SPECIAL REPORT 264

THE CMAQ PROGRAM: Assessing 10 Years of Experience

TRB

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TRANSPORTATION RESEARCH BOARD

THE NATIONAL ACADEMIES

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Assessing 10 Years of Experience

COMMITTEE FOR THE EVALUATION
OF THE CONGESTION MITIGATION AND
AIR QUALITY IMPROVEMENT PROGRAM

TRANSPORTATION RESEARCH BOARD

Board on Environmental Studies and Toxicology
DIVISION ON EARTH AND LIFE STUDIES

NATIONAL RESEARCH COUNCIL

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This report has been reviewed by a group other than the authors according to the procedures approved by a Report Review Committee consisting of members of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine. The views expressed in the individually authored papers that are included in this report are those of the authors and do not necessarily reflect the views of the committee, the Transportation Research Board, the National Research Council, or the project's sponsor.

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COMMITTEE FOR THE EVALUATION OF THE CONGESTION MITIGATION AND AIR QUALITY IMPROVEMENT PROGRAM

MARTIN WACHS, *Chair,* University of California, Berkeley
CARLA J. BERROYER, Wilbur Smith Associates, Hot Springs, Arkansas
DAVID S. CORDRAY, Vanderbilt University, Nashville, Tennessee
HENRY E. DITTMAR, Great American Station Foundation, Las Vegas, New Mexico
ERIC M. FUJITA, Desert Research Institute, Reno, Nevada
GENEVIEVE GIULIANO, University of Southern California, Los Angeles
JOEL L. HOROWITZ, Northwestern University, Evanston, Illinois
ALAN J. KRUPNICK, Resources for the Future, Washington, D.C.
T. KEITH LAWTON, Metro, Portland, Oregon
MICHAEL D. MEYER, Georgia Institute of Technology, Atlanta
MICHAEL R. MORRIS, North Central Texas Council of Governments, Arlington
ROBERT F. SAWYER, University of California, Berkeley
KENNETH A. SMALL, University of California, Irvine
KATHERINE F. TURNBULL, Texas Transportation Institute, College Station
KATHLEEN C. WEATHERS, Institute of Ecosystem Studies, Millbrook, New York
ARTHUR M. WINER, University of California, Los Angeles

National Research Council Staff
NANCY P. HUMPHREY, Study Director
KRIS HOELLEN, Senior Staff Officer
K. JOHN HOLMES, Senior Staff Officer

PREFACE

The Congestion Mitigation and Air Quality Improvement (CMAQ) program was enacted as part of the Intermodal Surface Transportation Efficiency Act (ISTEA) of 1991 and reauthorized by the Transportation Equity Act for the 21st Century (TEA-21) of 1998. After nearly a decade of the program's operation, congressional sponsors are interested in knowing whether it has been effective and whether its projects are cost-effective relative to other strategies for reducing pollution and congestion. Their questions were summarized in a request to the National Academy of Sciences for a study to evaluate the CMAQ program, included as Appendix A.

In response to this request, the Transportation Research Board (TRB) of the National Research Council (NRC) formed a committee of 16 experts chaired by Martin Wachs, Professor of Civil and Environmental Engineering and City and Regional Planning, and Director of the Institute of Transportation Studies at the University of California at Berkeley. Committee members have expertise in the areas of transportation and air pollution modeling, transportation demand analysis, urban planning, air chemistry and air quality monitoring, vehicle emissions (mechanical engineering), economics, environmental policy and program evaluation, human exposure assessment, and ecology. They also represent various institutional perspectives—metropolitan planning organizations, state departments of transportation, research institutes, foundations, and universities.

The following study tasks lay at the core of the requested performance review:

- An assessment of the effectiveness of projects funded under the program, including quantifiable and qualitative benefits;
- An estimate of the efficiency or cost-effectiveness of projects funded under the program, including their cost per ton of pollution reduction and per unit of congestion reduced; and
- A comparison of the cost-effectiveness of emission reductions achieved by CMAQ-funded strategies with that of other pollution reduction measures.

The committee welcomed the focus on cost-effectiveness and adopted a broad-based approach in response to its charge. It commissioned an analysis of the Federal Highway Administration–sponsored national database of all CMAQ-funded projects since the program's inception to examine spending trends over time and by region. The database was also reviewed as a potential source of information on project-level estimates of emission reductions and costs. The analysis was conducted by Harry S. Cohen, independent consultant, and is presented as Appendix C. Two papers were commissioned—one to review the literature on the cost-effectiveness of transportation-related strategies eligible for CMAQ funding, and the other to examine the cost-effectiveness of alternative strategies for controlling pollution, primarily through technology advances to meet new vehicle emission and fuel standards. The first review was undertaken by J. Richard Kuzmyak, transportation consultant, and the second by Michael Q. Wang of Argonne National Laboratories; the results are presented in Appendices E and F, respectively. The interpretations and conclusions presented in these appendices are those of the authors; the key findings endorsed by the committee appear in the body of the report.

The committee also conducted five in-depth case studies in selected metropolitan areas to gain insight into how the program operates in practice, the role of government agencies in program implementation, and the more difficult-to-measure qualitative outcomes of the program. The detailed results of these case studies can be found in Appendix D.

The committee supplemented its expertise with briefings at its meetings from state and local recipients of program funds, public interest groups, and other knowledgeable parties. In particular, the committee would like to thank Pam Burmich, California Air Resources Board; James Corless, Surface Transportation Policy Project; Connie Day, South Coast Air Quality Management District; Lawrence Dahms, Metropolitan Transportation Commission (Bay Area); Jennifer Dill, University of California at Berkeley; Eugene Murtey, California Department of Transportation; Martin Palmer, Washington Department of Transportation; Mark Pisano, Southern California Association of Governments; and Craig Scott, San Diego

Association of Governments. The committee was also assisted by input received from federal agencies involved in the program. Special thanks are extended to Michael J. Savonis, Team Leader for Air Quality Policy at the Federal Highway Administration, and Mark E. Simons, Policy Analyst with the U.S. Environmental Protection Agency, and to numerous other federal, state, and local agency staff and individuals who participated in the committee meetings and site visits. The report that follows, however, represents the consensus solely of the study committee.

The committee wishes to acknowledge the work of many individuals who contributed to the development of this report. Nancy P. Humphrey managed the study and drafted the final report under the guidance of the committee and the supervision of Stephen R. Godwin, TRB's Director of Studies and Information Services. Suzanne Schneider, Assistant Executive Director of TRB, managed the report review process. The report was edited and prepared for publication under the supervision of Nancy A. Ackerman, Director of Reports and Editorial Services, and Javy Awan, Managing Editor, TRB. Special appreciation is expressed to Rona Briere and Norman Solomon, who edited the report, and Alisa Decatur, who provided word processing support for preparation of the final manuscript. The committee also thanks Jocelyn Sands, who directed project support staff, and Amelia Mathis, who assisted with meeting arrangements and communications with committee members.

This report has been reviewed in draft form by individuals chosen for their diverse perspectives and technical expertise, in accordance with procedures approved by the NRC's Report Review Committee. The purpose of this independent review is to provide candid and critical comments that assist the institution in making the published report as sound as possible and to ensure that the report meets institutional standards for objectivity, evidence, and responsiveness to the study charge. The review comments and draft manuscript remain confidential to protect the integrity of the deliberative process.

The committee wishes to thank the following individuals for their review of this report: James Corless, Surface Transportation Policy Project, San Francisco; Robert G. Dulla, Sierra Research Inc., Sacramento, California; Steve Heminger, Metropolitan Transportation

Commission, Oakland, California; Arnold M. Howitt, John F. Kennedy School of Government, Harvard University, Cambridge, Massachusetts; John H. Suhrbier, Cambridge Systematics, Inc., Cambridge, Massachusetts; and Mary Lynn Tischer, Arizona Department of Transportation, Phoenix. Although these reviewers provided many constructive comments and suggestions, they were not asked to endorse the report's findings and conclusions, nor did they see the final draft before its release. The review of this report was overseen by Robert A. Frosch, John F. Kennedy School of Government, Harvard University, Cambridge, Massachusetts, and Lester A. Hoel, University of Virginia, Charlottesville. Appointed by NRC, they were responsible for making certain that an independent examination of this report was carried out in accordance with institutional procedures and that all review comments were carefully considered. Responsibility for the final content of this report rests entirely with the authoring committee and the institution.

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EXECUTIVE SUMMARY

The Clean Air Act Amendments (CAAA) of 1990 imposed strict new deadlines for meeting national air quality standards in nonattainment areas, including measures to ensure that transportation projects conform with pollutant reduction schedules. The 6-year, $6 billion Congestion Mitigation and Air Quality Improvement (CMAQ) program was established in the following year. While congestion mitigation is a goal of CMAQ, the primary policy focus since the program's inception has been on achieving the air quality goals of the CAAA by assisting nonattainment areas in meeting the new mandates. Enacted as part of the Intermodal Surface Transportation Efficiency Act (ISTEA) of 1991, CMAQ is the first and only federally funded transportation program explicitly targeting air quality improvement.

CMAQ's program structure reflects the basic philosophy of ISTEA: project planning and decision making are decentralized. The program sponsors—the Federal Highway Administration (FHWA) and the Federal Transit Administration, in cooperation with the U.S. Environmental Protection Agency (EPA)—provide broad policy guidance and project eligibility criteria. The states and metropolitan planning organizations (MPOs)—the key agencies responsible for transportation planning and determination of conformity at the regional level—are responsible for project selection and implementation.

STUDY CHARGE

The 1998 Transportation Equity Act for the 21st Century (TEA-21) reauthorized the CMAQ program for an additional 6 years and increased its funding to a minimum of $8.1 billion, representing about 4 percent of the 1998–2003 federal surface transportation program. Questions raised about the efficacy of the program during the reauthorization hearings, however, prompted a congressional request for an evaluation to address the following questions: How well is the program meeting its primary policy goal of improving air quality? Should more attention be paid to congestion alleviation as an important program policy goal in its own right? Can desired program outcomes, such as reduced motor vehicle trips, travel, vehicle emissions, and pollutant concentrations, be measured? Can the program's qualitative benefits be assessed? Are CMAQ projects cost-effective relative to other pollution reduction strategies? Should the program be broadened and project eligibility expanded to cover new pollutants and emission reduction strategies? To respond to the congressional request and address these questions, the Transportation Research Board of the National Research Council appointed the Committee for the Evaluation of the Congestion Mitigation and Air Quality Improvement Program. This report presents the committee's findings and recommendations.

OVERVIEW OF PROGRAM OPERATION

CMAQ funding is apportioned to the states by means of a formula that takes into account the severity of air quality problems and the size of affected populations. The states are required to spend the funds in nonattainment areas [those not in compliance with the National Ambient Air Quality Standards (NAAQS) set forth in the CAAA] and maintenance areas (those that have achieved compliance with the NAAQS and met requirements for redesignation from nonattainment status). The primary focus has been on areas designated as being in nonattainment for ozone and carbon monoxide, reflecting the pollutants of greatest concern when the CAAA and ISTEA were passed. Areas designated as being in nonattainment for particulate matter (PM_{10})[1] became explicitly eligible to receive CMAQ funds under TEA-21, reflecting increased concern about the adverse health effects of particulates; however, the CMAQ funding formula was not revised to include particulates as a factor.

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[1] PM_{10} is composed of coarse particles (i.e., between 2.5 and 10 micrometers in mean aerodynamic diameter) and fine particles ($PM_{2.5}$) with mean aerodynamic diameter of less than 2.5 micrometers.

CMAQ funds are focused primarily on the transportation control measures (TCMs) contained in the 1990 CAAA, with the exception of vehicle scrappage programs, which are not eligible (see Box ES-1). TCMs, which have been part of local transportation programs since the 1970s, are strategies whose primary purpose is to lessen the pollutants emitted by motor vehicles by decreasing travel demand (e.g., reducing motor vehicle trips, vehicle-miles traveled, and use of single-occupant vehicles) and encouraging more efficient facility use (e.g., reducing vehicle idling and stop-and-start traffic in congested conditions, managing traffic incidents expeditiously). In addition, CMAQ funds may be used for projects that reduce vehicle emissions directly through vehicle inspection and maintenance programs and fleet conversions to less polluting alternative-fuel vehicles. Intermodal freight facilities, strategies to reduce particulate emissions, and public education and other related outreach activities in support of TCMs are also eligible. The funds are intended primarily for new facilities, equipment, and services aimed at generating new sources of emission reductions. Operating funds that support these projects are generally restricted to a 3-year period. The CMAQ enabling legislation explicitly prohibits funding of construction projects that provide new capacity for single-occupant vehicle travel, such as the addition of general-purpose lanes to an existing highway or a new highway at a new location.

CMAQ projects can be proposed by cities, counties, transit and transportation authorities, state departments of transportation (often through their local district offices), and private and nonprofit entities in cooperation with a lead public agency. MPOs have the primary responsibility in a region for developing a consensus list of projects for funding and programming. An analysis of program obligations for the first 8 program years, drawn from an FHWA national database of all CMAQ projects, reveals that funding has been concentrated in two areas: transit and traffic flow improvements (see Figure ES-1). This pattern holds whether numbers or dollar values of projects are considered. Nevertheless, the categories include a wide range of projects—from infrastructure to operational improvements, and from more traditional measures, such as park-and-ride facilities and high-occupancy vehicle lanes, to strategies that many regions consider

BOX ES-1. Transportation Control Measures Included in the Clean Air Act Amendments of 1990, Eligible for CMAQ Funding

(i) Programs for improved public transit;

(ii) Restriction of certain roads or lanes to, or construction of such roads or lanes for use by, passenger buses or HOV;

(iii) Employer-based transportation management plans, including incentives;

(iv) Trip-reduction ordinances;

(v) Traffic flow improvement programs that achieve emission reductions;

(vi) Fringe and transportation corridor parking facilities serving multiple-occupancy vehicle programs or transit service;

(vii) Programs to limit or restrict vehicle use in downtown areas or other areas of emission concentration particularly during periods of peak use;

(viii) Programs for the provision of all forms of high-occupancy, shared-ride services;

(ix) Programs to limit portions of road surfaces or certain sections of the metropolitan area to the use of non-motorized vehicles or pedestrian use, both as to time and place;

(x) Programs for secure bicycle storage facilities and other facilities, including bicycle lanes, for the convenience and protection of bicyclists, in both public and private areas;

(xi) Programs to control extended idling of vehicles;

(xii) Reducing emissions from extreme cold-start conditions [newly eligible under TEA-21];

(xiii) Employer-sponsored programs to permit flexible work schedules;

(xiv) Programs and ordinances to facilitate non-automobile travel, provision and utilization of mass transit, and to generally reduce the need for SOV travel, as part of transportation planning and development efforts of a locality, including programs and ordinances applicable to new shopping centers, special events, and other centers of vehicle activity;

(*continued*)

BOX ES-1. *(continued)* **Transportation Control Measures Included in the Clean Air Act Amendments of 1990, Eligible for CMAQ Funding**

(xv) Programs for new construction and major reconstruction of paths, tracks or areas solely for the use by pedestrian or other non-motorized means of transportation when economically feasible and in the public interest. For purposes of this clause, the Administrator shall also consult with the Secretary of the Interior; and

(xvi) Programs to encourage removal of pre-1980 vehicles [excluded from eligibility under ISTEA and TEA-21].

Note: HOV = high-occupancy vehicle; SOV = single-occupant vehicle.

Source: FHWA (1999, 10–11).

nontraditional and innovative, such as traffic monitoring and incident management centers, special freeway service patrols, on-demand shuttle bus services on major corridors, bus traffic signal preemption systems, and commuter ferry service.

EVALUATION CONTEXT

Any evaluation of the CMAQ program must be undertaken with recognition of the magnitude of the air quality problem in the United States and with realistic expectations concerning the influence one relatively small program can have on reducing pollution. Transportation-generated pollutants from motor vehicle emissions are only one source of poor air quality in the nation's metropolitan areas, and influencing even this one source is not easy. Metropolitan areas have complex and varied built environments, extensive networks of transportation facilities, and travel modes dominated by drivers riding alone. Thus, most attempts to change the system will result in small modifications, although these changes can accumulate over time.

The resources provided by the CMAQ program to bring about such changes are modest by federal transportation program standards.

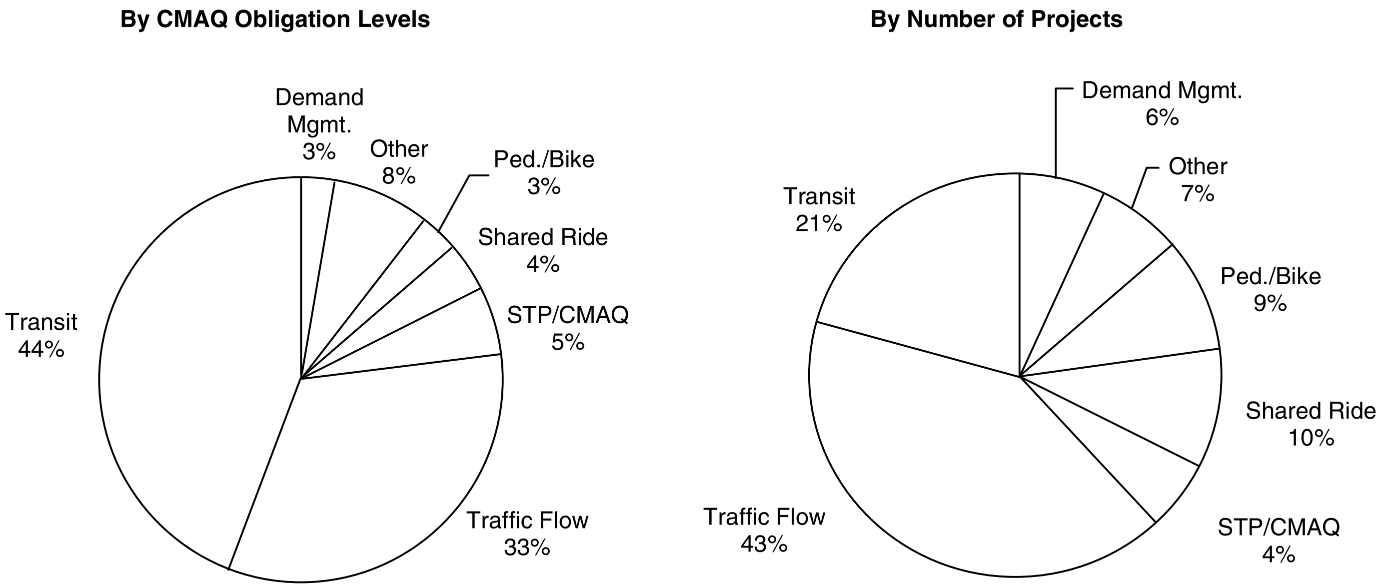

Figure ES-1 CMAQ spending priorities, fiscal years 1992–1999. Note: STP = Surface Transportation Program. (Source: FHWA CMAQ database.)

CMAQ funds constitute a relatively small fraction of any given region's total transportation budget—typically on the order of 2 to 3 percent—and the funds are often widely disbursed across a diverse program of eligible activities. Moreover, relative to new vehicle emission and fuel standards that apply to large segments of the vehicle fleet, most CMAQ-funded TCMs are highly local in scale (e.g., an intersection improvement, a bicycle path). Thus, it is not surprising that estimates of emission reductions from a region's CMAQ program amount to only a small fraction of the total emission reductions needed for a region to achieve and maintain the targets set by air quality regulations. Although the effects of any individual project may be small, it does not follow that the projects are unimportant. CMAQ-funded TCMs can help make the difference at the margin in whether an area meets pollution reduction targets and achieves or maintains conformity.

An evaluation of the CMAQ program necessarily involves a review of past performance. However, the pollution baseline against which project effectiveness is measured is changing. As vehicles and fuels become cleaner, some projects that were effective in the past may not be as successful in the future. Nevertheless, a retrospective evaluation is valuable to learn which projects have best met program objectives, and may still be effective for new nonattainment areas that become eligible for program funds. At the same time, new knowledge is emerging about the adverse health effects of various pollutants, such as particulates, that may require some refocusing of program funds and activities to target these pollution sources more directly. Thus, both a retrospective and a prospective evaluation of the CMAQ program are needed.

FINDINGS

A broad range of regional transportation planners, operating agency staff, air quality officials, and interest groups consulted for this study see value in the CMAQ program and support its continuation. Although support for the program is not universal, the positive reaction of these groups is predictable because the CMAQ program helps fund the mandates imposed on the transportation sector by the 1990 CAAA. The funds are restricted to projects that reduce pollution and congestion; CMAQ is the only transportation program with this focus. Without this restriction, the money would likely go to other uses, such as the backlog of transportation infrastructure rehabilitation and expansion needs. For many regions that have implemented most available pollution reduction strategies, CMAQ-funded TCMs offer an additional source of reductions that can help an area meet conformity requirements. The CMAQ program also encourages regions to experiment with nontraditional projects because it is focused on new facilities and services, supports alternatives to highway projects that are popular among elected officials and citizens, and affords the opportunity to fund small demonstration projects. Given the scarcity of available funding, this focus would probably not have occurred without CMAQ. The program motivates agencies to think seriously about new strategies for improving air quality, encourages interagency consultation and cooperation, and creates an opportunity for participation by a broad constituency in project identification and development. In addition, within broad constraints, CMAQ funds can be used for a wide range of eligible activities, providing local agencies great flexibility in comparison with many other transportation programs whose funds are limited to specific programmatic areas.

It is not possible to undertake a credible scientific quantitative evaluation of the cost-effectiveness of the CMAQ program at the national level. The scale issues discussed in the preceding section would make it difficult, even in the best of circumstances, to identify and segregate the effects of numerous small projects on regional air quality and congestion, much less combine them across regions. In other words, the effect of implementing CMAQ projects is generally small compared with that of other factors influencing emissions and air quality. In addition, the CMAQ program was never structured to be evaluated in a rigorous way. Methods for measuring the effects of many CMAQ-funded projects on emissions and air quality are limited at present, and few evaluations have been conducted following the completion of CMAQ projects to determine whether modeled estimates have been realized. Thus, the basic data needed to carry out a cost-effectiveness analysis are not available. Finally, the program's highly localized character—its decentralized decision structure, the specific pollution problems of different regions, and the diversity of strategies eligible for funding—hinders the application of common evaluation measures. Project costs and effects can vary greatly within one metropolitan area, as well as among areas. Project performance depends on the transportation systems already in place, the air quality and congestion mitigation measures already implemented, and the projects (CMAQ-funded and others) implemented together with any CMAQ projects. Therefore, an impractical number of local studies would have to be conducted to aggregate local results credibly into a national total.

The CMAQ program provides an opportunity to measure the cost-effectiveness of individual projects or groups of projects at the local level. Because of the variety and sometimes innovative nature of the projects funded, the CMAQ program constitutes a valuable laboratory for learning how well different types of projects perform in improving air quality and reducing congestion. To date, however, the evaluations that have been conducted have been of limited use. One reason for this is that none of the evaluations provide direct measurements of the primary final program outcomes—changes in pollutant concentrations and congestion levels. Another is that even the more sophisticated evaluations of necessity involve estimating such crucial effects as changes in traffic volumes or trips using models or inputs derived from models that were developed for regional analysis, and hence are too aggregate to capture the effects of highly location-specific projects. Some of these models, particularly emissions models, also have untested accuracy. Yet another problem is that most evaluations of TCMs are based on projected rather than actual outcomes. As a result of these problems, the levels of uncertainty of modeled estimates of project effects in some cases probably exceed the magnitude of the effects. Even when individual studies are reliable, it is difficult to make meaningful comparisons across projects because of differences in assumptions and methods. All these problems can be ameliorated with more attention to evaluation procedures. Thus, it is possible to make great improvements in the present ability to track the effectiveness of CMAQ projects.

The limited evidence available suggests that, when compared on the sole criterion of emissions reduced per dollar spent, approaches aimed directly at emission reductions (e.g., new-vehicle emission and fuel standards, well-structured inspection and maintenance

programs, vehicle scrappage programs) generally have been more successful than most CMAQ strategies relying on changes in travel behavior. The past record indicates that control strategies directly targeting emission reductions have generally been more cost-effective than attempts under CMAQ to change travel behavior. However, the cost-effectiveness of some CMAQ-eligible TCMs—those involving regional ridesharing, regional transportation demand management, and some pricing strategies—compares favorably with that of non-CMAQ-eligible control strategies. There is considerable uncertainty about these conclusions, however. First, the comparisons are based on estimates of emission reductions for the ozone precursors only (i.e., volatile organic compounds and oxides of nitrogen); estimates for carbon monoxide and particulates were not available, so that the value of projects that address these pollutants is understated. Second, the wide range of cost-effectiveness results for TCMs, even for the same type of CMAQ strategy, suggests that performance depends largely on context, that is, on where and how the projects are executed. Third, many TCMs may have benefits other than pollution reduction (e.g., congestion relief, ecological effects). Finally, the estimates for nearly all strategies are affected by modeling uncertainties. Modeled estimates have generally tended to overestimate emission reductions. These uncertainties are magnified for TCMs, which require predicting the travel as well as the emission effects of projects, adding to the uncertainty of the estimates.

