ways to reduce SOV use. Similar to other categories, TDM projects aim to optimize the performance of the existing local and regional transportation networks, thereby reducing emissions.

Separate sections within this document discuss TDM-related projects related to park and ride facilities, car sharing, public education and outreach, and value/congestion pricing. The projects detailed in this section are intended to represent other, broader types of TDM activities.

### B.6.2.2 Distribution of Projects

Figure B-35 shows the distribution of the projects within the TDM subcategory by State. The shading in each State shows the cumulative level of CMAQ funding obligated to projects in the subcategory between FY 2006 and FY 2012, which totaled over $315 million. All 357 TDM projects funded during this period are shown for each State. This figure shows TDM projects were funded across much of the country, with the highest funding levels in California. Relatively high funding was also allocated to Connecticut, Massachusetts, Pennsylvania, and Virginia on the east coast, as well as Michigan and Indiana in the Great Lakes region, and Tennessee, Texas, and Arizona across the south.

Figure B-36 shows the number of projects started and the CMAQ funding for these projects for each year during this timeframe. In general, projects in this category have ranged between approximately 35 and 60 projects per year. The CMAQ funding during this period has fluctuated, generally between $25 million and $50 million, with the exception of a notable spike in FY 2009 when funding reached over $60 million.

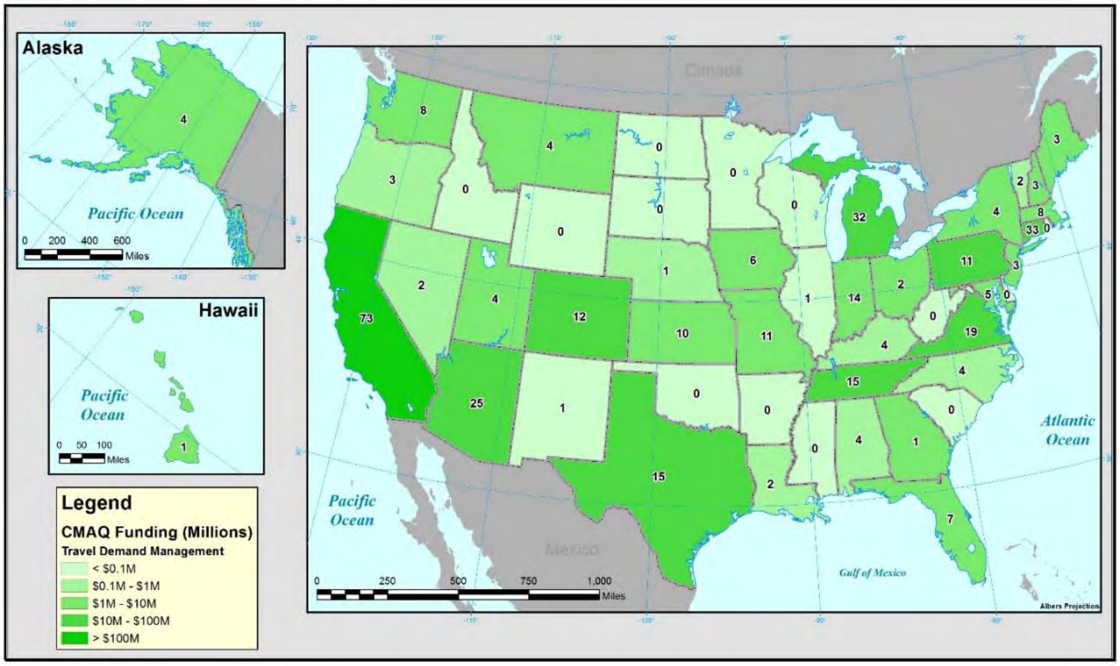

**Figure B-35. Distribution of Projects and Funding for Travel Demand Management by State**

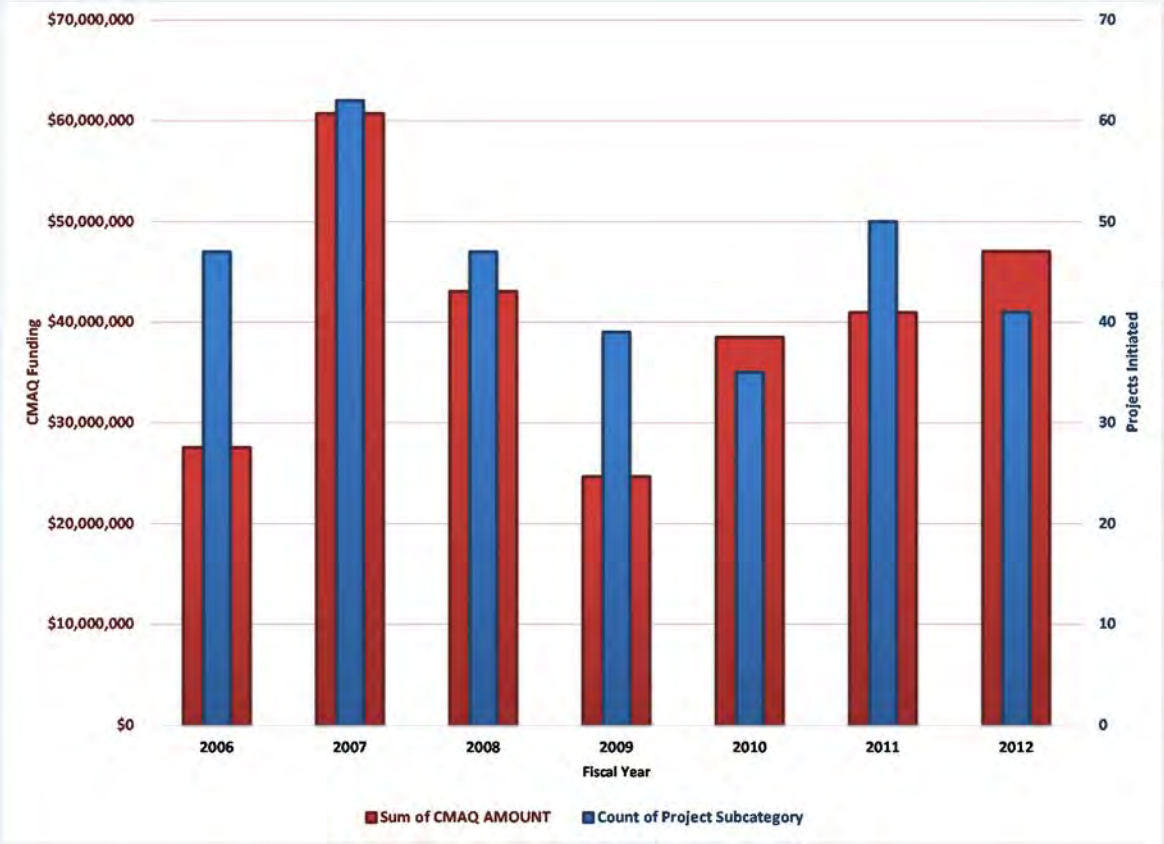

Figure B-36. Number of Travel Demand Management Projects Initiated Per Year

### B.6.2.3 Impacts of Case Study Projects

Table B-35 summarizes the case studies that were analyzed for this category.

Table B-35. Summary of Travel Demand Management Case Studies

| CMAQ ID | State | CMAQ Funding | Total Funding | Description |
|---|---|---|---|---|
| VA20090012 | Virginia | $1,676,900 | $2,096,125 | Employee Trip Reduction Program |
| CA20110041 | California | $9,882,319 | $10,566,699 | TDM program to encourage mode shift through outreach |

**Traffic/Congestion Mitigation Impacts**

The projects in this category have the potential to significantly reduce trips and/or VMT. Many projects involve either the reduction of trips and VMT due to mode shift to transit or teleworking, or VMT reductions caused by shifts to higher-occupancy modes, for example.

Analysis of the two case studies indicated that these individual projects were likely to have the following impacts on traffic/congestion mitigation:

- A total of over 1.2 million new transit trips, or roughly 121,000 transit trips per year due to a trip reduction program that encouraged workers to use alternate modes. Transit swipecards were provided to full-time City of Richmond employees, as well as vanpool subsidies for certified vanpool riders. Approximately 22% of the City's workforce have enrolled in the program using both services, which exceeds the program's original goal of 10% employee participation. Participation level is monitored closely by computerized monthly reports and swipecard usage.
- An annual reduction of 8.3 million VMT or 271,528 trips as a result of a TDM program to encourage alternate modes such as transit, bicycling, and walking, as well as vanpool, ride share, and teleworking.

Both projects examined here predicted strong gains in shifting SOV drivers to transit, higher-occupancy modes, and other alternate modes as a result of marketing and education on TDM, through the distribution of transit cards, and workplace programs.

### Emissions/Air Quality Impacts

Emission reductions estimates in this category typically are based on the reduced trips due to mode shift to transit, higher-occupancy modes, or teleworking, for example. The reduction in emissions can be estimated for a given project using appropriate emission factors for typical personal vehicles with an understanding of how many trips were reduced. Both case study projects reported an estimated reduction in emissions for at least one pollutant.

Table B-36 presents the estimated emissions reductions for VOCs, CO, NOx, $PM_{10}$ and $PM_{2.5}$ for the TDM case studies.

**Table B-36. Estimated Emissions Reductions for Travel Demand Management Case Studies**

| CMAQ ID | Year(s) | Estimated Emissions Reductions (kg/day) | | | | |
|---|---|---|---|---|---|---|
| | | VOC | CO | NOx | $PM_{10}$ | $PM_{2.5}$ |
| VA20090012 | 2009 | QA | QA | QA | QA | QA |
| CA20110041 | 2012 | 3.63 | NR | 3.57 | NR | 1.98 |

NR - Not reported
QA – Qualitative estimate

Both projects estimated a reduction in pollutants for which calculations were conducted. Analysis of these two case studies indicated that these individual projects were likely to have the following impacts on vehicle emissions and air quality:

- The Virginia project estimated an annual reduction of 20 tons of pollutants per year as a result of 20% participation level in the Richmond Employee Trip Reduction Program. With a constant participation level of 22%, an estimated 200 tons of pollutants has been reduced as a result of the program over the 10-year lifecycle.

- Using a TDM emissions model, an estimated 9.18 kg of pollutants per day are reduced through the California project.

**Human Health Impacts**

Of the two TDM case studies evaluated, neither reported human health impacts in the selection process.

### B.6.3 Park and Ride Facilities

#### B.6.3.1 Overview of Projects

Projects covering park and ride facilities fall within 1 of the 15 subcategories of TCM, which is 1 of the 17 categories of projects eligible for funding under the CMAQ program. The projects within this subcategory cover a wide variety of programs to encourage higher-occupancy modes and shared rides, reduce trips, and limit car travel. In particular, this subcategory includes fringe and transportation corridor parking facilities serving multiple-occupancy vehicle programs or transit service.

#### B.6.3.2 Distribution of Projects

Figure B-37 shows the distribution of park and ride facilities projects across the United States. Although states with the highest number of projects were on the east coast and California, the distribution of park and ride facilities projects were distributed fairly evenly across the United States.

Figure B-38 shows the number of projects started and the CMAQ funding for these projects for the year during this timeframe. In general, the number of projects initiated in this subcategory has fluctuated between 12 to 32 projects per year between FY 2006 and FY 2012. The CMAQ funding during this period was under $10 million for FY 2006 and FY 2007, but increased to $25 to $30 million for the next three years, before dropping to $15 to $20 million for FY 2011 and FY 2012. The total funding allocated during this time period in this subcategory totals over $135 million.

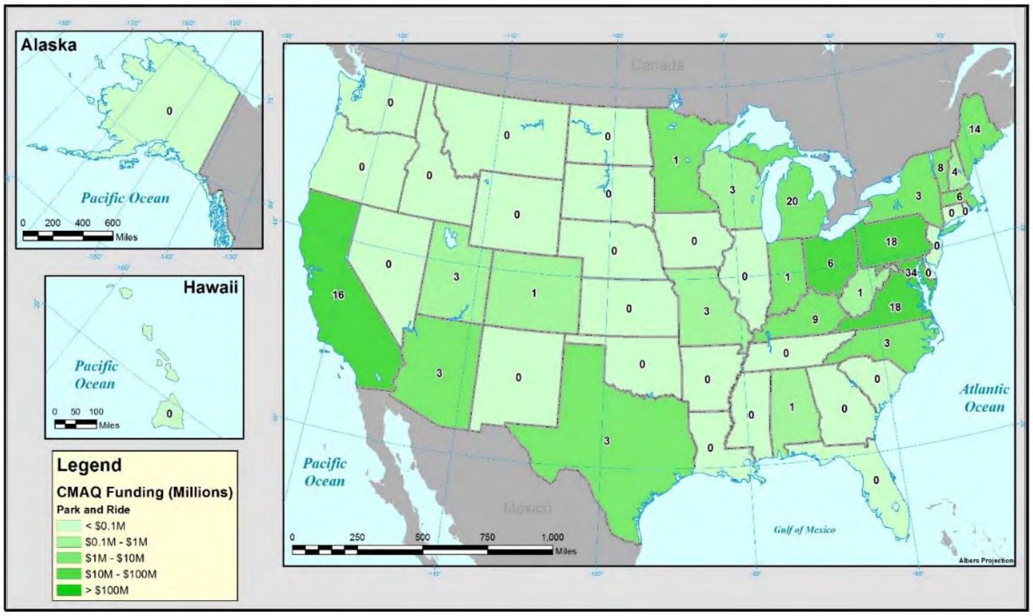

**Figure B-37. Distribution of Projects and Funding for Park and Ride Facilities by State**

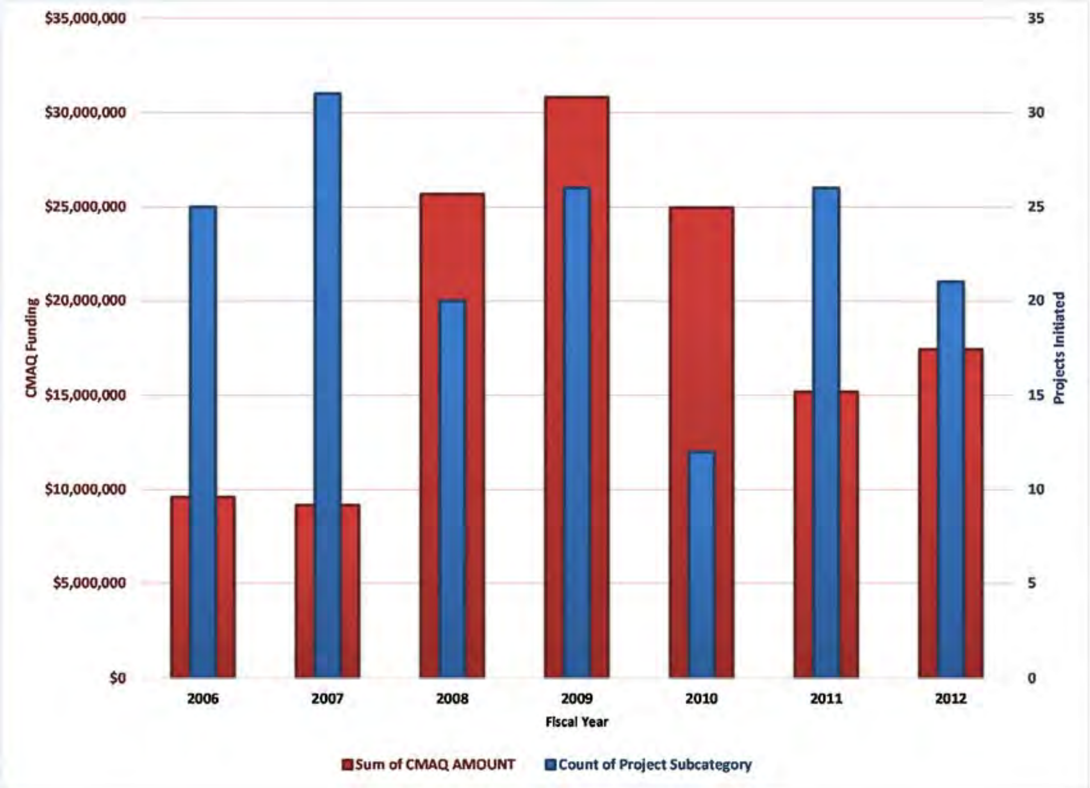

**Figure B-38. Number of Park and Ride Facilities Projects Initiated Per Year**

### B.6.3.3 Impacts of Case Study Projects

Table B-37 summarizes the case study that was analyzed for this category.

