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# Air Quality and Congestion Mitigation Measure Outcomes Assessment Study: Summary Report of Findings

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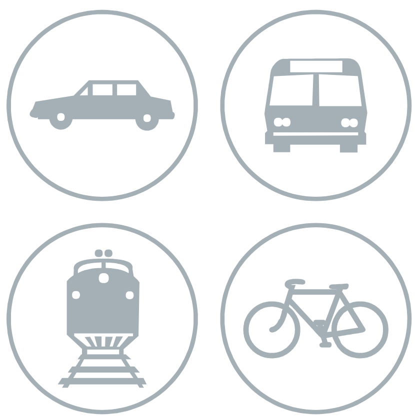

## Notice

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| 16. Abstract<br>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.<br>This Air Quality and Congestion Mitigation Outcomes Assessment Study: Summary Report of Findings presents the major findings of the study. Further details on study methodologies, case study results, and findings are presented in the separate Air Quality and Congestion Mitigation Outcomes Assessment Study: Final Technical Report. | | |
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# 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 Improvement (CMAQ) 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 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 peer reviewers participated in the selection of representative case study projects and assessed the

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

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 traffic 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 (VOCs) and nitrogen oxides (NOx). Specifically, changes in VOCs emissions were estimated for 61 case study sites, 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 sites. Specifically, $PM_{10}$ changes were estimated for 24 case study sites (33 percent) and $PM_{2.5}$ changes were estimated for 20 case study sites (almost 28 percent). (See information in Table 6 on page 31.)

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 sites comprehensively or consistently reported findings for these impacts. For instance, some case study sites 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 sites 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 project 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 emissions 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 carsharing 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 emissions, 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, providing equitable benefits to all 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.

Details on the study findings are presented in this report and this information is supplemented by a technical report.

# 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) to fund 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 "Summary Report of Findings" summarizes the major findings of the study. Additional details on study methodologies, case study results, and findings are available in the Air Quality and Congestion Mitigation Outcomes Assessment Study: Technical Report, which is available as a supplement to this report.

## 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 from transportation. An assessment of the emission reduction benefit expected from the implementation of projects must be provided. It is important to note for the purposes of this study, all projects funded with CMAQ funds as reported in FHWA's CMAQ database were included.

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

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 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 (CMAQ Guidance) dated November 12, 2013, 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. For an explanation see both Table 2 (Taxonomy of CMAQ Study Terms) and Table 4 (Number of CMAQ Projects and Case Studies by Major Project Type and Subcategory).

**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. Carsharing** |
| **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

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 the projects into the following seven major project reporting categories:

- Demand Management,
- Inspection/Maintenance and other Transportation Control Measures,
- Pedestrian/Bicycle,
- Shared Ride,
- Surface Transportation Program (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.

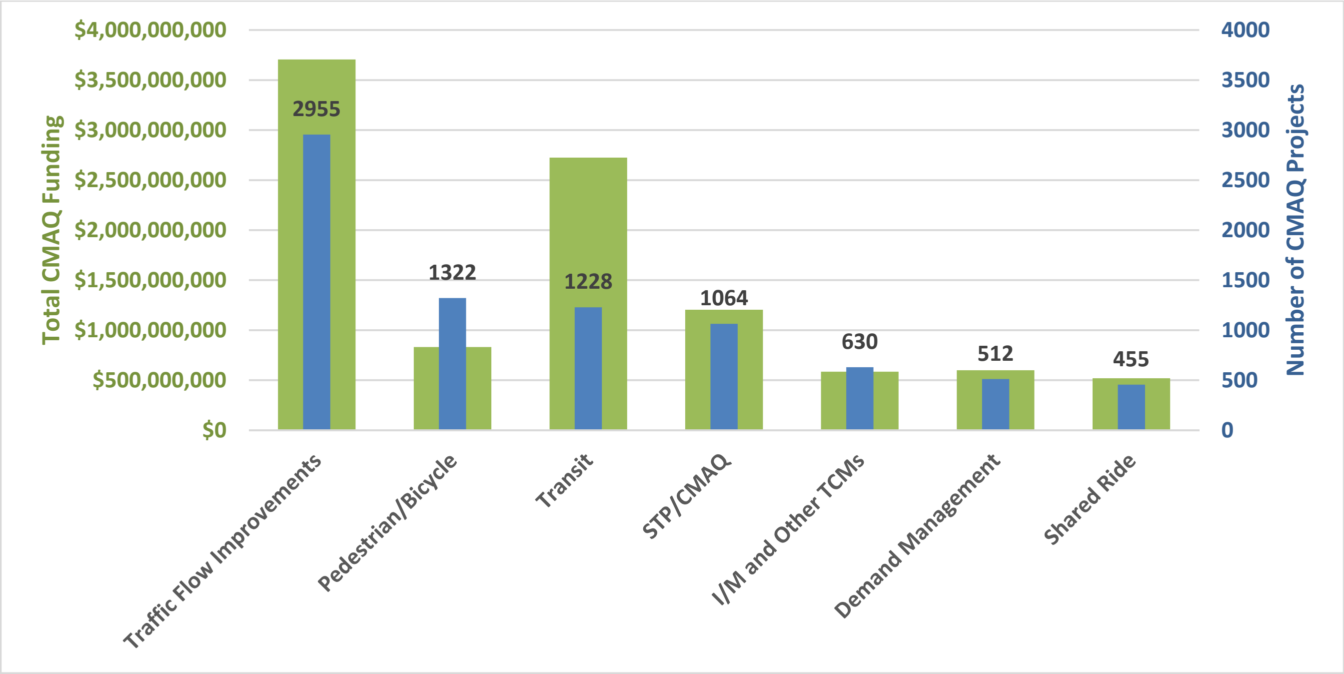


**Figure 1. Funding and Number of CMAQ Projects by Reporting Category**

## 1.4 Report Organization

The rest of the document is divided into six sections with the following information:

- Section 2, Study Approach
- Section 3, Findings on Distribution of CMAQ Project Obligations
- Section 4, Findings from Selected 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 Subcategories and Trends
- Appendix B, CMAQ Study Oversight Committee

To assist with analysis and comparisons, this study uses a classification of CMAQ project divisions based on, but slightly different than, the project types used in Table 1 and project categories used 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 4): the 26 subcategories 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. |

# 2 Study Approach

This section discusses 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.

The following graphic (Figure 2) illustrates the relationship of the various study components.