The historical performance of CMAQ projects does not provide a basis for confident projections about the future cost-effectiveness of these projects. Since the CMAQ program was enacted in 1991, the vehicle fleet has gradually become cleaner as newer vehicles meeting more stringent emission regulations have come to make up a larger share of the fleet, and alternative-fuel vehicles have become more common. These changes will alter the relative desirability and cost-effectiveness of different strategies. For example, it will probably be increasingly difficult to find cost-effective projects that address both congestion and air quality; traffic flow improvements undoubtedly had greater impacts when cars were "dirtier." Automobile emissions are increasingly a function of the small number of dirty cars and of certain types of driving, a fact that enhances the value of such strategies as use of remote sensing[2] and well-structured inspection and maintenance programs to detect and possibly repair heavily polluting vehicles, and vehicle scrappage programs designed to take these vehicles off the roads. Once cost-effective strategies have been applied in a nonattainment area, more stringent versions of these programs (e.g., enhanced inspection and maintenance, regional ridesharing) to achieve further emission reductions would probably be adopted only at much higher cost. As knowledge about the adverse health effects of such pollutants as particulates grows, strategies focused on diesel trucks and buses—the primary transportation-related emitters of these pollutants—may have important benefits.

RECOMMENDATIONS

The quantitative evidence reviewed by the committee on the benefits of the CMAQ program did not provide a strong basis for either supporting or opposing continuation of the program. Nonetheless, on the basis of its review of the available qualitative as well as quantitative evidence on program effectiveness, the committee reached a consensus on the following recommendations, which are broadly grouped in response to the study charge.

Program Continuation and Focus

1. ***The CMAQ program has value and should be reauthorized with the modifications recommended below.*** The potential benefits of the CMAQ program are sufficiently great, in the collective judgment of the committee, to warrant its continuation. This judgment is made despite the inadequacy of the data to support an overall quantitative cost-effectiveness evaluation, for the following reasons. First, CMAQ is the only federally funded transportation program explicitly targeting air quality improvement. Arguably the most important benefits of the CMAQ program are the incentives and resources provided to local agencies to think seriously about strategies for improving air quality and reducing congestion. Second, the funds provided are restricted to these purposes, offering an opportunity for

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[2] Remote sensing refers to a means of measuring pollution levels in a vehicle's exhaust while the vehicle is in use.

local nonattainment areas to experiment with nontraditional transportation approaches to pollution control, and to forge new partnerships and greater interagency cooperation in the development of such approaches. Third, some of the most promising TCMs in terms of cost-effectiveness (according to admittedly uncertain data) receive limited if any support from traditional transportation funding sources and thus depend on the CMAQ program for a full exploration of that promise. Fourth, the program helps nonattainment and maintenance areas fund the strict mandates and pollution control schedules required by the 1990 CAAA. Finally, CMAQ provides a flexible source of funds that can be used for a wide range of activities tailored to local pollution and congestion problems.

2. ***Air quality improvement should continue to receive high priority in the CMAQ program.*** Although the program was conceived to address both congestion mitigation and air quality goals, in practice the latter have been given greater weight in the program structure. Maintaining this focus on air quality is desirable because congestion management is already addressed by the much larger share of federal highway funds spent on infrastructure. The CMAQ program's legislative restriction on projects involving construction of new highway capacity should also be maintained, given the availability of other funding sources for those projects and their uncertain effect on air quality. Where it can be demonstrated that CMAQ-eligible congestion relief projects may make important contributions to emission reductions, those projects should be supported by the program. The primary criteria by which the cost-effectiveness of congestion relief and more generally all CMAQ-eligible projects are judged, however, should relate to the reduction of air pollution.

3. ***Consistent with maintaining a focus on the air quality dimensions of the program, state and local air quality agencies should be involved more directly in the evaluation of proposals for the expenditure of CMAQ funds.*** Program regulations encourage consultation with state and local air quality agencies in the development of appropriate project selection criteria and the agencies' involvement in project and program funding decisions, but the case studies conducted for this study suggest a more limited role in many regions. Air

quality agencies are expressly charged with reducing emissions of air pollutants and meeting national air quality standards, and many are knowledgeable about pollution problems and cost-effective control approaches. Thus, the role of air quality agencies should be strengthened so they can be more meaningful participants in the CMAQ project review process.

Program Scope

4. ***The components of air quality addressed by the CMAQ program should be broadened to include, at a minimum, all pollutants regulated under the Clean Air Act.*** To date the CMAQ program has focused primarily on ozone and carbon monoxide. Yet it is incongruous, for example, that particulates, now believed to pose a greater health hazard than any of the other criteria pollutants, are included in the CMAQ program only for project eligibility, not as part of the funding allocation formula. At a minimum, the eligibility criteria and allocation formula should include all pollutants regulated under the Clean Air Act, which would cover particulates, as well as sulfur dioxide and air toxics. Any changes to regulated pollutants, such as implementation of new standards for fine particulates ($PM_{2.5}$), should automatically be reflected in the eligibility criteria and funding formula. Moreover, when U.S. policies are put in place to address carbon dioxide and other greenhouse gas emissions, these other emissions should be considered for eligibility for CMAQ funding.

5. ***Any local project that can demonstrate the potential to reduce mobile source emissions should be eligible for CMAQ funds.*** The CMAQ program should encourage MPOs to select and approve the most cost-effective local strategies available for reducing mobile source emissions. For example, vehicle scrappage programs, which appear to be more cost-effective than many other types of projects routinely approved under the program, should be eligible for CMAQ funding. Current restrictions on the use of public funds for private purposes should be reviewed to permit such programs. Regions should also consider wider use of CMAQ funds for projects focused on heavy-duty diesel vehicles and freight transport that can demonstrate the potential to reduce particulate emissions.

6. ***Restrictions on the use of CMAQ funds for operating assistance should be relaxed if it can be demonstrated that using funds for this purpose continues to be cost-effective.*** The restriction on using CMAQ funds for operating expenses of newly initiated CMAQ projects for more than 3 years creates an incentive for making capital expenditures that may not be efficient, and may arbitrarily eliminate some cost-effective operating expenditures. The committee, however, recognizes that not all operating subsidies are cost-effective or will continue to be so. Thus, it recommends that all proposed CMAQ projects—capital or operating—be evaluated through a process, outlined below, that should help establish the cost-effectiveness of proposed and funded projects.

7. ***The use of CMAQ funds should be considered for land use actions designed to establish the conditions for long-term reductions in future mobile source emissions.*** The potential of land use strategies to reduce congestion or vehicle emissions is complex and unclear. There appears to be some evidence to support the link between urban design (i.e., the relative location of activity and housing, mixed-use design) and encouragement of travel modes other than the automobile. Thus with further study, projects that support transit- and pedestrian-oriented development might be made eligible for CMAQ funding.

Program Operation

8. ***The agency responsible for CMAQ project selection in each nonattainment area should develop a process by which projects can be identified, selected, and evaluated in the context of the specific air quality and congestion problems of that region. In turn, the federal CMAQ project approval process should be streamlined.*** The committee believes many nonattainment areas could do a better job of selecting projects for CMAQ funding that are linked more closely to the specific air quality and congestion problems of the region, and of developing the information needed to determine whether project and program objectives have been accomplished. For example, to help identify the most effective strategies, the lead agency could consult with local experts on the specific pollution and congestion problems of a region and examine the steps already taken or under

way to address those problems. Within this context, objectives for an area's CMAQ program could then be defined and measurable performance indicators developed so that individual project outcomes could be quantified. At a minimum, these indicators should include measures to estimate pollution reduction, but it would also be desirable to define and measure other effects, such as congestion mitigation and, where appropriate, effects on ecosystems or on economic development. With greater ability to measure regional program performance against objectives, responsible local agencies should be in a better position to document the effects of CMAQ projects, report on those effects to their constituencies, and provide more complete inputs to FHWA's national CMAQ database that could be used for evaluation purposes.

Projects should be precertified as long as a region can demonstrate that they are consistent with the program objectives outlined above. Determinations of project eligibility by federal program sponsors would no longer be required once a nonattainment area had instituted a process along the lines just described. The federal project approval process should be relaxed in exchange for the regions' development of more rigorous procedures for the selection and evaluation of projects for CMAQ funding.

Program Evaluation

9. ***Recipients of CMAQ funds should be given incentives to conduct more evaluations of funded projects, and federal program sponsors should provide guidance on best practices for these evaluations.*** One of the greatest benefits of the CMAQ program may well be the development of new strategies that can be adopted by other localities or incorporated into subsequent federal legislation. This benefit is now largely lost because there is no reliable way to gauge the success of different strategies. Local agencies must currently document the expected emission reduction potential of funded projects. They should also be expected to conduct more follow-up to determine whether the reductions have been realized and examine the factors that have made a project successful. The committee realizes it would be impractical for a region to evaluate all its CMAQ projects. Likely candidates include individual projects that are expensive or

controversial and groups of small projects (e.g., bicycle projects or traffic signal improvements) that together have measurable effects. FHWA, in consultation with EPA, should provide program recipients with guidance on best practices for conducting such evaluations, including examples and contacts for additional information.

Although program recipients might prefer the funds to be reserved for projects, evaluation is in the interest of both federal sponsors and local recipients, and thus is an entirely appropriate use of CMAQ funds. The best incentive to encourage more local project evaluation is to provide additional funds for this purpose.

10. ***A more targeted program of evaluation should be undertaken at the national level, to include in-depth evaluation studies, synthesis and dissemination of results, research on appropriate analysis methods, and monitoring.*** The CMAQ program offers a rare opportunity to evaluate a diverse group of implemented projects whose primary purpose is to improve air quality and reduce congestion. FHWA, in consultation with EPA, should take the lead in initiating a well-focused national program of evaluation financed by CMAQ funds set aside for this purpose. The program would fund a selected group of studies—perhaps drawing on a representative sample of CMAQ projects both within and across regions—in which competitively selected researchers would work with local agencies to collect baseline data and track project performance using credible evaluation criteria. FHWA or EPA should synthesize the results of these studies and maintain a cumulative database for their broad dissemination. Appropriate research designs, methods, and models for conducting evaluations of difficult-to-measure TCMs are also appropriate topics for study, but CMAQ should not be the sole funding source for this purpose because the results will have application well beyond the program. Finally, a national evaluation effort should include a monitoring component to maintain currency with the state of science relevant to the CMAQ program.

CONCLUDING REMARKS

Since its inception nearly a decade ago, the CMAQ program has provided nonattainment areas with a modest but valuable source of funds dedicated to meeting the air quality mandates set forth by the CAAA.

The program has offered incentives for regions to develop effective local pollution control and congestion mitigation strategies, drawing from a wide range of eligible projects. It has also encouraged broad participation by local agencies and public interest groups in strategy development, and has enabled them to experiment with nontraditional and innovative approaches. The committee believes that if the program is reauthorized on the basis of the above recommendations, program sponsors should be in a better position in the future to account for the cost-effectiveness of implemented projects, to evaluate the success of different strategies, to monitor advances in scientific knowledge and modify the program accordingly, and to share this information widely among program recipients and the general public.

REFERENCE

Abbreviation

FHWA	Federal Highway Administration

FHWA. 1999. *The Congestion Mitigation and Air Quality Improvement (CMAQ) Program Under the Transportation Equity Act for the 21st Century (TEA-21): Program Guidance.* U.S. Department of Transportation, April.

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INTRODUCTION

The Clean Air Act Amendments (CAAA) of 1990 strengthened the link between transportation and the environment, toughening requirements for transportation projects to conform with air quality standards. In the following year, passage of the Intermodal Surface Transportation Efficiency Act (ISTEA) established the first federally funded transportation program explicitly targeting air quality improvement—the Congestion Mitigation and Air Quality Improvement (CMAQ) program (Nichols 1996, 133). In an introductory statement for the new ISTEA legislation, Senator Daniel Patrick Moynihan traced traffic congestion and air pollution to the "inefficient use of the automobile as a mode of transport" (Moynihan 1991, 11). Those who testified before the Senate Committee on Environment and Public Works noted that "four decades of straightforward adding to 'supply' by building more urban highway lanes or diverting demand through additional transit facilities had been tried—and has had at most a partial success" (Moynihan 1991, 4–5). Hence, approximately 4 percent of total funding for the 1992–1997 federal surface transportation program, or $6 billion, was earmarked for CMAQ projects that would offer alternatives to single-occupant vehicle (SOV) travel, improve travel efficiency as a means of addressing traffic congestion, and promote cleaner motor vehicles in the nation's most polluted areas.

In 1998 the Transportation Equity Act for the 21st Century (TEA-21) reauthorized CMAQ for an additional 6 years (1998–2003) and increased its funding to a minimum of $8.1 billion. TEA-21 also included a request (see Appendix A) that the National Academy of Sciences conduct an evaluation of the CMAQ program. Hearings conducted during the reauthorization process had raised many issues that prompted this request. How well is the program meeting its primary policy goal of improving air quality? Should more attention be paid to congestion alleviation as an important program policy goal in its own right and project eligibility broadened to include more traditional congestion mitigation measures, such as projects to expand highway capacity? Can desired program outcomes, such as reduced motor vehicle trips, travel, vehicle emissions, and pollutant concentrations, be measured? Can the program's qualitative benefits be assessed? Are CMAQ projects cost-effective relative to other pollution reduction strategies? Should the program be broadened and project eligibility expanded to cover new pollutants and emission reduction strategies? To respond to the congressional request and address these questions, the Transportation Research Board (TRB) of the National Research Council (NRC) appointed the Committee for the Evaluation of the Congestion Mitigation and Air Quality Improvement Program. This report presents the committee's findings and recommendations.

The remainder of this chapter begins with a brief introduction to the CMAQ program. A more detailed discussion of the study charge, an overview of the committee's approach to the study, and a summary of the report organization are presented in the following sections.

Introduction to the CMAQ Program

From its inception, the primary policy focus of the CMAQ program has been on air quality improvement, reflecting the requirements placed on the transportation sector by the CAAA to help meet national air quality goals. The CAAA imposed strict deadlines for the achievement of National Ambient Air Quality Standards (NAAQS),[1] and required the transportation sector to contribute to emission reductions embodied in state implementation plans (SIPs)[2] to help meet air quality improvement targets in nonattainment areas (i.e.,

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[1] The 1970 Clean Air Act and the subsequent 1977 and 1990 amendments charged the Environmental Protection Agency (EPA) with the task of establishing the NAAQS on the basis of maximum acceptable atmospheric concentrations of six air contaminants considered to be harmful to public health, known as criteria pollutants: carbon monoxide, lead, nitrogen dioxide, ozone, particulates, and sulfur dioxide.

[2] SIPs codify a state's plan to comply with attainment timetables established by the CAAA.

areas not in compliance with the NAAQS). The CMAQ program was closely linked to the provisions of the CAAA. It provided funding for states to use in nonattainment areas to help them comply with strict new conformity requirements and schedules. The program was focused on the criteria pollutants of greatest concern at the time the CAAA and ISTEA were passed—carbon monoxide (CO) and the ozone precursors, volatile organic compounds (VOCs) and oxides of nitrogen (NO_x) (FHWA 1992, 2).[3]

While the focus of the CMAQ program reflected the goals of the CAAA, its structure reflected the basic philosophy of ISTEA. Program goals were determined by the Federal Highway Administration (FHWA) and the Federal Transit Administration (FTA) in cooperation with the Environmental Protection Agency (EPA). Within broad guidance regarding project eligibility, however, decisions about project selection and implementation were the responsibility of the states and metropolitan planning organizations (MPOs), the key agencies for transportation planning in metropolitan areas. The program thus reflected ISTEA's emphasis on strong local planning and decision making and an enhanced role for MPOs. The program was also viewed as a new partnership in which Congress joined with the states and local governments to fund a federal mandate (i.e., the requirements of the CAAA). In 1995 the National Highway System Designation Act authorized states to use CMAQ funds in maintenance[4] as well as nonattainment areas (FHWA 1996a).[5] This change reflected a realization that some level of funding was appropriate to both reward areas that had attained compliance and help them remain in compliance.

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[3] CMAQ funds could also be used for particulate matter (PM_{10}) reduction in PM_{10} nonattainment areas, but only if the project did not detract from or delay efforts to attain the ozone or CO standards, the primary program focus under ISTEA (FHWA 1992, 2–3).

[4] These are areas that have achieved compliance with the NAAQS and met requirements for redesignation from nonattainment status.

[5] Other changes were made as a result of the National Highway System Designation Act and a prior extensive review of the CMAQ program conducted in 1994 (FHWA 1996b). For example, experimental pilot projects and outreach activities were encouraged (FHWA 1996a).

Reauthorization of the program occurred in 1998 with the passage of TEA-21, which reaffirmed CMAQ's policy goal and focus on air quality improvement.[6] Funding for the program was increased by 35 percent—approximately the same rate of increase as that of other federal-aid highway programs—to a minimum of $8.1 billion over the 6-year life (1998–2003) of TEA-21. Proposed revisions to EPA air quality standards that would have increased the number of areas in nonattainment status supported this funding increase (Gardiner 1997, 14).[7] The legislation continued the policy change of 1995 that made maintenance as well as nonattainment areas eligible for CMAQ funding, and the apportionment formula was adjusted to reflect that change.[8] The legislation also made nonattainment and maintenance areas for particulate matter (PM_{10}) explicitly eligible for CMAQ funding in recognition of the growing evidence of particulates' adverse health effects (Heanue 1997, 20). The funding formula, however, was not modified to include particulates as a factor in apportioning CMAQ funds to the states. Finally, changes were made in project eligibility that are described in some detail in a subsequent chapter.

STUDY CHARGE

Origin of the Study

As noted earlier, during hearings on the reauthorization of ISTEA, questions were raised about the efficacy of the CMAQ program in reducing emissions and improving air quality (*AASHTO Journal* 1997a; *AASHTO Journal* 1997b). Some highway user groups objected

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[6] The full legislative text of the CMAQ program can be found in the U.S. Code—23 USC 149.

[7] EPA had proposed an 8-hour ozone standard to replace its 1-hour standard, and revised its standards for particulate matter to include, among other changes, concentrations of 2.5 micrometers or less in diameter ($PM_{2.5}$) (*Federal Register* 1997a; *Federal Register* 1997b). The standards were remanded in the wake of a lawsuit that was appealed by EPA to the Supreme Court. In February 2001, the Supreme Court ruled that EPA had the authority to set the new standards, but that implementation schedules were too stringent and needed to be revised (Lane 2001, A-1).

[8] Areas that were designated and classified as submarginal and maintenance areas for ozone were explicitly included in the apportionment formula, and new weighting factors for CO nonattainment and maintenance areas were introduced (FHWA 1999, 4).

to the expenditure of highway funds for air quality projects, which, they maintained, were often costly and ineffective in reducing mobile source emissions relative to other strategies (Fay 1997, 43). Such groups proposed elimination of the mandatory set-aside of highway funds for the CMAQ program, consolidation of the funds into a streamlined surface transportation program, and greater flexibility for state and local transportation officials to set their own transportation priorities (Fay 1997, 43).[9]

Other transportation officials supported continuation of the CMAQ program, but noted that its congestion mitigation aspect had been lost with the program's primary focus on air quality improvement (Smith 1996, 193). These officials called for greater emphasis on congestion mitigation as an important program goal, and recommended broadening eligibility to include more-traditional highway capacity expansion projects (e.g., freeway interchanges, lane widening) that, in their view, would relieve pollution-creating congestion (Smith 1996, 193–194).

Environmental groups advocated retention of the program because of its environmental benefits (funds are targeted to where the problems are), funding of federal mandates (clean air improvements), and support of projects that are not eligible for other federal program funding (Howell 1996, 205). They urged that CMAQ funds not be used for highway expansion projects, questioning the link between congestion mitigation and air quality improvement (*AASHTO Journal* 1997a; *AASHTO Journal* 1997c).[10] Instead, they argued, the program should continue to focus on air quality and ensure that congestion mitigation projects meet long-term air quality goals (Howell 1996, 202).

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[9] Highway user groups argued that the CAAA and its threatened sanctions offered enough incentive for state and local governments to include transportation control measures, the highest-priority projects for CMAQ funding, in their transportation plans without funds being earmarked for this purpose from the CMAQ program (Fay 1997, 43).

[10] The concern was that reducing congestion would encourage new and longer trips; shifts from other, less-polluting modes of travel; and more decentralized location of businesses and households—thereby creating even more demand for travel (*AASHTO Journal* 1997c).

Local governments supported reauthorization of CMAQ because it gave localities funding to help implement the federal mandate on clean air (Abramson 1996, 179). Moreover, they urged Congress to commit additional funds should the air quality standards for ozone and particulates be made more stringent, thus increasing the numbers of metropolitan areas in nonattainment (Abramson 1996, 178).

The U.S. Department of Transportation (USDOT) and EPA also supported reauthorization of CMAQ at increased funding levels in anticipation of more stringent air quality standards (*AASHTO Journal* 1997a; *AASHTO Journal* 1997b). However, they recognized that more time was needed to experience and assess the overall benefits of the CMAQ program (Nichols 1996, 140; Heanue 1997, 29; *AASHTO Journal* 1997b).

Congressional Study Request

Taking the different viewpoints summarized above into consideration, Congress decided to reauthorize the CMAQ program and seek an evaluation of its benefits and cost-effectiveness. The resulting legislative request identifies nine specific items for study:

- Task A—Evaluate the air quality impacts of emissions from motor vehicles.
- Task B—Evaluate the negative effects of traffic congestion, including the economic effects of time lost as a result of congestion.
- Task C—Determine the amount of funds obligated under the program, and perform a comprehensive analysis of the types of projects funded under the program.
- Task D—Evaluate the emission reductions attributable to projects of various types that have been funded under the program.
- Task E—Assess the effectiveness, including both quantitative and nonquantitative benefits, of projects funded under the program, and include in the assessment an estimate of the cost per ton of pollution reduction.
- Task F—Assess the cost-effectiveness of projects funded under the program with respect to congestion mitigation.
- Task G—Compare the costs of achieving the reductions in air pollutant emissions achieved under the program with those that would be

incurred if similar reductions were achieved by other means, including pollution controls on stationary sources.

- Task H—Include recommendations for improvements, including other types of projects, that would increase the overall effectiveness of the program.
- Task I—Include recommendations for expanding the scope of the program to address traffic-related pollutants that, as of the date of the study, were not being addressed by the program.

Interpretation of the Charge

The study committee viewed Tasks A through C above as important to set the context for the study. However, the committee relied on existing studies and databases to address these items, instead of conducting an extensive evaluation of its own. The primary emphasis of the study was on the remaining Tasks, D through I, which go to the heart of assessing program performance and making recommendations for improvement.

Program Versus Project Focus

In reviewing its charge, the committee drew a distinction between a program- and a project-level evaluation. At the program level, the key task is to determine whether program funds are being directed appropriately toward the intended goals—in this case air quality improvement and congestion mitigation—and with what effect. Another way of addressing this task is to examine whether there are other, more effective strategies for achieving these goals.

At the project level, the issues of effectiveness and cost-effectiveness, which feature so prominently in the congressional request, are highly context specific. The same strategy may have different effects in nonattainment areas with differing pollution problems. For example, a nonattainment area with a CO problem may select traffic flow improvement projects; decreasing stop-and-start traffic by smoothing traffic flows can often be effective in reducing localized concentrations of CO. In a nonattainment area with a NO_x problem, however, the same project could significantly increase vehicle speeds, thereby exacerbating ozone formation. The committee's task was to examine the relative payoff of different strategies funded under the program, recognizing that project rankings based on effectiveness and cost-effectiveness may differ by location.

Future Versus Historical Focus
The committee also distinguished between a retrospective and a prospective program evaluation. The consensus was that both were necessary to address the congressional request. Thus, the committee reviewed how the program has performed to date and attempted to summarize what could be gleaned about the track record of projects funded under the program. The committee also looked to the future and asked where the program should be headed in view of projected trends in air quality and congestion. That focus led to recommended changes in the program scope and emphasis to meet evolving needs.

STUDY APPROACH

Evaluation Issues and Committee Approach

The committee faced a number of challenges in conducting its evaluation. In this section, several of the key issues that affected the feasibility of what could be undertaken are raised, and their treatment by the committee is explained.

Complex Program Goals
Evaluation of the CMAQ program is complicated by the program's dual goals—air quality improvement and congestion mitigation. Given the legislative history of the program (following closely upon the CAAA of 1990), as well as its funding formula and regulations, which are focused heavily on the air quality objectives of the program, most would agree that CMAQ funds must be spent on projects that demonstrate some potential for improving air quality. The problem arises with the second goal—congestion mitigation. As noted, many believe this is a legitimate program goal and argue that projects that reduce congestion will also be beneficial for air quality. Others are less sanguine about such benefits. They believe many such projects, at least those that purport to lessen congestion by improving the efficiency of highway travel, would encourage new travel, thus reducing air quality benefits.

This divergence of opinion about the program's fundamental goals (some label CMAQ the "split personality" program) makes it difficult to achieve consensus on how the performance of the program should be measured. In the spirit of ISTEA, which emphasizes local decision making, the federal program sponsors have not provided guidance on this topic. Rather, it has been left up to the states and local governments that identify, select, and program projects for CMAQ funding to determine how to balance these goals. Different metropolitan areas have differing objectives for how and why they spend CMAQ funds. Thus from a programmatic standpoint, it is difficult to compare outcomes across regions. The committee did not endeavor to resolve this ambiguity regarding program goals. Rather, the study was focused primarily on evaluating the effects of CMAQ-funded projects on what most agree is the primary program goal—pollution reduction.