**Table B-37. Summary of Park and Ride Facilities Case Study**

| CMAQ ID | State | CMAQ Funding | Total Funding | Description |
|---|---|---|---|---|
| MI20090047 | Michigan | $293,310 | $366,638 | New Carpool Parking Lot |

**Traffic/Congestion Mitigation Impacts**

Since the projects in this subcategory involve ridesharing, they have the ability to increase vehicle occupancy and reduce the number of vehicles on the road, thus easing congestion. This particular project is estimated to have reduced daily VMT by 642 vehicle-miles that would have been travelled at speeds of 55 mph.

**Emissions/Air Quality Impacts**

Emission reductions estimates in this subcategory typically are based on the lower emission rates caused by reduced vehicle trips or reductions in VMT. The reduction in emissions can be estimated for a given project using appropriate emission factors for light-duty vehicles based on reductions in trips or VMT. This project reported an estimated reduction in emissions for two pollutants.

Table B-38 presents the estimated emissions reductions for VOCs, CO, NOx, $PM_{10}$ and $PM_{2.5}$ for the Park and Ride Facilities case study.

**Table B-38. Estimated Emissions Reductions for Park and Ride Facilities Project Case Study**

| CMAQ ID | Year(s) | Estimated Emissions Reductions (kg/day) | | | | |
|---|---|---|---|---|---|---|
| | | VOC | CO | NOx | $PM_{10}$ | $PM_{2.5}$ |
| MI20090047 | 2014 | 0.694 | NR | 0.607 | NR | NR |

NR - Not reported

This project estimated modest reductions in the two pollutants included in the analysis, based largely on VMT reductions due to increases in vehicle occupancy caused by shared rides from the carpool lot.

**Human Health Impacts**

The case study that was evaluated did not report human health impacts in the selection process.

### B.6.4 Car Sharing

### B.6.4.1 Overview of Projects

Projects covering car sharing are explicitly identified as 1 of the 17 categories of projects eligible for funding under the CMAQ program. Projects within this category involve the pooling of efficient, low-emission vehicles for shared use by users who have an occasional as opposed to a daily need for vehicle travel. Car sharing programs must be able to demonstrate an emissions reduction in order to qualify for CMAQ funding under this category.

### B.6.4.2 Distribution of Projects

Figure B-39 shows the locations of each of the 5 car sharing projects that have received CMAQ funds: Tennessee, Pennsylvania, Illinois, Rhode Island, and California. The shading in each State shows the cumulative level of CMAQ funding obligated to projects in the subcategory between FY 2006 and FY 2012. Pennsylvania and California each received nearly $2 million in CMAQ funding for these projects.

Figure B-40 shows the number of projects started and the CMAQ funding for these projects for each year during this timeframe. The CMAQ funding during this period has been varied from project to project. The projects that received funds near $2 million in FY 2006 and FY 2012 both were expansion projects for existing car sharing programs. The remaining CMAQ funds supported car share program development.

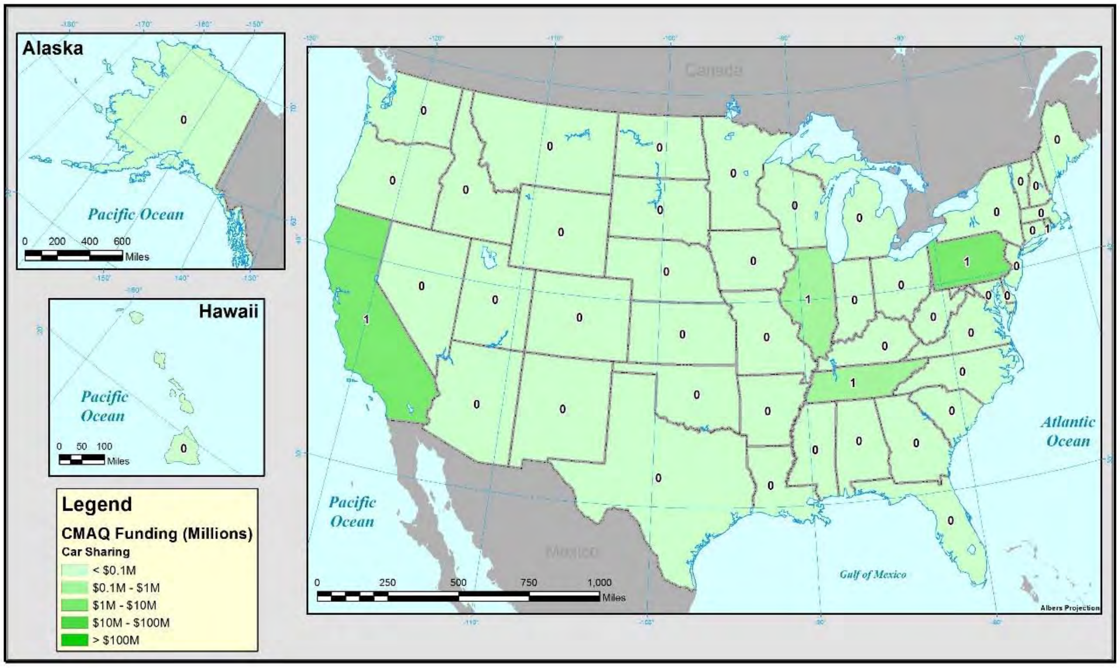

Figure B-39. Distribution of Projects and Funding for Car Sharing by State

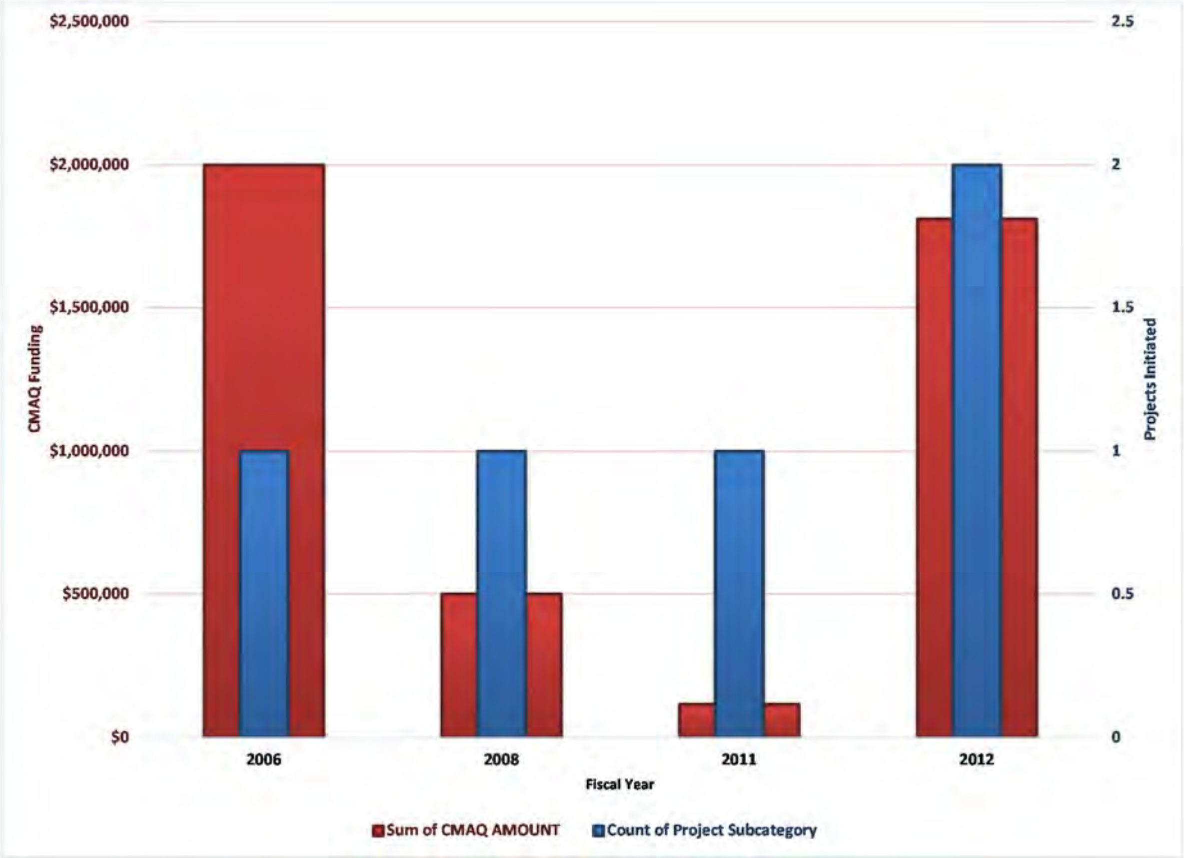

**Figure B-40. Number of Car Sharing Projects Initiated Per Year**

### B.6.4.3 Impacts of Case Study Projects

Table B-39 summarizes the case study that was analyzed for this category.

**Table B-39. Summary of Car Sharing Case Study**

| CMAQ ID | State | CMAQ Funding | Total Funding | Description |
|---|---|---|---|---|
| IL20080052 | Illinois | $2,521,024 | $3,151,280 | Chicago car sharing program, demo, car purchases and expansion |

**Traffic/Congestion Mitigation Impacts**

Car sharing projects involve reducing the dependency on automobile use by means of providing on-demand, short-term car rentals to individuals with an occasional need for a vehicle. Car sharing can have an impact on traffic/congestion mitigation, except where an individual may have taken public transportation instead.

Analysis of the case study indicated that this individual project was likely to have the following impacts on traffic/congestion mitigation:

- A reduction of 18.97 million VMT annually and 4,162 daily vehicle trips eliminated.

**Emissions/Air Quality Impacts**

Emission reductions estimates in this category typically are based on reduced congestion due to elimination of vehicle trips and VMT.

Table B-40 presents the estimated emissions reductions for VOCs, CO, NOx, $PM_{10}$ and $PM_{2.5}$ for the single car sharing case study.

**Table B-40. Estimated Emissions Reductions for the Car Sharing Case Study**

| CMAQ ID | Year(s) | Estimated Emissions Reductions (kg/day) | | | | |
|---|---|---|---|---|---|---|
| | | VOC | CO | NOx | $PM_{10}$ | $PM_{2.5}$ |
| IL20080052 | | 0.67 | NR | 0.58 | NR | NR |

NR - Not reported

**Human Health Impacts**

The car sharing case study examined did not report the human health impacts of the project.

## B.6.5 Value/Congestion Pricing

### B.6.5.1 Overview of Projects

Projects covering value/congestion pricing are 1 of the 3 subcategories of congestion reduction and traffic flow improvements, which is 1 of the 17 categories of projects eligible for funding under the CMAQ program. Overall the projects within this subcategory could involve:

- HOT lanes on which variable tolls are charged to drivers of low-occupancy vehicles using HOV lanes;
- New variably tolled express lanes on existing toll-free facilities;
- Variable tolls on existing or new toll roads;
- Network-wide or cordon pricing;
- Usage-based vehicle pricing, such as mileage-based vehicle taxation; and
- Parking pricing with time-of-day variations reflecting congested conditions.

### B.6.5.2 Distribution of Projects

All three of the selected projects within the Value/Congestion Pricing subcategory are located in California. As this category is one of particular interest with limited projects to examine, note that 6 other Value/Congestion Pricing projects involving dynamic parking pricing and highway congestion pricing are being evaluated separately as a part of the Urban Partnership Agreement (UPA)/Congestion Reduction Demonstration (CRD) National Evaluation. This evaluation is currently underway and includes an environmental analysis for each site that discusses air quality impacts.

Figure B-41 shows the number of projects started and the CMAQ funding for these projects between FY 2010 and FY 2012. In general, one project in this subcategory has been initiated per year during this timeframe. The CMAQ funding during this period was significantly higher for the project in FY 2010 than in the two subsequent years. The total funding allocated during this time period in this subcategory totals $26.2 million.