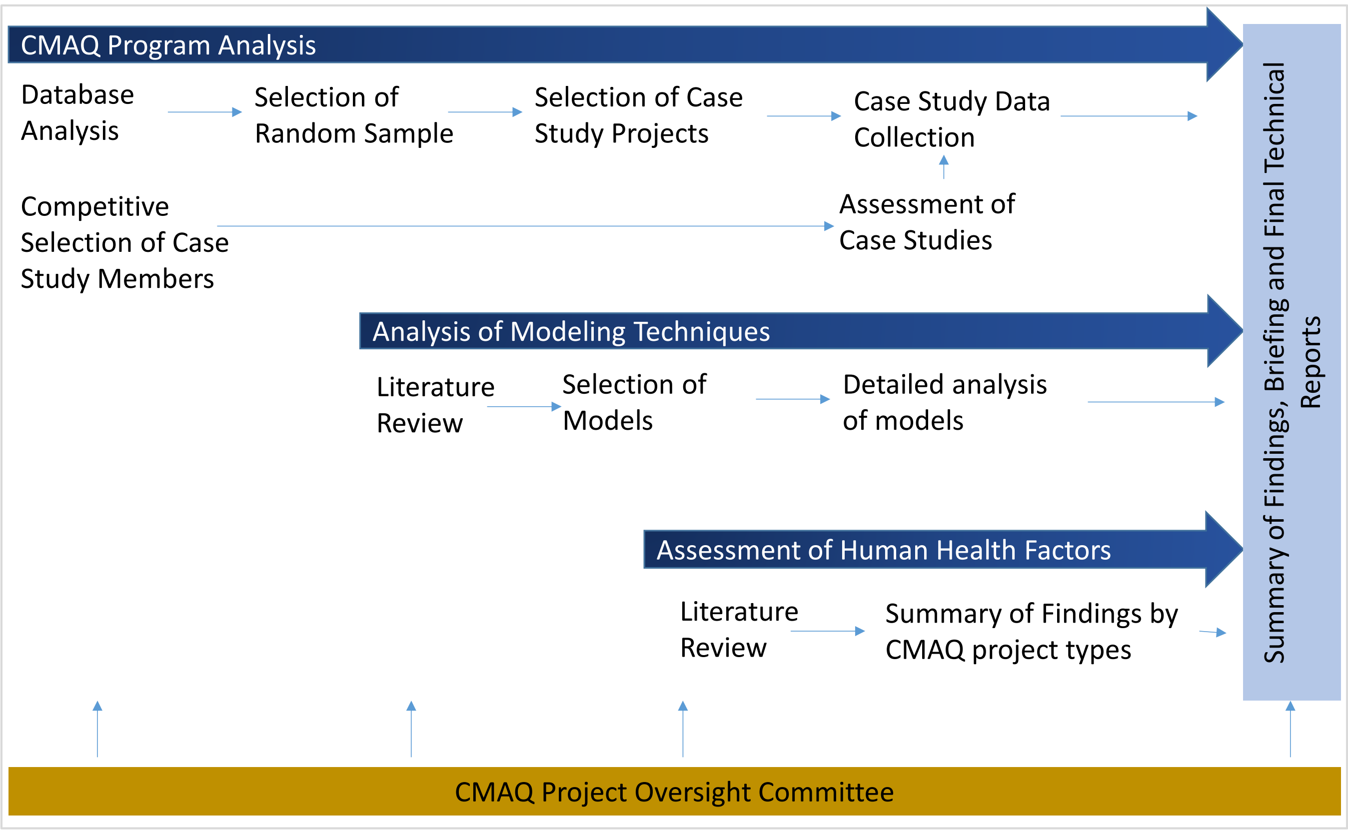


**Figure 2. CMAQ Outcomes Assessment Study Components**

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 emissions 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, 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 reviewed 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—see list of members in Appendix B. The Oversight Committee independently provided input to the development of a representative sample, the selection of case studies, and provided independent peer review of this "Summary Report of Findings" and the study's 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 case study projects based on the data.

### 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 (referred to as FY 2006) to 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 is therefore subject to the accuracy of those entries.

To help in the selection of a representative sample, all projects were each assigned into subcategories that more clearly identified the scope of the projects based on their given descriptions. These 26 subcategories (shown in Table 4 on page 21) were derived from the list of the 17 types of projects and programs eligible for CMAQ funding (shown previously in Table 1 on page 9).

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 five 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 selected sample size that was 10 times larger was used. The minimum selected sample size was 20 projects per subcategory. If the subcategory had less than 20 projects, all projects were included in the selected 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, four of the projects had to be dropped due to lack of information, leaving 72 case studies total.) Table 4 shows the number of projects selected from each subcategory. For each of the emerging and special interest subcategories, a single project was selected for the analysis.

#### Data Collection and Assessment Methodologies

In general, the data used to evaluate each of the case study projects were collected from the CMAQ database and verified and supplemented by the study team by communications with the project sponsors. Following a script for data collection, trained data collectors compiled missing case study project information, including general information, estimated travel impacts, estimated emissions impacts, and estimated human health impacts. Where necessary, additional documentation from the project sponsors was requested. 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, traffic impacts, and emissions impacts. This CST assessment included an analysis of both direct and indirect impacts. Human health impacts, as reported by project sponsors, were also collected.

### 2.1.2 Analysis of Emission Estimation and Modeling Routines

The estimated effectiveness of the CMAQ program directly rests on the project sponsor's ability to model the impact of a particular project and make a determination of the project suitability. 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.

Activities included the identification and critical review of ten CMAQ emission analysis models, routines, or techniques. 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 MS-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 more of the emission reductions from a strategy through a larger number of equation variables requiring more and different types of data. The analysis of emission 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 emissions impacts of CMAQ project types and the linkage with 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 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 applying a proven strategy for conducting independent reviews of federally funded projects. More specifically, independent experts were recruited to conduct assessments of the methods and the data reported by a representative sample of case studies.

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 data** – 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 is 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 emissions estimates was addressed only in the final selected list of projects, at which time projects without data 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 –** Changes in air quality resulting directly from CMAQ projects are very difficult to quantify, even with detailed monitoring studies, due to various confounding factors. There is very limited ability to link any long-term benefits in the context of a single project. Some of the benefits of a particular CMAQ project may be hard to attribute and may occur over the long-term. As a result, the travel and air quality 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, the models typically used by project sponsors were assessed for reasonableness and capability for estimating 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 emissions estimate might not be as realistic as reported. Similarly, the effectiveness of these projects may vary. Some projects may have daily benefits, while others may have benefits at the point of project implementation. Also, the life of benefits in years may vary depending upon the type of project. 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 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. Additional detail on the case study selection methodology is included in Section 2.1.1. 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 3 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.

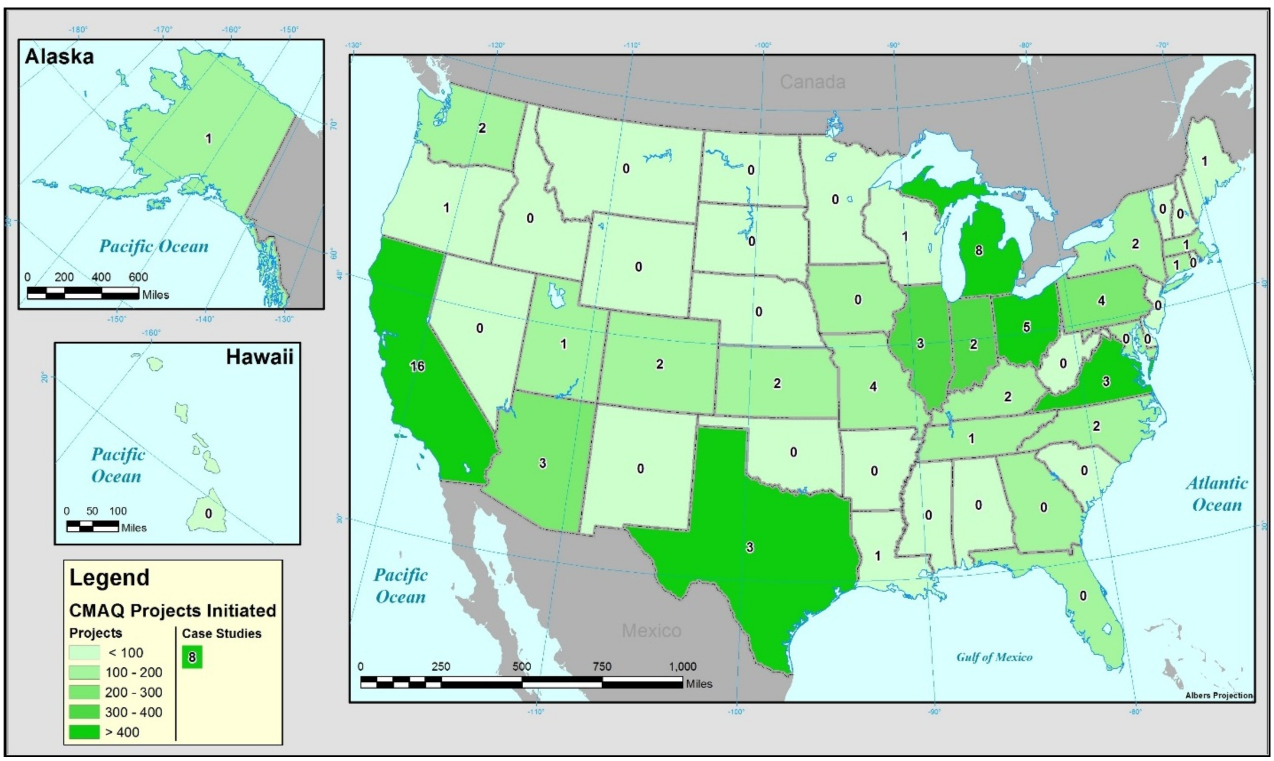


**Figure 3. Map showing the distribution of CMAQ projects across the United States, and the number of projects selected as a case study from each State.**