Difficulty of Measuring of Final Outcomes

Ideally, a comprehensive evaluation of the CMAQ program would include an attempt to quantify the effects of projects funded under the program on desired final outcomes—improved air quality and human health, and reduced congestion.[11] These outcomes should be measurable by such performance indicators as reductions in concentrations of criteria pollutants and numbers of pollution-related illnesses and deaths for the air quality improvement goal, and faster travel speeds and reductions in travel delay for the congestion relief goal.

In practice, however, the relatively small changes that result from CMAQ projects are difficult to measure. First, the outcomes are the result of a complex set of causal relations that presents measurement difficulties at every step. Second, the current state-of-the-art estimation process does not account for potential feedback effects. Figure 1-1 shows how emission reductions are estimated; outcomes for each CMAQ project change are estimated, and these become inputs for subsequent estimates of emission reduc-

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[11] Note, however, that not every CMAQ project results in both outcomes. For example, inspection and maintenance programs, a CMAQ-eligible activity, affect only vehicle emissions, not congestion.

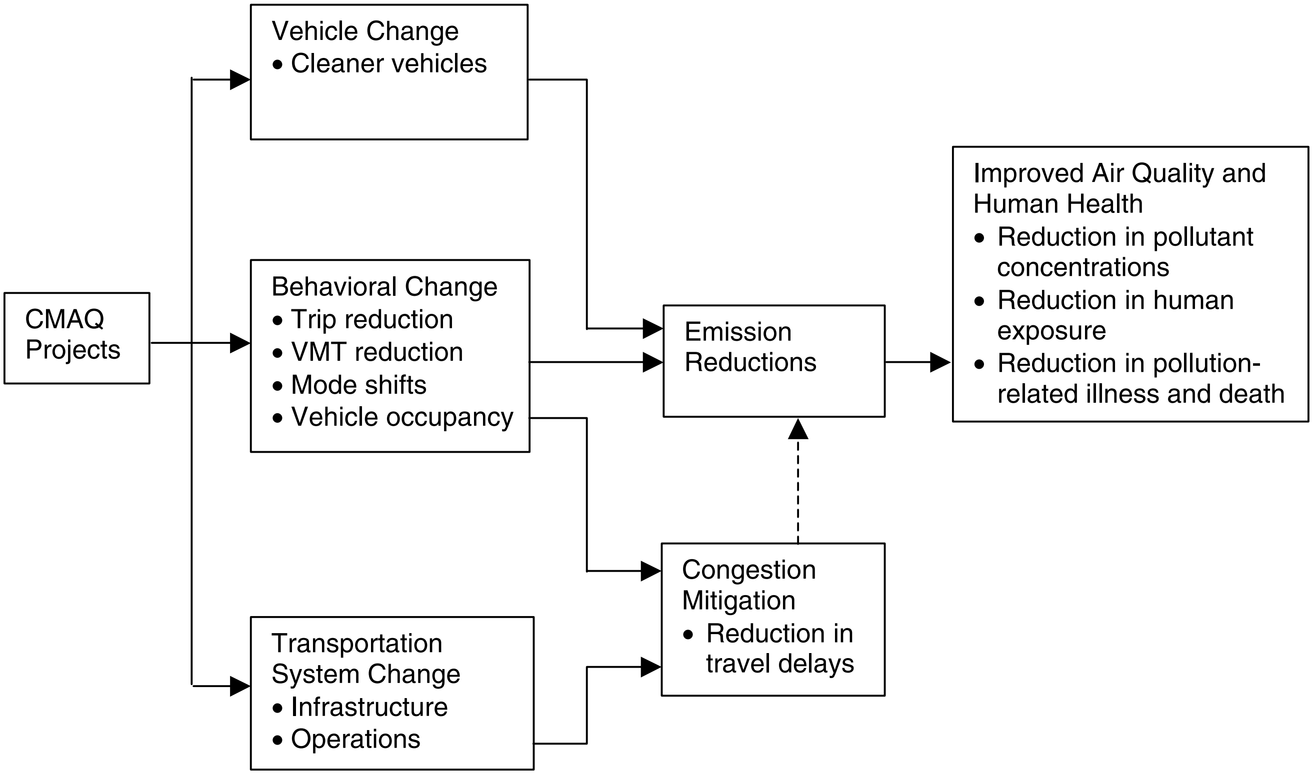

FIGURE 1-1 Flow of potential CMAQ project outcomes (VMT = vehicle-miles traveled).

tions and air quality improvements. In reality, the impact of any project is more complex. For example, trip reductions may reduce congestion, which in turn may result in more trips being made. Third, most CMAQ projects are small in scale and result in correspondingly small changes in travel behavior and emission levels. Fourth, these changes represent only a portion of a complex set of factors that affect ambient air quality levels and human health risks. For example, measuring the effects of a CMAQ project on reducing ozone, a key program concern, depends not only on the tailpipe emissions of the precursor pollutants, but also on the mix of NO_x and VOCs already in the local atmosphere, the transport of ozone or its precursors into the area, and local weather conditions (NRC 1991). Complex air quality models are used to relate reductions in precursor emissions to atmospheric concentrations of ozone, but such models are usually incapable of reliably predicting small changes in air quality that might be attributable to the typical CMAQ project, and indeed were not designed for this purpose. Thus significant uncertainty exists at every step of the impact estimation process.

Furthermore, CMAQ projects may have effects beyond those on air quality and congestion, which fall broadly into three categories: environmental, economic, and social. For example, environmental outcomes of CMAQ projects could include effects on ecosystems, as well as on levels of carbon dioxide (CO_2) and other greenhouse gases. Economic outcomes might encompass improved access and economic development. Social outcomes could include enhanced community liveability and quality of life and improved mobility for lower-income populations. Measuring these effects is difficult. With regard to ecological effects, for example, ground-level pollutants, whose sources are sometimes hundreds of miles distant, are known to alter the chemistry and composition of surface water and soils, as well as to affect sensitive plant and animal life (TRB 1997, 31–32). Identifying which types of CMAQ projects could have effects on ecosystems and the general nature of those effects may be possible, but the ability to pinpoint measurable effects of individual projects is unlikely. Many of the other outcomes of CMAQ projects, such as improved quality of life or more liveable communities, are general in nature and lack well-developed performance measures, much less the data needed to quantify the effects. And even if the data were available, measuring such a long chain of impacts with a reasonable degree of confidence would be difficult because of the uncertainties involved at each step of the analysis and the small magnitude of the effects of any single project.

Other outcomes of the CMAQ program are apt to be more process- than goal-oriented. For example, the program's broad scope and range of eligible activities may encourage greater involvement by nontraditional interests (e.g., air agencies, public interest groups, freight interests) in local transportation planning and decision making. The CMAQ program also provides a unique source of funds that can be used to support experimental, start-up projects and to leverage other funds in support of innovative transportation approaches to pollution reduction. These outcomes should also be taken into account, but they are difficult to verify and measure in any systematic way.

Because of these difficulties, the committee decided to limit its focus to the measurement of emission reductions in assessing the effects of CMAQ-funded projects on air quality and human health. Other outcomes were treated qualitatively to the extent that data were available for examining changes that may have been introduced by the CMAQ program.

Lack of a Program Evaluation Component

The CMAQ program was never structured to provide for a comprehensive technical evaluation of the program at the national level. FHWA established a national database of all CMAQ-funded projects, and required program recipients to report annually on the funds obligated for each project and to estimate the emissions reduced for each affected pollutant. Presumably, the reporting requirement was intended to enable tracking of project results and progress. Consistent with the decentralized focus of the program, however, no provision was made for collecting the data in a uniform way so that projects could be compared across regions. Thus, the FHWA database proved insufficient for evaluating the effectiveness of CMAQ projects.

Changing Program Context

The changing context within which CMAQ operates also makes evaluation difficult, particularly with respect to how well the program addresses its primary goal of pollution reduction. Cars have become cleaner since the program was enacted in 1991, and they will continue to do so as new-vehicle emission standards are phased in and the fleet turns over. Some CMAQ projects, such as traffic flow improvements, that were implemented in the early program years, are likely to have shown greater emission reductions than they could yield today or in the future. Thus, what may be learned about the effectiveness and cost-effectiveness of past projects may not hold true in the future. Similarly, great progress has been made in many metropolitan areas toward addressing the pollutants that were of greatest concern when the program was enacted—CO and ozone—and that remain its primary focus. More progress could certainly be made in reducing these pollutants, but new concerns have arisen with emerging knowledge about the adverse health effects of particulates and air toxics, which have not been a program priority. This moving-target aspect of the CMAQ program makes it necessary to qualify the relevance of past program performance.

Methods of Analysis

In light of the constraints detailed above, the committee adopted a broad-based approach to its charge. The committee's approach included a review of existing related studies, an analysis of the CMAQ database, the commissioning of papers to obtain detailed analyses of two important topics, and the conduct of five case studies.

Review of Existing Studies

The committee was fortunate to be able to draw on several major studies related to its work. The NRC (2000) critique of the MOBILE model (the primary tool for emissions analysis), the National Cooperative Highway Research Program report on quantification of the benefits and costs of transportation control measures (NCHRP 2000), and the NRC (2001a) evaluation of the effectiveness of vehicle inspection and maintenance programs address many of the analytical and modeling limitations involved in quantifying the outcomes of CMAQ projects.

At least four other NRC reports were important for understanding the air quality problems addressed by the program—the NRC (1991) study on ozone and the more recent studies on airborne particulate matter (NRC 1998; NRC 1999; NRC 2001b). Finally, three other TRB reports were helpful in understanding the links among transportation, the environment, and congestion (TRB 1994; TRB 1995; TRB 1997). These reports, among others, provided the contextual information necessary to address Tasks A and B of the congressional request (evaluating the air quality impacts of emissions from motor vehicles and evaluating the negative effects of traffic congestion).

Analysis of CMAQ Database

The committee commissioned an analysis of FHWA's national CMAQ database (see Appendix C). This analysis was helpful in analyzing the general types of projects funded under the program and differences in spending priorities among geographic areas (Task C of the congressional request, determining the amount of funds obligated under the program and performing an analysis of the types of projects funded). The committee also examined the database as a potential source of information about project-level emission reductions and costs.

Commissioned Papers

This study is not the first attempt to measure the effectiveness and cost-effectiveness of many of the types of projects now funded under the CMAQ program. Transportation control measures, in particular, have been part of urban transportation policy since the early 1970s (Meyer 1999, 575). The committee therefore commissioned a paper (included as Appendix E) to review the relevant literature, with a focus on more-recent studies and on available postimplementation studies aimed at determining the extent to which projected outcomes of CMAQ strategies (e.g., emission reductions) were realized (Tasks D, E, and F of the congressional request—evaluating emission reductions attributable to CMAQ projects, assessing the quantitative and qualitative benefits of the projects, and assessing the cost-effectiveness of projects with regard to congestion mitigation, respectively). In view of the inadequacies of the models and data on which the results of many prior studies are based, the paper focuses on a small set of studies and strategies for which more in-depth and reliable data were available, as well as contextual information for interpreting the results.

The committee commissioned a second paper (included as Appendix F) to examine the cost-effectiveness of alternative strategies for controlling pollution, primarily from non-CMAQ-eligible mobile and point sources (Task G of the congressional request, comparing the costs of air pollutant reductions achieved under CMAQ with those achieved by other means). Recognizing the need for consistency between the two papers, the committee requested that the authors adopt similar approaches to such issues as level of aggregation for reporting emission reductions, related weighting factors, and treatment of costs. Both authors were charged with discussing the sources and extent of uncertainty for each class of strategy reviewed. Together, the two reviews provide a thorough scan of the relevant literature.

Case Studies

The committee conducted five case studies in selected metropolitan areas—Los Angeles, Chicago, Houston, Washington, D.C. (tristate area), and Albany—to gain better insight into how the CMAQ program operates in the field. The case studies helped the committee understand the many contexts in which the CMAQ program functions and the roles of different governmental agencies in implementing the program, including local views on program goals, strengths, weaknesses, and areas for improvement. Finally, the case studies helped the committee understand some of the difficult-to-measure qualitative aspects of the program (Task E of the congressional request, assessing the quantitative and qualitative benefits of CMAQ projects). To supplement the case studies, the committee heard briefings from local program administrators and other stakeholders at several of its meetings.

REPORT ORGANIZATION

The items included in the congressional request are addressed in the remainder of this report. In Chapter 2, an overview of air quality and congestion problems, which provide the context for the CMAQ program, is presented, along with a brief discussion of emerging trends that could affect the future direction of the program. Implications for program evaluation are considered. In Chapter 3 an overview of program operations to date is provided, including a review of funding allocations and eligible activities, a history of program spending trends by project category and geographic area, and a review of program operation in the case study sites. The committee's assessment of the program's results is given in Chapter 4. What is known about the cost-effectiveness of CMAQ projects is reviewed; the cost-effectiveness of alternative strategies for pollution reduction is examined; and the qualitative aspects of the program are addressed, drawing again on the case studies. The findings presented in Chapters 2 through 4 served as the basis for the committee's summary findings and recommendations, which are presented in Chapter 5.

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Abbreviations

AASHTO	American Association of State Highway and Transportation Officials
FHWA	Federal Highway Administration
NCHRP	National Cooperative Highway Research Program
NRC	National Research Council
TRB	Transportation Research Board

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2

CONTEXT OF THE CMAQ PROGRAM

As noted in Chapter 1, the primary policy goal of the CMAQ program is to improve air quality; congestion mitigation is another program objective to the extent that it supports this goal. In this chapter, the role of the CMAQ program in meeting both goals is discussed. The chapter begins with a brief overview of the air quality problem in the United States, its effect on human health and the environment, the contribution of transportation to the problem, the costs imposed by motor vehicle pollution, and the regulatory and planning process for pollution control. Within this broader context, the specific role of the CMAQ program in helping meet air quality standards is addressed. The discussion then turns to the role of the CMAQ program in reducing congestion. Congestion is defined, measurement of the extent and costs of congested travel on U.S. highways is reviewed, the link between congestion and air quality is examined, and the specific role of the CMAQ program in helping alleviate traffic congestion is discussed. In a final section, the changing air quality and travel context within which the CMAQ program operates and the effect of this context on the future direction of the program are considered. The chapter ends with conclusions and a review of implications for evaluation of the CMAQ program.

THE CMAQ PROGRAM AND AIR QUALITY IMPROVEMENT

Air Quality Standards

Protection of public health is the primary purpose of air quality regulation. The Clean Air Act Amendments (CAAA) of 1970 (Public Law 91-604, 84 Stat. 1676) required, and the U.S. Environmental Protection Agency (EPA) developed, National Ambient Air Quality Standards (NAAQS) for six criteria pollutants considered harmful to public health—carbon monoxide (CO), lead, nitrogen dioxide (NO_2), ozone, particulate matter (PM_{10}),[1] and sulfur dioxide (SO_2). Primary standards were established that set allowable concentrations of and exposure limits for these criteria pollutants to protect public health with "an adequate margin of safety" (NRC 2000, 16). Secondary standards were also established to protect the public welfare against environmental and property damage (NRC 2000, 16). EPA is required to review and update the NAAQS for major air pollutants every 5 years on the basis of the latest scientific evidence.

Another category of pollutants, known as hazardous air pollutants or air toxics, is also regulated under the Clean Air Act. Air toxics are emitted from thousands of sources, such as electric utilities, automobiles, and dry cleaners. The CAAA of 1990 mandated the development of technology-based emission standards for the 188 relevant pollutants, as well as an assessment of remaining risks (EPA 2001a, 80). According to the most recent EPA inventory, highway vehicles are responsible for about 30 percent of the 4.6 million tons of air toxics released nationwide (EPA 2001a, 82). The inventory does not include diesel particulate matter, which EPA recently listed as a mobile source air toxic and is addressing in several regulatory actions discussed in the final section of this chapter.

In 1997 EPA revised the NAAQS for ozone and PM on the basis of a review of the adverse health effects of exposures to ambient pollutant levels allowed by the then-current standards. The new standard for ozone extended the exceedance period from a 1-hour averaging time to an 8-hour standard to protect against longer exposure periods, and also tightened the standard for most nonattainment areas, changing from a 1-hour daily maximum of 0.12 parts per million (ppm) ozone concentration to a 0.08 ppm 8-hour standard (*Federal Register* 1997a, 38,856).[2] Moreover, whereas prior standards focused on PM_{10}, the new standards for PM targeted $PM_{2.5}$ for the first time

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[1] PM_{10} is composed of coarse particles (i.e., between 2.5 and 10 micrometers in mean aerodynamic diameter) and fine particles ($PM_{2.5}$) with mean aerodynamic diameter of less than 2.5 micrometers.

[2] The new 8-hour standard is not a daily maximum, like the 1-hour standard, but instead is based on the 3-year average of the fourth-highest daily maximum 8-hour average.

on the basis of epidemiological studies that revealed associations between ambient PM concentrations and various adverse health effects, including mortality (*Federal Register* 1997b, 38,652). The 24-hour averaging standard for PM_{10} was also made more stringent. Challenges to the new standards in the Appellate and Supreme Courts have stalled the initial phase of implementation, but these standards were not to take full effect until 2012 and 2018 for ozone and $PM_{2.5}$, respectively. As of this writing, EPA still needs to satisfy the Court that its new ozone standard can be implemented in a manner compatible with the 1990 CAAA.[3]

As of September 2000, the most recent period for which data are available, 101 million people, slightly more than one-third (35 percent) of the U.S. population, were living in 114 areas designated as being in nonattainment for at least one of the criteria pollutants (EPA 2001a, 76).

Health and Environmental Effects of Criteria Pollutants and Air Toxics

Concentrations of criteria pollutants that exceed regulated levels are believed to contribute significantly to adverse health effects, which can range from illness to premature death. The adverse health effects of CO and ozone have been known for some time. CO enters the blood stream and links to hemoglobin, reducing delivery of oxygen to the body's organs and tissues. The health threat from lower levels of CO is most serious for those who suffer from cardiovascular disease (EPA 2001a, 11). However, impairment of cognitive skills, vision, and work capacity may occur with elevated CO levels in healthy individuals (EPA 2001a, 11). The health effects associated with exposure to levels of ozone above the 1-hour standard range from short-term effects, such as chest pain, decreased lung function, and increased susceptibility to respiratory infection, to possible long-term consequences, such as premature lung aging and chronic respiratory illnesses (EPA 2001a, 29).

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[3] The issue is that requirements for controls in nonattainment areas depend on the areas' classification (e.g., moderate, serious, severe, extreme), which is keyed to the 0.12 ppm standard in the CAAA. If the standard changes, it is not clear how areas should be classified.

New epidemiological evidence, obtained largely during the 1990s, led to the promulgation of revised PM standards in 1997 and intense scrutiny concerning PM's adverse health effects, including premature death (NRC 1998, ix). Both coarse and fine particulates can accumulate in the respiratory system. Coarse particles aggravate respiratory conditions such as asthma. Fine particles are also associated with exacerbation of asthma and other respiratory-tract diseases, decreased lung function, increased hospitalization for cardiopulmonary diseases, and premature death (EPA 2001a, 41).[4] Air toxics are known to cause or are suspected of causing cancer and having other serious human health effects (EPA 2001a, 79). Relative to criteria pollutants, however, less information is available about the health and environmental impacts of individual hazardous air pollutants (EPA 2001b, 26).

Pollutant deposition can also have adverse effects on ecosystems. SO_2 is a well-known precursor to acid deposition (acid rain), as is the ozone precursor NO_2 (EPA 2001a, 61). Acids are delivered to ecosystems through the deposition of dry particles and gases (such as nitric acid vapor); rain and snow; and, in coastal and high-elevation areas, clouds or fog. Although nitrogen is an essential plant nutrient, deposition of atmospheric nitrogen in some regions of the United States contributes to acidification of sensitive soils and surface waters; groundwater pollution; and eutrophication[5] of downstream waters, such as estuaries and near-coastal ecosystems (Driscoll et al. 2001).

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[4] The issuance of new standards for $PM_{2.5}$ has focused considerable attention on the need to review the science that underlies the standards. For example, Congress directed the EPA Administrator to arrange for an independent study by the National Research Council (NRC) on the most important research priorities relevant to setting PM standards, among other tasks, and added substantial funds to EPA's budget to support the expansion of PM research. Three NRC reports addressing this issue have been published to date (NRC 1998; NRC 1999; NRC 2001a). In addition, EPA has funded five national centers to conduct PM research. The Health Effects Institute, a nonprofit independent research institute that addresses the health effects of air pollution caused by motor vehicles, has also conducted several major reviews and reanalyses of a number of key studies (HEI Perspective 2001), and the American Lung Association has published a review of recent peer-reviewed studies on the health effects of PM air pollution (ALA 2000).

[5] The process by which a body of water acquires a high concentration of nutrients, especially phosphates and nitrates, that lead to excessive algae growth and depletion of oxygen in the water.

For example, approximately 30 percent of the nitrogen loading to the Chesapeake Bay and the New York Bay caused by human action is due to atmospheric deposition (Hinga et al. 1991; Fisher and Oppenheimer 1991). Ozone and its precursors can also affect sensitive vegetation and ecosystems. Specifically, they can lead to reduced crop and commercial forest yields and increased plant susceptibility to disease, pests, and the adverse effects of harsh weather (EPA 2001a, 29). Overall, acidic deposition can significantly affect the cycling of nutrients and the acidity of land or water ecosystems. In addition, fine particulates are a major cause of haze and poor visibility in a number of areas, including many national parks (EPA 2001a, 41).

Formation of Criteria Pollutants

Air pollutants either are directly emitted from sources ("primary" pollutants) or are formed in the atmosphere through physical and chemical processes ("secondary" pollutants), resulting in ambient concentrations that can adversely affect the health of exposed populations. Of the six criteria pollutants, CO, SO_2, and lead are primary pollutants; NO_2 has both primary and secondary origins; and ozone is a secondary pollutant formed by the action of sunlight and chemical reactions involving volatile organic compounds (VOCs) and oxides of nitrogen (NO_x)[6] (NRC 2000, 16–17). Airborne PM is a combination of primary and secondary pollutants (NRC 2000, 17). Carbonaceous particles from combustion sources (i.e., motor vehicles; utilities; industrial, commercial, and institutional boilers; and area source combustion) and windblown dust account for most of the primary PM. Ammonium sulfate and ammonium nitrate from the oxidation of SO_2 and NO_x, respectively, are important components of secondary particles, though a significant fraction of organic carbon PM can also result from the chemical reactions of VOCs. Other important constituents of airborne PM include heavy metals and polycyclic aromatic hydrocarbons (PAH).

The distinction between primary and secondary pollutants is important in designing appropriate pollution control strategies. For

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[6] NO_x emissions from motor vehicles, the primary focus of this report, consist of a mixture of NO and NO_2 (TRB 1995, 44).

example, emissions of transportation-related PM, CO, and NO_2—primary pollutants—tend to be concentrated on and near congested highways and at other locations where traffic densities are high. Thus targeted improvements, such as relieving traffic bottlenecks or otherwise reducing emissions (e.g., substituting cleaner-burning fuels) can reduce CO, NO_2, and PM. In contrast, ozone and secondary fine particles typically are regional problems, not amenable to geographically targeted projects. Furthermore, ambient concentrations of secondary pollutants are not always proportional to their source emissions because the rates at which they form are not necessarily proportional to quantities of precursor gases. In the case of ozone, knowing the relative concentrations of precursor VOCs and NO_x is critical to selecting appropriate abatement strategies. For example, in regions with low levels of VOCs relative to NO_x, characteristic of some highly polluted urban areas, strategies that lower VOCs will reduce peak ozone concentrations; however, lowering NO_x can lead to lower or higher ozone in the urban center, depending on the relative concentrations of VOC and NO_x, the specific mix of VOCs present, and the proximity to NO_x emissions, as well as the effects of local meteorology on transport and dispersion. These processes are complex and depend on many meteorological and chemical variables, which are described in more detail in Appendix B.

Contribution of Transportation to Pollutant Formation

The principal sources of polluting emissions are as follows:

- Transportation (on- and off-road vehicles);
- Stationary sources (e.g., fuel combustion by utilities and industrial, commercial, and residential sources);
- Industrial process sources (e.g., chemical manufacturing, petroleum refining, solvents, and waste disposal); and
- Other sources [e.g., biogenic emissions from natural and agricultural sources and from other combustion (NRC 2000, 17)].

In 1999, the most recent year for which data are available, emissions from transportation sources, also known as mobile source emissions, contributed to more than half (53 percent) of nationwide emissions of EPA's criteria pollutants (see Table 2-1). Nearly two-thirds (64 percent) of mobile source emissions are from highway (on-road) vehicles, although the range is considerable for each pollutant source (see Figure 2-1). For example, highway vehicles are the dominant source of U.S. CO emissions. In 1999 highway vehicles contributed 51 percent of total CO emissions nationwide (see Table 2-1 and Figure 2-1). In many urban areas, mobile sources account for more than 90 percent of total CO emissions, for example, as documented in the emission inventories for the San Francisco Bay Area and the South Coast Air Quality Management District (Los Angeles area). Nevertheless, in 1999 CO levels were the lowest recorded in the last 20 years; currently there are only six areas of the country with CO levels violating the NAAQS (EPA 2001a, 2). More specifically, CO emissions from highway vehicles have decreased by approximately 50 percent during the past 20 years despite nearly a 60 percent increase in vehicle-miles traveled (VMT) (EPA 2001a, 13).