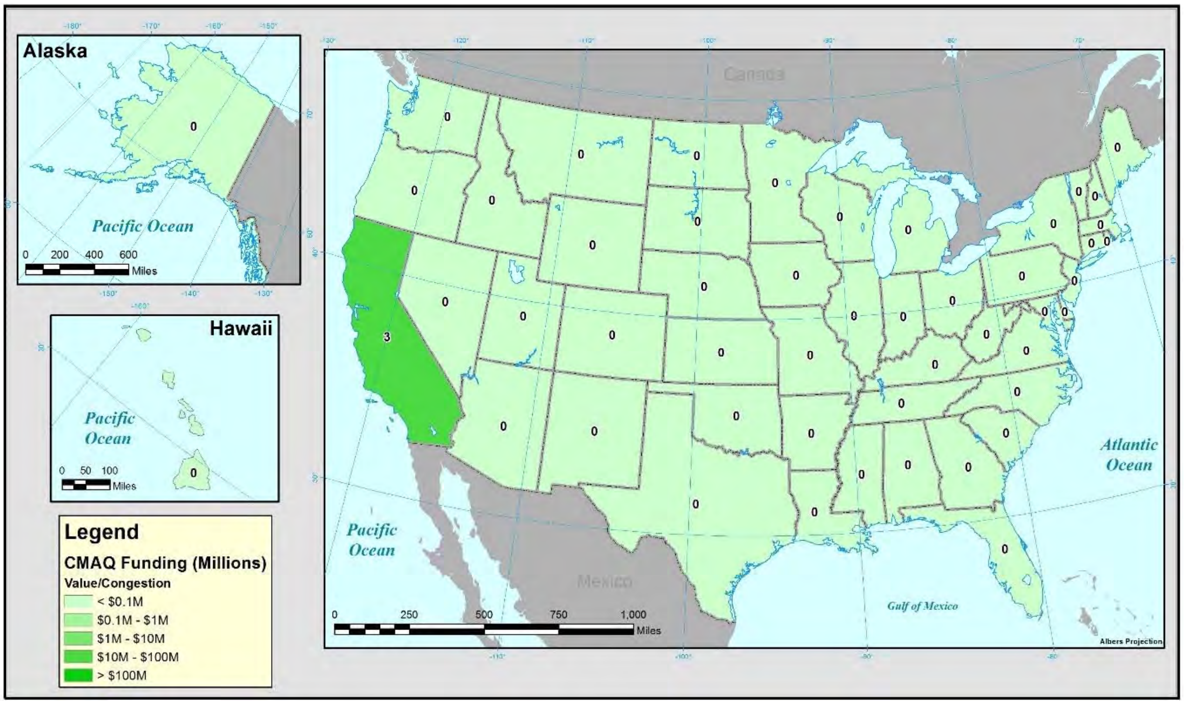

**Figure B-41. Distribution of Projects and Funding for Roundabouts by State**

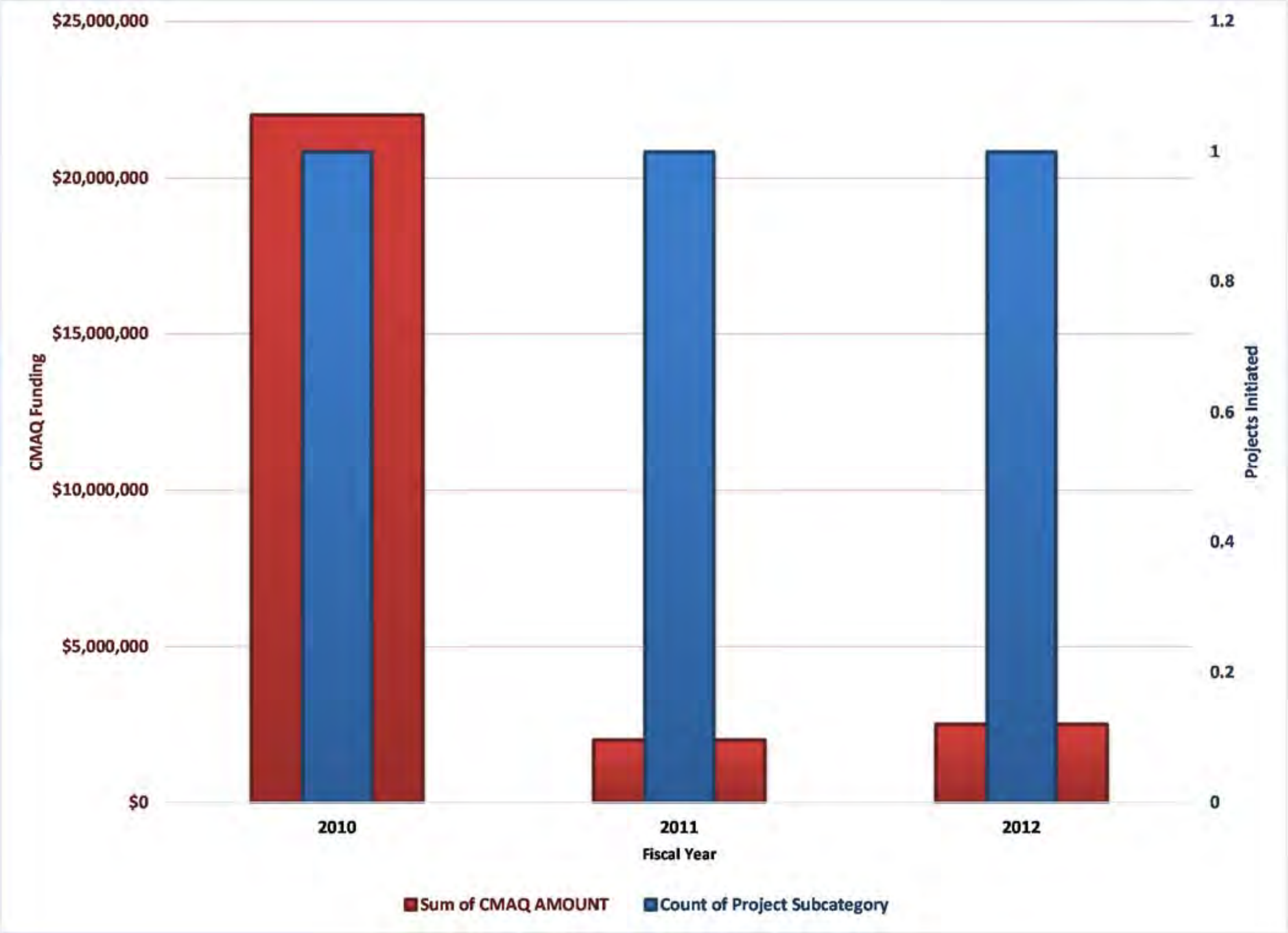

**Figure B-42. Number of Value/Congestion Pricing Projects Initiated Per Year**

### B.6.5.3 Impacts of Case Study Projects

Table B-41 summarizes the case study that was analyzed for this subcategory.

**Table B-41. Summary of Value/Congestion Pricing Project Case Study**

| CMAQ ID | State | CMAQ Funding | Total Funding | Description |
|---|---|---|---|---|
| CA20110128 | California | $2,000,000 | $2,260,000 | Parking Pricing Pilot and Enforcement Program |

**Traffic/Congestion Mitigation Impacts**

Since the projects in this subcategory involve demand-based pricing, they have the ability to significantly impact usage during congested periods, causing changes in general traffic patterns and easing congestion.  This particular project included three different methods to cause VMT and trip reductions.

Analysis of this case study indicated that this individual project was likely to have the following impacts on traffic/congestion mitigation in the following ways:

- Free 1-year bus passes were distributed to 1000 people, 19% of which previously drove personal vehicles, resulting in trip and VMT reductions.
- A car share program added 5 new vehicles and 11 business memberships, resulting in trip and VMT reductions.
- A parking pricing program increased blocks with parking availability, resulting in fewer vehicles looking for a parking space and less distance required to find an available parking space, resulting in reduced VMT.

Together, these three strategies resulted in a combined estimated reduction of 151 trips per day and 1,649 miles per day.

### Emissions/Air Quality Impacts

Emission reductions estimates in this subcategory typically are based on the lower emission rates caused by mode shift to transit, reduced vehicle trips, or reductions in VMT.  The reduction in emissions can be estimated for a given project using appropriate emission factors for light duty vehicles based on reductions in trips and VMT.  This project reported an estimated reduction in emissions for all pollutants.

Table B-42 presents the estimated emissions reductions for VOCs, CO, NOx, $PM_{10}$ and $PM_{2.5}$ for the Value/Congestion Pricing Project case study.

**Table B-42.  Estimated Emissions Reductions for Value/Congestion Pricing Project Case Study**

| CMAQ ID | Year(s) | Estimated Emissions Reductions (kg/day) | | | | |
|---|---|---|---|---|---|---|
| | | VOC | CO | NOx | $PM_{10}$ | $PM_{2.5}$ |
| CA20110128 | 2014 | 0.123 | 3.002 | 0.279 | 0.078 | 0.033 |

This project realized modest reductions in all pollutants included in the analysis, based largely on trip and VMT reductions due to transit usage and the car share program, as well as VMT reductions from the parking pricing program.

### Human Health Impacts

The human health impacts resulting from this Value/Congestion Pricing Project are expected to result from improved emergency response times and lower vehicle crash risks associated with trip and VMT reductions.  There is also an expectation that individuals will transition to transit and walk more to transit stations or car share pickup locations as a result of this program.

## B.7 Other

### B.7.1 Pedestrian/Bicycle

#### B.7.1.1 Overview of Projects

Projects covering pedestrian/bicycle programs are explicitly identified as 1 of the 17 categories of projects eligible for funding under the CMAQ program. The pedestrian/bicycle programs are designed to encourage and facilitate the use of non-motorized modes of transportation. These projects typically include:

- The construction of pedestrian and bicycle lanes and paths;
- Installation of bike racks, bike lockers, and support facilities;
- Non-construction outreach related to safe bicycle use;
- Establishing coordinator positions for marketing, public education, and safety programs.

#### B.7.1.2 Distribution of Projects

Figure B-43 shows the distribution of the projects within the pedestrian/bicycle subcategory by State. The shading in each State shows the cumulative level of CMAQ funding obligated to projects in the subcategory between FY 2006 and FY 2012. The number of pedestrian/bicycle projects funded during this period is shown for each State. This figure shows pedestrian/bicycle projects in 43 states, making it 1 of the most widely deployed CMAQ subcategories. The pedestrian/bicycle project subcategory is the highest quantity of CMAQ projects, accounting for 17% of the total number of projects receiving CMAQ funding since FY 2006. Note that many of these projects contain smaller funding amounts—the pedestrian/bicycle project subcategory represents just under 9% of the total CMAQ funding for the same period.

Figure B-44 shows the number of projects funded and the CMAQ funding for these projects for each year during this timeframe. In general, the number of projects and funding have both grown each year, with the exception of 2010. The number of CMAQ-funded pedestrian/bicycle projects has more than doubled from 2006 to 2012, up from 128 to 261. The amount of pedestrian/bicycle CMAQ funding during this period has more than tripled, up from $61 million to $198 million.

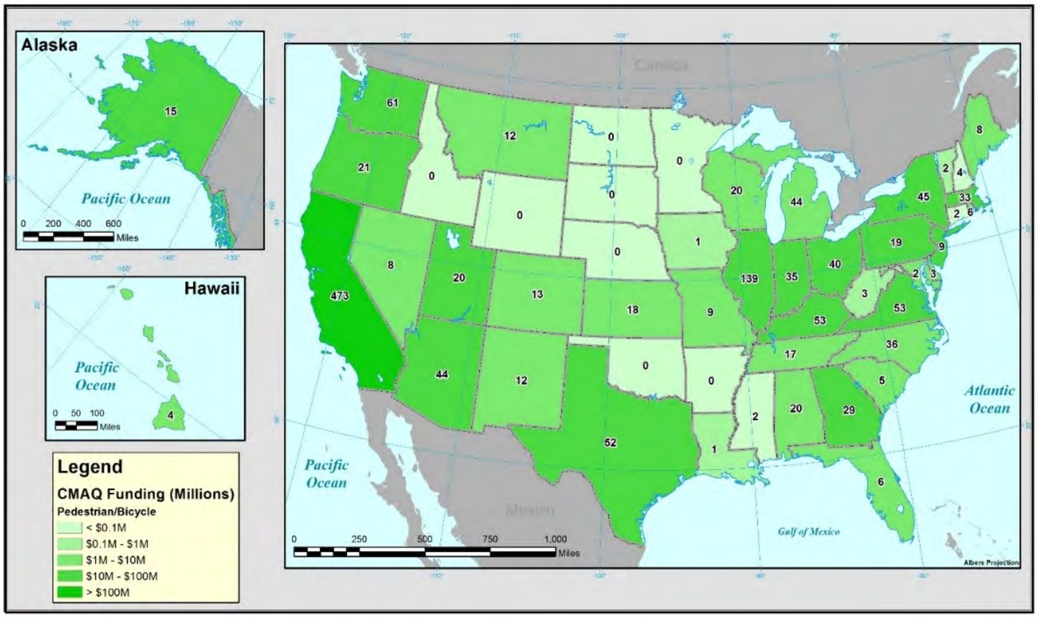

Figure B-43. Distribution of Projects and Funding for Pedestrian/Bicycle Projects by State

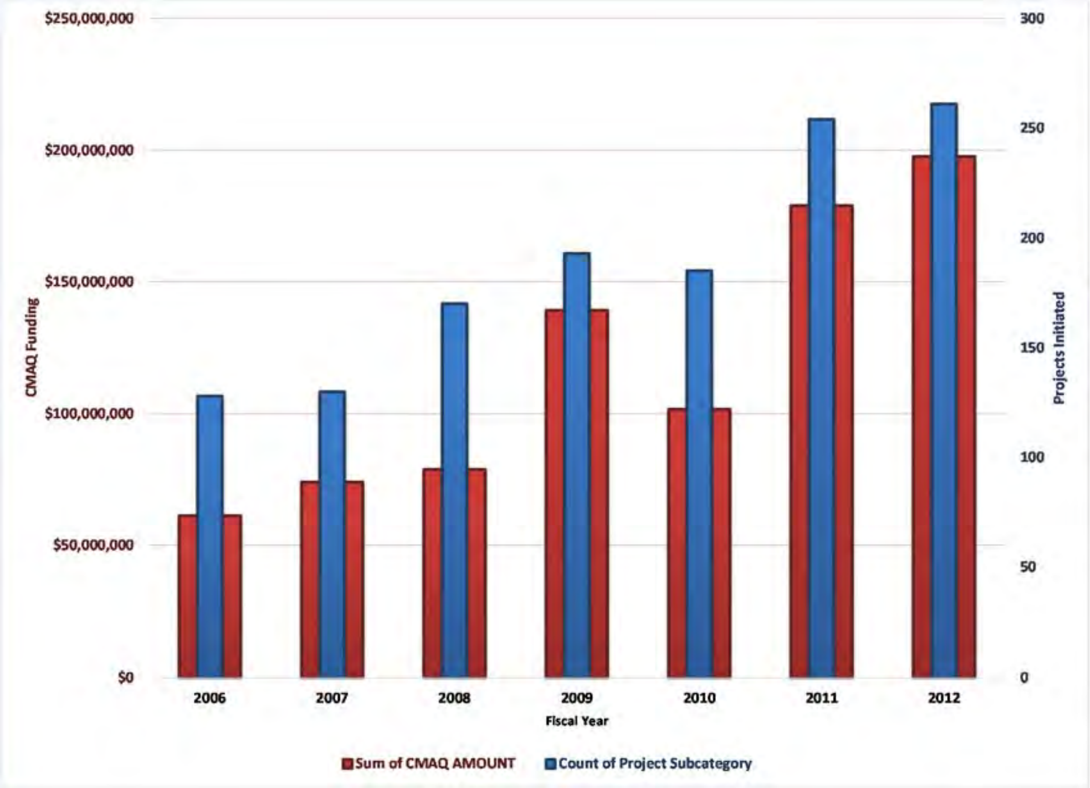

Figure B-44. Number of Pedestrian/Bicycle Projects Initiated Per Year

### B.7.1.3 Impacts of Case Study Projects

Table B-43 summarizes the nine case studies that were analyzed for this subcategory.