**Table 3. CMAQ Projects and Case Studies by State (FY2006 – 2012)**

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

**Table 4. 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** |

### 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. 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.

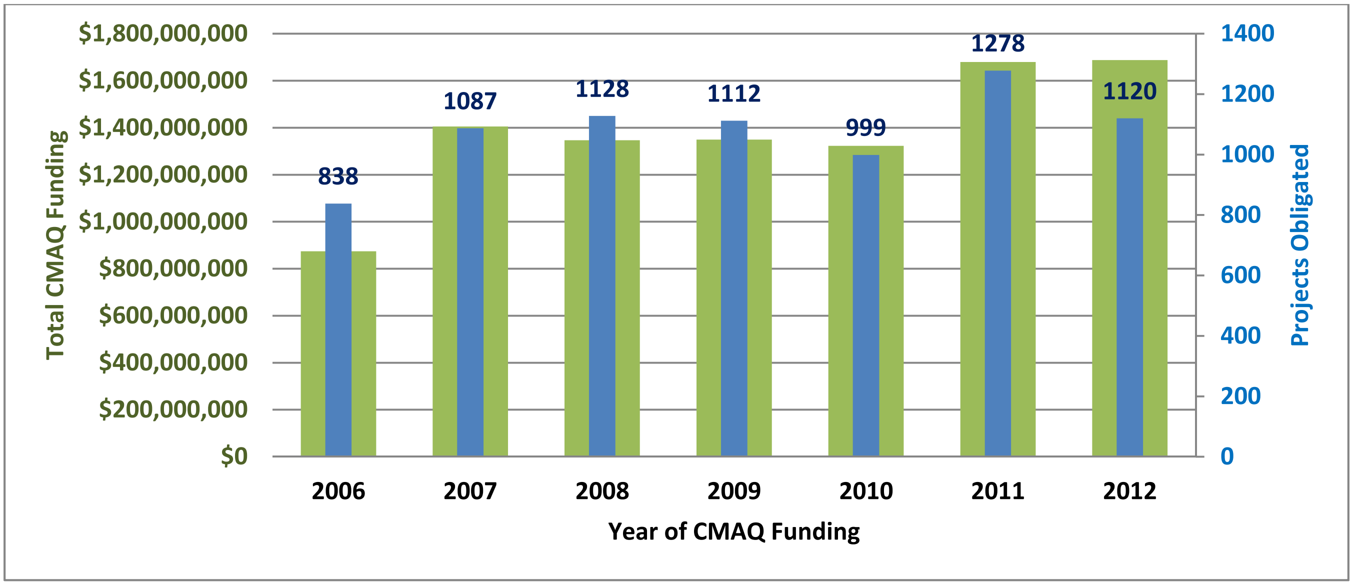


**Figure 4. Funding and Number of CMAQ Projects per year**

Figure 5 shows that 4,087 of these projects, approximately half all 8,166 CMAQ projects in the study timeframe, cost between $100,000 and $1 million. This figure uses a logarithmic scale 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.

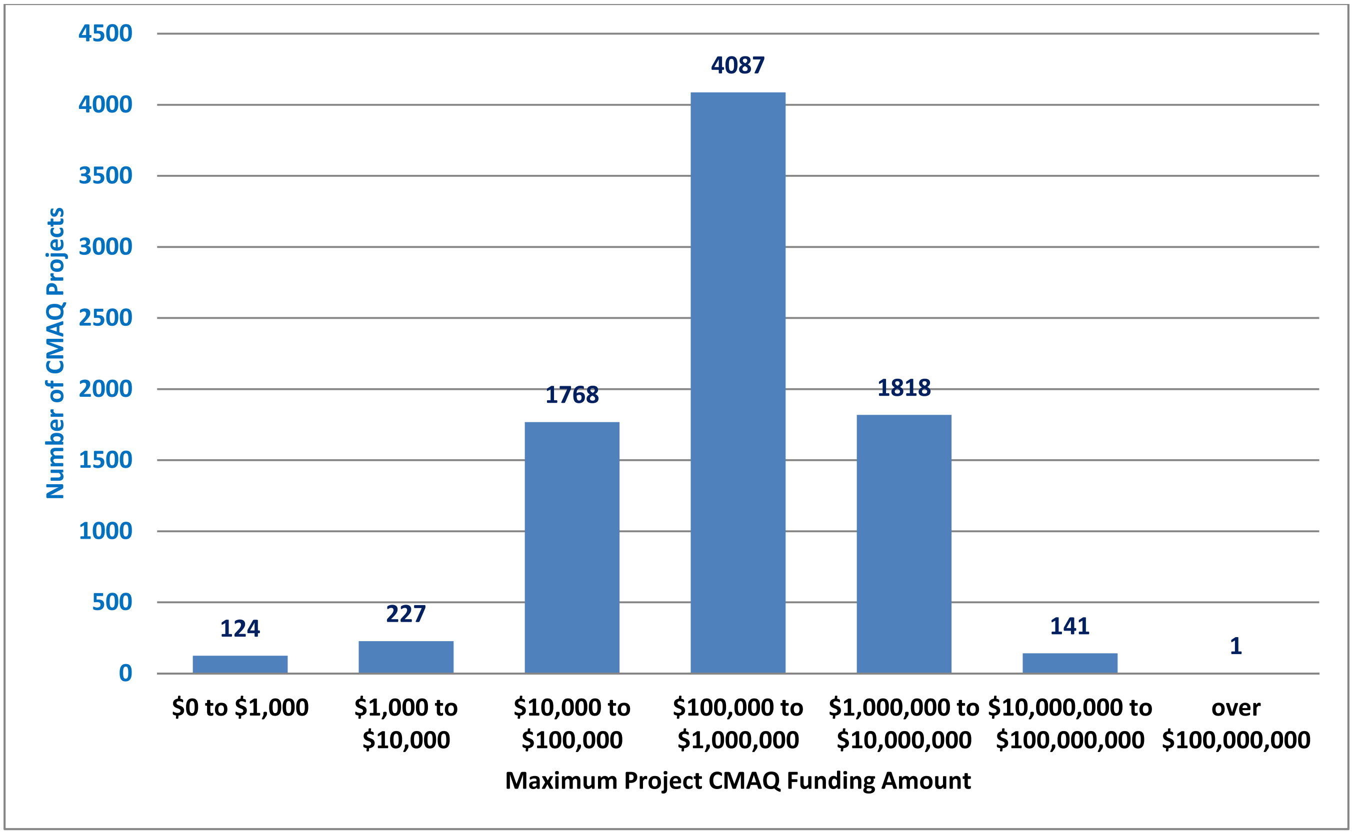


**Figure 5. Log Distribution of Number of Projects by Maximum Funding Amount for all CMAQ projects**

Figure 6 shows the relative percentage of projects within each funding range. This figure uses a logarithmic scale to show the distribution. The case study projects for all funding amounts under $100,000 are under-represented (27 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 3) and project type (see subcategories in Table 4).