TABLE 2-1 Contribution of Transportation to Emissions of Criteria Pollutants in the United States, 1999 (millions of short tons)

	Pollutant						
Source Category	**CO**	**NO_x**	**VOCs**	**PM_{10}**	**Lead**	**SO_2**	**Total**
Transportation							
Total	75.1	14.1	8.5	0.8	0.5	1.3	100.3
Highway vehicle share	49.9	8.6	5.3	0.3	0.02	0.4	64.5
Fuel combustion	5.3	10.0	0.9	1.0	0.5	16.1	33.8
Industrial processes	7.6	0.9	8.0	1.3	3.2	1.5	22.5
Miscellaneous	9.4	0.3	0.7	20.6[a]	0.0	0.01	31.0
Total	**97.4**	**25.3**	**18.1**	**23.7**	**4.2**	**18.9**	**187.6**
Share of total (percent)							
All transportation	77.0	56.0	47.0	3.0	12.0	7.0	53.0
Highway vehicles	51.0	34.0	29.0	1.3	0.5	2.1	34.0

Note: CO = carbon monoxide; VOCs = volatile organic compounds; NO_x = oxides of nitrogen; PM_{10} = particulate matter (with mean aerodynamic diameter less than 10 micrometers); SO_2 = sulfur dioxide.

[a] Includes windblown dust and natural sources (i.e., wind erosion).

Source: EPA (2001a).

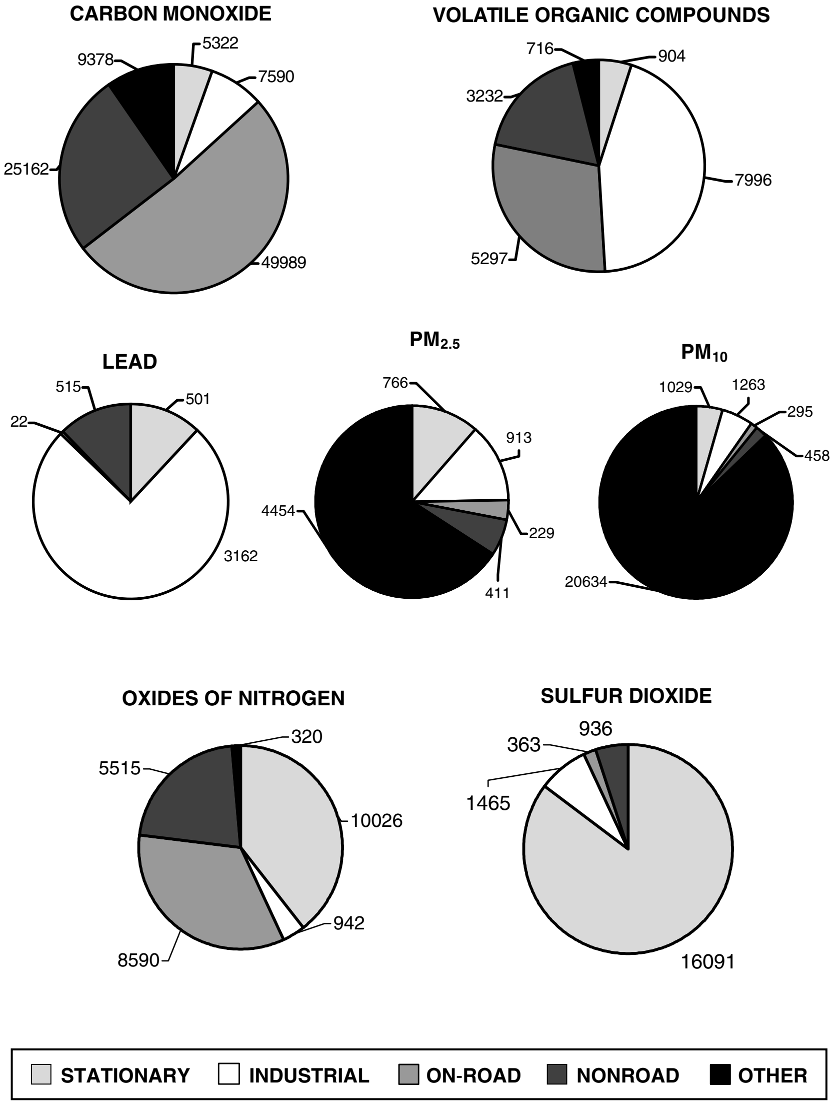

FIGURE 2-1 Sources of criteria air pollutants. Estimated total annual emissions of criteria pollutants from stationary sources, industrial processes, transportation (on-road and nonroad), and miscellaneous sources for 1999. Emissions are shown in thousands of short tons except for lead, which is shown in short tons. (Source: EPA 2001a, Appendix A.)

During the last 20 years, ozone levels (1-hour and 8-hour) have improved considerably (EPA 2001a, 29). Urban ozone levels, historically the most severe, have shown marked improvement in response to stringent control programs (EPA 2001a, 29). Mobile source emissions are a major source of VOCs and NO_x—the precursors of ozone and fine particulate matter. In 1999 highway vehicles contributed 29 percent of VOCs and 34 percent of NO_x emissions nationwide. VOC emissions from highway vehicles declined 18 percent during the past 10 years, but NO_x emissions increased by 19 percent during the same period (EPA 2001a, 37). This poor performance of NO_x emissions may reflect the lack of attention paid to the role of this important pollutant in ozone formation until relatively recently (NRC 1991).

According to the national emissions inventory for 1999, tailpipe emissions from highway vehicles represented a small share (1.3 percent and 3.4 percent) of directly emitted (i.e., primary) PM_{10} and $PM_{2.5}$, respectively, from all sources (see Figure 2-1). However, tailpipe emissions account for a substantially higher portion of PM in urban areas, where the majority of mobile source emissions occur. For example, ambient source apportionment studies show that particulate emissions in motor vehicle exhaust account for nearly 40 percent of the fine PM in Denver and Los Angeles (Watson et al. 1998; Fujita et al. 1998; Schauer et al. 1996). Including dust from paved roads and secondary ammonium nitrate from NO_x emissions, motor vehicles may contribute as much as 50 to 75 percent of the fine PM in Denver and Los Angeles. In contrast, windblown dust from unpaved roads and, to a lesser extent, agriculture and forestry, wildfires, and managed burns occurs mainly in rural areas. Coarse particles are relatively short-lived in the atmosphere, tending to be removed rapidly or deposited within a short distance from the point of their release.[7] Carbonaceous fine particles from combustion sources and secondary particles (i.e., nitrates, sulfates, and organic carbon formed in the atmosphere from the conversion of gaseous NO_x, SO_2, and VOCs), which range in size from 10 nanometers to 1 micrometer, are much longer lived and

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[7] Little is known, however, about the influence of exposure to road dust on the risks of mortality and disease.

are transported longer distances than coarse particles. Fine and ultrafine particles also occur in far greater numbers than coarse particles. The greater numbers and longer lifetimes in the atmosphere of fine and ultrafine particles, as well as their ability to be inhaled into the deep lung, result in greater human exposure and potential health impacts than is the case for coarse particles.

Transportation is a minor source of SO_2 and no longer accounts for a large share of pollution from lead. Highway vehicles currently account for less than 1 percent of total lead emissions, primarily because of the use of unleaded gasoline (see Table 2-1 and Figure 2-1). Highway vehicles contribute about 2 percent of directly emitted SO_2; coal-burning power plants are consistently the largest contributor (see Table 2-1). However, these percentages are somewhat misleading. Similar to emissions of NO_x, SO_2 emissions from motor vehicles react in the atmosphere to form sulfate aerosols and hence are an important precursor to $PM_{2.5}$ (EPA 2001a, 61).

The transportation sector also contributes to the formation of greenhouse gases. Approximately one-third of total U.S. anthropogenic emissions of CO_2 comes from the transportation sector (NRC 2000, 20).[8] About one-quarter of the total is attributable to highway vehicles (NRC 2000, 20).

Emissions from highway vehicles vary by vehicle and fuel type. The primary emissions of gasoline-powered vehicles—passenger vehicles and panel trucks—are CO, VOCs, NO_x, and SO_2, although research is under way to characterize PM emissions from high-emitting gasoline vehicles (see Figure 2-2).[9] The primary emissions of diesel vehicles—mainly heavy trucks and buses—are NO_x, CO, PM, VOCs, and SO_2 (see Figure 2-2). Emissions of NO_x and PM from heavy trucks and buses are of greatest concern. Heavy-duty vehicles are a dominant source of directly emitted fine and ultrafine particles

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[8] Note, however, that there is no air quality standard for CO_2—the principal greenhouse gas—because CO_2 is not toxic and therefore has no direct negative health effects.

[9] Estimates of PM emissions from light-duty vehicles are highly uncertain. They are generally based on EPA's PART5 model, which a recent NRC study characterized as "seriously out of date" (NRC 2000, 70).

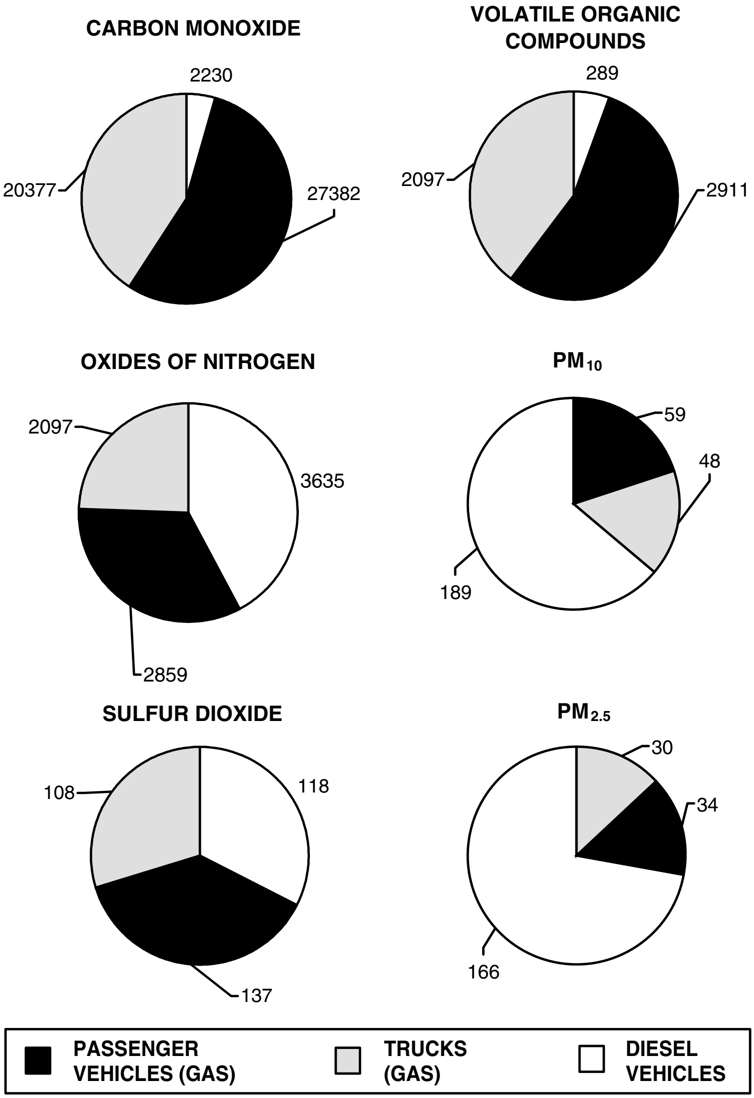

FIGURE 2-2 Estimated mobile source emissions by vehicle and fuel type. MOBILE5 and PART5 estimates of 1999 emissions from the on-road motor vehicle fleet. It is likely that MOBILE5 underestimates gasoline VOC and diesel NO_x emissions. Emissions are shown in thousands of short tons. (Source: EPA 2001a, Appendix A.)

($PM_{2.5}$), and PM from diesel exhaust was recently declared an air toxic (EPA 2001a, 79; ARB).[10] Because of the high sulfur content of diesel fuel, emissions of SO_2 from heavy-duty vehicles are also of concern; moreover, the high sulfur content defeats diesel engine control measures. As discussed subsequently, tighter exhaust emission standards for heavy-duty diesel engines and a related rule on low-sulfur diesel fuel should go a long way toward reducing these pollutant sources.

Emissions from highway vehicles in specific nonattainment areas may represent much greater pollutant contributions than the national averages. Ozone precursors are a good example. In the South Coast Air Basin, which includes some of the most polluted areas of the Los Angeles region, emissions of VOCs and NO_x from highway vehicles account for 52 percent and 72 percent, respectively, of emissions from all sources on the basis of 1997 data provided by the South Coast Air Quality Management District; the national averages at that time were 28 percent and 34 percent, respectively (EPA 2001a, Appendix A).

Costs of Motor Vehicle–Related Air Pollution

Several attempts have been made to estimate the economic cost of the health impacts of pollution. However, far fewer studies have focused specifically on the health costs of motor vehicle emissions.[11] Estimating health costs requires a complex set of steps: estimating emissions related to motor vehicle use; estimating changes in exposure to air pollution; relating these changes to changes in physical health effects; and finally relating those effects to changes in

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[10] See the California Air Resources Board website (www.arb.ca.gov) for more information on California's approach to diesel PM emissions.

[11] Small and Kazimi (1995) estimate the health costs of PM and ozone from motor vehicles for the Los Angeles area. Krupnick et al. (1996, 338) summarize the literature from the United States and Europe on the primary social costs of air pollution from transportation sources, present the results of a more complete life-cycle analysis of the air pollution–related damages from all major refinery emissions and from vehicular emissions contributing to particulate concentrations, and discuss key issues in estimating health damages. Several of these studies either appear or are discussed in Greene et al. (1997).

economic welfare, including placing a value on reduction of mortality risk and illness (McCubbin and Delucchi 1999, 254). The most recent comprehensive analysis of the costs of the health effects of criteria pollutants from all emission sources related to motor vehicle use in the United States was conducted by the Federal Highway Administration (FHWA) as an addendum to its 1997 Federal Highway Cost Allocation Study (FHWA 2000). According to that analysis, the economic cost of motor vehicle–related air pollution was estimated at approximately $40 billion (in 1990 dollars) using methods developed by EPA in a cost–benefit study (EPA 1997).[12] Cost ranges could not be developed from the EPA data, but a high and low estimate of the costs of air pollution attributable to motor vehicle use, ranging from about $30 billion to $349 billion (in 1991 dollars), was taken from a study by McCubbin and Delucchi (1998, 55) to reflect the very large uncertainties of the estimates.

The absolute levels of cost are surely open to challenge; however, what the results show about the relative importance of the various cost elements is perhaps of greater interest. Both the FHWA and McCubbin and Delucchi studies cited here show that the majority of the costs are attributable to PM, reflecting the serious health consequences related to PM inhalation. In addition, diesel vehicles are estimated to cause more damage per mile than gasoline vehicles because heavy-duty diesel vehicles account for a greater share of PM emissions (FHWA 2000; McCubbin and Delucchi 1999, 253).

Regulation of Mobile Source Emissions

Requirements of the 1990 Clean Air Act Amendments[13]

As noted earlier, in 1990 Congress enacted a series of amendments to the Clean Air Act to intensify air pollution control efforts across the nation and overhaul planning provisions in those areas that did not meet the NAAQS. The 1990 CAAA strengthened requirements

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[12] If EPA's higher mortality valuation is used, the costs increase to approximately $65 billion (in 1990 dollars) (FHWA 2000). In both cases, the costs of road dust (a major source of PM_{10}) and air toxics, mortality costs for ozone, and other environmental costs (e.g., crop damage) are excluded from the analyses.

[13] This section draws heavily on *Special Report 245* (TRB 1995, 14–17).

for reducing emissions from transportation sources. Strict monitoring and sanctions for nonperformance were designed to bring nonattainment areas into compliance. The legislation specified deadlines for reaching attainment that varied with the severity of air quality problems. Areas classified as being in marginal nonattainment had 3 years from the baseline year (1990) to reach attainment; moderate areas, 6 years; serious areas, 9 years; severe areas, 17 years; and extreme areas—only one, Los Angeles—20 years.

Required levels of effort also varied with the severity of air quality problems. Nonattainment areas with ozone classifications of moderate or worse had to submit plans showing reductions of at least 15 percent in the emissions that create ozone within 6 years from the 1990 baseline, net of any growth in emissions during that period. In addition, with the exception of moderate nonattainment areas, these areas had to achieve additional emission reductions of 3 percent per year until attainment was achieved. Nonattainment areas classified as severe or extreme had to adopt transportation control measures (TCMs) aimed at decreasing automobile travel.

Moderate or worse nonattainment areas with only CO designations were required to forecast VMT annually beginning in 1992, and if actual VMT exceeded that forecast, to be ready to adopt contingency TCMs. The latter were required for CO nonattainment areas designated as serious.

Conformity Requirements

Conformity serves as the primary tool for ensuring that transportation activities in nonattainment and maintenance areas are consistent with the achievement of air quality standards. The concept of transportation conformity, introduced in the CAAA of 1977, was made considerably more rigorous in the 1990 CAAA (FHWA 1997, 2). The latter required metropolitan planning organizations (MPOs) and the U.S. Department of Transportation (USDOT) to demonstrate that transportation plans, programs, and projects would not cause or contribute to any new violations of air quality standards, increase the frequency or severity of existing violations, or delay timely attainment of the NAAQS (FHWA 1997, 2). This requirement applied to all local transportation projects funded or approved by FHWA or the Federal Transit Administration (FTA).[14]

Conformity determinations require a set of planning activities that involve both the states and MPOs. The 1990 CAAA required each state to develop a state implementation plan (SIP) addressing each pollutant for which the state had failed to meet the NAAQS and indicating how the state intended to meet the standards on schedule (FHWA 1997, viii). The SIP assigns emission reduction targets to each source category, primarily stationary sources and mobile source emissions. The mobile source emissions budget included in an SIP represents the highest level (or ceiling) of emissions allowed from all projects included in local-area transportation plans in a state.[15]

At the local level, MPOs are responsible for demonstrating that transportation plans and programs conform to the emissions budgets in the SIP.[16] The Intermodal Surface Transportation Efficiency Act (ISTEA) of 1991 complemented the CAAA by strengthening metropolitan-area planning requirements to help make these conformity determinations. Under ISTEA, MPOs must have long-range (20-year) transportation plans in place. Shorter-term (typically 6-year) transportation improvement programs (TIPs)—prioritized multiyear lists of projects for which funds must be available or committed for the first 2 years—when analyzed, must show emissions consistent with those allowed in the SIP mobile source emissions budget for that nonattainment area (FHWA 1997, 1). Under ISTEA's metropolitan planning requirements, projects cannot be approved, funded, advanced through the planning process, or implemented unless they

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[14] Conformity analysis must also include regionally significant transportation projects—projects on a facility that serves regional transportation needs and would normally be included in the modeling of a metropolitan area's transportation network—that are not funded or approved by FHWA or FTA, but are sponsored by recipients of FHWA/FTA funds.

[15] These budgets are developed on the basis of emission inventories in the SIP, which in turn are based on the number of vehicles in a region, their age, the rate of fleet turnover to newer and cleaner vehicles, seasonal temperatures, and projections of travel activity (FHWA 1997, 3).

[16] In rural areas, conformity determinations are the responsibility of USDOT and the project sponsor, which is usually the state DOT (FHWA 1997, 2). The latter is often responsible for conformity determinations in PM nonattainment areas, which tend to be rural or small city areas.

are in a fiscally constrained and conforming transportation plan and TIP (FHWA 1997, vii). If a conformity determination cannot be made by modifying either the TIP or the SIP to offset the excess emissions, or if more than 3 years passes before a new conformity determination is made, the determination lapses, and no new projects may advance (FHWA 1997, 5).

Contribution of CMAQ to Meeting Air Quality Attainment Goals

CMAQ Projects and Air Quality Improvement

As noted earlier, the primary focus of the CMAQ program has been on ozone and its precursors—VOCs and NO_x—and CO, reflecting the pollutants of greatest concern at the time the 1990 CAAA and ISTEA were passed. Projects aimed at reducing PM_{10} emissions became explicitly eligible for funding under the reauthorization of the CMAQ program in the Transportation Equity Act for the 21st Century (TEA-21), reflecting increased concern about the adverse health effects of PM. However, PM is still not recognized directly as a factor in the CMAQ funding allocation formula (see Table 3-2 in Chapter 3).

CMAQ regulations (FHWA 1999, 10) give first priority for funding to transportation activities in approved SIPs and maintenance plans and then to the TCMs included in the CAAA, with the exception of vehicle scrappage programs. All CMAQ projects must be included in an area's TIP and meet conformity requirements.

As discussed in Chapter 1, the type of pollutant for which areas are in nonattainment may influence CMAQ project selection. Areas with CO problems may select traffic flow improvements to eliminate CO hotspots. On the other hand, areas that have an NO_x problem may not choose traffic flow improvements, at least not those that would significantly increase vehicle speeds, which would in turn increase NO_x emissions.

Of course, CMAQ is not the only revenue source for dealing with local transportation strategies to improve air quality. For example, Maryland chooses to use state funds to pay for regional TCMs needed to help the Washington metropolitan area stay within its SIP budgets. Simply focusing on Maryland's CMAQ expenditures would result in underestimating that state's spending on air quality improvement projects in the Washington area.

Benefits of Air Quality Improvement Projects

CMAQ program recipients must demonstrate expected emission reductions for each project funded under the program. States are required to report annually on the potential reductions of each relevant pollutant (CO, VOCs, NO_x, and PM_{10}) for inclusion in FHWA's national CMAQ database (FHWA 1999, 22). No attempt is made to take the next step to determine how these projects actually affect pollutant concentrations or public health.

Estimating the emission benefits of TCMs and other CMAQ-eligible projects requires the use of models or model inputs whose results are highly uncertain. Pollutant emissions from highway vehicles are currently estimated using a mobile source emission factor model, such as the MOBILE and PART5 models developed by EPA and the motor vehicle emission inventory (MVEI) suite of models developed by the California Air Resources Board. A recent NRC (2000) report provides a comprehensive evaluation of the MOBILE model, reviewing the accuracy and uncertainties of modeled emission estimates, as well as other modeling techniques. The MOBILE and MVEI models are intended for use in deriving emission inventories for entire regions.[17] They are not well suited to evaluating smaller-scale operational improvements, such as many typical CMAQ projects.

THE CMAQ PROGRAM AND CONGESTION MITIGATION

Defining Congestion

Economists observe that when a scarce and valued good is free or underpriced, demand will outstrip supply, creating shortages (TRB 1994, 27). This phenomenon is readily seen in the nation's metropolitan areas each day as motorists attempt to commute to work at desired peak travel times, creating levels of demand that exceed road capacity (i.e., congested conditions). In the absence of pricing or

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[17] These models provide emission factors separately for classes of vehicles and technology classes. To estimate total on-road emissions in a given area, either the vehicle class emission factor is multiplied by estimates of vehicle travel distances by vehicle class for the area and summed, or the fleet-average emission factor is multiplied by total travel distance for the area. In addition to vehicle class and travel distances, model inputs (some required and some optional) include ambient temperature, average vehicle speed by vehicle class, fuel characteristics, vehicle inspection and maintenance parameters, and vehicle age distributions.

rationing, the primary incentive for individual motorists to travel is guided by the costs each experiences directly, known as private costs—vehicle operating expenses and the value of that driver's travel time. The travel decision, however, is not affected by the delay costs imposed on others (known as social costs) as a result of the decisions of individual motorists to travel at a particular time, although individual drivers are affected by the total delay they encounter. The increment of delay added by any one motorist may be small. When increments are accumulated over all the motorists that follow, however, the delay can be substantial (TRB 1994, 28–29). For example, if traffic density is already near the facility capacity, delays will mount rapidly and service will decline markedly, resulting in the stop-and-start conditions so common during peak travel periods (TRB 1994, 28). Of course, if delays become bad enough, some motorists will change their behavior even in the absence of pricing, by either changing the times of their trips or canceling their trips. However, these shifts are rarely adequate to reduce congestion appreciably without additional incentives (TRB 1994, 28).

The socially optimal level of travel on a highway facility at peak travel times occurs when the marginal benefits of additional trips just equal the total costs they impose on all motorists (TRB 1994, 29). From an efficiency perspective, some amount of congestion is desirable, even at socially optimal traffic levels. The reason is that some motorists knowingly choose to travel even at congested times. Thus, they are willing to pay a portion of the social costs of the trip because the expected trip benefits exceed the private costs for these travelers.

A key attribute of congested travel is delay, which is often characterized as either recurring or nonrecurring. Recurring delay refers to the reduced driving speeds and resulting delays that typically occur each day during peak travel times. The delays are attributable to high volumes of traffic relative to roadway capacity. Nonrecurring delay occurs because of incidents—crashes, breakdowns, or other occurrences—that temporarily reduce highway capacity. A recent study of congestion on freeways and principal arterial streets in 68 urban areas revealed that, on average, incident delays accounted for more than half (54 percent) of total delays in these areas (Schrank and

Lomax 2001, 8).[18] The distinction between recurring and nonrecurring congestion is important because different strategies are often deployed to address the two.