**Table B-43. Summary of Pedestrian/Bicycle Case Studies**

| CMAQ ID | State | CMAQ Funding | Total Funding | Description |
|---|---|---|---|---|
| CA20080008 | California | $598,000 | 3,646,888 | San Lorenzo River Bike/Ped Bridge |
| CA20090121 | California | $1,565,000 | $2,829,000 | Highway 9 Safety Improvements with bike lanes and pedestrian paths |
| CA20110291 | California | $185,000 | $385,000 | San Francisco Cargo Way Bay Trail Bike Lanes |
| CA20120171 | California | $620,000 | 1,121,460 | SMART Trail-Hearn Avenue to Joe Rodota Trail |
| IN20080018 | Indiana | $753,369 | $753,369 | Construct 2.5 mile trail to complete a vital link in the off-road network |
| NC20090033 | North Carolina | $505,670 | $126,440 | Construction of Sidewalks |
| UT20100009 | Utah | $517,970 | $869,583 | D&RGW Rail/Trail |
| WA20110016 | Washington | $456,263 | $1,393,383 | Green River Trail system between Milton and Pacific. |
| WI20070003 | Wisconsin | $302,722 | $302,722 | Holton Street Bike/Ped Path |

**Traffic/Congestion Mitigation Impacts**

The projects in this category generally expect to increase the number of bicycle and pedestrian trips, which will impact general travel patterns and mitigate congestion by removing a comparable number of vehicle trips.

Examination of the nine case studies indicated that these individual projects were likely to have the following impacts on traffic/congestion mitigation:

- One California project estimated 1588 new bike/walk trips occurred as a result of the new bike path.
- A second California project noted an additional 20 pedestrian trips per hour and 48 bike trips per hour during peak hours, which represent a 48 percent and 84 percent increase, respectively.
- The North Carolina project did not have data available, but noted an increase in pedestrian traffic.
- The Utah project estimated that 106 daily car trips would shift to 127 bike trips for commuting, given average vehicle occupancy of 1.2. This was estimated to result in a reduced VMT of 1736 per day, and additional 2083 bike miles traveled per day.
- The Washington project estimated a daily reduction of 75 vehicle trips, or 282 VMT due to an increase of 20 walking trips and 55 bike trips daily.

- The Wisconsin project estimated 50 new biking or walking trips that would replace car trips, and have an average trip length of three miles.

**Emissions/Air Quality Impacts**

Emission reductions estimates in this subcategory typically are based on vehicle trips that have shifted to bicycle or pedestrian trips as a result of the project improvements. The reduction in emissions can be estimated by calculating the emissions generated for the average trip length for each vehicle trip that is eliminated.

Table B-44 presents the estimated emissions reductions for VOCs, CO, NOx, $PM_{10}$ and $PM_{2.5}$ for each of the nine case studies.

**Table B-44. Estimated Emissions Reductions for Pedestrian/Bicycle Case Studies**

| CMAQ ID | Year(s) | Estimated Emissions Reductions (kg/day) | | | | |
|---|---|---|---|---|---|---|
| | | VOC | CO | NOx | $PM_{10}$ | $PM_{2.5}$ |
| CA20080008 | 2008 | 0.37 | NR | 0.29 | 0.10 | NR |
| CA20090121 | 2009* | 10.88 | 61.45 | 6.89 | 0.53 | 0.37 |
| CA20110291 | 2011* | 4.36 | 24.65 | 2.76 | 0.21 | 0.15 |
| CA20120171 | 2012* | 14.62 | 82.6 | 9.26 | 0.71 | 0.50 |
| IN20080018 | 2008 | 0.15 | 1.46 | 0.22 | NR | NR |
| NC20090033 | 2009* | 0.0849 | 0.0986 | 0.0164 | NR | NR |
| UT20100009 | 2013 | 1.05 | 11.76 | 1.29 | NR | NR |
| WA20110016 | 2011 | <9.07 | <9.07 | <9.07 | NR | NR |
| WI20070003 | 2007 | 0.10 | NR | 0.11 | NR | NR |

NR - Not reported
* – Data not reported by sponsor. Data retrieved from FHWA CMAQ Public Access System (PAS) database.

Analysis of these case studies indicated that all of these individual projects were likely to reduce emissions and improve air quality for multiple pollutants. Each project estimated the additional bicycle or pedestrian trips that would eliminate some vehicle trips, and calculated the estimated emissions reductions that would result using either informal means or a model, such as the Mobile vehicle emissions model, for example.

**Human Health Impacts**

Of the nine pedestrian/bicycle case studies evaluated, only two reported human health impacts in the selection process. A California project estimated the project significantly increased bicycling and walking, while also slowing vehicular traffic in the corridor, which thus increased exercise and improved physical health. The North Carolina project noted that increased walking traffic would improve physical health and improve access equity.

## B.7.2 Other

### B.7.2.1 Overview of Projects

Projects in this section comprise those that could not be definitively identified by their project description in the CMAQ database, or appeared to span multiple categories in said description. As such, the projects in this group cover a wide variety of programs that span the entirety of the CMAQ program.

### B.7.2.2 Distribution of Projects

Figure B-45 shows the distribution of projects across the United States that fall within this subcategory. Oklahoma and South Dakota have received the most funding for projects within this subcategory from FY 2006 to FY 2012, followed by Texas and California. South Dakota has implemented 90 of the 227 projects during this period, followed by Alaska with 23 projects.

Figure B-46 shows the number of projects started and the CMAQ funding for these projects for the year during this timeframe. In general, 10 to 25 projects in this subcategory have been initiated per year between FY 2006 and FY 2012, with the exception of a spike in 2011 of over 79 projects. The CMAQ funding during this period has fluctuated from a low of about $10 million in FY 2006 to over $91 million in FY 2012. The total funding allocated during this time period in this subcategory totals over $260 million.

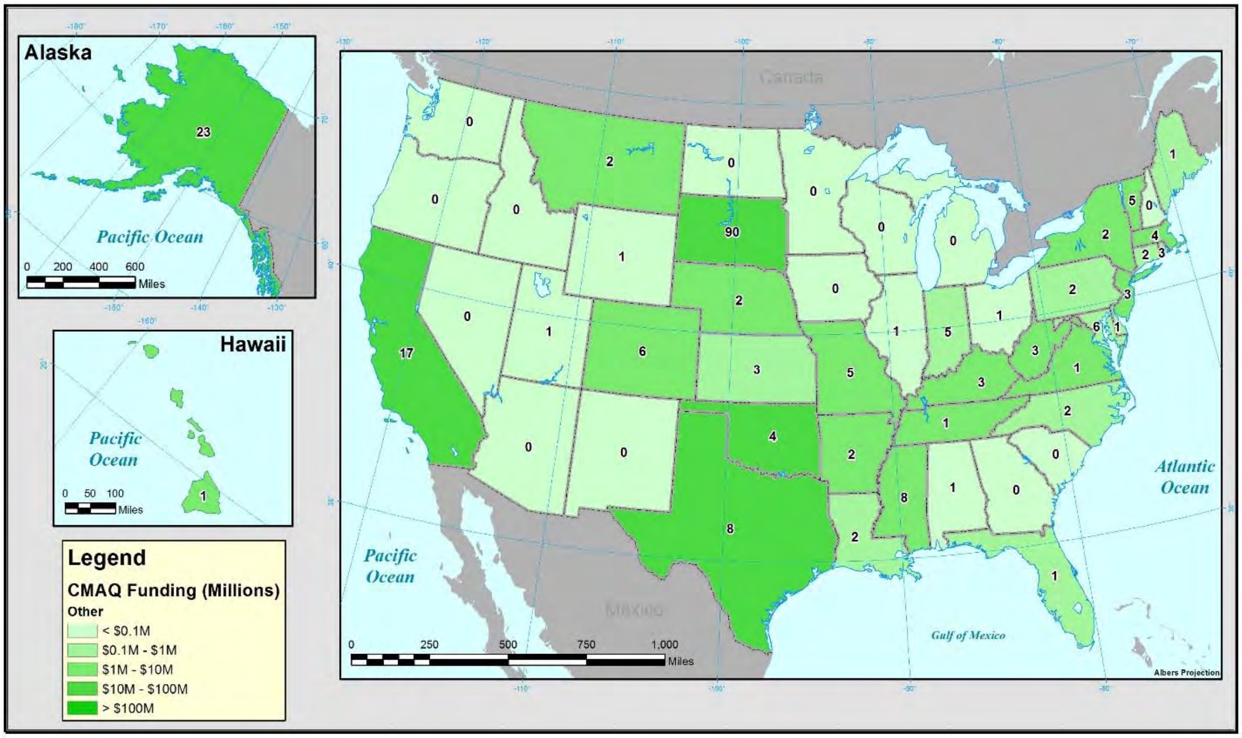

**Figure B-45. Distribution of Projects and Funding for Projects Classified as Other by State**

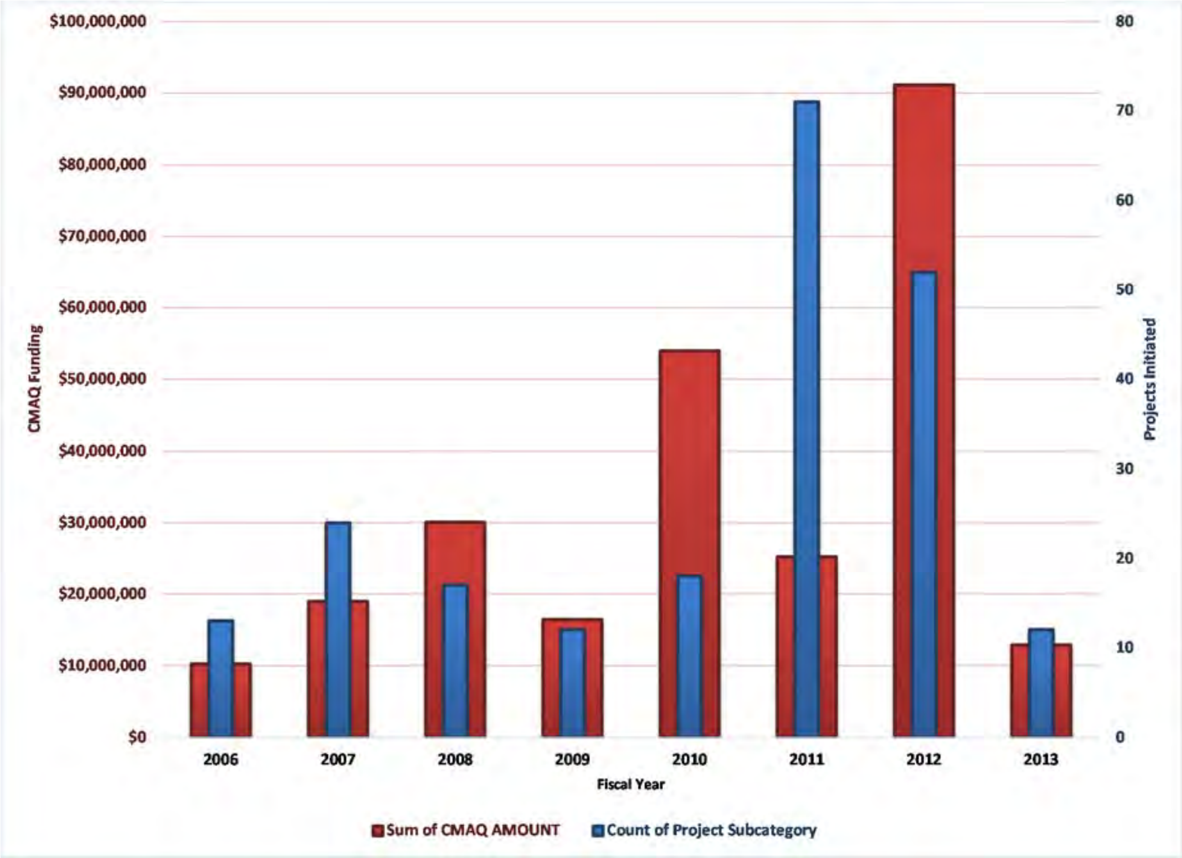

**Figure B-46. Number of Projects Classified as Other Initiated Per Year**

### B.7.2.3 Impacts of Case Study Projects

Table B-45 summarizes the case studies that were analyzed for this category.

**Table B-45. Summary of Project Case Studies for Projects Classified as Other**

| CMAQ ID | State | CMAQ Funding | Total Funding | Description |
|---|---|---|---|---|
| CO20060012 | Colorado | $39,645 | $49,555* | Pilot tests of a local high-emitting vehicle remote sensing program and a voluntary change of ownership program |
| CT20130007 | Connecticut | $821,000 | $1,026,000 | Funded the additional incremental cost of alternatively fueled vehicles. |

*Note: Only $13,993 in total project funding was actually spent.

#### Traffic/Congestion Mitigation Impacts

Because projects in this group include those from all CMAQ categories, traffic/congestion mitigation impacts are likely to vary from project to project in terms of significance and cause of the impact.

No Traffic/Congestion Mitigation Impacts were estimated for either of the case study projects.

**Emissions/Air Quality Impacts**

Emission reductions estimates in this subcategory may be caused by a number of different factors, since the projects in this group cover the entirety of the CMAQ program.

Table B-46 presents the estimated emissions reductions for VOCs, CO, NOx, $PM_{10}$ and $PM_{2.5}$ for the case studies in this subcategory.

**Table B-46. Estimated Emissions Reductions for Case Studies of Projects Classified as Other**

| CMAQ ID | Year(s) | Estimated Emissions Reductions (kg/day) | | | | |
|---|---|---|---|---|---|---|
| | | VOC | CO | NOx | $PM_{10}$ | $PM_{2.5}$ |
| CO20060012 | 2014 | NR | 0.66 | NR | NR | NR |
| CT20130007 | 2011 | 0.20 | 2.54 | 3.84 | NR | 0.05 |

NR - Not reported

The Colorado case study estimated the impact of repairing the single vehicle based on its annual mileage and emissions before and after the repair. The Connecticut case study used the Clean Cities Emissions Benefit Tool to estimate emissions reductions for four pollutants, given each vehicle would be driven 9880 miles per year, or 38 miles per weekday.