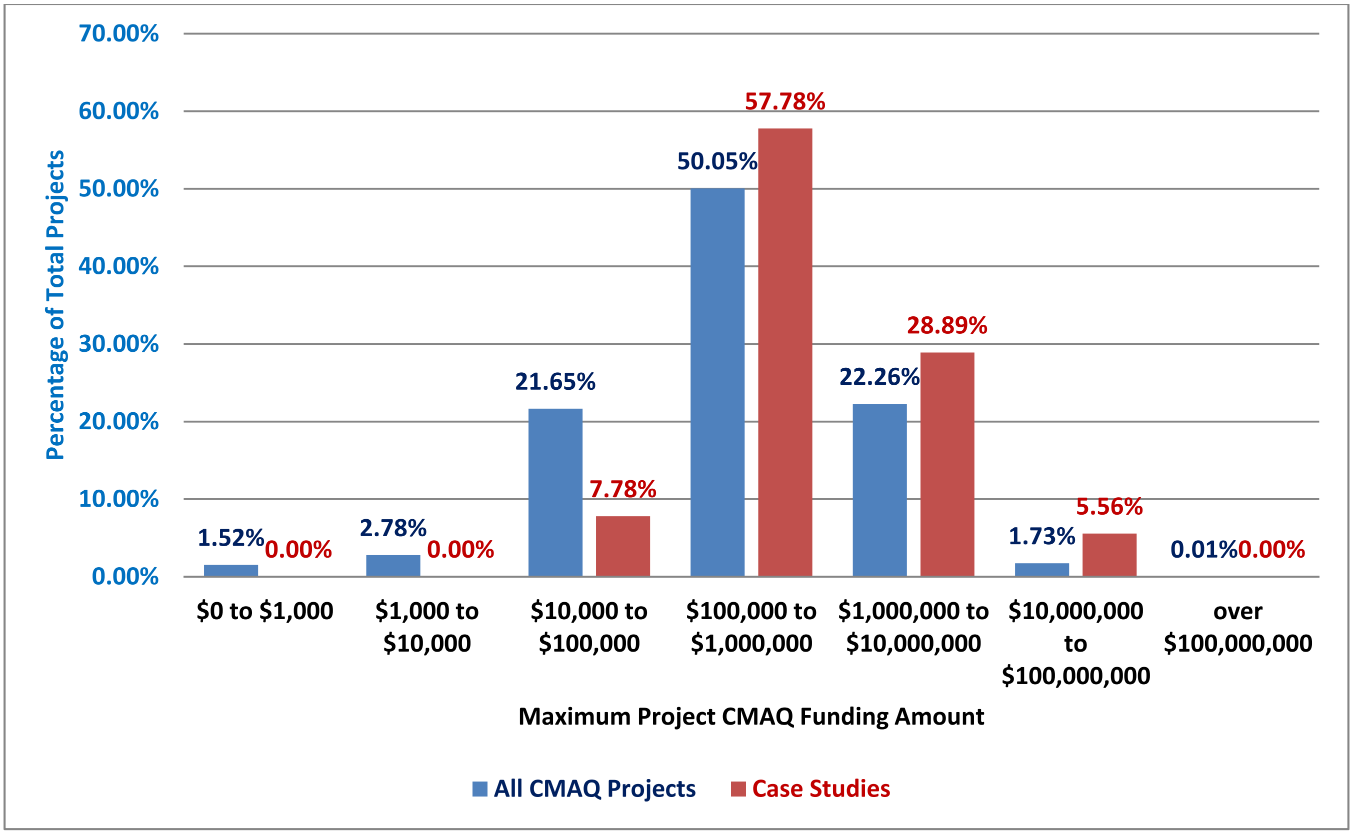


**Figure 6. Log Distribution of Percentage of Projects by Funding Amount for all CMAQ projects and for all selected as Case Studies**

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 has 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 are fewer in number. The converse is true for the major project types ‘Other’ and the transportation demand management major project type—where the projects are greater in number and often lower cost.

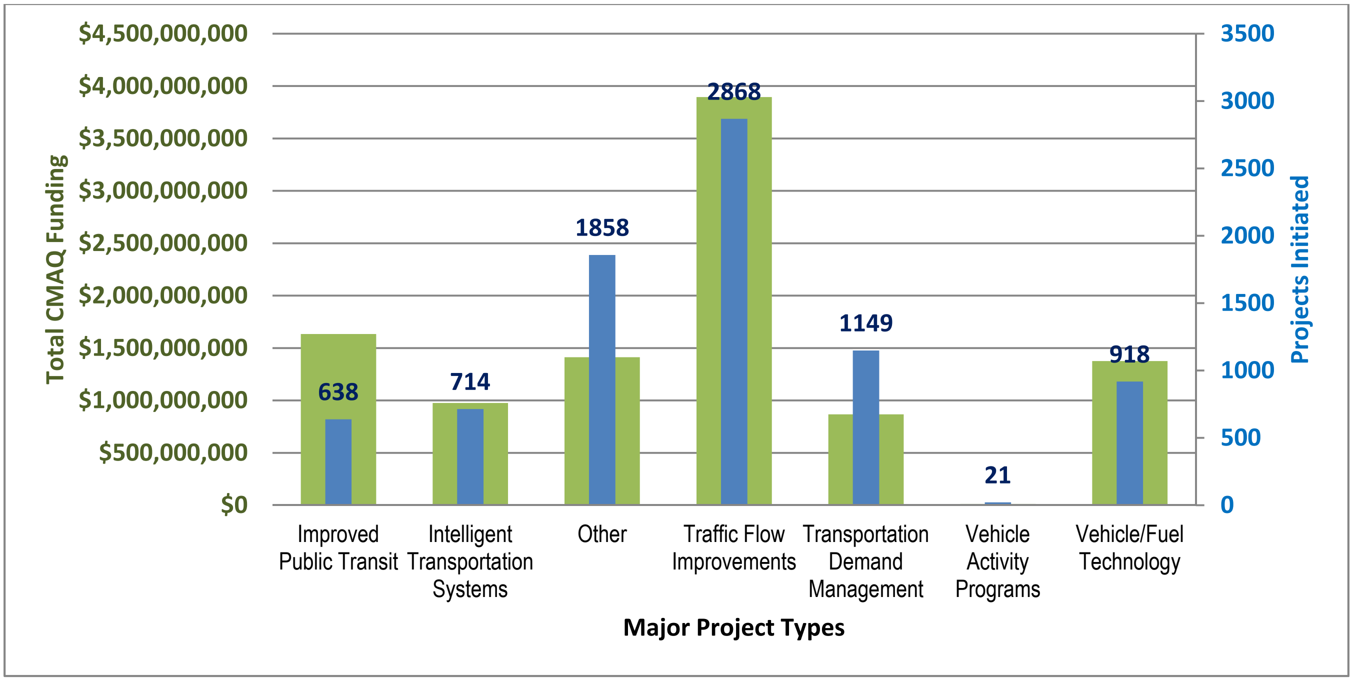


**Figure 7. Funding and Number of CMAQ Projects obligated in each Major Project Type.**

In Appendix A – CMAQ Study Subcategories and Trends, CMAQ projects were analyzed by major project type to understand the distribution by project type and funding.

## 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.

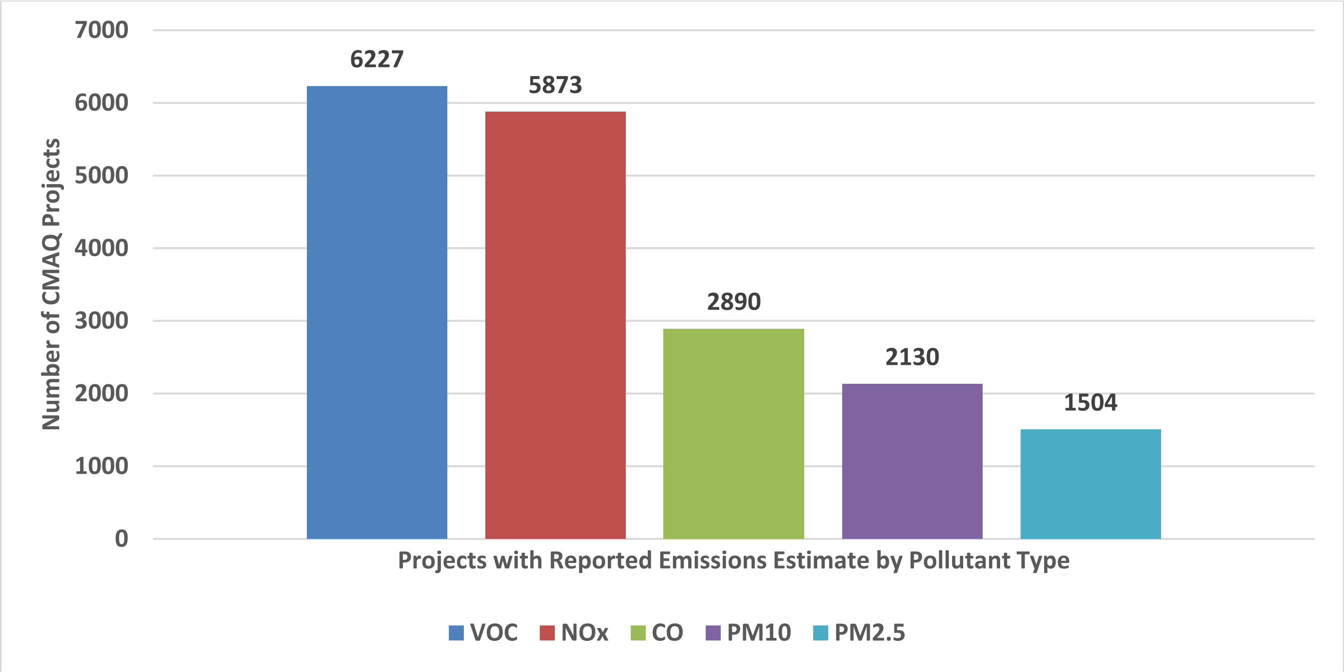


**Figure 8. Count of Projects with Emissions Estimates for each Pollution Type**

Table 5 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 includes CMAQ projects in the database reported as Previously Reported ("PR") and Qualitative Analysis ("QA") only. 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 5. 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% |

# 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 sites comprehensively or consistently reported findings for these impacts. For instance, some case study sites reported changes in emissions that were likely derived from assumed traffic or congestion mitigation impacts, but 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 reporting changes for the various travel impacts by major project type 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 impacts. Travel impacts reported by case study sites were included in this report and are summarized below, grouped by major project type.