Costs of Congestion

The two primary costs of congestion are vehicle operating costs and the value of travel time. Valuing vehicle operating costs—primarily fuel costs—is relatively straightforward. Valuing travel time is more complex, and a large literature exists on the topic.[19] Evidence suggests that different population subgroups value time differently (Small 1999, 148). As previously noted, some drivers are more willing than others to drive in congested conditions. Another complication arises from the fact that not all trips are valued equally. For example, the time spent commuting to work typically is valued at a higher rate than that spent on discretionary trips.[20] The value of time also depends on trip characteristics, including length and total amount of time spent traveling (Small 1999, 149). For example, there is some evidence that people value travel time savings more on medium-length trips than on short or long trips (Small 1999, 148). In addition to estimating the costs of congestion to commuters, a full accounting requires consideration of the costs imposed on businesses and consumers by delays in freight movement.

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[18] This estimate was developed separately for freeway and arterial travel. The freeway figure is based on a detailed methodology developed by FHWA and updated for the Schrank and Lomax report to estimate the ratio of recurring to incident delay on freeways. The resulting 1.4 ratio was multiplied by the amount of recurring freeway delay in each urban area. Incident delay on arterial streets was estimated as a constant 1.1 ratio of recurring delay on these roads. Crash rates are higher on arterials, and recurring delay is lower (Schrank and Lomax 2001, Appendix B).

[19] A good review of the literature is given by Small et al. (1999).

[20] One review of studies revealed that the value of time for the journey to work averages about 50 percent of the before-tax wage rate; the range across different industrialized cities is from 20 to 100 percent (Small 1999, 147). Using a stated-preference survey approach, Calfee and Winston (1998) found a relatively low value (19 percent of the before-tax wage rate on average) for commuter willingness to pay for reductions in travel time under a range of different travel scenarios. Their explanation for this finding is that some of those with high values of travel time had opted for residential and workplace locations with short commutes or low levels of congestion, and thus were not represented in the sample.

In an annual study by the Texas Transportation Institute (TTI), the costs of congestion are estimated for a sample of 68 urban areas, classified from small to very large in terms of their population size.[21] Estimates include the costs of fuel and time wasted. It is estimated that in the sample of 68 urban areas, congestion resulted in 4.5 billion hours of delay and 6.8 billion gallons of wasted fuel in 1999, for a total cost of $78 billion (Schrank and Lomax 2001, 42–44).[22] Delay represents by far the largest cost component, estimated at $69.2 billion in 1999. The TTI methodology has been criticized for overestimating congestion levels and costs by assuming an arbitrary cut-off point at which congestion begins.[23] Nonetheless, the study does provide an order-of-magnitude estimate of the social costs of congestion.

Measurement of Congestion and Trend Analysis

Measurement of congestion has been a topic of interest to the transportation profession since the 1950s (Meyer 1994, 33). In more recent years, alternative approaches have been advanced to address the questions of whether and to what extent highway congestion is worsening. The majority of attention has been focused on urban highways, where population size and density create the conditions most conducive to high levels of congestion.

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[21] Data are provided for urbanized areas; only developed land with a density of greater than 1,000 persons per square mile is included in the boundary. Population sizes range from more than 3 million to less than 500,000. Data on urban-area travel volumes are taken from FHWA's Highway Performance Monitoring System database, and supplemented by supporting information from various state and local agencies (Schrank and Lomax 2001, 4).

[22] As shown in Appendix B (Schrank and Lomax 2001), delay costs are determined by applying a dollar value to the hours of delay in recurring and nonrecurring congestion for both passenger and commercial vehicles. Passenger vehicle occupant time is valued at $12.40 per person-hour with vehicle occupancy rates of 1.25 persons per vehicle. Commercial vehicle operating cost is valued at $2.85 per mile. Fuel costs are determined by applying statewide average fuel costs to vehicle-hours of recurring and nonrecurring delay at average peak-period congested speeds and associated average fuel economy, and multiplying the product by 250 working days.

[23] The TTI approach assumes arbitrarily that congestion exists when average daily traffic per lane exceeds 15,000 vehicles on freeways and expressways and 5,500 vehicles on principal arterial streets. The percentage of daily travel in uncongested conditions varies by urban area, but the length of the peak travel period is held constant at 50 percent of the average daily VMT for all urban areas (Schrank and Lomax 2001, Appendix B).

TABLE 2-2 Growth in Urban Miles, Lane Miles, and Vehicle-Miles Traveled

				Percent Change		
	1980	1990	1999	1980–1990	1990–1999	1980–1999
Urban miles	624,000	744,644	846,059	19.3	13.6	35.6
Urban lane miles	1,395,245	1,670,496	1,911,303	19.7	14.4	36.9
Urban vehicle-miles traveled (in millions)	855,265	1,275,484	1,598,065	49.1	25.3	86.9

Note: An urban highway is defined as any road or street within the boundaries of an urban area, including or adjacent to a municipality or urban place, with a population of 5,000 or more (BTS 2001).

Source: BTS 2001, 7–8, 47.

A gross measure of congestion can be obtained by examining the gap between travel demand and highway capacity over time. For example, annual data collected by FHWA and reported by the Bureau of Transportation Statistics on urban road mileage and travel show that capacity increases have not kept pace with the growth in travel (see Table 2-2). Between 1980 and 1999, the most recent year for which data are available, VMT in urban areas grew nearly 2.5 times faster than additions to urban supply, measured either as highway miles or lane miles. The gap between highway demand and supply narrowed during the 1990s, mainly because of a slowing in the rate of growth of VMT. However, the shortfall may be larger because the data cannot distinguish between real additions to highway capacity and additions that result from reclassification of rural road and lane mileage to an urban designation.

Attempts to measure urban highway congestion directly have proven difficult. Very limited data are available nationally on levels of delay.[24] One of the best-known measures was developed by TTI in the study just cited, but not all researchers agree that the index is valid, for the reasons previously discussed. Yet while these critiques

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[24] For example, FHWA has developed a measure of congestion on urban Interstate highways on the basis of traffic volume information and roadway capacity for sampled sections of highway. Unfortunately, numerous changes in the calculation of highway capacity preclude meaningful trend analysis.

may call into question the validity of the TTI measures of absolute congestion levels and costs, the approach offers a consistent way of examining relative changes in congestion levels over time.

The most recent TTI report (Schrank and Lomax 2001) provides two indicators of congestion derived from estimates of travel delay due to the extra time spent in congested traffic.[25] Both indicators compare travel times in peak periods with those in free-flow conditions; one index is based solely on recurring delay, and the other includes both recurring and nonrecurring delay.[26] Many urban areas exhibit substantial levels of congestion as measured by one or both indicators.

The trend data show that between 1982 and 1999, 47 of the 68 urban areas studied suffered a growing time penalty from traffic volume increases and incidents. The relevant congestion index increased by 17 points during this period, resulting in a 3.5-minute or greater increase in a 20-minute commute trip during congested periods (Schrank and Lomax 2001, 14). Large urban areas experienced the heaviest time penalty, with up to 7 minutes being added to a congested-period trip (Schrank and Lomax 2001, 14). In another indicator of worsening congestion, the report indicates that, on average, the percentage of daily traffic in the congested periods (i.e., traffic moving at less than free-flow speeds) in all 68 urban areas grew from about 32 percent in

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[25] The methodology for estimating travel delay is explained in detail in Appendix B of Schrank and Lomax (2001). Travel delay is measured in two steps. First, recurring delay is measured by estimating travel speeds for each freeway and arterial link on the basis of placing each link in one of five travel speed categories—uncongested or one of four congested categories ranging from moderate to extreme—and weighting the links by the amount of VMT on each link to estimate vehicle delay. The travel speed for each link represents the average speed for both roadway directions during the peak period. The latter is estimated using a roadway congestion index—a measure of daily traffic volume per lane—that helps identify the length of time for which the areawide system may experience congestion. Second, incident delay is calculated by multiplying recurring hours of delay by a ratio of recurring to incident delay, using a different ratio for freeways and arterial streets.

[26] To calculate the travel rate index (TRI), the ratio of freeway peak-period travel rates (measured in minutes per mile) to freeway free-flow travel rates, weighted by freeway peak-period VMT, is added to the same calculation applied to principal arterial streets, and the result is divided by the freeway plus arterial street peak-period VMT (Schrank and Lomax 2001, Appendix B). A TRI of 1.30, for example, indicates that the average peak-hour trip takes 30 percent longer than a trip in free-flow conditions. The travel time index involves the same comparisons as the TRI, with the addition of delay rates from incidents (Schrank and Lomax 2001, Appendix B).

1982 to 45 percent in 1999, or from 5 to about 7 hours per day (Schrank and Lomax 2001, 17). Again, very large urban areas fared worse.

Congestion measures that focus on the driver and self-reported travel surveys instead of on facility-based measures, such as highway capacity and traffic volumes, paint a somewhat more favorable picture of congestion trends. For example, data from the Nationwide Personal Transportation Survey (NPTS) indicate that average commute trips by private vehicle were 3 miles longer in 1995 than in 1983 in metropolitan statistical areas (MSAs).[27] However, average commute times were only 2.9 minutes longer in 1995 than in 1983, with average trip times being nearly 21 minutes in 1995 (see Figure 2-3). These results are not much different from the averages found in the TTI study when travel time changes between 1982 and 1999 were compared for 47 of the 68 urban areas in the TTI sample. However, the NPTS results show much smaller travel time increases for large MSAs—a 2-minute increase for MSAs with a population of more than 3 million versus a 7-minute increase for the same population size group in the TTI study. Changes in survey methodology and the problems associated with self-reported data may affect the validity of the NPTS results. However, those results may also reflect real behavioral changes in response to congestion—changes in residences, jobs, and job locations. Thus, the driver- and facility-based approaches to measuring congestion may simply measure different aspects of the congestion problem.

Congestion and Air Quality

Several of the most congested metropolitan areas are the most polluted. More specifically, of the 15 top-ranked urban areas on one or both of TTI's congestion indices, 8 are rated as being in nonattainment for ozone, while 10 are rated as being in nonattainment for at least one of the criteria pollutants (see Table 2-3). Of course, air quality is determined by more than vehicle emissions; meteorology and topography play important roles, as previously discussed. To the

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[27] Except in the New England states, where MSAs consist of towns and cities, an MSA is defined as a county or group of contiguous counties that contains at least one city of 50,000 inhabitants or more, or "twin cities" with a combined population of at least 50,000. In addition, contiguous counties are included in MSAs if, according to certain criteria, they are socially and economically integrated with the central city (Hu and Young 1999, G-9).

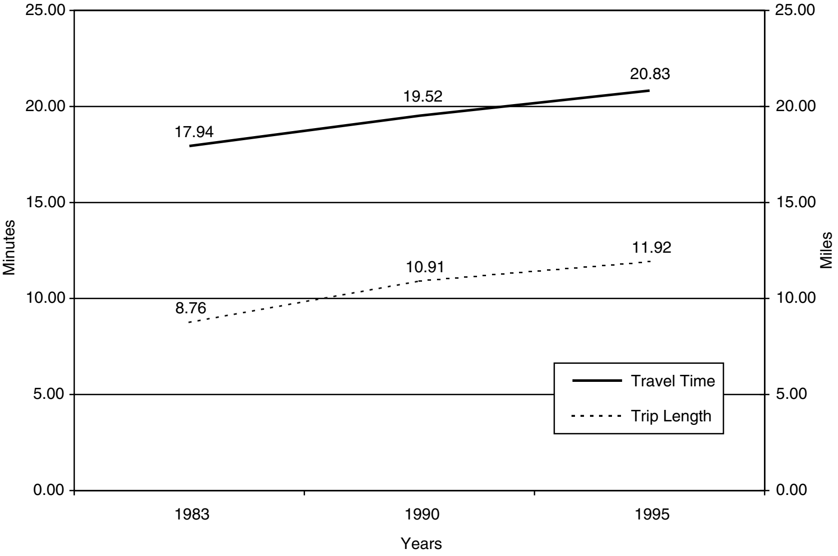

FIGURE 2-3 **Private-vehicle trip lengths and travel times in MSAs, 1983, 1990, 1995. (Data are from the 1995 NPTS.)**

extent that motor vehicle emissions contribute to poor air quality, however, congested travel plays a role.

Tailpipe emission rates and thus air quality are linked to congestion in a complex way. The distribution of vehicle speeds and accelerations[28] in traffic varies by type of road facility and amount of traffic volume to produce potentially large variations in emission levels (TRB 1995, 99). Emission levels vary in a nonlinear manner with vehicle speed and acceleration. Generally speaking, at the very low

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[28] As vehicle speeds increase, higher loads are placed on engines, increasing emissions. Sharp accelerations contribute particularly to CO and VOC emissions by causing a vehicle to operate in a fuel-rich mode. The air/fuel ratio, controlled by the fuel injection system, or by a carburetor on older vehicles, is the most important variable affecting the efficiency of catalytic converters and thus the level of tailpipe emissions (TRB 1995, 42). Sharp accelerations that command fuel enrichment have little effect on NO_x emissions, which are highest under fuel-lean conditions (TRB 1995, 42).

TABLE 2-3 Air Quality Status of Congested Urban Areas

Urban Area	Population (thousands)	Rank on TTI Congestion Rating		Air Quality Status (Areas in Nonattainment)
		TRI	TTI	
Los Angeles, CA	12,600	1	1	Extreme ozone; serious CO; serious PM_{10}
San Francisco–Oakland, CA	4,025	2	3	Ozone (unclassified)
Seattle-Everett, WA	1,995	3	2	
Washington, DC–MD–VA	3,490	4	4	Serious ozone
Chicago, IL–Northwestern IN	8,085	5	7	Severe ozone
San Diego, CA	2,700	5	9	Serious ozone
Boston, MA	3,020	7	4	
Portland–Vancouver, OR–WA	1,490	8	8	
Atlanta, GA	2,860	9	10	Serious ozone
Las Vegas, NV	1,260	9	16	Serious CO
Denver, CO	1,860	11	11	Serious CO; moderate PM_{10}
Houston, TX	3,130	12	11	Severe ozone
New York, NY–Northeastern NJ	16,430	13	16	Severe ozone; moderate CO
Miami–Hialeah, FL	2,100	13	14	
Detroit, MI	4,020	15	13	

Note: EPA classifications of nonattainment areas as of July 20, 2000. TRI = travel rate index; TTI = travel time index (see text for definitions); CO = carbon monoxide; PM_{10} = particulates between 2.5 and 10 micrometers and less than 2.5 micrometers in mean aerodynamic diameter. Population data are for urbanized areas; only developed land with a density of greater than 1,000 persons per square mile is included in the boundary.

Source: Schrank and Lomax (2001, Tables A1 and A2).

speeds characteristic of congested conditions, stop-and-start traffic, punctuated by vehicle accelerations and decelerations, contributes to high emission levels. Vehicle emissions are lowest in moderate speed ranges, at which vehicle speeds are more uniform and traffic is moving smoothly. At higher speeds, emission levels again rise, reflecting engine load from aerodynamic drag and high-speed accelerations from merging maneuvers on freeways, as well as lane-changing and passing behavior on both freeways and high-speed arterial roads (TRB 1995, 116).

These relationships are well illustrated in the most recent version of the model used by EPA to estimate vehicle emission rates—

MOBILE6. Speed correction factors (SCFs) provide a way of adjusting vehicle emissions for the effects caused by differences in engine performance and driving behavior, including average speeds, aggressive driving (i.e., with sharp accelerations), and driving on different highway facilities (Brzezinski et al. 1999, 1).[29] Results for several pollutants—hydrocarbons,[30] CO, and NO_x—are available for two major road types (freeways, and arterials and collectors); two different emission standards that are proxies for different vehicle model years;[31] and average speeds, ranging from 2.5 mph (4 km/h) to 65 mph (104 km/h) for gasoline-fueled passenger vehicles and light trucks (Brzezinski et al. 1999, 8, 20).[32]

Graphing SCFs by average vehicle speed for normal-emitting, recent-model-year vehicles illustrates the patterns discussed previously. For VOCs, CO, and NO_x, SCFs are highest at very low average vehicle speeds [i.e., below an average speed of about 15 to 20 mph (24 to 32 km/h) for freeways and of about 30 mph (48 km/h) for arterial and collector roads], indicating high vehicle emission rates (see Figures 2-4 and 2-5). For freeways, SCFs tend to flatten out between average speeds of 20 and 35 mph (32 and 56 km/h). At average speeds above 35 mph (56 km/h), SCFs for freeways start to rise again but do not regain the levels reached at average speeds

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[29] In MOBILE6, SCF is defined as the ratio of the predicted emissions at any average speed to the predicted emissions at 19.6 mph (31.4 km/h) for the same vehicle traveling either on freeways or on arterial and collector roads (Brzezinski et al. 1999, 20). To estimate emissions at a desired speed, predicted emissions at 19.6 mph are multiplied by the appropriate SCF.

[30] Results are available for total hydrocarbons and for nonmethane hydrocarbons, denoted as VOCs in this report.

[31] Results for Tier 0 emission standards, which applied to vehicle model years 1981 through 1993, include both normal- and high-emitting vehicles. Results for Tier 1 standards, which began with model year 1994 and are currently in effect, include only normal-emitting vehicles (NRC 2000, 24).

[32] There are no freeway data for speeds below 13.1 mph (21 km/h) and no arterial/collector data for speeds above 24.8 mph (39.7 km/h). Above 30 mph (48 km/h), the results for average speed and emission levels for freeways converge with those for arterial and collector roads (Brzezinski et al. 1999, 12–13). Below 7.1 mph (11.4 km/h), the effect of average speed on emissions is assumed to be the same for freeways and arterial/collector roads; between 7.1 and 13.1 mph, freeway emissions are calculated by linear interpolation (Brzezinski et al. 1999, 15). At idle, emissions are assumed to be the same as those that occur at an average speed of 2.5 mph (4 km/h) (Brzezinski et al. 1999, 2).

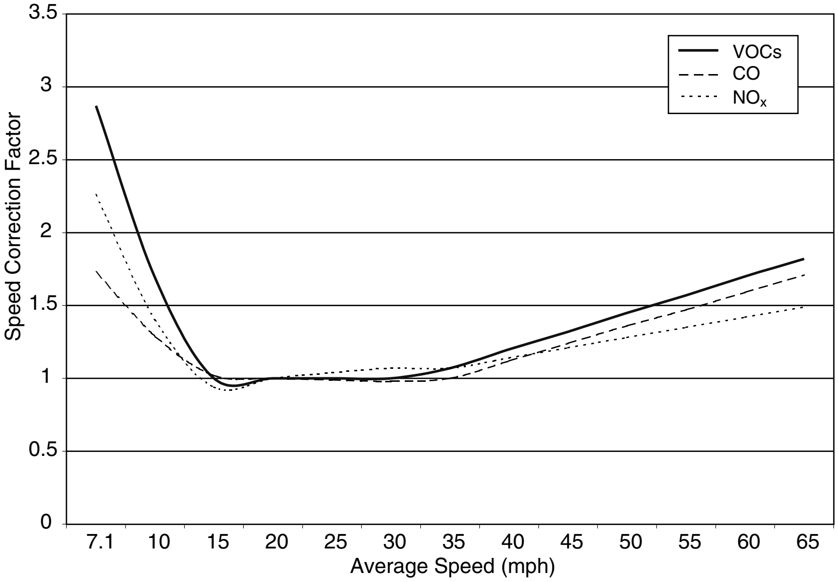

FIGURE 2-4 **Speed correction factors from MOBILE6 for freeways by average speed (mph) for Tier 1 normal-emitting gasoline-fueled passenger vehicles and light trucks. [Source: Brzezinski et al. (1999, 53).]**

below 15 to 20 mph (24 to 32 km/h). For arterial and collector roads, SCFs decline more gradually as average speeds increase, up to nearly 30 mph (48 km/h), where they flatten out briefly. There are no separate data for arterials and collectors above average speeds of 30 mph (48 km/h). Emission rates of PM_{10} as a function of average speed are not as well established as rates for the other pollutants. Industry data suggest that diesel PM exhaust emissions follow the same trend as VOCs up to average speeds of about 50 mph (80 km/h); PM_{10} emission levels at higher speeds are not well understood (TRB 1995, 92).

In summary, the relationship between congestion and vehicle emissions is complex. The amount of emissions from vehicles traveling under congested conditions depends on the distribution of

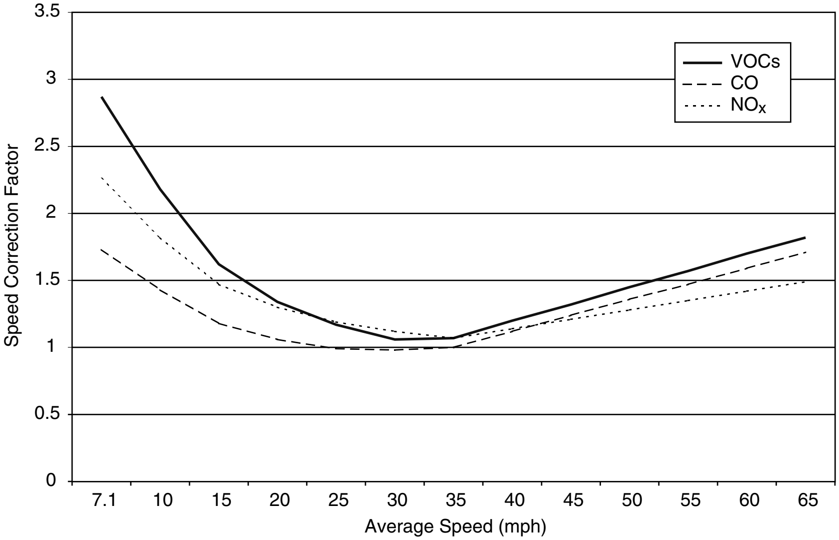

FIGURE 2-5 **Speed correction factors from MOBILE6 for arterial and collector roadways by average speed (mph) for Tier 1 normal-emitting gasoline-fueled passenger vehicles and light trucks. [Source: Brzezinski et al. (1999, 54).]**

vehicle operating speeds and accelerations, and the relations are nonlinear. For all pollutants, it appears that emission levels are highest at very low speeds, are moderate in the midspeed ranges, and rise again at high speeds. These patterns suggest that projects designed to relieve highly congested stop-and-start traffic will reduce emissions, at least in the short term. However, congestion relief projects must be selected carefully to ensure that traffic speeds do not become so high that emission levels again increase.

Contribution of CMAQ to Congestion Mitigation

CMAQ Projects and Congestion Relief

The CMAQ legislation and regulations clearly prohibit projects that expand highway capacity for single-occupant vehicle (SOV) travel (e.g., the addition of general-purpose lanes to an existing facility), even if they relieve congestion. However, as Table 2-4 shows, there are several CMAQ-eligible project categories that directly address congestion relief. Many of these projects fall under the category of traffic flow improvements and include traffic signalization projects, intersection improvements, and certain intelligent transportation systems measures (e.g., electronic toll collection systems). The primary objective of these projects from a congestion perspective is to improve traffic efficiency by alleviating recurring congestion. Other projects, such as construction of high-occupancy vehicle (HOV) lanes, carpool and vanpool programs, and demand management programs (such as employer trip reduction programs)—to the extent that they encourage higher vehicle occupancies—can also relieve recurring congestion and improve traffic flow. Traffic management centers and incident removal programs are CMAQ-eligible as well; these projects are focused primarily on nonrecurring congestion. Finally, although a

TABLE 2-4 Examples of CMAQ-Eligible Projects That Provide Congestion Relief and Their Effects

CMAQ-Eligible Project Type	Effects on Congestion	Type of Trip Affected
Traffic flow improvements	Direct	
Traffic signalization	Recurring delays	All trips
Intersection improvements	Recurring delays	All trips
ITS measures	Recurring delays	All trips
Traffic management centers	Recurring delays	All trips
HOV lanes	Recurring delays	Work trips
Shared ride	Direct	
Carpool and vanpool programs	Recurring delays	Work trips
Related parking programs	Recurring delays	Work trips
Demand management	Direct	
Trip reduction measures	Recurring delays	Work trips
Flexible work hours	Recurring delays	Work trips
Traffic flow improvements	Direct	
Traffic management centers	Nonrecurring delays	All trips
Incident management programs	Nonrecurring delays	All trips
Transit projects	Indirect, recurring delays	All trips
Bicycle and pedestrian projects	Indirect, recurring delays	All trips

Note: ITS = intelligent transportation systems; HOV = high-occupancy vehicle.

less direct approach, transit, bicycle, and pedestrian projects may also help mitigate highway congestion to the extent that they encourage trips to shift from automobiles to other modes.