**Human Health Impacts**

Because the projects in this group span the entirety of the CMAQ program, there is no consistent cause or human health impacts between the projects. The Connecticut project estimated a positive environmental and physical health impact due to lower emissions from the clean fuel vehicles that were purchased to replace traditionally fueled vehicles. No human health impacts were reported for the other case study project.

## B.7.3 Dust Mitigation

### B.7.3.1 Overview of Projects

Projects designed to mitigate dust are not explicitly identified as 1 of the 17 categories within the CMAQ funding eligibility guidance. However, a substantial number of projects within the CMAQ database (168, or 2% of the total) were identified as having a focus on dust mitigation.

The majority of projects within this subcategory involve paving of unpaved surfaces (e.g., dirt roads, parking lots, shoulders), or the purchase of street sweepers. Other projects involve the use of dust suppressants (e.g., $MgCl_2$, $CaCl_2$) to treat unpaved roads. These projects focused the emission reduction estimates on $PM_{10}$ (dust), with 70% of the projects estimating measureable improvements for that pollutant type.

### B.7.3.2 Distribution of Projects

Figure B-46 shows the distribution of the projects within the dust mitigation subcategory by State. The shading in each State shows the cumulative level of CMAQ funding obligated to projects in the subcategory between FY 2006 and FY 2012. The number of dust mitigation projects funded during this period is shown for each State. This figure shows the greatest number of dust mitigation projects occurred in 4 western states: Arizona, California, Oregon, and Wyoming. The highest CMAQ funding levels in this subcategory occurred in the same four states plus Montana. These numbers are consistent with the large number of unpaved road mileage and arid climate regions.

Figure B-47 shows the distribution of dust mitigation project quantity and funding between FY 2006 and FY 2012. The data show a good deal of fluctuation in the funding amount during those years, with a high of approximately $20 million in 2008 and a low of $8 million in 2010. There was a fairly consistent quantity of projects funded per year with the exception of 2011 seeing several more projects as compared with other years.

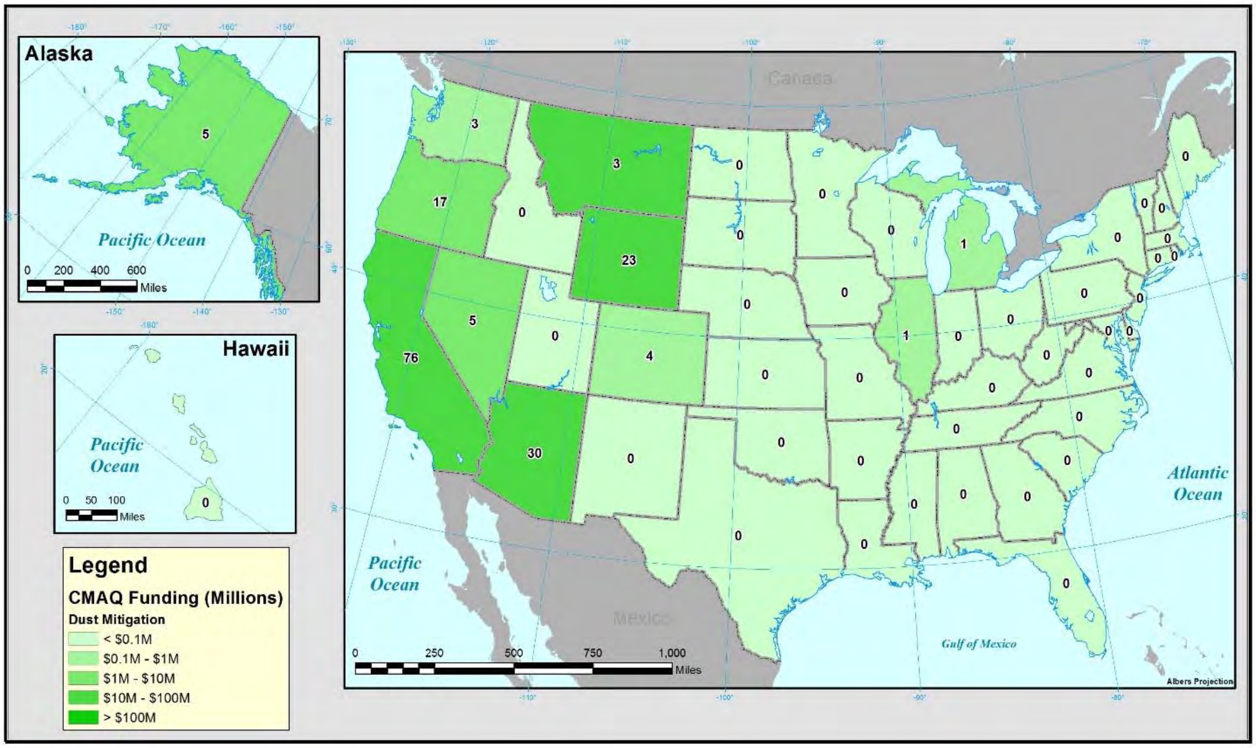

**Figure B-47. Distribution of Projects and Funding for Dust Mitigation Projects by State**

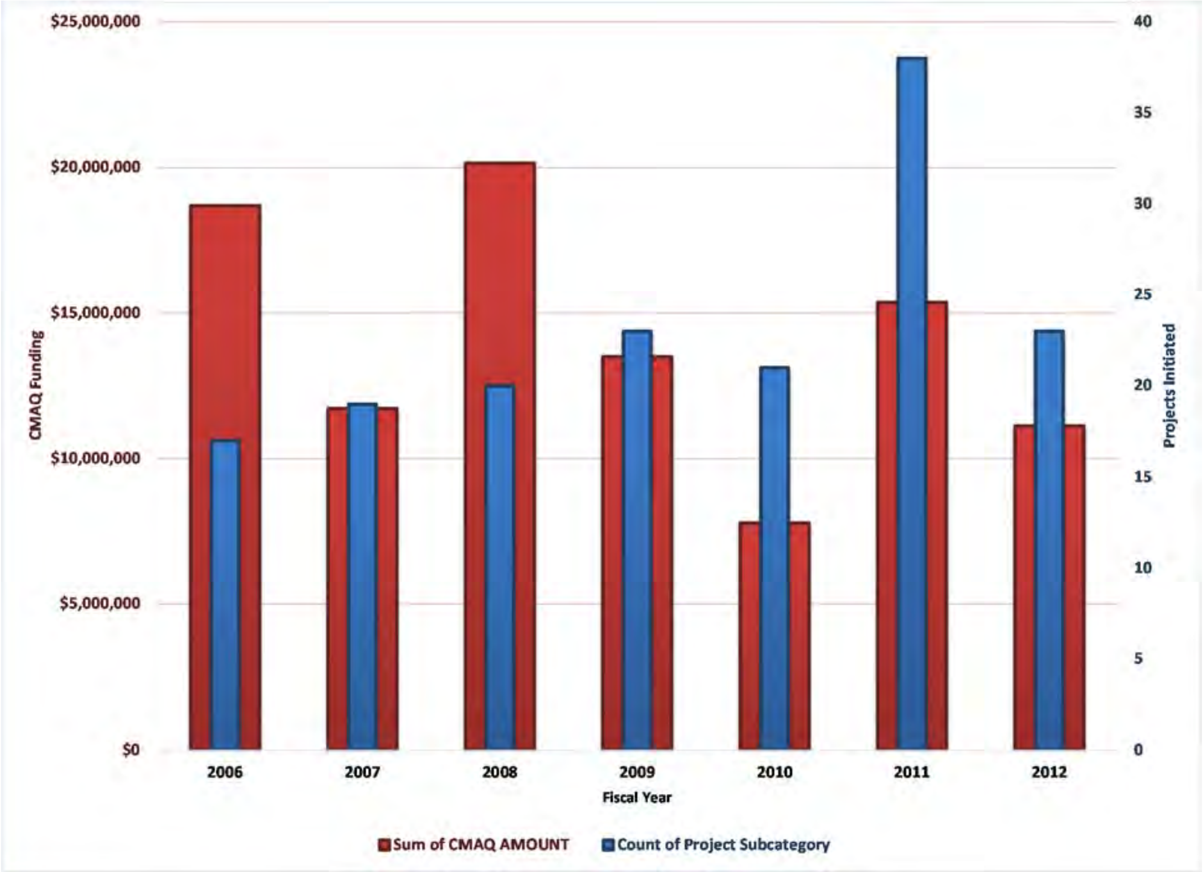

**Figure B-48. Number of Dust Mitigation Projects Initiated Per Year**

### B.7.3.3 Impacts of Case Study Project

Table B-47 summarizes the one case study that was analyzed for this subcategory. The project is for the purchase of $PM_{10}$ certified street sweepers—since the Phoenix area is in non-attainment for $PM_{10}$.

**Table B-47. Summary of Dust Mitigation Case Study**

| CMAQ ID | State | CMAQ Funding | Total Funding | Description |
|---|---|---|---|---|
| Arizona | AZ20120011 | $1,439,403 | $1,439,403 | Purchase 9 $PM_{10}$ Certified Street Sweepers |

**Traffic/Congestion Mitigation Impacts**

Since the project in this subcategory involves dust mitigation measures on existing roadways, it is unlikely to significantly impact general traffic patterns or mitigate congestion.

No traffic/congestion impacts were provided for the case study project, which is consistent with other projects of this type.

### Emissions/Air Quality Impacts

Emission reductions estimates in this subcategory typically are based on reductions in large particulate matter ($PM_{10}$). As stated previously, approximately 70% of the 168 projects in this subcategory reported an estimated reduction in emissions for $PM_{10}$. The projects in this subcategory use different methods to estimate $PM_{10}$ reductions through, paving unsurfaced roads, reducing dust on existing unsurfaced, or removing dust from paved roads. Table B-48 presents the estimated $PM_{10}$ emissions reductions for this case study.

**Table B-48. Estimated Emissions Reductions for Dust Mitigation Case Study**

| CMAQ ID | Year(s) | Estimated Emissions Reductions (kg/day) | | | | |
|---|---|---|---|---|---|---|
| | | VOC | CO | NOx | $PM_{10}$ | $PM_{2.5}$ |
| AZ20120011 | 2012 | NR | NR | NR | 437.71 | NR |

NR - Not reported

As expected, the Arizona project indicated significant reduction in $PM_{10}$ by the purchase of the $PM_{10}$ certified street sweepers.

### Human Health Impacts

This case study did not report any human health impacts.

## B.7.4 Freight/Intermodal

### B.7.4.1 Overview of Projects

The projects in this subcategory cover a wide range of technical areas from improvements to port facilities (i.e., shore power, rail improvements) and port operations (i.e., truck traffic reduction).

The MAP-21 CMAQ program guidance explains that these emissions reduction projects fall generally into two categories: primary efforts that target emissions directly or secondary projects that reduce net emissions. Successful primary projects could include new diesel engine technology or retrofits of vehicles or engines. Secondary projects reduce emissions through modifications or additions to infrastructure and the ensuing modal shift.

These projects had a wide use of estimated emissions benefits. The majority of projects reported estimated reductions in a least three or more pollutant types.

### B.7.4.2 Distribution of Projects

Figure B-49 shows the distribution of the projects within the freight/intermodal subcategory by State. The shading in each State shows the cumulative level of CMAQ funding obligated to projects in the subcategory between FY 2006 and FY 2012. The number of freight/intermodal projects funded during this period is shown for each State. This figure shows the greatest number freight/intermodal projects occurred in California and the Mid-Atlantic region. The highest total CMAQ funding levels in this subcategory occurred in California and Georgia, with both states totaling approximately $40 million each.

Figure B-50 shows the distribution of freight/intermodal project quantity and funding between FY 2006 and FY 2012. The data show an increase in the number of projects initiated each year through 2010, with a slight lessening through 2011 and 2012. The total CMAQ funding levels showed steady increases each year, with the exception of 2007.

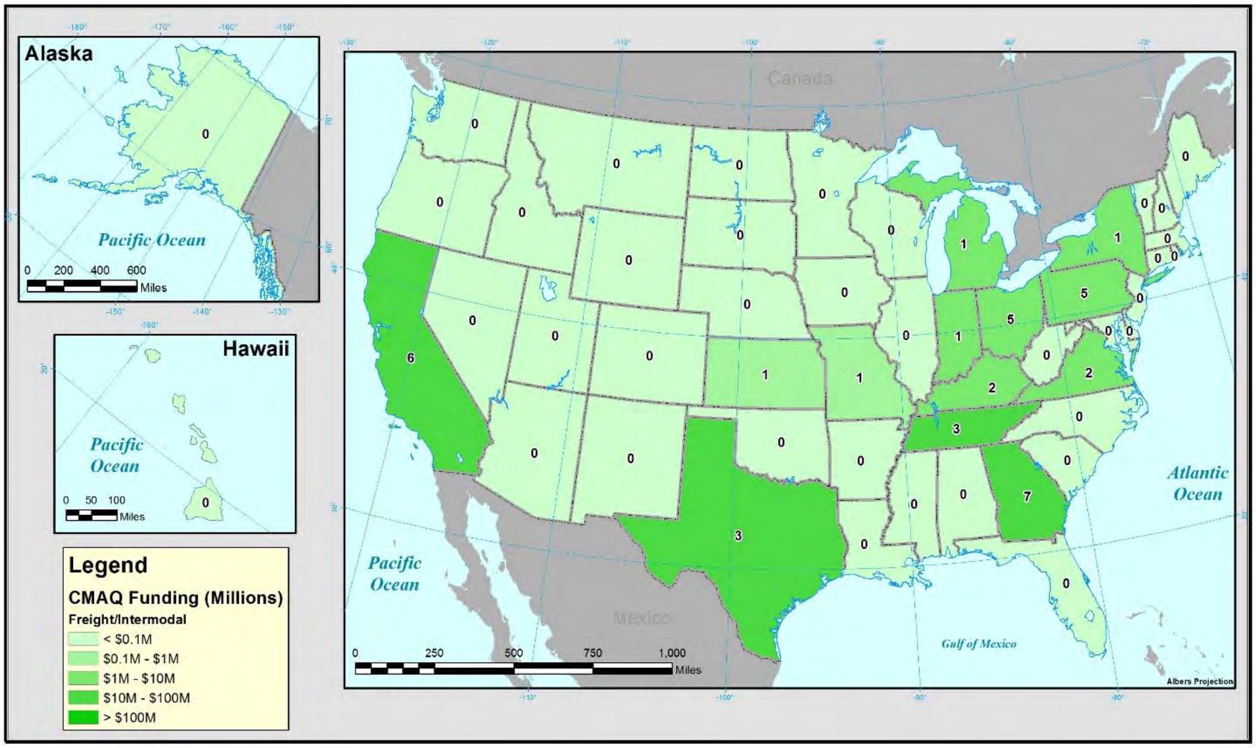

Figure B-49. Distribution of Projects and Funding for Freight/Intermodal Projects by State