- Vehicle/Fuel Technology (9 case studies): this major project type had very few reported traffic or congestion impacts in the case study projects because the project type primarily concerns individual vehicles, not reducing the amount of travel.
- Vehicle Activity Programs (2 case studies): as expected, the case study projects in this major project type had no reported traffic or congestion impacts because the projects reduce emissions from individual vehicles, not reduce travel.
- Traffic Flow Improvements (26 case studies): as expected, this major project type had a high number of case study projects 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 reporting this data. Overall, 15 of the 26 case

study projects reviewed in this major project type (58 percent) reported estimated improvement in at least one travel impact factor.

  - Traffic Signalization case studies estimated an average speed improvement of 11 mph.
  - Traffic Engineering case studies that estimated changes in traffic volume calculated 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 (5 case studies): this major project type had a very high number of case study projects 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 in this major project type (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 (8 case studies): the case study projects in this major project type had the highest percentages of projects reporting estimated travel impacts in the areas of reduced vehicle trips, reduced VMT, and increased transit trips. As expected, reducing VMT was the most widely reported estimate—at 88 percent of the projects. Overall, all eight of the case study projects reviewed in this major project type (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 (8 case studies): this major project type had a high number of case study projects 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 in this major project type (50 percent) reported estimated improvement in at least one travel impact factor.

  - Transportation Demand Management had 3 case studies reporting an estimated average VMT reduction of approximately 800 miles per day.

- Other (14 case studies): this major project type had a high number of case study projects reporting estimated travel impacts in the areas of reduced vehicle trips, reduced VMT, increased bike/walk trips, and increased bike/walk miles traveled. The percentage of these 14 projects reporting an increase in bike/walk trips and an increase in bike/walk miles traveled was 36 percent and 21 percent, respectively, which is expected since this major project type includes the bicycle and pedestrian project subcategory.. Overall, 7 of the 14 case study projects reviewed in this major project type (50 percent) reported estimated improvement in at least one 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 assessment of the CSTs noted that the methodology and assumptions used to estimate impacts were reasonable especially when traffic impacts were the focus of the CMAQ effort. In several other subcategories such as pedestrian/bicycling, travel demand management (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 6 shows the number and percentages of CMAQ case study projects reporting estimated emissions reductions for the individual pollutants. This includes all 72 case study projects, including 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.

As shown in Table 6 for the case study projects, estimated emissions reductions were reported most frequently for VOCs and NOx. Specifically, changes in VOCs emissions were estimated for 61 case study sites, 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 CO emissions were estimated for 39 case studies, or 54 percent. The PM emissions reductions were estimated for less than half of case study sites. Specifically, $PM_{10}$ changes were estimated for 24 case study sites (33 percent) and $PM_{2.5}$ changes were estimated for 20 case study sites (almost 28 percent).

**Table 6. 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 for at least one project and many case study projects estimated emissions for more than one pollutant.

The text below provides details on the percentage of case study projects reporting changes for the individual pollutants by major project type and average reported emissions reduction estimates for some pollutants in particular subcategories.

Table 7 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 sites 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 (9 case studies): this major project type had a very high percentage of case study projects reporting an estimated reduction in NOx—89 percent. This aligns with the expectations of the 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 (2 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 show 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. This is expected with the subcategories in this major project type that includes various traffic and congestion improvements. 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. Emissions impacts were estimated using various methods; for some projects, methods and assumptions were not reported. Most commonly, reduction in VOC, CO, and NOx emissions were reported and 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 assumed traffic impacts. Emissions impacts seemed to be underreported for some case study projects relative to similar CMAQ projects.

    - Traffic Signalization case studies reported an estimated average decrease 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 (5 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. This is expected with the subcategories in this major project type focused on traffic and congestion improvements. This major project type also had some percentages of projects reporting 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 (8 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 is expected with the subcategories in this major project type focused on the improvement of traffic and congestion through public transportation.  This major project type also had some percentages 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 (8 case studies):  this major project type had a high number of projects reporting an estimated reduction in VOC and NOx—75 percent for both.  This aligns with the expectation of the subcategories focused on the reduction of SOV usage.  There were quite low percentages of case study projects reporting of any reduction of the 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 some percentages 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.
  - 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 reported an estimated average decrease in VOC pollutants of 18 kilograms/day and in NOx pollutants of 4 kilograms/day.

**Table 7. 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 |
| **ITS** | 143.30 | 65.50 | 373.30 | 13.45 | 0.00 |
| **Improved Public Transit** | 41.11 | 42.92 | 496.80 | 7.46 | 0.06 |
| **TDM** | 23.86 | 18.77 | 3.00 | 0.08 | 1.98 |
| **Other** | 17.61 | 126.57 | 82.60 | 437.71 | 26.00 |

The assessment by the CSTs noted that the selected case studies as a whole were representative of CMAQ projects. The results of the assessments noted that while various methodologies were used to calculate estimated emissions reductions, the methods used by the case study projects to estimate emissions impacts seemed reasonable. Also, all projects reported at least some emission impacts, though the reported impacts varied and were dependent on the assumed traffic impacts. The assessments noted that in some cases, the sensitivity of the estimated impacts depended greatly on the assumptions. Examples noted by the CSTs included:

- Emissions impacts resulting from non-project changes made at the same time as CMAQ project changes need to be distinguished from those resulting from the CMAQ project,
- Emissions impacts of the projects depend on the replacement year of the buses, and
- Emissions impacts of the projects depended greatly on accuracy of VMT estimates.

For one subcategory, traffic signalization, less 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

Estimated human health impacts are not required as part of the CMAQ program, 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., 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 estimated 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 request the estimating and 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. Only 3 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 the 40 percent of 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 collected as  available.

# 5 Findings of Analysis of Emission Estimation and Modeling Techniques

As explained in the CMAQ Guidance, 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 FHWA does not prescribe to the CMAQ applicant any specific quantitative analysis method. States and MPOs have developed their own quantitative analysis methods or have adopted them from others.

Through a comprehensive literature and Internet search, 10 analysis models used to evaluate the expected air quality outcomes for the CMAQ program were identified and reviewed. The effort assessed the validity of these methods and proposed recommendations to improve further development and application of the methods. 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 these best available local inputs is considered good practice.

## 5.1 Models Analyzed

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 in this study 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.

In determining the final group, 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. Eight of the 10 models are used currently by State DOTs and MPOs. The 10 models selected for critical review were:

1. California Air Resources Board – Methods to Find the Cost-Effectiveness of Funding Air Quality Projects
2. Center for Clean Air Policy – Transportation Emissions Guidebook Maricopa Association of Governments (Phoenix, Arizona)
3. Metropolitan Washington Council of Governments
4. Michigan Department of Transportation
5. Montana Department of Transportation
6. Multi-Pollutant Emissions Benefits of Transportation Strategies (FHWA-HEP-07-004)
7. Regional Transportation Council of Southern Nevada (Las Vegas, Nevada)
8. Texas Department of Transportation – The Texas Guide to Accepted Mobile Source Emission Reduction Strategies

9. Wasatch Front Regional Council (Salt Lake City, Utah)

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., average annual daily traffic, 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,
- 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 study, *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*.