Many CMAQ-eligible congestion relief strategies are focused on work trips (see Table 2-4). Work trips are a major source of traffic volume during peak hours and have a higher valuation than other trip types in terms of travel time, but work trips account for only part of total trip taking. The 1995 NPTS revealed that trips to and from work represented about one-fifth of all person-trips using weighted NPTS data (Hu and Young 1999, 17). When trips made as part of a work trip (e.g., work to supermarket) were included, the number of work trips rose to approximately 30 percent, also using the weighted NPTS data.[33] In addition, most CMAQ-eligible strategies represent an attempt to change traveler behavior through voluntary, nonmarket approaches. Price-based strategies, such as parking pricing and congestion pricing, have been found to provide stronger incentives for desired behavioral change (Apogee 1994, ii). Some market-based approaches, such as fare and fee subsidies for transit, carpools, and vanpools, are CMAQ-eligible to encourage greater use of alternative travel modes (FHWA 1999, 18). Other pricing strategies, such as congestion pricing, are not explicitly eligible; however, demand for these uses of CMAQ funds is small because such measures are frequently unpopular and have not been widely implemented.

Induced Traffic

In assessing the final outcome of projects aimed at relieving congestion, an important complication is the need to account for resulting changes in travel behavior. As travel times are improved on a facility, it is natural for travelers and potential travelers to adjust to the facility's increased attractiveness. Such adjustments are likely to include shifts in the time of day of trips and may also include changes in route or mode. For example, in a city where several major arterials and a rail line serve an employment area, relieving bottlenecks on one arterial

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[33] The data represented all trips of less than 75 miles for all purposes and all days of the week.

will probably divert some traffic from other arterials and may also cause some rail commuters to choose to drive instead. People who previously timed their trips inconveniently to avoid the worst congestion may now decide to travel closer to peak hours. And some new trips may be made just because it is more convenient to do so than before.

Over a long enough time period, changed conditions may also affect land use patterns and vehicle fleets in a way that generates new traffic. For example, building a new highway through a previously undeveloped area is well known to attract development to the area unless this is rigorously excluded by zoning. As a more subtle example, improved conditions on a commuter highway may cause some families to buy a second car for commuting purposes; doing so will probably then increase their nonwork trips, even on roads far removed from the improvement being analyzed.

Such shifts can also occur when a project attracts traffic away from a roadway by applying some incentive. For example, when a new rail line or carpool lane diverts peak-hour traffic from a particular expressway, new traffic is likely to shift to that expressway from some or all of the sources just mentioned. The same is true of telecommuting or other trip reduction policies.

Whatever the source of behavioral shifts, the story does not end with simply calculating the traffic from a first-round prediction of improved roadway conditions. The new traffic undoes some of the improvement that would otherwise take place; this in turn reduces the incentive for changing travel behavior. Only by simultaneously modeling travel behavior and congestion formation can the net result be predicted. The net change brought about by such simultaneous adjustments on the facility in question is called *induced travel, induced traffic,* or *induced demand.*[34]

It is common for evaluations conducted during project planning to account for some but not all sources of induced traffic. Conventional

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[34] Some analysts restrict the term "induced travel" to change resulting from movement along a short-run demand curve, and use the term "induced demand" to represent long-run changes resulting from a shift in that short-run demand curve (Lee et al. 2000, B-4). Although it is hazardous to use the terms "short" and "long" because the time spans for these shifts may overlap, "short-run" generally refers to changes that can be made without altering the capital stock, whereas "long-run" changes would result from alterations in the vehicle fleet or land use patterns.

traffic models usually take account of route shifts, but may or may not consider changes in modes and times of travel. Newly generated trips often are not estimated. When the models used to analyze a project incorporate induced travel, they can account for the resulting loss of first-round benefits on the facility in question, as well as any additional gains or losses of benefits on other facilities.

Understanding induced travel is necessary for complete analysis of both the air quality and congestion relief objectives of CMAQ projects. For air quality analysis, it is especially critical to distinguish between shifts that do or do not generate new motor vehicle traffic, although shifts of traffic from other locations or times of day, even if they do not change total trips, VMT, or emissions, can also affect air quality. For congestion relief analysis, it is critical to know whether induced traffic occurs as a result of diversion from other congested facilities. If traffic diversion takes place, the analysis must consider the congestion benefits on those other roads.

Because of the conceptual complexity of the simultaneous determination of travel behavior and congestion, there is considerable confusion regarding the interpretation of induced traffic. Opinions range from its having negligible importance to its completely undermining any hoped-for congestion benefits.[35] As noted below, the empirical evidence greatly narrows this range. In any case, it is useful to recognize that the existence of induced travel is simply an application of the basic economic principle of downward-sloping demand curves. When the first-round effects of any project reduce travel time on a facility, the cost of travel on that facility to users and potential users is reduced, resulting in more use.[36] What makes the situation more complicated is the simultaneous adjustment of congestion, as

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[35] It is even theoretically possible for more than 100 percent of the first-round benefits to be eliminated by induced demand if the diversion comes from a transit system subject to increasing returns to scale, as in the "Downs-Thomson paradox" described by Arnott and Small (1994).

[36] The amount of new travel demanded depends on the elasticity of demand, a measure of the responsiveness of the quantity demanded to changes in the price (i.e., the ratio of the percent change in the quantity demanded to the percent change in the price of the good) (Lee et al. 2000). If travel demand is elastic, traffic volumes will increase more than if travel demand is relatively inelastic. Each of the many mechanisms causing travel shifts may have a different demand elasticity.

described above. Only by considering at the same time both the supply and demand mechanisms can the final outcome be predicted.

A large literature has been produced by those attempting to measure the size of induced travel effects.[37] While there is ongoing debate over the details, the empirical evidence suggests that these effects are significant and need to be incorporated in any complete assessment of the results of congestion relief measures.

FUTURE PROGRAM DIRECTION

The context within which the CMAQ program operates has changed since the legislation was enacted in 1991 and is likely to continue to do so. This changing context has important implications for the future direction of the program.

Emerging Knowledge About Critical Pollutants

Knowledge about key pollutants and their health effects has changed considerably during the life of the CMAQ program. Since the program was enacted, CO has diminished in importance as a critical pollution problem in many metropolitan areas. Significant progress has also been made in the past decade toward attainment of the ozone standard, most notably in the South Coast Air Basin that includes the Los Angeles metropolitan area.[38] However, NO_x continues to be a problem for conformity determinations in the South Coast Air Basin and also in such metropolitan areas as Houston and Washington, D.C.

At the same time, as discussed earlier in this chapter, other pollutants, such as PM and air toxics, have become of increasing concern as knowledge about their adverse health effects has grown. This has

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[37] See TRB (1995, Chapter 4 and Appendix B) and Cervero and Hansen (2000) for critical reviews of the key literature. See also the February 1996 volume of *Transportation* (Coombe 1996), a special issue devoted to the topic of induced travel; Cohen (1998); Fulton et al. (2000); Barr (2000); papers from the 79th TRB Annual Meeting, including Noland and Cowart (2000) and Chu (2000); and the discussion of demand elasticities embedded in the VMT forecasts of the Highway Economic Requirements System model used by FHWA to estimate cost-beneficial highway investments (FHWA and FTA 2000, 7-12–1-13; Lee et al. 2000).

[38] EPA shows a downward trend for all the criteria pollutants in the Los Angeles–Long Beach MSA from 1990 through 1999 (EPA 2001a, 205).

certainly been the case for PM. In 1997 EPA issued new standards to regulate fine particles on the basis of epidemiological studies that found a close correlation between ambient particulate matter concentrations and increased mortality and illness from cardiac and pulmonary respiratory disease. A subsequent intensive research initiative established a more definitive causal relation between exposure levels and adverse health effects (HEI Perspective 2001).[39] Much remains to be done, however, to understand the underlying mechanisms more precisely. Current research is focused on characterizing the chemical and physical nature of fine particle emissions and their transformation in the atmosphere, and the levels and chemical composition of exposure in the general population and in specific microenvironments (HEI 1999).[40]

Work is also under way to link atmospheric concentrations of fine particles to their sources, with particular emphasis on the contribution of exhaust from diesel vehicles.[41] Although tailpipe emissions from highway vehicles represent a small share of directly emitted PM on a national basis, they account for a substantially higher proportion of longer-lived atmospheric concentrations of fine particles in urban areas, for example, up to 40 to 50 percent in the Denver and Los Angeles metropolitan areas, as previously noted. Heavy-duty diesel trucks and buses are the major source of PM emissions from highway vehicles (Figure 2-2). As the implementation schedule for the new EPA standards for $PM_{2.5}$ and the nonattainment area designa-

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[39] A newly published study (Pope et al. 2002) has established that long-term exposure to combustion-related fine particulate air pollution is an important environmental risk factor for cardiopulmonary mortality and significant increases in lung cancer mortality. The associations between fine particulate air pollution and cardiopulmonary and lung cancer mortality are observed even after controlling for cigarette smoking, body mass index values, diet, occupational exposure, and regional and spatial differences.

[40] EPA, state and local air pollution agencies, the Health Effects Institute, the U.S. Department of Energy, the Coordinating Research Council, the American Petroleum Institute, and vehicle and engine manufacturers are all currently sponsoring research in these areas.

[41] The work is being conducted at several of the EPA-funded PM Centers and EPA-funded PM Supersites. The latter are charged with characterizing PM, supporting health effects and exposure research, and using state-of-the-art testing methods to conduct and evaluate comprehensive measurements of airborne gases and particles.

tions are finalized, changes in the focus of the CMAQ program may be required to recognize this important pollutant source.

Air toxics are also regulated under the Clean Air Act, but have not been a focus of the CMAQ program. Nearly 200 pollutants have been identified as toxic air contaminants that derive from a broad range of sources.[42] In 1998 California identified particulate emissions from diesel exhaust as a toxic air contaminant and potential carcinogen. The state has launched an aggressive program to develop appropriate control strategies for both new and existing diesel-fueled engines and vehicles.[43] As the underlying science advances, the CMAQ program could also direct more attention to heavy-truck, bus, and freight projects focused on reducing diesel exhaust. In sum, to ensure that the CMAQ program remains effective and relevant in mitigating the future air quality impacts of transportation sources, adaptations to accommodate changing ambient air pollutant trends and the priorities that emerge from new research findings and the next generation of human exposure assessments must be considered.

Future Trends in Mobile Source Pollution

The primary factors that will affect future levels of highway vehicle emissions include the introduction of new emission control technologies in response to more stringent new-vehicle emission standards, use of cleaner-burning fuels, fleet turnover, and growth in VMT. The first three factors will tend to decrease the future benefits of many CMAQ-eligible TCMs, while growth in VMT will tend to increase future benefits. For example, once the latest round of light-duty vehicle emission standards (Tier 2) have been fully implemented in 2009, exhaust emission standards for CO, VOCs, and NO_x will be

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[42] Primary emissions from motor vehicles and other combustion sources are highly complex mixtures containing many hundreds of organic and inorganic constituents of gaseous and solid material. Hazardous air pollutants in gaseous state include benzene, 1,3-butadiene, and formaldehyde; volatile and semivolatile organic compounds that are precursors to ozone; organic aerosols; and other hazardous secondary air pollutants, such as formaldehyde, acetaldehyde, and nitrated polycyclic aromatic hydrocarbons. Many organic compounds are emitted at elevated temperatures, forming ultrafine and nuclei-range particles.

[43] See the California Air Resources website (http://www.arb.ca.gov) for more information on California's Diesel Risk Reduction Program.

TABLE 2-5 Federal Exhaust Emission Standards for Light-Duty Vehicles

Model Year	Durability Requirement (miles)	CO (g/mi)	Total Hydrocarbons (g/mi)	NO_x (g/mi)
Precontrol[a]		84	10.6	4.1
1970–1971[a]	50,000	34 (59)	4.1 (61)	—
1972	50,000	39 (53)	3.4 (68)	—
1973	50,000	39 (53)	3.4 (68)	3.0 (27)
1975–1976	50,000	15 (82)	1.5 (86)	3.1 (24)
1977–1979	50,000	15 (82)	1.5 (86)	2.0 (51)
1980	50,000	7.0 (92)	0.41 (96)	2.0 (51)
1981–1993 Tier 0	50,000	3.4 (96)	0.41 (96)	1.0 (76)
1994–2003 Tier 1	50,000	3.4 (96)	0.41 (96) (0.25)[b] (98)	0.4 (90)
	100,000	4.2 (95)	0.31[b] (97)	0.6 (85)
2004–2009 Tier 2	100,000	4.2 (95)	0.09[b] (99)	0.07 (98)

Note: Percentage decreases from precontrol levels are in parentheses.

[a] Standards are adjusted to current test procedures.

[b] Emission standards were originally written for total hydrocarbons and later for nonmethane hydrocarbons or VOCs as denoted by this footnote.

Source: Adapted from NRC (2001b, 27).

95, 99, and 98 percent lower, respectively, than precontrol emission rates (see Table 2-5).[44] The introduction of on-board diagnostic (OBD) technologies as a new approach to vehicle inspection and maintenance (I&M) represents a technological innovation for monitoring the performance of vehicle emission control equipment (NRC 2001b, 12).[45] All light-duty vehicles built after 1996 are equipped with the OBDII system, and states are required by EPA to start phasing in OBD checks starting in 2002 (NRC 2001b, 97). OBDII has the potential to ensure that vehicles will continue to operate cleanly as

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[44] Current (Tier 1) vehicle exhaust emission standards are already 95, 97, and 85 percent lower, respectively, than precontrol emission rates (see Table 2-5).

[45] Current OBD technology provides rapid verification of the operation of both exhaust and evaporative emission control components but does not measure emissions directly. It alerts motorists to potential problems by illuminating a malfunction indicator light and provides mechanics with diagnostic information about the source of the malfunction (NRC 2001b, 12).

they age, and may encourage manufacturers to produce more durable emission control systems. Current experience is too limited, however, to know how OBD will function over the lifetime of a vehicle; perhaps more important, how drivers will heed the malfunction warnings, particularly when vehicles are no longer under warranty; and how effective OBD checks will be, especially as a substitute for more traditional I&M tailpipe testing (NRC 2001b, 12).

As noted earlier, in the coming decades, as cleaner vehicles become a larger share of the fleet and as OBD systems help reduce in-use emissions, the pollution reduction benefits of many TCMs will be lower than those derived during the past decade. For example, traffic flow improvements that are beneficial in reducing high levels of CO and VOCs in congested traffic may have less value. That having been said, the relatively slow turnover of the vehicle fleet—the average age of passenger vehicles in 1999 was 8.9 years—and the unknowns regarding the performance of OBD systems mean it will take some time before fleetwide emission levels are affected (Wards Communications 2000, 44).

During the next two decades, high emissions from gasoline-fueled vehicles will come primarily from two sources: (*a*) heavy engine loads resulting from certain types of driving and (*b*) high-emitting vehicles. Regarding the first of these, results from dynamic testing of exhaust emissions from properly functioning vehicles show that modern, low-mileage vehicles have low CO, VOC, and PM emission rates during the second phase of the test, which represents relatively nonaggressive driving and fully warmed-up vehicles.[46] Emission rates are substantially higher for properly functioning vehicles starting cold[47] and during intermittent high-engine-load conditions induced by hard

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[46] Running exhaust emissions from the second test phase include emissions from the tailpipe or through the crankcase after the vehicle is warmed up and in a stabilized mode. Exhaust emission rates are determined from dynamometer tests using the Federal Test Procedures (FTP). The FTP tests are used to certify new vehicles and to check compliance over time.

[47] Cold-start exhaust emissions occur from the time the engine starts, after being off for 1 or more hours for a catalyst-equipped vehicle and 4 or more hours for a non-catalyst-equipped vehicle, until the coolant achieves its nominal operating temperature. Cold-start emissions are incremental emissions that are added to running exhaust emissions.

accelerations and grades. One sharp acceleration may cause as much pollution as the entire remaining trip (Carlock 1993). High-emitting vehicles are the other major contributors to on-road vehicle emissions. The distributions of emission rates among in-use vehicles are highly skewed, such that a relatively small fraction of high emitters accounts for a disproportionate fraction of total emissions (NRC 2000, 77). This fraction is likely to increase during the next two decades as the Tier 2 emission standards are implemented and absorbed into the vehicle population. TCMs that are focused on these two pollutant sources (e.g., strategies to reduce vehicle cold starts, remote sensing to detect high-emitting vehicles) are likely to have big payoffs.[48]

Emission standards for heavy-duty diesel engines will also be tightened. Beginning with the 2004 model year, all heavy-duty vehicles will be required to meet an NO_x level approximately 80 percent below the initial standard established in 1985 (see Table 2-6).[49] PM emission standards will also be significantly tightened starting in model year 2007 (see Table 2-6). A related rule, reducing sulfur in diesel fuel and thereby enabling new diesel engines to run cleaner, is slated to take effect in 2006. As previously discussed, however, much remains to be done to reduce diesel emissions, especially particulates, and this could well become a more important focus area of the CMAQ program.

The impact of cleaner vehicles, however, both diesel- and gasoline-powered, may be retarded by growth in VMT. In the past, travel growth appears to have offset some of the projected gains from stricter vehicle emission standards (TRB 1995, 16).[50] The question thus arises of whether metropolitan travel growth and related

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[48] Remote sensing refers to a method for measuring pollution levels in a vehicle's exhaust while the vehicle is in use. If OBD systems are effective, they could also prevent vehicles from becoming high emitters.

[49] The 2004 standard will be implemented in October 2002 for engine manufacturers, subject to a settlement agreement with EPA concerning the use of devices to defeat emission testing on earlier vehicles (Schimek 2001, 436).

[50] For example, when the 1990 CAAA was passed, EPA estimated that gains in tailpipe emissions could be offset by 2002 for CO and VOCs and by 2004 for NO_x. Thus, the act mandated measures designed to limit automobile trips in the most severely polluted areas and required strict monitoring of VMT growth in less severe nonattainment areas.

TABLE 2-6 Federal Exhaust Emission Standards for Heavy-Duty Diesel Engines

Model Year	NO_x	PM, Heavy Duty	PM, Urban Bus
1985	10.7	NA	NA
1988	10.7	0.60	0.60
1990	6.0 (44)	0.60	0.60
1991	5.0 (53)	0.25 (58)	0.25 (58)
1993	5.0 (53)	0.25 (58)	0.10 (83)
1994	5.0 (53)	0.10 (83)	0.07 (88)
1996	5.0 (53)	0.10 (83)	0.05 (92)
1998	4.0 (63)	0.10 (83)	0.05 (92)
2004 (2002)	2.0 (81)	0.10 (83)	0.05 (92)
2007–2010	0.2 (98)	0.01 (98)	0.01 (98)

Note: Standards are in grams per brake-horsepower hour; NA = not applicable. Percentage decreases from precontrol levels are in parentheses.

Source: Adapted from Schimek (2001, 437).

congestion are likely to worsen in the future. Arguing for a slowing in the rate of VMT growth are findings that travel effects due to the entrance of women into the workforce have largely been absorbed, that the ratio of vehicles to licensed drivers is 1 to 1 (Hu and Young 1999, 9), and that a growing proportion of the population of older motorists drive less.[51] FHWA, for example, forecasts an average annual urban VMT growth rate of 2 percent for 1998 through 2017, a sharp decline from the 3.2 percent average annual rate of growth in urban travel between 1987 and 1997 (FHWA and FTA 2000, 2-10, 9-3). More flexible work policies and electronic advances that enable working at home or from a nearby telecommuting center may also limit work trips and peak-period travel, although there is some evidence that telecommuting can result in an increase in non-commute-related personal vehicle trips (Koenig et al. 1996). More essential, telecommuting may change the time of day and location of travel, with important

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[51] However, there is evidence that older drivers are driving more than in the past. For example, in 1995 older drivers took more trips and drove more than their corresponding cohorts in 1990 (Hu and Young 1999, 49).

effects on emissions.[52] The results of the NPTS, which show relatively constant average commuter trip times over a period of several years, suggest that in the longer run, households respond to increasing VMT and higher levels of congestion by moving farther away from metropolitan centers. As jobs follow people, commute times are kept relatively constant (TRB 1994, 114–115).

On the other hand, arguing for continuing growth in congestion for many metropolitan areas are projected increases in population and income—major determinants of travel in a region (Hansen et al. 1993, 6–29). Thus a definitive judgment about growth in VMT and congestion is simply not possible on the basis of the available data (Meyer 1994, 58). Both are likely to persist in many metropolitan areas, but some regions may see a slowing in the rate of travel growth, which in turn would decrease the benefits of traffic-related CMAQ strategies.

Advances in Analytic Methods for Estimating Strategy Effects

Estimating the pollution reduction potential of many CMAQ-eligible strategies may become easier in the future as new measurement tools become available and more appropriate models are developed. For example, although it may never be possible to measure changes in concentrations of important regional pollutants, such as ozone and PM, due to a particular project, methods for measuring changes in vehicle emissions at the tailpipe and human exposure levels are being developed. Remote sensing of vehicle exhaust emissions is already possible, as are remote readings of exhaust measurements (NRC 2001b, 103).[53] A new generation of real-time instruments and sophisticated experimental designs has also been developed for characterization of human exposure to $PM_{2.5}$ and gaseous pollutants in many micro environments, including a wide range of in-vehicle and

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[52] For example, travel at midday or in the afternoon under noncongested conditions and in locations removed from a central city may be less polluting than travel in the morning peak-period commute.

[53] CO emissions can be measured reliably using remote sensing techniques. Less-certain results are available for VOCs and NO_x, and measurement of PM is an important research priority. Attention to quality assurance and quality control is essential (NRC 2001b, 116–117).

indoor atmospheres affected by the penetration of vehicle-related emissions (Monn 2001).[54]

New models are also under development that will be more appropriate for estimating the emission effects of many small-scale CMAQ projects. Future generations of mobile emission models will predict emissions as a function of vehicle operation, such as idle, steady-state cruise, and various levels of acceleration and deceleration. Two modal modeling approaches currently under development are the Comprehensive Modal Emissions Model (CMEM) (Barth et al. 2000) and the Mobile Emissions Assessment System for Urban and Regional Evaluation (MEASURE) (Guensler et al. 1998).[55] USDOT, EPA, and the Department of Energy are sponsoring the development of a suite of integrated analytical and simulation models and supporting databases for transportation and air quality analysis (TMIP 1999). Known as the TRansportation ANnalysis and SIMulation System (TRANSIMS), the modeling system pairs data from a second-by-second traffic simulation model with a modal emission model (CMEM) to derive microscale-level emission estimates from changes in traffic signalization and other traffic operational changes; inputs are also provided for air quality modeling at appropriate temporal and geographic scales. The application of these new models should provide for more accurate microscale assessments of the travel-related effects (e.g., changes in traffic flows, speeds), emission effects, and possibly even air quality impacts of many CMAQ projects.

CONCLUSIONS AND IMPLICATIONS FOR PROGRAM EVALUATION

Transportation is one of the many sources of poor air quality in the United States. The primary goal of the CMAQ program is to reduce pollution from motor vehicles. Program funds are targeted to areas with the worst air quality (nonattainment and maintenance areas).

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[54] Other references on exposure assessment of air pollutants include Rodes et al. (1998), Long et al. (2000), Moosmuller et al. (2001), and Janssen et al. (1998).

[55] The modal model under development at the University of California, Riverside, by Barth et al. is based on 300 vehicles tested under a variety of laboratory driving cycles. The modal approach under development at the Georgia Institute of Technology is a modal emissions model based on geographic information systems, using statistical analysis of historical laboratory and instrumented vehicle data.

Ozone and its precursors and CO are the primary pollutants of concern, reflecting the critical pollution problems at the time the 1990 CAAA and the 1991 ISTEA were passed. Projects aimed at reducing PM_{10} emissions became explicitly eligible for CMAQ funding when TEA-21 reauthorized the program, but particulates are not reflected in the funding formula.

A region's particular air quality problems and conformity requirements can influence how program funds are deployed. For example, nonattainment areas with significant air quality problems often look to CMAQ to help fund TCMs or other eligible projects for which credit can be taken toward meeting rate-of-progress requirements or SIP commitments. The type of local air quality problem may affect project choices as well. For example, areas having NO_x problems may not undertake certain traffic flow improvements that would significantly increase vehicle speeds, even if such projects are CMAQ eligible, because those improvements can exacerbate ozone formation.

CMAQ program regulations require that states report annually, by the relevant affected pollutants, on the potential emission reductions of funded projects. No attempt is made to determine how these projects might affect pollutant concentrations, human exposure levels, or public health. Estimating emission reductions with any degree of certainty is often difficult because the available emissions models for making such projections, or their inputs, are not well suited to the purpose. The models were developed to assess regional emission effects, not to evaluate TCMs, whose impacts are modest and often focused on particular transportation corridors or subregions.

Congestion is a major problem in many large metropolitan areas. Congestion mitigation is another important goal of the CMAQ program; however, the legislation authorizing the CMAQ program prohibits spending on certain traditional congestion relief projects. For example, projects to provide new capacity for SOV travel, such as the addition of general-purpose lanes to an existing facility or a new highway at a new location, are ineligible even if those projects could help alleviate congestion. The reason for this is that such projects are viewed as not supporting the CMAQ program's primary goal of reducing motor vehicle emissions because they encourage vehicular travel. Nor is it likely that many of these projects would meet conformity requirements, another program requisite. Nevertheless, CMAQ funds can be used to support a wide range of other congestion relief strategies.