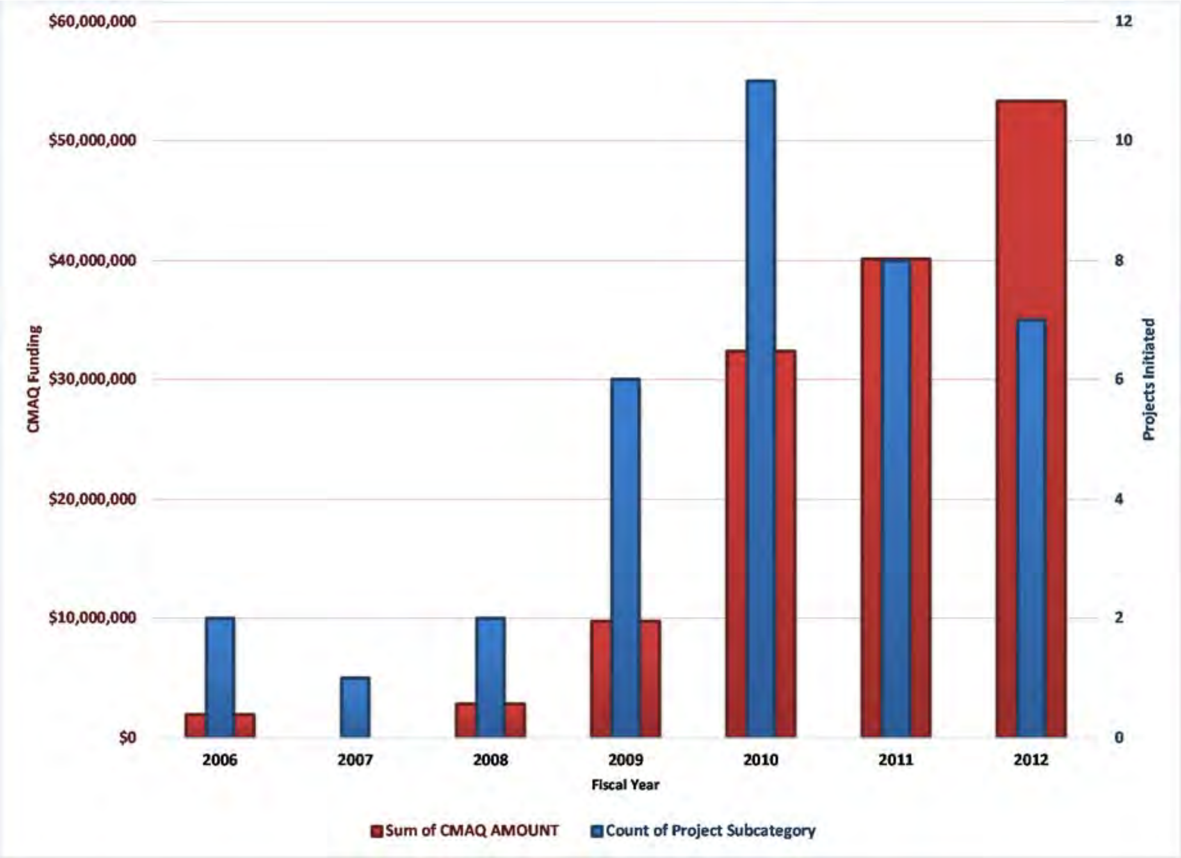

**Figure B-50. Number of Freight/Intermodal Projects Initiated Per Year**

### B.7.4.3 Impacts of Case Study Project

Table B-49 summarizes the one case study that was analyzed for this subcategory.

**Table B-49. Summary of Freight/Intermodal Case Study**

| CMAQ ID | State | CMAQ Funding | Total Funding | Description |
|---|---|---|---|---|
| Ohio | OH20100035 | $1,065,000 | $1,332,000 | Norfolk Southern Doublestack Clearance Project |

**Traffic/Congestion Mitigation Impacts**

As stated above, the projects in this subcategory typically impact general travel patterns or mitigate congestion. Analysis of the case study indicated that this individual project proposed to mitigate congestion and reduce overall truck trips by shifting freight to rail though the addition of doublestack capability along the Norfolk Southern rail line in the project area. The project was estimated to have the following impacts on traffic/congestion mitigation:

- Vehicle trips moved from highway to rail: 79,454 annual trips
- VMT reduction: 3,421,807 miles annual travel reduction

### Emissions/Air Quality Impacts

Emission reductions estimates in this subcategory typically are based on engine technology improvements, or VMT reductions through modal shift. The subject project in the case study predicts the latter. Table B-50 presents the estimated emissions reductions for the three pollutants identified in the case study.

**Table B-50. Estimated Emissions Reductions for Freight/Intermodal Case Study**

| CMAQ ID | Year(s) | Estimated Emissions Reductions (kg/day) | | | | |
|---|---|---|---|---|---|---|
| | | VOC | CO | NOx | $PM_{10}$ | $PM_{2.5}$ |
| OH20100035 | 2008 | 3.19 | NR | 126.57 | NR | 26.0 |

NR - Not reported

### Human Health Impacts

This case study did not report any consideration of human health impacts.

## B.7.5 Innovative Projects

### B.7.5.1 Overview of Projects

Innovative projects incorporate new strategies that better meet travel needs and also may show promise in reducing emissions, but do not yet have supporting data. The FHWA has supported and funded some of these projects as demonstrations to determine their benefits and costs. Such innovative strategies are not intended to bypass the definition of basic project eligibility, but seek to better define the projects' future role in strategies to reduce emissions.

An innovative project is expected to reduce emissions by decreasing VMT, fuel consumption, congestion, or by other factors. Agencies are encouraged to creatively address their air quality problems and to consider new services, innovative financing arrangements, public-private partnerships, and complementary approaches that use transportation strategies to reach clean air goals.

### B.7.5.2 Distribution of Projects

Figure B-51 shows the distribution of the projects within the Innovative Projects category by State. The shading in each State shows the cumulative level of CMAQ funding obligated to projects in the category between FY 2006 and FY 2012. The three Innovative Projects funded during this period are shown to be in California, Louisiana, and Nevada.

Figure B-52 shows the number of projects started and the CMAQ funding for these projects for year during this timeframe. These projects were initiated in FY 2004, FY 2011, and FY 2012. The CMAQ funding varies by project, with the California project receiving $1.50 million of the total $1.59 million that has been funded for this period.

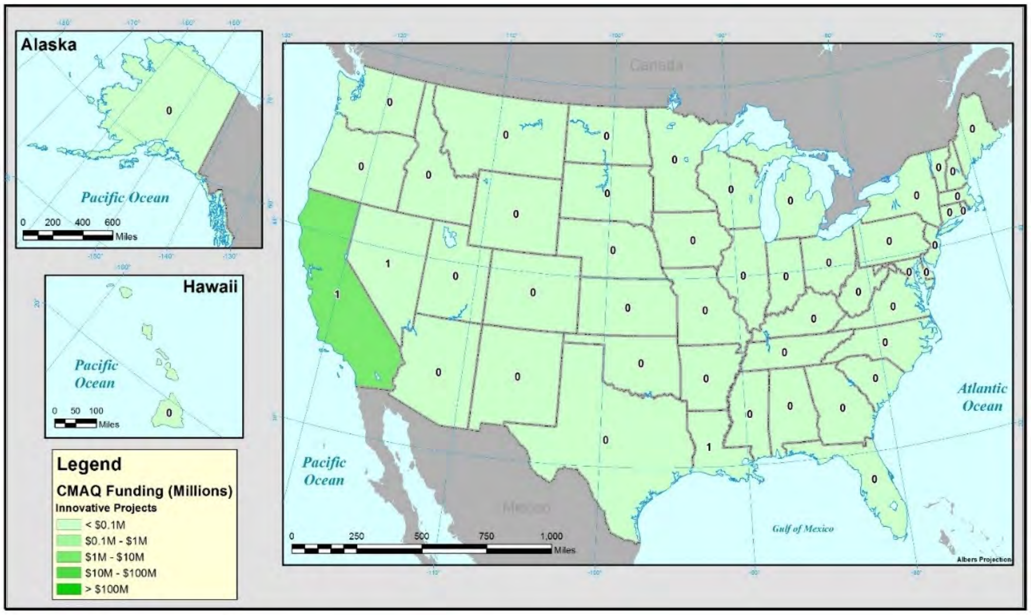

Figure B-51. Distribution of Projects and Funding for Innovative Projects by State

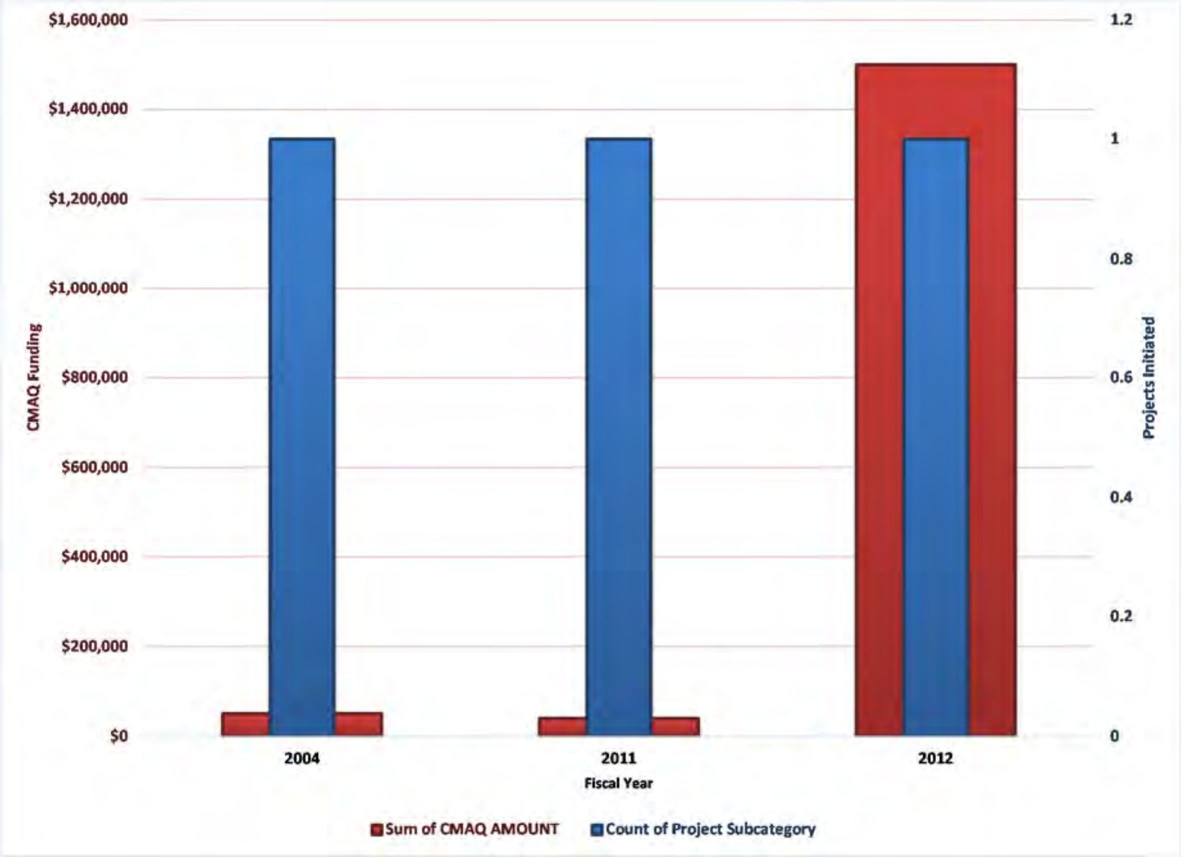

Figure B-52. Number of Innovative Projects Initiated Per Year

### B.7.5.3 Impacts of Case Study Project

Table B-51 summarizes the case study that was analyzed for this category.

**Table B-51. Summary of Innovative Projects Case Study**

| CMAQ ID | State | CMAQ Funding | Total Funding | Description |
|---|---|---|---|---|
| LA20040001 | Louisiana | $4,399,274 | $5,499,092 | Continuous flow intersection improvements. |

**Traffic/Congestion Mitigation Impacts**

Since the projects in this category can vary widely in scope, traffic or congestion impacts are also expected to vary by project.

The case study project that was examined estimated over an 80 percent reduction in delay, over 143 seconds, during the PM peak period.

**Emissions/Air Quality Impacts**

Emission reductions estimates in this category are also likely to vary by project given the broad scope of this category.

The case study project reported an estimated reduction in emissions for two pollutants.

Table B-52 presents the estimated emissions reductions for VOCs, CO, NOx, $PM_{10}$ and $PM_{2.5}$ for the Innovative Project case study.

**Table B-52. Estimated Emissions Reductions for the Innovative Projects Case Study**

| CMAQ ID | Year(s) | Estimated Emissions Reductions (kg/day) | | | | |
|---|---|---|---|---|---|---|
| | | VOC | CO | NOx | $PM_{10}$ | $PM_{2.5}$ |
| LA20040001 | 2004 | 17.61 | NR | 4.04 | NR | NR |

NR - Not reported

Analysis of this case study indicated that this individual project was likely to have the following impacts on vehicle emissions and air quality:

- Reductions in both VOC and NOx given the reduced delay estimated in VISSIM modeling and input to the EPA MOBILE6 model.

### Human Health Impacts

The human health impacts resulting from Innovative Projects are likely to vary considerably, depending upon the nature of the individual projects.  The case study that was evaluated estimated safety impacts associated with an approximately 40 percent reduction in crashes.