## 5.2 Findings

The CMAQ methods identified and analyzed in the 10 models were organized by the project type—that is, the subcategories defined in this project. The research team reviewed ninety-three analysis equations and methodologies. Table 8 shows the strategy analysis methodology count by project type.

**Table 8. Number of Model Equations by CMAQ Project Type**

| CMAQ Project Type | Number |
|---|---|
| Pedestrian/Bicycle | 10 |
| Travel Demand Management | 9 |
| Traffic Signalization | 8 |
| Transit Facilities, Systems, and Services | 8 |
| Intersection Improvements | 6 |
| Freeway Management Systems | 5 |
| New Bus Services | 5 |
| Park and Ride Facilities | 5 |
| Traffic Engineering (Roadway Improvements) | 5 |
| Diesel Engine Retrofits | 4 |
| Dust Mitigation | 4 |
| Idle Reduction | 4 |
| Alternative Fuel Vehicles/Fueling Facilities | 3 |
| Conventional Bus and Paratransit Replacements | 3 |
| General ITS | 3 |
| Value/Congestion Pricing | 3 |
| Freight/Intermodal | 2 |
| High-Occupancy Vehicle and Managed Lanes | 2 |
| New Rail Services | 2 |
| Roundabouts | 1 |
| Traveler Information Systems | 1 |
| Public Education/Outreach (Information/Marketing) | 0 |
| Extreme Low-Temperature Cold Start Programs | 0 |
| Carsharing | 0 |

The models covered a wide variety of CMAQ-funded actions. The fact that no public education/outreach, extreme low-temperature cold start program, or carsharing equation or methodology was identified does not mean that a method does not exist, merely that the 10 models reviewed for this study did not offer a method to analyze these project types.

The review and assessment of the models identified only minor issues. The vast majority of the equations in the models 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 93 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 provide instructions for using the equations and methodologies but very few provided "real world" examples. The development by some MPOs and State DOTs 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 emission project input consistency review, separate from the 10 models analyzed above, examined if emission factor model inputs for CMAQ evaluations use best available local data and are consistent with those used for transportation conformity and SIP development. In conformity analyses, emissions estimation inputs are expected to be more localized for the regulatory application and can provide more accurate estimates compared to use of national defaults in the MOVES and MOBILE emissions models. The use of these best available local inputs is considered good practice. This review was done through a two-step process. A sample of 45 case studies as part of this study was compiled using some basic screening criteria. Researchers then performed a secondary and more thorough examination of 10 CMAQ projects from the pool of this project's case studies to establish a better understanding of the state-of-the-practice with regards to the emissions factors used in the evaluation of CMAQ projects. Observations from the review of 10 sampled CMAQ projects, though not necessarily indicative of the CMAQ program, are:

- 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 U.S. 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 to calculate emissions factors. However, this could not be verified based on the information identified and reviewed in this study.

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

- 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.
- Before-after studies are not required by the CMAQ program; however, having some before-after studies would help improve emission estimation methods. A before and after study is particularly helpful in validating and improving the 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-after studies can be challenging. Depending on the project type, project implementation, and the scale and measured outcomes of the before-after study, these studies can be resource-intensive for an agency with limited funding and may not be appropriate at the project level.

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

The growing emphasis on 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.

The Study's broad objective was to assess the transportation and human health impacts associated with actions funded under the CMAQ program. This human health impacts assessment was completed via 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. This variance in the literature on the impacts of CMAQ project types suggests the need for more evidence-based research. Some high-level findings related to transportation and human health impacts from CMAQ project types are described below.

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 either a reduction or elimination of vehicle trips, changing when travel occurs, or improvements in vehicle operating speeds away from congested conditions. These transportation changes impact the amount of vehicle emissions generated. The reduction or elimination of vehicle trips lessens the amount of vehicle emissions generated associated with 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. Limiting vehicle idling, typically through local regulations, reduces those vehicle emissions generated from idling. Vehicle technology improvements directly impact the emissions generated from the vehicle.

The transportation literature and current emission reduction analyses performed by agencies address mass estimates (kilograms/day) of pollutant reductions from proposed CMAQ projects. However, they 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. Some additional insights from the literature on transportation and emission impacts are provided below:

- 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 reporting directly measured pollutant changes. Where pollutant changes are reported, these studies rely on the translation of 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, and 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 that seek to reduce vehicle use include ridesharing, TDM, public education, and improved transit. 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 two 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.
- 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. Generally, these projects improve traffic flow resulting in an increase in vehicle speeds away from congested operations to a more uniform traffic flow rate where vehicle emission rates are generally lower.
- Projects that mitigate congestion reduce vehicle idling emissions. Idling activity or very slow vehicle operating speeds produces the highest vehicle emission rates. More efficient traffic operations in a system will generally reduce these emissions.

The health effects of air quality improvements generally relate to changes in regional air quality that impact respiratory illnesses. However, limited evidence and very few examples exist in published literature that quantify 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. Projects can impact 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.

Some of the additional highlights from the literature on human health impacts are provided below.

- 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. The 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. Much documentation exists 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 transit, walking, bicycling, and carsharing 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 transit, 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 level 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 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 cut across 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 transit has also been shown to improve access to essential services, resulting in equity benefits for vulnerable communities.

# Appendix A – CMAQ Study Subcategories 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.

### 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 liquefied petroleum gas. 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 within $PM_{2.5}$ non-attainment and maintenance areas. 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 total projects obligated. Figure 9 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.

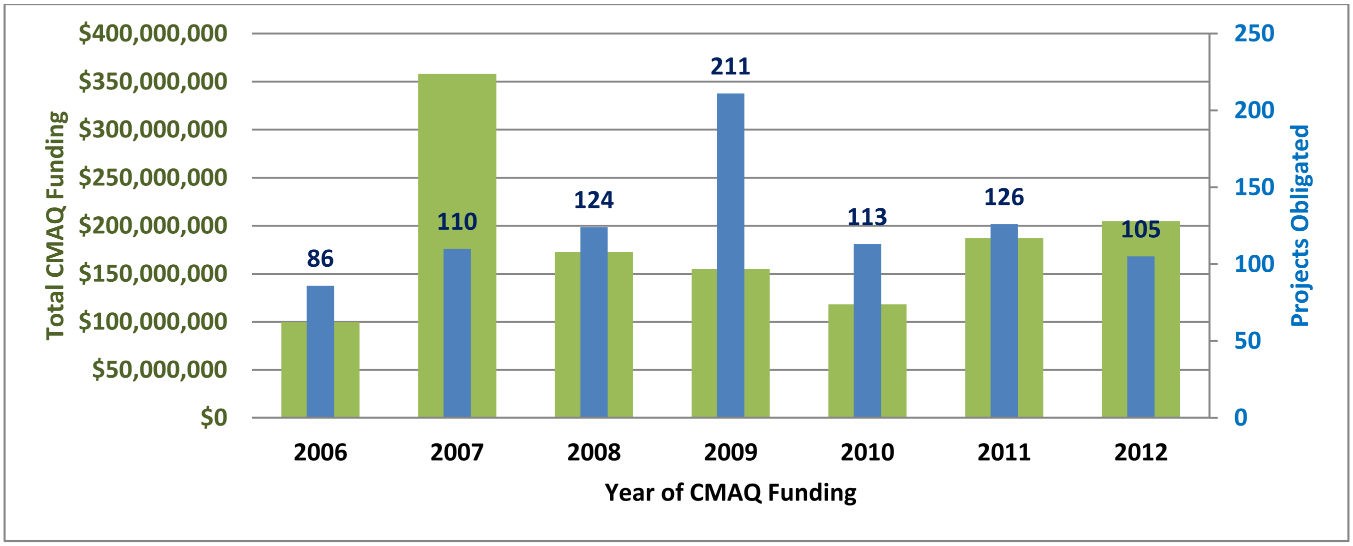


**Figure 9. Funding and Number of CMAQ Projects per year in Vehicle/Fuel Technology Project Type**

### 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 10 shows the total CMAQ funding and the number of projects obligated for the Vehicle Activity Programs project type during the 2006-2012 timeframe.