The context within which the program operates has changed since the program's inception and will continue to do so. For example, as vehicles become cleaner, some TCMs may become less effective, while other strategies (e.g., vehicle scrappage programs) that target remaining air pollution sources (e.g., high-emitting vehicles) will become more valuable. Moreover, emerging knowledge about the health effects of various pollutants may require some redirection of CMAQ funds when the program is reauthorized. For example, as knowledge about the adverse health effects of particulates and air toxics has grown, projects that address the key transportation-related sources of these pollutants (e.g., heavy trucks and buses) may warrant greater attention. Fortunately, advances in measurement tools and models should make it easier to assess the pollution reduction potential of many CMAQ strategies and may even enable the analysis to be extended to an assessment of project effects on human exposure levels.

This chapter has provided information about the air quality and congestion context within which the CMAQ program operates to help the reader understand how the program has developed, provide perspective on the problems it attempts to address, and highlight some of the key changes that may affect its future direction. In the following chapter, an overview of program operations and spending trends to date is provided.

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Abbreviations

ALA	American Lung Association
BTS	Bureau of Transportation Statistics
EPA	U.S. Environmental Protection Agency
FHWA	Federal Highway Administration
FTA	Federal Transit Administration
HEI	Health Effects Institute
NCHRP	National Cooperative Highway Research Program
NRC	National Research Council

TMIP	Travel Model Improvement Program
TRB	Transportation Research Board

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3

OVERVIEW OF CMAQ PROGRAM OPERATIONS

In this chapter, an overview of the CMAQ program since its inception is provided. A description of how program funds are allocated and for what activities is first presented. An analysis of program spending trends is then provided, focusing on the types of projects funded to date and differences in project spending priorities by geographic area. Drawing from the case studies conducted by the committee (see Chapter 1), a discussion of how the program operates in five large metropolitan areas is then presented. The chapter ends with a brief summary and findings.

PROGRAM OPERATION

Funding Allocation

The CMAQ program is funded by the Highway Trust Fund, which finances federal highway and mass transportation assistance programs. As noted in Chapter 1, under the Intermodal Surface Transportation Efficiency Act (ISTEA), the 6-year, $6 billion CMAQ program represented slightly less than 4 percent of the $155 billion authorized for highways, highway safety, and mass transportation. Although CMAQ funding was increased to $8 billion during the 6-year life of the Transportation Equity Act for the 21st Century (TEA-21), total transportation authorizations also increased, so that the share represented by the CMAQ program stayed the same. CMAQ is one of the smaller federal-aid transportation programs. For example, the Surface Transportation Program (STP), which provides flexible funding for transit as well as highway projects, was authorized at $33.3 billion during the life of TEA-21 (DOT 1998). And the National Highway System program, which funds projects involving highways of national significance connecting major population centers, was funded at $28.6 billion during the same period.

The CMAQ program is also modest when viewed from a regional perspective. For example, the Los Angeles region has some of the nation's poorest air quality and thus qualifies for and receives the maximum apportionment of CMAQ funds.[1] However, these grants represent on the order of 4 to 5 percent of annual federal funds and only 2 to 3 percent of total annual revenues coming to the Los Angeles region. Moreover, in many regions, CMAQ funds are widely disbursed over a diverse program of eligible activities.

The CMAQ program may be modest relative to other federal-aid transportation programs and to any given region's transportation budget, but the funds are targeted to where the problems are—to those nonattainment and maintenance areas in states with the most severe ozone and carbon monoxide (CO) air quality problems.[2] For example, between 1992 and 1999, the most recent year for which national data are available, six states—California, New York, Texas, New Jersey, Pennsylvania, and Illinois—received more than half of all CMAQ apportionments (see Table 3-1). California alone received about 65 percent more than the next-largest state apportionment—to New York—reflecting the severity of its air quality problems. Fourteen states accounted for about three-quarters of CMAQ obligations for the 8-year period (see Table 3-1).[3]

Program funds are apportioned by statute to the states each year on the basis of the severity of air quality problems and the size of

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[1] The California Department of Transportation (Caltrans) suballocates CMAQ funds to nonattainment and maintenance areas in the state using the same formula by which national-level CMAQ funds are allocated to California.

[2] According to congressional staff, at the inception of the program, CMAQ funding formulas also offered a way to distribute funds to those large states that otherwise would not have fared as well under the new ISTEA funding formulas (presentation to the committee by Chris Bertram, Professional Staff Member, Subcommittee on Ground Transportation, House Committee on Transportation and Infrastructure, October 12, 1999).

[3] The release of funding caps on CMAQ funds to large states such as New York and California under TEA-21 resulted in directing even more funds to the largest states with populations living in nonattainment and maintenance areas.

TABLE 3-1 CMAQ Fiscal Year 1992–1999 Apportionments to the 14 Largest State Recipients

State	FY 1992–1999 Apportionment ($)	Percentage of Total	Cumulative Percentage
California	1,333,663,021	16.8	16.8
New York	809,478,328	10.2	27.0
Texas	688,177,010	8.7	35.7
New Jersey	458,052,764	5.8	41.4
Pennsylvania	452,995,651	5.7	47.1
Illinois	394,636,727	5.0	52.1
Ohio	325,911,956	4.1	56.2
Massachusetts	320,496,439	4.0	60.3
Maryland	245,089,591	3.1	63.3
Florida	244,339,637	2.8	66.2
Michigan	215,138,968	2.7	68.9
Connecticut	183,116,191	2.3	71.2
Virginia	163,119,202	2.1	73.2
Georgia	131,472,852	1.7	74.9

Source: FHWA CMAQ database.

affected populations. More specifically, the population of each of a state's nonattainment or maintenance areas for ozone or CO that meets the classification contained in the CAAA is multiplied by the appropriate weighting factor as listed in Table 3-2 (FHWA 1999, 4). Particulate matter (PM_{10}) is noticeably absent as a factor in the federal apportionment formula. CMAQ funds can be spent on projects in nonattainment and maintenance areas for PM_{10} (FHWA 1999, 7), but the formula has not been revised to give weight to those areas in allocating the funds.[4] Each state is guaranteed at least ½ of 1 percent of each year's authorized CMAQ funding, regardless of whether it has any nonattainment or maintenance areas. In states without such areas, the minimum allocation may be used for

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[4] States that have nonattainment or maintenance areas for particulate matter (PM_{10}) only (i.e., no ozone or CO nonattainment or maintenance areas) and thus receive only the minimum apportionment are encouraged to use the funds in these areas. Technically, they may use their minimum apportionments for projects eligible under the STP or the CMAQ program anywhere in the state (FHWA 1999, 7–8).

TABLE 3-2 Weighting Factors Used for CMAQ Apportionments Under TEA-21 [23 U.S.C. Title 23 Sec. 104(2)(B)]

Pollutant	Classification at the Time of Annual Apportionment	Weighting Factor
Ozone or CO	Maintenance (these areas had to be previously eligible as nonattainment areas)	.8
Ozone	Submarginal	.8
	Marginal	1.0
	Moderate	1.1
	Serious	1.2
	Severe	1.3
	Extreme	1.4
CO	Nonattainment (for CO only)	1.0
Ozone and CO	Ozone nonattainment or maintenance and CO maintenance	1.1 × ozone factor[a]
	Ozone nonattainment or maintenance and CO nonattainment	1.2 × ozone factor[a]
Minimum apportionment, all states	½ of 1 percent of total annual apportionment of CMAQ funds	NA

Note: NA = not applicable.

[a] The ozone factor ranges from 0.8 to 1.4, depending on the area's ozone designation.

any eligible project under the CMAQ program or the STP (FHWA 1999, 5).[5]

States having designated nonattainment or maintenance areas are required to spend CMAQ funds in those areas. However, as is true of most federal grant programs, the states are under no statutory obligation to suballocate the funds according to the federal apportionment formula; a state may use its CMAQ funds in any ozone, CO, or PM_{10} nonattainment or maintenance area (FHWA 1999, 5). The

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[5] STP funds may be used by states and localities for any federal-aid road or highway project, for bridges on any public road, and for transit capital projects. Many projects eligible for CMAQ funding are also eligible under other funding programs. For example, funding for transit capital and operating assistance is available from the Federal Transit Administration (FTA) and many states. The Transportation Enhancements Program—a set-aside of STP funds—is also used for a variety of nontraditional projects, including bicycle and pedestrian facilities, as well as restoration of historic transportation facilities, landscaping and scenic beautification, and mitigation of water pollution from highway runoff.

federal program sponsors have recommended that states consult with the affected metropolitan planning organizations (MPOs) in making these funding decisions.

The federal share for most eligible CMAQ projects is 80 percent, and up to 90 percent if the funds are used on the Interstate system. That share may be increased to 100 percent for some projects mentioned specifically in the statute.[6]

Eligible Activities

According to CMAQ program guidance, the primary purpose of the program is to fund projects in nonattainment and maintenance areas that are aimed at reducing transportation-related emissions (FHWA 1999, 1). The highest-priority projects are transportation control measures (TCMs) identified in applicable state implementation plans (SIPs) as critical for a state to attain and maintain the National Ambient Air Quality Standards (NAAQS) (FHWA 1999, 2). TCMs refer to both supply-side strategies designed to improve traffic management and demand-side strategies intended to manage travel demand by such means as encouraging higher vehicle occupancies; reducing trips and travel, at least during peak hours; and providing nonmotorized forms of transportation (Apogee Research, Inc. 1994, 1; Meyer 1999, 576). All projects funded under the CMAQ program must come from a conforming transportation plan and transportation improvement program (TIP) to be consistent with the requirements of the CAAA (FHWA 1999, 9).

CMAQ funds are intended primarily for new facilities, equipment, and services whose primary purpose is to reduce emissions. In many cases, serving this purpose requires capital investment in transportation infrastructure or establishment of a new demand management program (FHWA 1999, 9). For example, transit projects are

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[6] For purposes of the CMAQ program, these projects may involve traffic control; signalization; commuter carpooling and vanpooling; and installation of traffic signs, traffic lights, or priority control systems to give precedence to emergency vehicles or transit vehicles at signalized intersections. However, no more than 10 percent of all sums apportioned for all federal-aid systems in any fiscal year may be used for these purposes (FHWA 1999, 31).

eligible, but only if they expand service (e.g., express buses) or offer cleaner vehicles (e.g., alternative-fuel buses).[7] Maintenance and reconstruction projects are not eligible because they involve maintaining existing levels of highway and transit service, thus offering no progress toward reduction of emissions and improvement of ambient air quality levels (FHWA 1999, 8). Moreover, other funding sources are available for such activities.

Operating assistance can be an eligible CMAQ activity, but only when the intent is to help start up new transportation services with demonstrated potential to reduce air pollution. Most operating assistance under CMAQ is limited to 3 years (FHWA 1999, 9–10). CMAQ funding may not displace existing operating funds or be used to further subsidize operations of existing facilities or services.

In its program guidance, the Federal Highway Administration (FHWA) lists specific activities eligible for CMAQ funding. For example, with one exception—older-vehicle scrappage programs that are explicitly excluded[8]—the TCMs included in the CAAA (listed in Box 3-1) are appropriate activities. In addition, CMAQ funds may be used for inspection and maintenance (I&M) programs (construction of facilities, equipment purchase, and operating assistance for 3 years); alternative-fuel vehicles (purchase of publicly owned vehicles, fueling facilities, and other needed infrastructure);[9] public education, marketing, and other outreach activities aimed at advertising transportation alternatives to single-occupant vehicle (SOV) travel

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[7] Projects providing diesel replacement buses are also eligible, but the emission impacts of such proposed projects must be documented so they can be compared with the impacts of other CMAQ proposals (FHWA 1999, 15).

[8] Vehicle scrappage programs are controversial because of high ownership of older vehicles among the working poor (Nichols 1996, 157) and the incentives such programs provide for owners to keep older, polluting vehicles if they can be remunerated for them (Kienitz 1997, 57).

[9] TEA-21 contains special provisions for alternative-fuel projects that are part of a public–private partnership. For example, CMAQ funds can be used to purchase privately owned vehicles or fleets using alternative fuels, but the funding is limited to the federal share of the incremental cost of an alternative-fuel vehicle as compared with that of a conventionally fueled vehicle (FHWA 1999, 13).

BOX 3-1. Transportation Control Measures Included in the Clean Air Act Amendments of 1990, Eligible for CMAQ Funding

(i) Programs for improved public transit;

(ii) Restriction of certain roads or lanes to, or construction of such roads or lanes for use by, passenger buses or HOV;

(iii) Employer-based transportation management plans, including incentives;

(iv) Trip-reduction ordinances;

(v) Traffic flow improvement programs that achieve emission reductions;

(vi) Fringe and transportation corridor parking facilities serving multiple-occupancy vehicle programs or transit service;

(vii) Programs to limit or restrict vehicle use in downtown areas or other areas of emission concentration particularly during periods of peak use;

(viii) Programs for the provision of all forms of high-occupancy, shared-ride services;

(ix) Programs to limit portions of road surfaces or certain sections of the metropolitan area to the use of non-motorized vehicles or pedestrian use, both as to time and place;

(x) Programs for secure bicycle storage facilities and other facilities, including bicycle lanes, for the convenience and protection of bicyclists, in both public and private areas;

(xi) Programs to control extended idling of vehicles;

(xii) Reducing emissions from extreme cold-start conditions [newly eligible under TEA-21];

(xiii) Employer-sponsored programs to permit flexible work schedules;

(xiv) Programs and ordinances to facilitate non-automobile travel, provision and utilization of mass transit, and to generally reduce the need for SOV travel, as part of transportation planning and development efforts of a locality, including programs and ordinances applicable to new shopping centers, special events, and other centers of vehicle activity;

(*continued*)

BOX 3-1. *(continued)* **Transportation Control Measures Included in the Clean Air Act Amendments of 1990, Eligible for CMAQ Funding**

(xv) Programs for new construction and major reconstruction of paths, tracks or areas solely for the use by pedestrian or other non-motorized means of transportation when economically feasible and in the public interest. For purposes of this clause, the Administrator shall also consult with the Secretary of the Interior; and

(xvi) Programs to encourage removal of pre-1980 vehicles [excluded from eligibility under ISTEA and TEA-21].

Source: FHWA (1999, 10–11).

(carpooling, vanpooling);[10] intermodal freight facilities (capital improvements and operating assistance); projects focused on PM_{10} reduction;[11] experimental pilot projects (projects that offer an innovative approach to emission reductions); and—under TEA-21—projects focused on the deployment of magnetic levitation transportation technology (planning, engineering, and construction) and intercity rail, including high-speed rail, projects[12] (FHWA 1999, 13, 16, 18–20).

Under TEA-21, eligibility criteria have been relaxed to encourage innovative, experimental projects provided an activity can be defined as a transportation project that can reasonably be expected to result in emission reductions (FHWA 1999, 20). FHWA regulations require

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[10] These activities may be funded for an indefinite period. Similarly, projects that support rideshare programs, such as new locations for matching services and upgrades for computer matching software, may also be funded for an indefinite period (FHWA 1999, 16–17).

[11] Such projects include paving dirt roads, replacing diesel buses, and purchasing more effective street sweeping equipment (FHWA 1999, 8).

[12] FHWA and the Federal Transit Administration (FTA) recently ruled that the current policy, which permits CMAQ funding for projects in close proximity to nonattainment and maintenance areas where it can be demonstrated that the air quality benefits will be realized primarily in these areas, should not be modified to allow high-speed rail projects outside of these areas (*Federal Register* 2002, 2278).

that project proposals have the concurrence of the MPO, the state department of transportation (DOT), and FHWA or the Federal Transit Administration (FTA), and also be coordinated with the Environmental Protection Agency (EPA) and state and local air agencies (FHWA 1999, 20). Finally, such projects must be explicitly identified in annual reports to FHWA, and before-and-after studies are required to determine actual project impacts (FHWA 1999, 20).

CMAQ funds may be used for projects implemented cooperatively under public–private partnership arrangements. TEA-21 encourages projects initiated by the private sector or nonprofit entities, but it remains the responsibility of the cooperating public agency to apply for CMAQ funds through the metropolitan planning process and to oversee and monitor the public investment (FHWA 1999, 11–12).

As noted earlier, the CMAQ legislation explicitly prohibits construction projects that will add new capacity for SOV travel (e.g., the addition of general-purpose lanes to an existing facility or a new highway at a new location).[13] Older-vehicle scrappage programs are also ineligible, as are rehabilitation and maintenance activities (as previously discussed). Finally, CMAQ funds may not be used to finance statutory mandates imposed on the private sector or nonprofit entities by the CAAA or any other federal law (e.g., phase-in of alternatively fueled vehicle fleets) (FHWA 1999, 8).

Determination of Project Eligibility

Figure 3-1 summarizes the CMAQ project selection process as envisioned by the federal program sponsors. However, as the committee's case study results show, practices differ across the regions.

CMAQ projects can be proposed by many different organizations—counties, cities, transit operators and transportation authorities, and state DOTs (typically the local district office in a nonattainment area). Private or nonprofit sponsors must have public partners. The MPOs and state DOTs typically play major roles in determining

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[13] The exception is a high-occupancy vehicle (HOV) facility that is available to SOVs only at off-peak travel times [Intermodal Surface Transportation Efficiency Act of 1991, Sec. 1008; Congestion Mitigation and Air Quality Improvement Program, Sec. 149 (b)(3)].

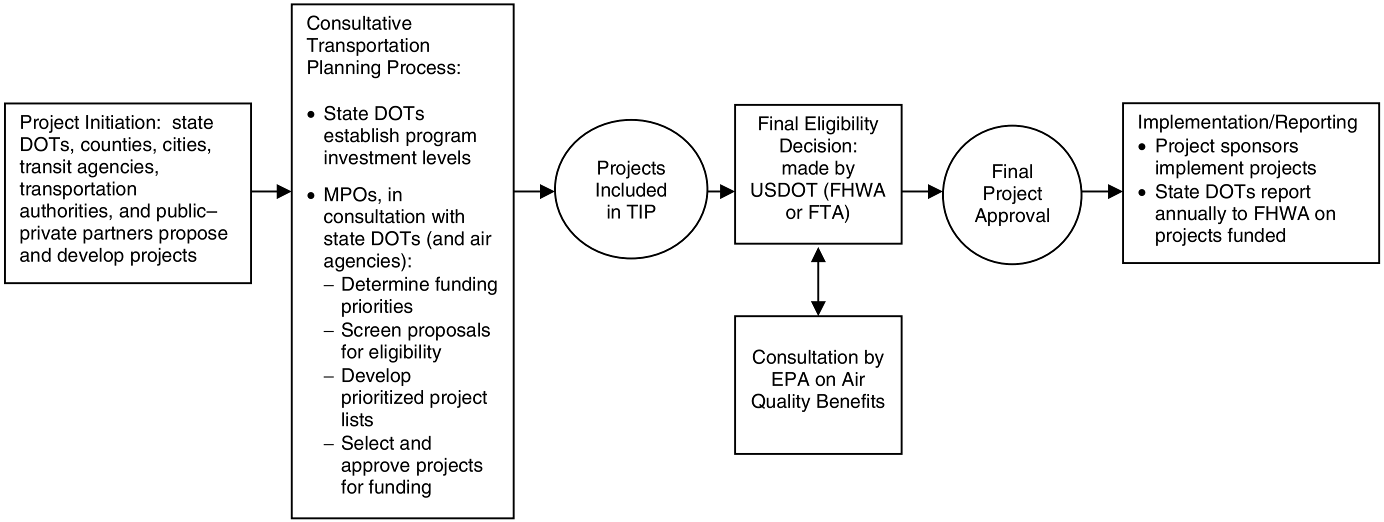

FIGURE 3-1 CMAQ project selection process. [Adapted from FHWA and FTA (2000, 18).]

availability of CMAQ funds, establishing investment priorities, and determining recommended slates of projects. The extent of involvement of a state DOT depends on the state and on whether responsibility for managing transportation projects lies at the state or local level. At a minimum, the state DOT determines the amount of CMAQ funds available to nonattainment and maintenance areas[14] and may also recommend projects in these areas. The MPO typically has lead responsibility for the prioritization, evaluation, and selection of CMAQ projects for funding.[15] The MPO is also responsible for ensuring that selected projects come from or are included in a conforming transportation plan and TIP. FHWA urges state DOTs and MPOs to consult with state and local air quality agencies to develop lists of priority projects for CMAQ programming that are expected to have the greatest impact on pollution reduction (FHWA 1999, 24). In practice, however, the extent of interagency consultation varies widely, as do the approaches used for identifying and selecting appropriate projects for CMAQ funding. Final determinations of project eligibility rest with the program sponsors—FHWA or FTA, depending on the nature of the project (FHWA 1999, 23). EPA plays a consultative role in the program and may be called upon by FHWA or FTA to review the estimated pollution reduction benefits of specific projects.

HISTORY OF CMAQ PROGRAM SPENDING

Many projects are eligible for funding within the dual focus areas of the CMAQ program—air quality improvement and congestion mitigation. This section presents a summary and analysis of program expenditures, by activity, for the period for which data are available in the CMAQ database. The discussion draws heavily on an analysis of that database conducted for this study (see Appendix C).

The CMAQ database is a national database of all CMAQ-funded projects, providing information on type of project, location, funding level, and estimated emission reductions. The database currently

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[14] The state DOT is not required to suballocate CMAQ funds on the same basis as the federal apportionment formula, but it must use the funds in nonattainment and maintenance areas unless, of course, the state does not have such areas.

[15] The state DOT may assume this role in rural states and states that receive only the minimum allocation.

covers the first 8 years of the program—federal fiscal years 1992 to 1999—and is the primary source of information on project spending trends reported here. A critical assessment of the database as a source of data on project-level emission reduction estimates and costs is provided in Chapter 4.

Classification of Projects

FHWA requires the states to report annually on the amount of CMAQ funds obligated for each project financed by the program. FHWA further instructs the states to classify CMAQ projects into six categories[16] and to report project-level obligations by this classification scheme:

- Transit,
- Other shared ride (e.g., vanpool and carpool) programs,
- Traffic flow improvements,
- Demand management (e.g., employer trip reduction programs),
- Bicycle and pedestrian projects, and
- Other projects not covered by the above categories.

States in which there are no nonattainment or maintenance areas or where funding results in less than the minimum apportionment may use a portion of their CMAQ funds for either STP- or CMAQ-eligible activities. These projects are designated as "STP/CMAQ" in the CMAQ database.

The six categories are broad and include many different types of projects. For example, projects categorized as providing traffic flow improvements range from retiming of traffic signals to construction of HOV lanes. Similarly, transit projects range from the purchase of replacement buses to the addition of parking spaces at park-and-ride lots near transit stations. For this study, FHWA's classification scheme was expanded to add subcategories (see Table 3-3). The purpose of this expansion was not only to gain a better understanding of the specific types of projects funded by the program, but also to provide a better link with data on cost-effectiveness available in the literature.

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[16] Under TEA-21, two additional categories were added: public–private partnerships and experimental pilot projects (FHWA 1999, 22).

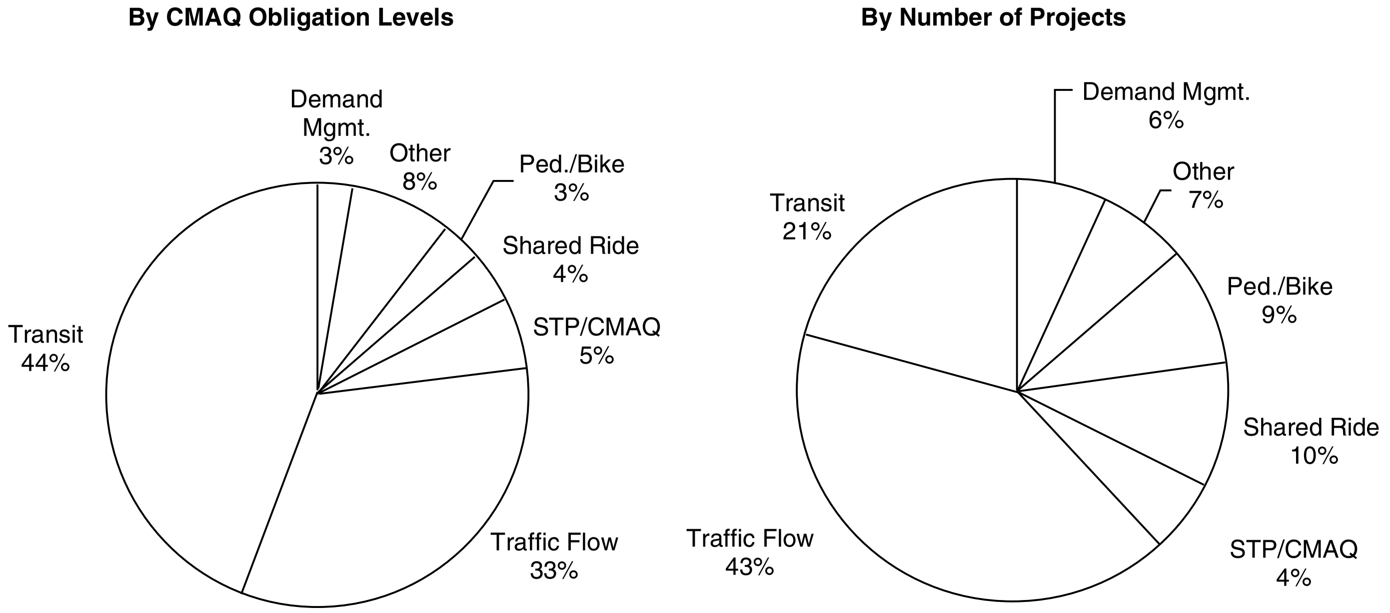
TABLE 3-3 Expansion of CMAQ Database Project Classification Scheme

Project Category	Project Subcategories
Transit	Alternative-fuel vehicles
	Conventional-fuel transit vehicles
	Park-and-ride facilities
	Station and bus stop improvements
	Transit service expansion
	Other transit improvements
Shared ride	Park-and-ride facilities
	Other shared ride
Traffic flow	Congestion and incident management
	HOV lanes
	Traffic signal improvements
	Turn lanes and other intersection improvements
	Traveler information
	Other traffic flow improvements
Demand management	Employee trip reduction
	Other demand management
Bicycle and pedestrian	No subcategories
Other projects and unclassifiable	Alternative-fuel vehicles
	Paving and sweeping to reduce PM
	Rail freight
	Vehicle inspection and maintenance
	All other improvements
STP/CMAQ	No subcategories

Spending Trends

Figure 3-2 and Table 3-4 provide a summary of CMAQ program spending for the 8-year period from fiscal years 1992 through 1999. During this period, approximately three-quarters of CMAQ funds was obligated in two project categories—transit (44 percent) and traffic flow improvements (33 percent). Another 10 percent was obligated in three project categories—shared ride (4 percent), demand management (3 percent), and bicycle and pedestrian (3 percent). The remainder—other projects and STP/CMAQ—accounted for 8 percent and 5 percent, respectively.