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# Appendix C – CMAQ Case Study Team Technical Experts

The following people comprised the Case Study Teams and provided the assessments of the selected projects.

| Name | Affiliation | Education | Exp (yrs) |
|---|---|---|---|
| Jeffrey Ang-Olson | ICF International | M.S in City Planning and Transportation Engineering<br>B.S. in Electrical Engineering | 17 |
| Harold Mallory Brazil | Metropolitan Transportation Commission | B.S/CMB in Urban Planning<br>Graduate Coursework | 26 |
| Tom Carlson | Sierra Research, Inc. | B.S. in Atmospheric Science | 30 |
| Douglas Eisinger | Sonoma Technology, Inc.<br>University of Hawaii | Ph.D. in Environmental Policy Analysis<br>MPP in Energy & Environment Policy<br>B.A. in Government | 30 |
| Rebecca E. Goldberg | Cameron Engineering & Associates, LLP | A.S. in Engineering Science<br>B.S. in Civil Engineering | 14 |
| Michael Grant | ICF International | M.S. in Public Policy & Management<br>B.S. in Economics, Government & Politics | 20 |
| Christopher Gray | Fehr & Peers | M.S. in Science in Planning | 19 |
| Randall Guensler | Georgia Institute of Technology | Ph.D. in Civil & Eng. Trans.<br>M.S. in Civil & Eng. Env.<br>B.S. in Individualized Eng. | 25 |

| Name | Affiliation | Education | Exp (yrs) |
|---|---|---|---|
| K. Barbara Joy | Earth Matters, Inc. (Independent Consultant) | B.S. in Environmental Econ.<br>M.S. in Traffic Engineering Modeling (ongoing) | 29 |
| Kara Kockelman | The University of Texas at Austin | Ph.D./M.S./B.S. in Civil Engineering<br>M.S. in City & Regional Planning | 17 |
| J. Richard Kuzmyak | Renaissance Planning Group | M.S. in Public Policy & Adm.<br>B.S. in Civil Engineering | 38 |
| Scott A. Peterson | Central Transportation Planning Staff | M.S. in Urban Affairs Environmental Planning<br>B.S. in Cartography | 20 |
| Darlene Reiter | Bowlby & Associates, Inc. | Ph.D./B.S./M.S. in Civil Engineering | 25 |
| Matt Riffkin* | InterPlan | B.S. in Engineering and Economics | 28 |
| Michael Savonis | ICF International | M.S. in Regional Planning<br>B.S. in Chemistry | 28 |
| Eric Schreffler | Eric Schreffler, Transportation Consultant (ESTC) | M.S. in Transportation<br>B.A. in Urban Studies | 32 |
| Timothy V. Sexton | Washington State Department of Transportation | B.S. in Anthropology<br>M.S. in Urban & Regional Planning<br>M.S. in Environmental Health | 10 |
| Kevan Shafizadeh | California State University, Sacramento | Ph.D./M.S./B.S. in Civil & Environmental Engineering | 15 |
| Sarah J. Siwek | Sarah J. Siwek and Associates | M.S. in Public Administration<br>B.S. Political Science | 35 |
| Yanzhi (Ann) Xu | Georgia Institute of Technology | Ph.D. in Transportation Systems Engineering<br>B.S. in Environmental Science | 8 |

* Deceased June 2014

# Appendix D – CMAQ Study Oversight Committee

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# Appendix E – CMAQ Study Oversight Committee Comments

The following matrix contains the independent peer review comments from the CMAQ Oversight Committee on the CMAQ Study Summary Report of Findings and Final Technical Report.

| ID | Section or other reference | Comment | Response to Comment |
|---|---|---|---|
| 1. | Overall | Does the length of the report may present an obstacle toward readers digesting the information and drawing conclusions regarding the CMAQ Program? | The Final Technical Report does contain a great deal of material. The intent is that this report is a detailed reference of the study that was conducted. The Summary Report of Findings, which was also reviewed, is much shorter and will be the companion report that summarizes the study. Both reports will be posted on the FHWA web site. |
| 2. | Overall | I notice that the projects “reported” impacts. To me, “reported” suggests a measurement of actual results. I bet that in almost all cases the applicant or programming agency estimated benefits in advance of the project. I suggest using “estimated” instead of “reported,” unless discussing post-implementation impacts. | This has been addressed throughout the document. In most instances the use of the term “reported” is used in conjunction with the term “estimated”. |
| 3. | Overall | When presenting numbers of projects, sometimes commas appear in the numbers. Sometimes not. Should be consistent throughout. | Addressed throughout the document. Using a comma with numbers greater than 999, e.g., 1,000. |
| 4. | Acronyms, Exec. Sum. | E85 is a fuel that is 85% ethanol; it isn’t just ethanol. I assume the same is true for M85. | E85 changed to “ethanol fuel blend”. M85 changed to “methanol fuel blend” |
| 5. | Exec. Sum. | Need to re-write the sentence. “As part of the study, MAP-21 requires that was the execution of the…” | Sentence removed. |
| 6. | Exec. Sum. | I would spell out VOC, NOx, CO, and PM the first time used to help the reader. | Revised. |

| ID | Section or other reference | Comment | Response to Comment |
|---|---|---|---|
| 7. | Exec. Sum. | For the paragraph beginning with "For the 72 case studies…" and ending with "…(almost 28 percent)" a table that summarizes these numbers might be more useful to the reader. | Inserted a reference to Section 4.2, Table 6, page 26. |
| 8. | Exec. Sum. | "While no standardized methodology was used to account for human health impacts, one was not required for this program." This sentence needs clarification. | Revised to "The CMAQ program does not require the estimating and reporting of human health impacts, therefore no standardized methodology is available to account for human health impacts." |
| 9. | Exec. Sum. | "MAP-21 required a review of available information in this area and <u>expand</u> the body of knowledge as it pertains to the CMAQ program." I think you mean "…expansion of…". | Changed to "…area to expand…". |
| 10. | §1.1, ¶2 | MAP-21 guidance is so far silent on what projects can be used to address the PM set-aside. I believe the eligibility of retrofit projects was addressed under SAFETEA-LU. | The PM discussion was removed because it was not germane to the introduction. |
| 11. | §1.1, ¶2, third line | Should read as "…portion of <u>**their**</u> funds …"<br>(not "…<u>**its**</u> funds …") | This discussion was removed. |
| 12. | §1.3, ¶2 | The seven categories listed are not necessarily used by programmers to classify proposals. Perhaps the categories are used by states in reporting on the CMAQ program to FHWA? | Clarified that the categories are used by states in reporting on the CMAQ program to FHWA. |
| 13. | §1.3, Figure 1 | Labels for the two "Y" axes are missing ("Funding" on the left axis; and "Number of Projects" on the right axis) | Axes labels added. |

| ID | Section or other reference | Comment | Response to Comment |
|---|---|---|---|
| 14. | §1.4, Various | Report readability can be enhanced by standardizing references to the seventeen (17) CMAQ Guidance project eligibility categories. For example, report pages 2 and 6 reference "17 projects and programs", page 7 references "17 CMAQ project subcategories", and page 9 references "17 categories of projects". | Revised with addition of Table 2 and throughout to consistently state, "17 types of CMAQ eligible projects and programs".<br>Convention:<br>Project types: the 17 divisions used in the FHWA guidance to describe the CMAQ-eligible projects and programs.<br>Categories: the seven divisions used by FHWA in the guidance and the CMAQ reporting database.<br>Subcategories: the 26 divisions identified by Battelle to analyze the different CMAQ projects in the study.<br>Major project types: the seven groups created by Battelle to aggregate similar CMAQ projects in the study. |
| 15. | §2.1.1 | You should clarify that "The CMAQ Database" you're talking about is the database of projects maintained by FHWA. | Clarified that this is the FHWA database of CMAQ projects. |
| 16. | §2.1.1 | Reference is made to an in-depth analysis of the CMAQ database. Yet, nowhere in the report is the CMAQ database defined, explained, described. May need to add a paragraph introducing/defining the database before describing the analysis. | Explanation of the FHWA CMAQ database added. |
| 17. | §2.1.1, subsection on "Methodology…" | "actions receiving CMAQ funding" – my recollection is that the selection criterion was projects that were obligated (entered in FMIS) during this period. "Receiving funding" will, I think be understood to mean "programmed." | Changed to "…surface transportation actions receiving CMAQ funding that were obligated…". |
| 18. | §2.1.1, subsection on "Methodology…" | What fiscal year are you using? Federal or state or other? | Changed to, "…since Federal fiscal year 2006 (referred to as FY 2006)." |

| ID | Section or other reference | Comment | Response to Comment |
|---|---|---|---|
| 19. | §2.1.1, subsection on "Methodology…" | "This assessment involves the analysis of a sample of transportation actions receiving CMAQ funding since fiscal year (FY) 2006." Are you using federal fiscal year (FFY) or state's fiscal year? | Changed to, "…surface transportation actions receiving CMAQ funding that were obligated since Federal fiscal year 2006 (referred to as FY 2006)." |
| 20. | §2.2 | I would delete the word "confounding". I don't know that they are confounding- just difficult. | Revised to "multiple". |
| 21. | §2.2 | I would add here (Considerations of when CMAQ project benefits begin and how long they are effective) that estimated benefits may decline over time as additional traffic uses a project. An example is an intersection project to improve traffic flow that degrades over time due to increased traffic. | Addressed in the revised text. |
| 22. | §2.2 1-5 | ". . . how to estimate human health impacts. . ." – The report on page 33 acknowledges that the causal link from projects to health impacts have limited evidence. I believe the link is there, but pushing programming agencies to attempt this is a formula for chaos. If you think the difference in approaches in bullet 4 is a concern, this will be orders of magnitude worse. I think the recommendation should be for the academics to step up and research the connection, and figure out a way to make in the "real world" of the agencies. | This section 7 has since been removed. This bullet was not moved to another section. Section 2.2 does have a programmatic study limitation that states: "Lack of Human Health Information – Since human health benefits are a recent addition and are not required, a vast majority of CMAQ projects do not report on these benefits." |
| 23. | §2.2 bullets | I would add that the life of benefits in years may vary depending upon the type of project. An intersection improvement may only have a useful life with benefits of 2 or 3 years due to returning congestion versus a bike lane which may have longer lasting benefit. | Added sentence in the third-to-last sub-bullet explaining that the benefits depend on project life. |

| ID | Section or other reference | Comment | Response to Comment |
|---|---|---|---|
| 24. | §2.2 last bullet point | "Significant differences in project sponsors' approaches. . ." I didn't see this stated earlier – perhaps I missed it – but this is a really important point when comparing project impacts. I know it must be disappointing to say that the comparisons being made are very approximate, but it should be acknowledged earlier in the discussion. | Section 7 has since been removed and this bullet was moved into section 2.2. |
| 25. | §3, ¶1 | "all CMAQ projects initiated " – see above note. The fact that a project was obligated during the time frame is not the same as initiated. Projects often are obligated multiple times for different phases (engineering, right of way, construction), or because they are multi-year projects. | Revised to "all CMAQ projects receiving obligations". Changed all other instances of "initiated" to "obligated". |
| 26. | §3.1, ¶1, sentence 1 | I would mention the state that did not have any CMAQ. 49 out of 50 immediately draws the reader to wonder who does not use CMAQ. | This information has been removed because it distracted from the main discussion. |
| 27. | §3.1, line above Figure 3 | Change to read "… subset of these **8,166** projects …"<br>Without the number, it reads as if all case studies are from CO, MI, TX, OH, IL, and VA. | Changed to "…subset of **all** 8,166 projects…". |
| 28. | §3.2, Table 5 | I really like this table- very well laid out and informative. | No revision needed. |
| 29. | §3.3, ¶2 | This paragraph could be tightened up to better tell the reader the spread in costs of the projects. It took me 2 times to read it to understand what it was trying to say. Maybe if the figure is on the same page it will be more apparent. | Revised to keep some text with figure, explain log scale ranges, and update graph scale to show ranges. |
| 30. 3 | §3.3, 1st sentence | Incomplete sentence. | Corrected. |
| 31. 4 | §3.3, ¶2 | Is figure 5 really a logarithmic scale? It seems as if the y axis is linear and the x axis is a range. | The x axis range is logarithmic. Text has been revised for clarity. |

| ID | Section or other reference | Comment | Response to Comment |
|---|---|---|---|
| 32. | §3.3, Figure 5 | I think you need to have ranges in the x axis. From your chart, it looks like you have 4,087 projects that cost $1 million but I think you mean that you have are the 4,087 that cost more than $100,000 and $1,000,000 or less. . | Revised to keep some text with figure, explain log scale ranges, and update graph scale to show ranges. |
| 33. | §3.3, Figures 5 & 6 | Are figures 5 and 6 “log distributions”? | Revised to keep some text with figure, explain log scale ranges, and update graph scale to show ranges. |
| 34. 5 | §3.3, second to last paragraph | Fewer in number than what? | Added: “the transit projects”. |
| 35. | §3.4 | Text infers that 66% of projects reported non-zero emissions. Which suggests that 33% did not report any emission benefit. Can the report provide a brief explanation about how projects without emission benefits can be funded through a Program (CMAQ) that requires demonstration of emission benefits? | Revised text to explain that 97% of projects reported and that the remaining 3% may be due to recording errors. |
| 36. | §4, Tables 5-9 | Cells in these Tables are shaded with varying shades of green. Can the report describe the criteria used for the shading on each table? | All tables were removed, except for what is now Table 7. The green shading is now removed. |
| 37. | §4.1 | I would reorder the bullet points so that you do not lead with the first two which have no traffic or congestion impact. I would possibly order by magnitude of impact or number of case studies. | The order was selected to be consistent with Table 4, discussions in other sections of this summary report, and discussions in all sections of the final technical report. |
| 38. 6 | §4.1 | The statistic, 4,000 personal auto trips per day, seems high- might want to double check the number. | Number is correct. The average of the 3 case studies reporting is 4,274 vehicle trips reduced. |
| 39. | §4.1 & §4.2 | After each project type, I would put in parenthesis how many projects were studied, so Vehicle/Fuel Technology (9 cases): xxx. This allows the reader to get a better sense of scale. | Revised as suggested. |

| ID | Section or other reference | Comment | Response to Comment |
|---|---|---|---|
| 40. | §4.1, bullet 3, sentence 5 | Why were methods and assumptions not reported for these types of projects? I would have assumed for traffic flow, you would have to of shown AQ benefits to be eligible for inclusion in the TIP. | The methods and assumptions may have been reported in the CMAQ application; however, they are not required to be reported in the CMAQ database and they happened not to be reported to the study team despite best efforts to obtain said methods and assumptions.<br>This is noted in the first paragraph of the section, "…some case study projects reported changes in emissions that were likely derived from assumed traffic or congestion mitigation impacts, but these travel impacts were not reported in this category. For the purposes of this report, traffic or congestion mitigation impacts were only counted if reported by the project sponsor." |
| 41. | §4.1, last ¶ | My interpretation of this paragraph is that the impact methods for some (unnamed) categories was "good," and for some (named) categories was "bad." Having been in on evaluating projects myself, I know that the methods for some of the unnamed categories are not very good either. I suspect the goodness or badness is more a function of the tools available to a particular programming agency. I suggested not naming the categories with "bad" methods and simply observing the quality of the analysis varies. | The interpretation is correct. These are the findings of the assessments from the Case Study Teams and these findings are important to include in the report. Additional details provided at the end of section 4.2 and in section 5. |
| 42. 7 | §4.2 | This is the first time you mention 2 STP projects, I think. You might need additional information for why you are looking at STP projects. | Revised explanation. |
| 43. 8 | §4.2, Table 7 | I don't really understand the purpose of Table 7- why do I care what the highest estimated reduction is? | The table is meant to show a range of possible values to provide context. |