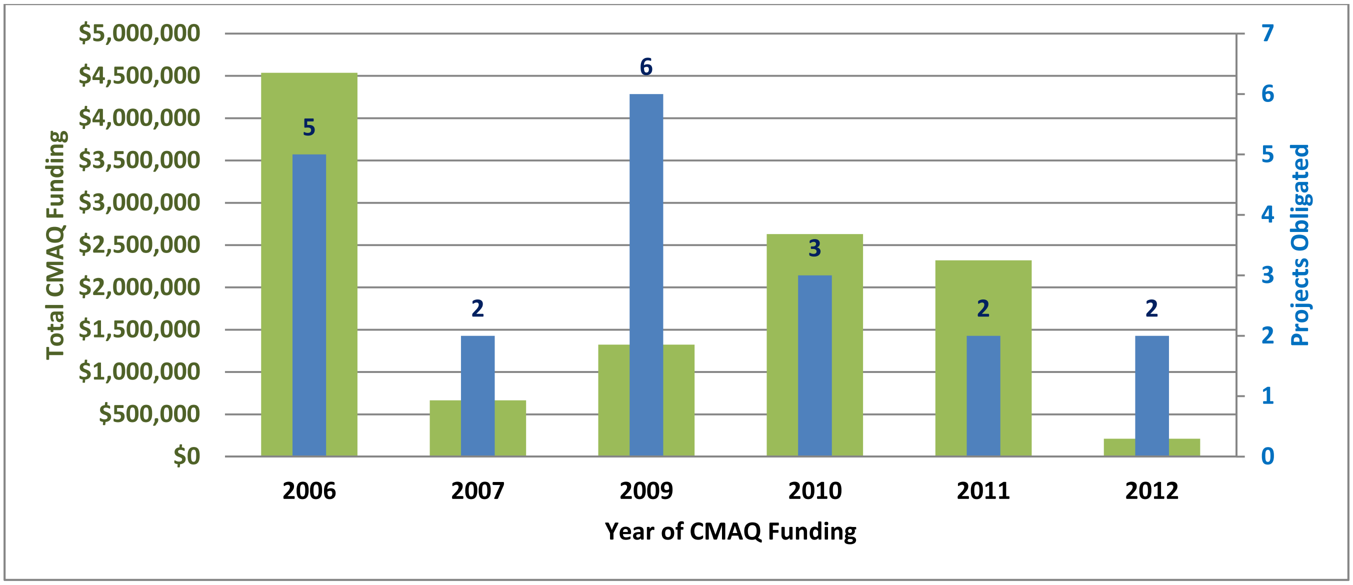


**Figure 10. Funding and Number of CMAQ Projects per year in Vehicle Activity Project Type**

### 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 total projects obligated as shown previously in Figure 7. Figure 11 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.