| ID | Section or other reference | Comment | Response to Comment |
|---|---|---|---|
| 44. 9 | §4.2 | What exactly does this sentence mean? Are you saying that traffic flow improvement projects produced the highest average/total/highest level of reductions? I think the sentence can be re-worded to be clearer. | Sentence has been removed. |
| 45. 10 | §4.2, list before last paragraph | Add “transit” before “projects” in second bullet. | Revised. |
| 46. 11 | §4.2, last paragraph | Is there some reason for this lack of information? I would have thought that traffic signalization would have the most documentation since the numbers were probably generated through a traffic simulation model. | No reason was readily discerned. One explanation may be that project sponsors were not able to produce the information in the time allotted. |
| 47. | §4.2, Table 8 | I assume the shading is for quintiles, or something like that? An explanation would be helpful. For this table in particular, I don’t think they are useful because the general emission rates for different pollutants are very different. In particular PM2.5 is much lower than VOC or NOx – VOC is about 20 times higher than PM2.5 in our region. Also, as should be apparent, emissions estimates are dependent on methods, and since methods vary from project type to project type and from region to region, citing the greatest reductions presumes comparability that I don’t think exists. | All the other tables with shading were removed, except for the cited table, which is now Table 8. The green shading is now removed, because it implied comparability between pollutants that does not exist. |
| 48. | §4.3 | The text notes that few projects reported human health benefits. However, it should also be noted that the FHWA CMAQ Guidance has never mentioned human health benefits as an item to be considered in project selection. Kind of unfair to fault project sponsors and/or states for not reporting these benefits, when they were not asked for. | Revised to note that reporting of human health impacts is not required as part of the CMAQ program. |

| ID | Section or other reference | Comment | Response to Comment |
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| 49. | §4.3 | Last three bullets under the first paragraph are repeated under the second paragraph. Doesn't look like they belong in the group under the first paragraph. | Fixed. This was due to an error with the document's cross-referencing feature. |
| 50. 12 | §4.3 | But can't this [human health impact] be quantified? This does not seem like qualitative information, but rather something that is quantifiable. | Some of this information is quantifiable; however, the study was limited to the information from project sponsors. |
| 51. | §4.3, Table 9 | Given the small numbers of projects reporting human health impacts, I don't think the shading is appropriate. | Removed table. |
| 52. | §4.4 | As I read the individual project type sections, I kept looking to see if particular project types were "better" or "worse" in terms of cost, impacts, analytic methods or descriptions. But, what seemed to be the situation is that individual projects of each type were better or worse.<br>So, I wonder if the real point is that some programming agencies do a better job, and others do a worse job, of estimating costs, analyzing impacts, or documenting projects. | The discussion of the CST's assessment has been added in section 4.4. However, this is not intended as a ranking of individual projects, project types, or project sponsors, but rather an assessment of findings related to project types. |
| 53. 13 | §4.4.1 | This is quite a statement [The reported emissions reductions for several projects appear to be significantly overstated.]- are you saying that they don't believe the numbers? If so, shouldn't this be stated somewhere? Does this call into question the validity of Table 7 information on this project type? | This statement has been revised based on further input from the CST. |
| 54. 14 | §4.4.3 | There is also the concern that improvements would degrade over time as more cars used the corridor/intersection since it has improved service. This would make the year of estimate more important in determining reductions. | The limitations are also discussed in other areas of the report. |

| ID | Section or other reference | Comment | Response to Comment |
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| 55. 15 | §4.4.6 | What percentage [of TDM projects] reported travel impacts? You give this information for most of the other categories. | Fifty percent. |
| 56. 16 | §4.4.7 | Once again, I think this statement [The reported emissions reductions for several projects appear to be significantly overstated.] could use some elaboration. | This statement was misreported in this section due to an editorial error that has been corrected. |
| 57. 17 | §5.1 | This is the exact same text from previous page. It should be in one place or the other but not both. | Corrected. |
| 58. | §5.2, middle of page | "emission factors used for SIP development and conformity analysis" – the MOVES model operates in both inventory and emission rate mode. From discussions at meetings I've been at, I think a lot of state air agencies and MPOs are using inventory mode – it's a less complicated and runs faster. Generating emissions factors is a good thing, but you should take out the reference to SIP development/conformity analysis. | Revised. We are emphasizing the need for best available local data in generating the emission factors for project-level analysis is good practice. The language is less now about the consistency, though we do retain the statement that consistency was unable to be verified. |
| 59. 18 | §5.2.1.1 | What is the percentage? You shouldn't say they are more prevalent without providing some numerical basis for the reader to judge the percent/amount. | Information added. |
| 60. 19 | §5.2.1.1 | This is 12 years later- so there should not be "will" but "do" | Removed "will". |
| 61. | §5.3.1 | Can links to web sites be included in the text? It would help practitioners looking for the details. I suppose it's tacky, but it would also help practitioners to know which equations/methods had errors. At least let the agencies with problematic equations/methods know that they have a problem. | In general, links to Web sites are limited to the References appendix. The authors avoided linking information in the study directly to specific entities. The authors will work through FHWA to provide feedback to agencies where needed. |

| ID | Section or other reference | Comment | Response to Comment |
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| 62. | §5.4 | This table is in the section after the one it belongs in. Table 21 seems ok, but then the tables after that also seem to be in the wrong section. | Corrected. |
| 63. | §5.9, “input” bullet point | We run MOVES in inventory mode for both conformity and SIP purposes. I’m guessing that many other regions are as well – it’s a lot simpler than rate mode. Given this, there are no emission rates with which CMAQ can be consistent. | The text has been revised as follows: “Make efforts to use the best available local inputs when generating emission factors used in the project-level analysis.” |
| 64. | §5.9, last bullet | “need for more before-after studies” – agree, but having tried to do some, it’s not easy. Projects can take a long time to complete, and even within a project category, there can be very different project types. We found this in the bike/ped category, where we had bridges spanning dangerous roads/railroads, suburban trails, and urban lanes, along with other types. Each type has its own impacts. I think if someone wants this, it will have be done from the national level. | Language modified to encourage studies to improve the process for inputs and assumptions used in the travel activity estimates; and acknowledge the challenges to conduct these studies. |

| ID | Section or other reference | Comment | Response to Comment |
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| 65. | §5.9, last bullet point | It is hard to overstate how difficult it can be to conduct before and after studies. Project delays make it difficult to get good before data (i.e., the data are collected, and then the project gets held up for a couple of years, to the data are out of date.)<br>We tried it with an emphasis on bike/ped projects, for which there seemed to be no suitable "before" study. We ended up doing intercept surveys (supplemented by counts) afterwards and got some decent results, but then realized that there are significant differences between projects, so extrapolating results was nearly impossible. It would have taken a couple more years of study to get enough data; the agency didn't have the interest.<br>I guess my point is to suggest softening this, lest someone up the food chain decides to mandate before-and-after studies. This would be a lot of effort for questionable gain. | The difficulty and expense of before and after studies is explained. |
| 66. | §6, ¶4 | The sentence ". . . changes in either pollutant concentrations. . ." got me to thinking about regional concentrations (for which the CMAQ impact is generally quite small) versus hot spots, which are interesting but hard to estimate. But hot spots do relate to environmental justice issues, so perhaps a brief discussion is warranted. | The issue of environmental justice is outside the scope of this study. |

| ID | Section or other reference | Comment | Response to Comment |
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| 67. | §6, ¶4 | "Human health impact studies require the more focused pollutant concentrations and exposures instead of regional mass estimates to form linkages between projects and health effects."<br>This is true, but one ends up chaining estimation processes, and the final result is highly uncertain. This is compounded by the fact that CMAQ projects in general have emissions impacts that are a small fraction of a region's total emissions. I think we're better off doing our best to estimate emissions impacts and leave the health estimates to the thesis-writers. | The quoted sentence is meant as explanation to contrast a general difference between human health impact studies and transportation air quality studies. The authors were tasked with addressing human health impacts as part of the project scope, and acknowledge these inherent uncertainties. No change requested or made in this section. |
| 68. | §6.2.1.1 | The figures on the number of alt-fuel vehicles and alt-fuel consumed would be more informative if they were put in the context of the overall vehicle fleet and fuel consumption. Ditto for estimates of change in emissions on page 42. | Revised with information on the size of the US vehicle fleet. |
| 69. | §6.2.1.1 | The issues of fueling safety are well-taken, but are there actual data on the number of injuries and deaths associated with fueling? I assume they're pretty low compared to other health impacts (crashes, respiratory illness, etc.). A few facts would help put the discussion in perspective. | The references did not provide the information requested. |
| 70. | §6.2.1.1, ¶2 | The point about EV emissions being zero at the tailpipe but non-zero at the power plant also applies to fuel cells – tailpipe emissions may be zero, but there are emissions associated with generating the hydrogen. | Revised to: "Although <u>hydrogen fuel cell vehicles and</u> electric vehicles emit no exhaust or …" |

| ID | Section or other reference | Comment | Response to Comment |
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| 71. | §6.2.1.1, ¶3 | The Philadelphia project is not the only one out there – Chicago tried fuel cell buses in the 90's, for example. The text should indicate that this is an example, not the only effort. | Revised to: "For example, in 2002, the Delaware Valley Regional Planning Commission…" |
| 72. | §6.2.1.2 | Perhaps add some discussion of future vehicle standards – as conventional engines are made cleaner and more fuel efficient, the relative advantages of (current) alt-fuel vehicles will be reduced. | This may be true; however, analysis of the future potential of specific technologies is beyond the scope of this study. |
| 73. | §6.2.2.2 | I'm pretty sure that difficulty starting in cold weather is no longer an issue for diesel engines – I recall a manufacturer (or maybe US EPA) stating this. I imagine that the awareness of this is still limited, though. | This may be true for diesel engines in many circumstances; however, the Extreme Low-Temperature Cold-Start Programs subcategory is not specific to only diesel engines. |
| 74. | §6.2.3.4 | I'm not the expert on it, but when I hear "managed lane" I think of HOV lanes, HOT lanes, variable toll lanes, truck lanes, etc., not just HOT lanes. | HOV lanes are certainly considered a type of managed lanes. Some revisions made for consistency. The subcategory could be more accurately described as HOV and other Managed Lanes. |
| 75. | §6.2.3.4 | The next paragraph talks about managed lanes in response to, among other things, declining air quality. Perhaps air quality was still declining in 1992, but air quality in general is improving and has been for a while. Consider some qualifying wording. | Phrase removed. |
| 76. | §6.2.5 | I'm not familiar with "Transit-proented developments." Perhaps you could add an explanation (or change the spelling)? | Spelling corrected to Transit-oriented developments (TOD) |

| ID | Section or other reference | Comment | Response to Comment |
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| 77. | §6.2.6 | To be honest, my eyes keep glazing over at the blizzard of numbers. Is there some way to make clearer the kinds of impacts found in the literature? (e.g., a lead-in paragraph that says something like, "TDM projects can be inferred to improve health via increased physical activity and reduced VMT. . .") | There is a considerable amount of detail throughout the entire section. There are some more general discussions in the TDM subcategory under section 6.2.6.2. |
| 78. | §6.2.6.1 | Having said that, this somehow caught my eye: ". . . 23 percent increase . . . Around 32 percent of the baseline sedentary population in the intervention community . . as compared to 18 percent before. . ." Going from 18% to 32% is more than a 23% increase. Or am I misreading it? | The data are correct, the increase was observed in the intervention community with no change in the comparison community. The 32% and 18% are proportions of those communities that met the physical activity recommendation. Text revised to clarify. |
| 79. | §6.2.7.1, ¶3 | I don't see an area to which this statement applies:<br>"The study estimated that converting 35 percent of trips less than 0.5 miles would amount to reducing approximately 30 tons of VOCs, 400 tons of CO, and 15 tons of NOx per day." | The area of the study was across the entire US. Text revised accordingly. |
| 80. | §6.2.7.2 | I think "hydroscopic" should be "hygroscopic." | Corrected. |
| 81. | §6.2.7.2 | I think the first part of this sentence needs to be deleted: "Human exposure to traffic-generated road dust contains over 20 different species of allergens. . ." | Corrected by removing "Human exposure to…" |

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| 82. | §6.3 | "‥ .few studies reporting directly measured pollutant changes from CMAQ-funded projects, strategies, or programs."<br>A number of sections noted that there were no studies of the impact of CMAQ-funded projects. Impacts should be independent of fund source, so I'm not sure that this note is all that significant. | The note conveys that the researchers looked for studies that would be applicable in this assessment of CMAQ project outcomes. |
| 83. | §A-1 & A-5 | Section 3.5.1, page 14 – The second bullet identifies "replacement transit bus …. to expand the existing fleet" as being included in this "Vehicle/Fuel Technology" category. The first bullet in Section 3.5.5, identifies "new bus …. to increase capacity" as being included in the "Improved Public Transit" category. These are very similar CMAQ expenditure types, is there any double counting between these two categories? | Note that these sections were moved to Appendix A.<br>The authors understand that there are similarities between the two subcategories. The "Conventional Bus" subcategory contains projects identified by their description as changing existing buses to cleaner, lower emitting vehicles. The "New Bus" subcategory" contains projects identified by their description as purchasing additional buses. There is no "double counting" between the two subcategories because each project was only assigned to one subcategory. There may be instances in any subcategory of a project the appears a better fit for a different subcategory—the authors made the best judgment call for classification given the available information in the CMAQ project database. |
| 84. | §A-2 | Section 3.5.2, page 15 – There appears to be a word missing in the first bullet, as follows. "The projects within this category generally involve either: a) on-board idle reduction devices on vehicles that will primarily [**benefit**] the nonattainment or maintenance area". | Note that this section was moved to Appendix A.<br>Sentence corrected. |

| ID | Section or other reference | Comment | Response to Comment |
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| 85. | §A-6, bullet on ‘Car Sharing’ | “efficient, low-emission vehicles” – car-sharing services don’t necessarily use only low-emission vehicles. Zipcar in particular advertises a range of vehicles to suit the user’s purpose. | Note that this section was moved to Appendix A.<br>Revised as suggested. |

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