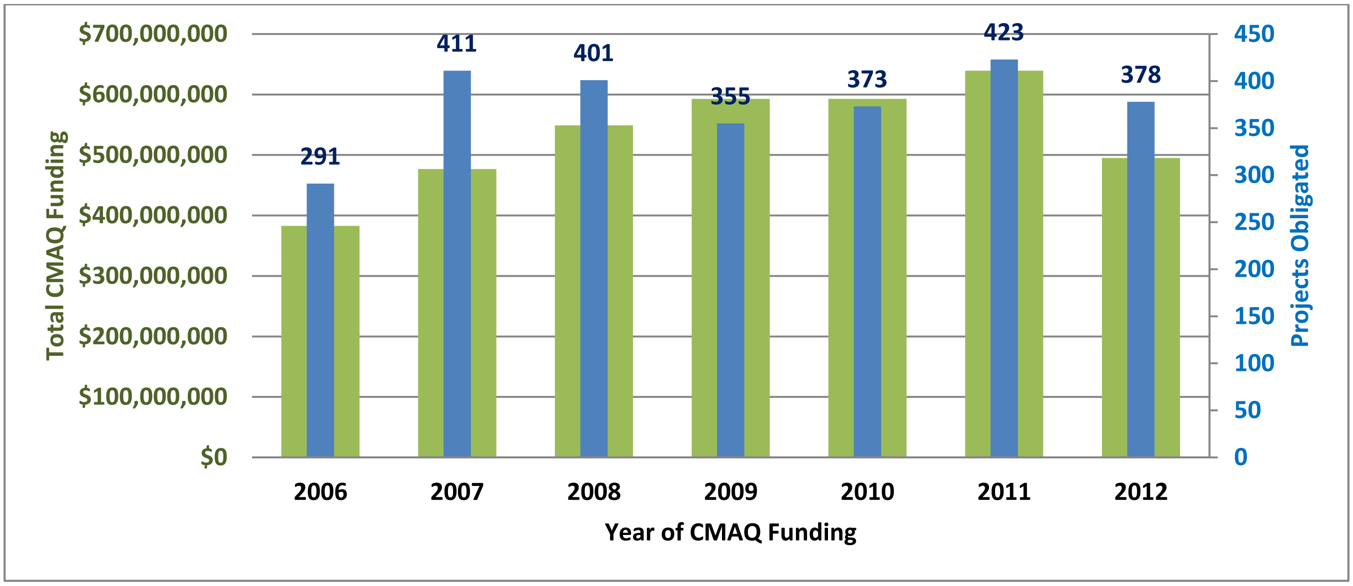


**Figure 11. Funding and Number of CMAQ Projects per year in Traffic Flow Improvement Project Type**

## 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 9 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.

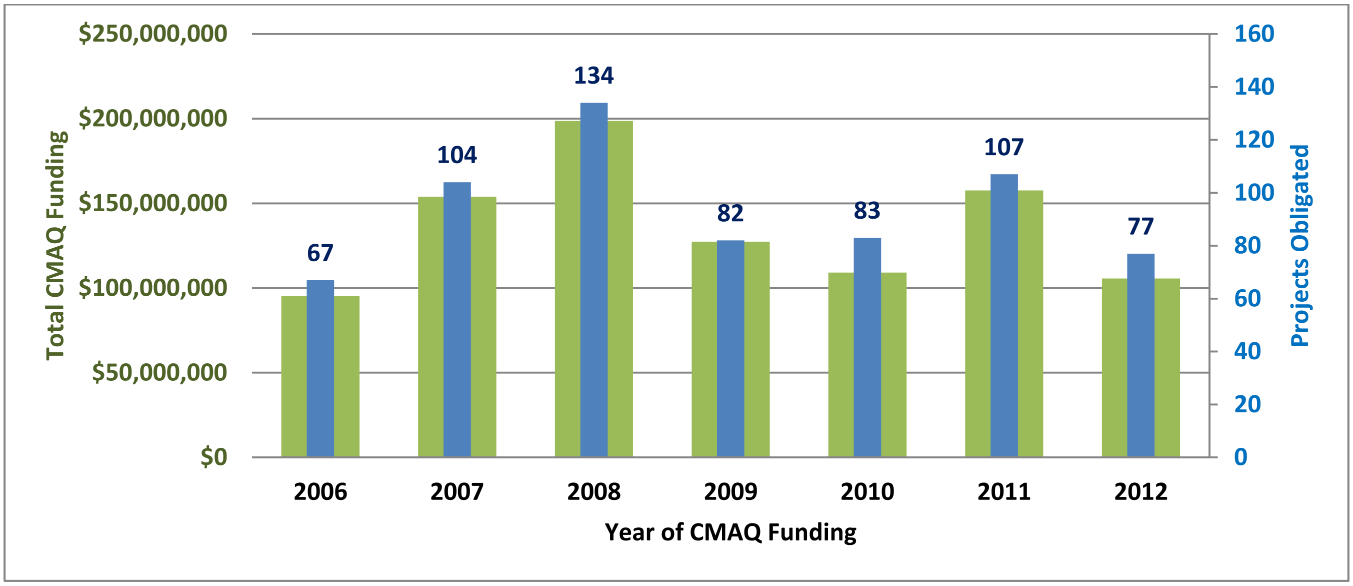


**Figure 12. Funding and Number of CMAQ Projects per year in Intelligent Transportation Systems Project Type**

## 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 13 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.

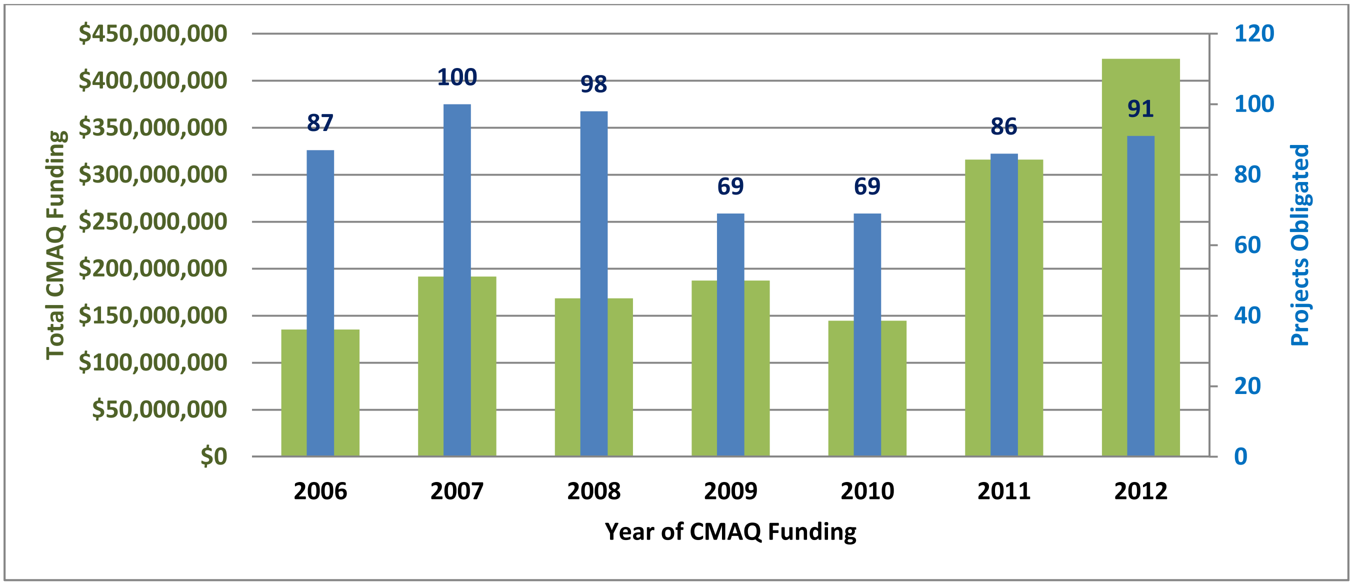


**Figure 13. Funding and Number of CMAQ Projects per year in Improved Public Transit Project Type**

## 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.

- Travel Demand Management: 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, carsharing, 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:

    - High Occupancy Toll 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 14 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.

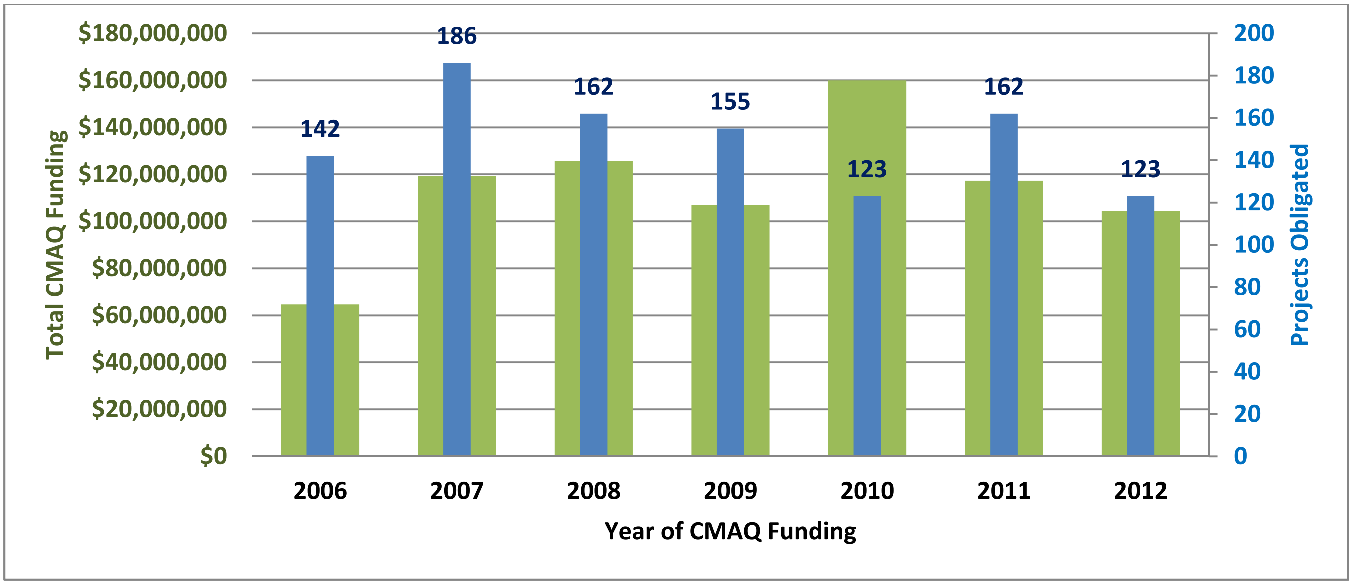


**Figure 14. Funding and Number of CMAQ Projects per year in Transportation Demand Management Project Type**

## 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 one 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 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.

- 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 15 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.

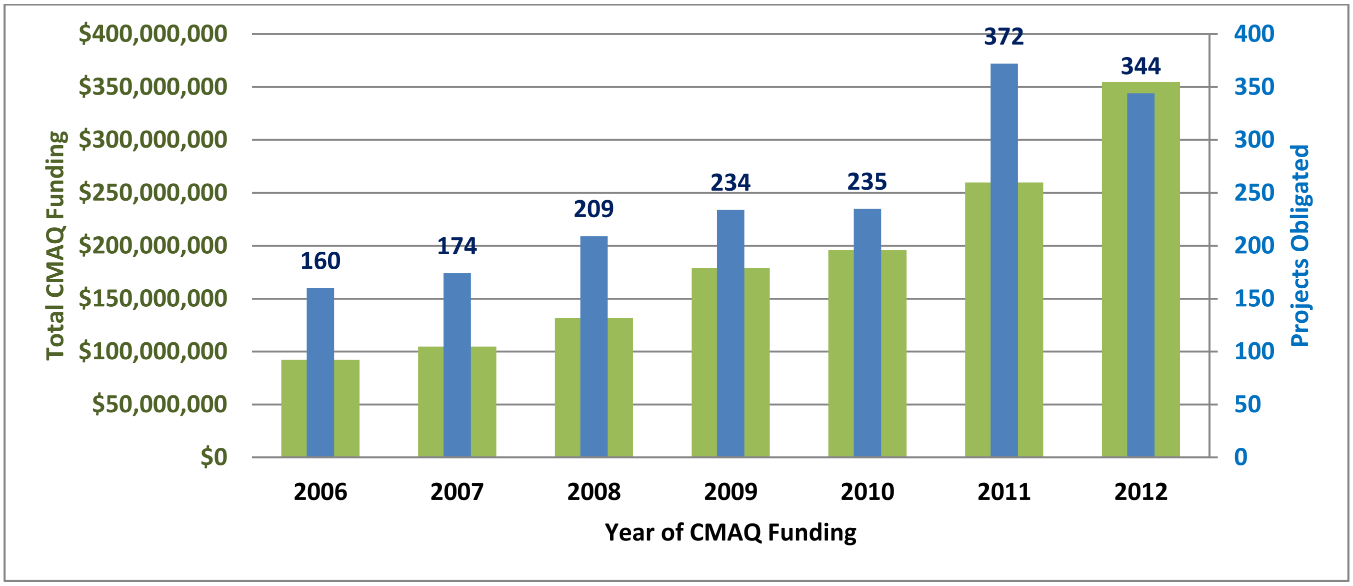


**Figure 15. Funding and Number of CMAQ Projects per year in Other Project Type**

# Appendix B – CMAQ Study Oversight Committee

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