The data were reanalyzed by numbers of projects within broad project categories instead of dollar value to account for the fact that


By CMAQ Obligation Levels

By Number of Projects

FIGURE 3-2 CMAQ spending priorities, fiscal years 1992–1999. (Source: FHWA CMAQ database.)

TABLE 3-4 CMAQ Obligations by Type of Project for Each Fiscal Year

Project Category and Subcategory	Percentage for Fiscal Year								
	FY 1992	FY 1993	FY 1994	FY 1995	FY 1996	FY 1997	FY 1998	FY 1999	Total
Transit									
Alternative-fuel vehicles	0.3	6.9	2.9	3.5	2.6	4.3	1.5	1.9	3.1
Conventional-fuel transit vehicles	17.8	11.1	17.1	15.5	9.5	9.3	8.7	14.2	12.7
Park-and-ride facilities	1.4	2.5	1.5	1.2	1.3	0.8	0.7	2.1	1.5
Station and bus stop improvements	9.4	3.6	2.3	4.6	5.4	4.5	5.2	5.5	4.8
Transit service expansions	0.0	6.4	4.3	13.3	6.8	2.2	1.8	13.5	7.2
Other transit improvements	20.9	18.1	12.6	13.1	14.2	13.1	15.9	15.4	14.9
Subtotal	49.8	48.6	40.6	51.2	39.8	34.1	33.8	52.6	44.1
Traffic flow									
Congestion and incident management	1.9	5.3	10.8	9.9	7.7	8.0	4.6	10.5	8.1
HOV lanes	23.5	0.8	0.8	2.4	8.7	7.8	1.8	1.8	4.6
Traffic signal improvements	5.7	7.4	9.6	8.5	12.0	10.7	8.8	4.7	8.5
Traveler information	0.8	6.4	1.8	0.7	0.2	0.6	1.1	0.4	1.3
Turn lanes and other intersection improvements	4.0	2.9	2.6	3.2	7.0	11.4	3.6	2.8	4.7
Other traffic flow improvements	0.1	4.5	9.8	4.6	2.6	4.8	15.0	4.9	5.9
Subtotal	36.0	27.2	35.3	29.4	38.2	43.3	35.0	25.2	33.1

(*continued*)

TABLE 3-4 (*continued*) **CMAQ Obligations by Type of Project for Each Fiscal Year**

Project Category and Subcategory	Percentage for Fiscal Year								
	FY 1992	**FY 1993**	**FY 1994**	**FY 1995**	**FY 1996**	**FY 1997**	**FY 1998**	**FY 1999**	**Total**
Shared ride									
Park-and-ride facilities	0.8	1.6	1.1	3.0	1.2	1.3	1.0	0.5	1.4
Other shared ride	2.1	4.0	3.1	2.0	1.6	1.7	2.7	2.5	2.4
Subtotal	2.9	5.6	4.2	5.0	2.8	3.1	3.7	2.9	3.8
Pedestrian and bicycle	3.0	3.0	2.2	1.5	4.0	4.9	4.4	2.7	3.2
Demand management									
Employee trip reduction	0.0	0.2	1.1	0.8	1.8	0.2	1.2	0.6	0.8
Other demand management	1.2	1.7	3.1	1.9	2.5	2.3	2.4	1.5	2.1
Subtotal	1.2	2.0	4.3	2.7	4.2	2.4	3.5	2.1	2.9
STP/CMAQ	6.6	6.8	6.3	3.5	5.2	6.1	7.9	3.3	5.4
Other projects and unclassifiable									
Alternative-fuel vehicles	0.0	0.5	0.8	1.5	0.0	1.3	0.6	0.0	0.6
Paving and sweeping to reduce PM	0.3	0.7	2.5	0.8	0.1	0.4	1.1	0.9	0.9
Rail freight	0.0	0.5	0.2	0.9	0.0	0.8	0.3	0.1	0.4
Vehicle inspection and maintenance	0.1	0.1	2.5	2.6	2.8	2.3	8.9	9.9	4.2
All other improvements	0.1	4.9	1.1	0.9	2.9	1.2	0.8	0.2	1.5
Subtotal	0.5	6.8	7.1	6.7	5.9	6.0	11.7	11.1	7.6
Grand total	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**

per-project obligation levels are not the same for each project category (see Figure 3-2). For example, transit projects are typically characterized by larger dollar values obligated per project; thus, they account for a smaller share of the CMAQ program when number of projects is the basis of comparison (see Figure 3-2). Nevertheless, transit and traffic flow improvements still account for nearly two-thirds of all funded CMAQ projects. Shared ride, bicycle and pedestrian, and demand management projects, which typically have smaller obligation levels per project, predictably account for a larger share of the projects—10 percent, 9 percent, and 6 percent, respectively.

An analysis of CMAQ projects by size (see Table 3-5) shows that project costs in many program categories are modest.[17] For example, the median or 50th-percentile project in the pedestrian and bicycle, shared ride, and demand management categories costs near or below $200,000. Several types of traffic flow improvements were also funded at this level, although projects focused on HOV lanes and congestion and incident management tended to be larger. The median transit and rail freight projects were among the largest, with project costs in the range of $300,000 to $725,000 for transit and up to more than $1.1 million for rail freight (see Table 3-5). To provide some perspective, however, federally assisted highway rehabilitation and transit capital projects typically cost several millions of dollars.

Trends over Time

Table 3-4 shows spending by project category and subcategory for each year since the inception of the program. With few exceptions, there are large year-to-year variations in funding that exhibit no discernable trends at the national level. In fact, one of the explanations for these variations is the local nature of the program; changes in CMAQ spending are easier to observe at the state and local levels. The exception is HOV projects, which accounted for nearly

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[17] Costs were derived from the CMAQ database by examining each project subcategory for fiscal years 1992–1999 and identifying the median or 50th-percentile project. Results were also provided for the 5th- and 95th-percentile projects to show the range of project costs. As an example of how to interpret the results, the entry of $55,940 for conventional-fuel transit vehicles means that 5 percent of the projects in this category cost $55,940 or less.

TABLE 3-5 CMAQ Project Size Analysis, Fiscal Years 1992–1999 ($)

	Project Amount Percentiles		
Project Subcategory	**5%**	**50%**	**95%**
Transit			
Alternative-fuel vehicles	29,363	384,000	4,280,456
Conventional-fuel transit vehicles	55,940	725,502	8,450,760
Park-and-ride facilities	11,973	312,000	5,196,934
Station and bus stop improvements	17,200	480,000	9,918,000
Transit service expansions	34,350	411,843	9,150,000
Other transit improvements	36,440	255,800	6,858,239
Shared ride			
Park-and-ride facilities	3,948	68,531	906,332
Other shared ride	24,000	158,000	1,360,600
Traffic flow			
Congestion and incident management	30,000	473,800	5,867,543
HOV lanes	67,600	509,000	20,870,416
Traffic signal improvements	7,731	134,012	1,680,011
Turn lanes and other intersection improvements	4,000	110,531	1,416,150
Traveler information	8,800	182,000	5,203,574
Other traffic flow improvements	12,895	400,000	5,433,560
Demand management			
Employee trip reduction	24,000	219,000	2,193,000
Other demand management	25,020	177,060	1,055,400
Pedestrian and bicycle	5,416	92,650	1,298,400
Other projects and unclassifiable			
Alternative-fuel vehicles	26,300	275,120	2,322,250
Paving and sweeping to reduce PM	20,502	169,643	1,868,782
Rail freight	26,370	1,165,000	4,563,000
Vehicle inspection and maintenance	15,071	400,000	12,625,500
All other improvements	28,064	210,104	2,705,564
STP/CMAQ	6,631	271,078	5,297,026
All project subcategories	9,362	194,000	3,550,635

Note: Percentiles were developed using the CMAQ database for fiscal years 1992–1999. Amounts in different years were considered to be different projects, which has the effect of understating project size. However, some entries in the database actually represented more than one project, which has the effect of overstating project size.

Source: FHWA CMAQ database.

one-quarter of all CMAQ obligations in fiscal year 1992, reflecting a large investment by California in CMAQ-funded HOV projects that year. In the following 2 years, HOV projects accounted for less than 1 percent of total CMAQ obligations, rising to 9 and 8 percent in fiscal years 1996 and 1997, respectively, but falling back to under 2 percent in fiscal years 1998 and 1999 (see Table 3-4).

The federal regulations promulgated after reauthorization of the CMAQ program under TEA-21 required that states report experimental pilot projects and public-private partnerships as separate project categories (FHWA 1999, 20). Some states were already identifying such projects. For example, six states reported 21 experimental pilot projects between fiscal years 1996 and 1999 for a total cost of $20.8 million, or less than 1 percent of program obligations during this period. Projects ranged from traffic calming (Maine), to transponder purchases for automatic toll collection (Florida), to special street sweeping activities to control PM_{10} and a statewide air quality education project (Alaska), to telecommuting and teleconferencing projects (Arizona), to alternative fuel and other pilot transit projects (Texas), to a golf cart transportation program (California). No further project detail is provided in the FHWA database.

Four projects were listed as public–private partnerships, all in fiscal year 1999. The projects were undertaken in two states and the District of Columbia for a total cost of $880,000. They included three public education and ozone action programs and a ferry project. Again, only cursory project detail is provided. In short, the CMAQ database offers a limited record of CMAQ spending on experimental pilot projects and public–private partnerships.

Trends by Region

Analysis of CMAQ program obligation levels by the 10 DOT regions (see Figure 3-3 and Table 3-6) reveals large variations in how CMAQ funds are obligated across the regions. For example, during fiscal years 1992 through 1999, transit projects accounted for the largest share of total CMAQ spending in Regions 1, 2, 3, 5, 9, and 10. Typically, these are regions with large metropolitan transit systems. Traffic flow improvement projects accounted for the largest share of

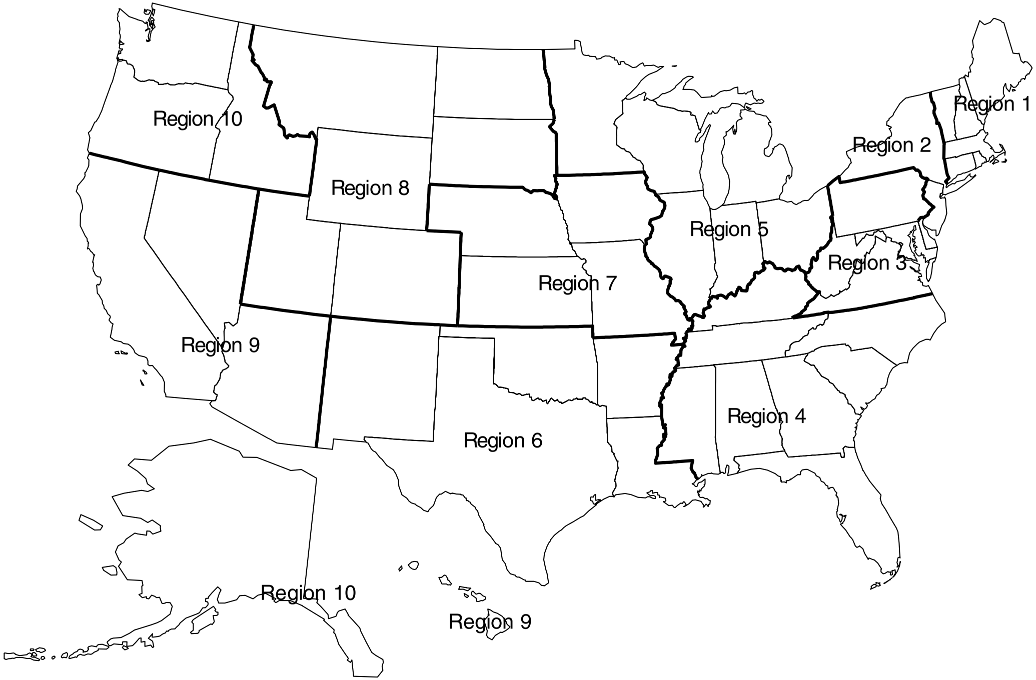

FIGURE 3-3 U.S. Department of Transportation regions.

TABLE 3-6 CMAQ Obligations by Type of Project for Each Region (FY 1992–1999)

	Percentage for Region										
Project Category and Subcategory	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**Total**
Transit											
Alternative-fuel vehicles	1.0	2.0	1.7	1.6	4.6	2.6	0.0	0.3	5.9	4.1	3.1
Conventional-fuel transit vehicles	9.7	8.7	26.2	5.6	13.3	1.3	9.3	1.6	19.7	13.1	12.7
Park-and-ride facilities	4.9	0.4	2.3	0.0	3.4	0.5	0.4	0.0	0.0	5.2	1.5
Station and bus stop improvements	9.5	9.4	1.6	1.9	8.1	4.1	0.8	0.4	1.8	1.9	4.8
Transit service expansions	16.5	1.1	11.4	6.3	5.1	2.1	0.0	0.6	13.3	2.3	7.2
Other transit improvements	14.7	25.1	9.2	9.4	10.0	11.2	11.6	1.8	18.3	20.1	14.9
Subtotal	56.3	46.7	52.4	24.8	44.4	21.8	22.0	4.7	59.0	46.6	44.1
Traffic flow											
Congestion and incident management	3.1	5.9	4.8	13.7	7.9	22.8	9.0	4.6	6.4	0.8	8.1
HOV lanes	3.0	0.5	0.5	1.4	0.4	3.9	0.0	3.6	16.4	1.2	4.6
Traffic signal improvements	7.2	5.3	8.3	14.5	12.4	8.3	7.0	13.4	6.8	4.1	8.5
Traveler information	0.4	3.7	0.6	3.4	0.3	2.0	0.0	0.0	0.2	0.0	1.3
Turn lanes and other intersection improvements	3.5	5.3	4.4	12.5	4.5	8.0	7.4	3.5	0.8	0.4	4.7
Other traffic flow improvements	1.8	4.3	13.4	6.8	8.3	12.0	3.6	1.1	1.7	3.2	5.9
Subtotal	19.0	25.1	32.0	52.5	33.8	57.1	27.0	26.1	32.4	9.7	33.1

(*continued*)

Table 3-6 (*continued*) **CMAQ Obligations by Type of Project for Each Region (FY 1992–1999)**

Project Category and Subcategory	**Percentage for Region**										
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**Total**
Shared ride											
Park-and-ride facilities	2.0	0.9	5.4	0.2	0.6	1.8	0.5	2.0	0.3	1.2	1.4
Other shared ride	4.4	1.5	1.8	3.7	1.9	2.1	1.7	6.2	2.1	2.4	2.4
Subtotal	6.4	2.4	7.1	3.9	2.5	3.9	2.2	8.3	2.4	3.6	3.8
Pedestrian and bicycle	1.7	4.6	0.6	2.7	3.3	2.1	0.1	4.6	2.3	18.7	3.2
Demand management											
Employee trip reduction	4.3	0.9	0.6	0.1	0.1	0.6	0.2	0.1	0.6	0.5	0.8
Other demand management	2.4	4.3	0.9	3.8	1.6	1.4	1.0	1.3	0.7	4.3	2.1
Subtotal	6.7	5.2	1.6	3.9	1.7	2.0	1.2	1.5	1.3	4.8	2.9
STP/CMAQ	2.6	2.5	2.7	8.6	0.0	10.2	29.5	48.2	0.9	2.5	5.4
Other projects and unclassifiable											
Alternative-fuel vehicles	1.1	1.1	0.5	0.4	0.2	2.1	0.0	0.0	0.1	0.3	0.6
Paving and sweeping to reduce PM	0.0	0.0	0.0	0.0	0.0	0.2	10.3	4.5	0.6	8.8	0.9
Rail freight	1.2	1.5	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.4
Vehicle inspection and maintenance	3.2	10.4	1.4	1.6	11.8	0.1	0.6	0.6	0.0	2.0	4.2
All other improvements	1.8	0.6	1.8	1.6	2.2	0.4	7.1	1.5	0.9	2.9	1.5
Subtotal	7.3	13.6	3.7	3.6	14.3	2.9	18.0	6.6	1.7	14.1	7.6
Grand total	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**

total CMAQ spending in several of the regions where transit spending was low, particularly Regions 4 and 6. Region 10 spent approximately 20 percent of its total CMAQ obligations on bicycle and pedestrian projects. The largest expenditure for this project type in the other regions was 5 percent. Large differences in regional spending priorities reflect the decentralized character of the program and differing local conditions.

Program Impact on Transportation Spending Priorities

The Federal Management Information System (FMIS), a financial management database developed by FHWA to track federally funded projects, was also explored as a source of information on CMAQ spending. A primary objective was to investigate whether the CMAQ program has had a measurable impact on transportation spending priorities. The primary difficulty was in separating the effects of CMAQ from those of its enabling legislation—the 1991 ISTEA—which itself brought about major changes in the use of federal transportation funds. Under ISTEA, for example, highway and transit funds could be interchanged more flexibly, and two new programs—STP and CMAQ—provided local governments with funds that could be spent on a wide range of locally determined transportation priorities. Nevertheless, a pilot study of pre- and post-ISTEA federal highway spending in the Albany, New York, nonattainment area was undertaken to explore the impacts of the introduction of the CMAQ program.[18] The results showed that prior to 1991, the vast majority of funds was expended on highway projects. After 1991, the largest expenditure of funds was still on highways, but highway funds were also used to support bicycle and pedestrian, transit, and rideshare projects; CMAQ funds were dominant in the latter two project categories.

Despite the indication that CMAQ funds did play a role in supporting a more diverse set of projects in the post-ISTEA Albany area,

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[18] The results of this effort were summarized in a memorandum entitled "The Impact of the CMAQ Program on Types of Projects Funded Under Title 23 of the United States Code in Albany, New York," by Michael Savonis, Team Leader for Air Quality at FHWA, which was presented to the committee on March 23, 2001.

extending the analysis to other nonattainment areas was not considered fruitful.[19] First, project detail is poor in FMIS. Thus, manual manipulation was required to group like projects together; certain CMAQ-eligible project categories, such as demand management, were simply absent from the project detail. Second, an analysis of CMAQ obligations by funding category from FMIS compared with the FHWA national CMAQ database showed a serious undercount in the former of such categories as transit, bicycle and pedestrian, HOV, and I&M projects. Finally, under TEA-21, FMIS no longer tracks data on transit projects, a major funding category of the CMAQ program. For all these reasons, it was simply not possible to obtain the data needed to separate the effects of the CMAQ program from those introduced by its much larger enabling legislation.

CASE STUDY RESULTS

As discussed in Chapter 1, several in-depth case studies were undertaken in selected metropolitan areas to expand the committee's understanding of how the CMAQ program operates at the state and local levels. State DOTs, MPOs, transit agencies, transportation authorities, cities and counties, state and local air agencies, and other selected public interest and business groups were interviewed to solicit their views concerning:

- The air quality planning and policy context in which CMAQ program and project decisions are made;
- Perceived program goals and objectives, including both primary and secondary objectives and likely effects of discontinuing the program;
- Decision-making procedures for CMAQ project identification, selection, design, implementation, costs, and evaluation (e.g., effectiveness measures); and
- Program strengths and weaknesses and suggested areas for improvement.

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[19] Several of the limitations of the FMIS database were detailed in a memorandum by Harry Cohen, consultant to the committee, entitled "FMIS Data on CMAQ Projects," dated July 21, 2000.

Five case study sites—Los Angeles; Chicago; Houston; Washington, D.C. (tristate area); and Albany—were selected to reflect a diversity of air quality problems and their severity, metropolitan area size, and growth context (see Table 3-7). Although the results cannot be generalized across all nonattainment and maintenance areas covered under the program, the case study sites include some of the largest metropolitan areas and users of CMAQ funds. Indeed, these five metropolitan areas alone account for slightly more than one-third of total current CMAQ obligations. Moreover, four of these metropolitan areas are among the nation's 12 largest (FHWA and FTA 2000, 6); the exception is Albany, which was selected to help understand how the program operates in a smaller metropolitan area. A copy of the questionnaire used for the case studies and summaries of each of the associated site visits are presented in Appendix D.

TABLE 3-7 Criteria for Selection of Case Study Sites

Criterion	Case Study Sites
Severity of Air Quality Problem	
Pollutant and severity	
Ozone, extreme	Los Angeles
Ozone, severe	Chicago
Ozone, serious	Houston; Washington, D.C.
Ozone, marginal	Albany
CO, serious	Los Angeles
PM_{10}, serious	Los Angeles
Population Size	
Greater than 10 million	Los Angeles
1 to 10 million	Chicago; Washington, D.C.; Houston
Less than 1 million	Albany
Population Growth, 1982–1999	
High (greater than 20 percent)	Houston; Washington, D.C.; Los Angeles
Moderate (10 to 20 percent)	Chicago
Low (less than 10 percent)	Albany

Note: Data on the severity of the air quality problem were provided by EPA (classifications of nonattainment areas as of July 20, 2000). Data on population size and population growth were drawn from the Texas Transportation Institute's 2001 Urban Mobility Report (Schrank and Lomax 2001, 37).

The operational aspects of the program (its context and decision-making procedures) as viewed by those interviewed in the five site visits are discussed in this chapter. Evaluative comments are provided in Chapter 4.

Air Quality Context

As noted earlier, CMAQ funds are targeted to areas with ozone and CO pollution problems. Not surprisingly, in those case study sites with serious air quality problems, the CMAQ program is viewed as an important element in maintaining conformity with the NAAQS and SIP budget targets. For example, when the Washington, D.C., area is in danger of exceeding its SIP mobile source emissions budget, TCMs from an areawide agreed-upon list are implemented; Northern Virginia and the District of Columbia use CMAQ funds for these projects.[20]

In updating conformity estimates, some nonattainment areas account for the travel- and pollution-reducing effects [e.g., reductions in trips or in vehicle-miles traveled (VMT)] of CMAQ-funded TCMs through modeling. When the effects are too small to be identified by a regional model, the projected emission reductions are often quantified for a conformity determination using "off-model" calculations. Travel effects are estimated (e.g., projected changes in vehicle speeds, trips, or VMT), and emission factors from the MOBILE model, or the EMFAC model in California, are then used to estimate emission reductions. Some regions take a further step and include CMAQ-funded TCMs in the nonattainment area's SIP. Typically, TCMs are incorporated in the SIP for credit only when the funds have been fully committed and project implementation is certain.

CMAQ-eligible projects differ widely in their potential for reducing emissions, and hence the amount of credit that can be taken for them. For example, northeastern Illinois was able to take an approximately 30-ton-per-day credit in its 1999 Rate of Progress plan for a CMAQ-funded enhanced I&M program in the Chicago area. By comparison, other CMAQ-funded TCMs for the area, which summed to

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[20] Maryland uses state funds to finance its share.

several hundred projects over several years, provided only an additional 2-tons-per-day credit. The total SIP mobile source emissions budget for the area is 200 tons per day. Nevertheless, the additional 2 tons per day may be sufficient to put a region over the conformity threshold. As the Chicago case study illustrates, although the amount of emissions reduced by an individual CMAQ-funded project may be small, a group of such projects may be sufficient to help keep an area in conformity and within the targets of SIP emission budgets.

As discussed earlier, the type of air quality problem in a region can affect the selection of projects for CMAQ funding. For example, the Houston–Galveston metropolitan area is designated a severe nonattainment area for ozone. The area must pay particular attention to reducing NO_x (the region previously received an NO_x waiver), so that many grade separation projects that were previously candidates for CMAQ funding are no longer desirable from an air quality perspective; elimination of bottlenecks increases vehicle speeds and thus NO_x emissions.

In an area such as Albany without a serious air quality problem—the area is a marginal nonattainment area for ozone—meeting conformity requirements is not as important a consideration in the selection of projects for CMAQ funding. Improved air quality, for example, is not an explicit criterion for project selection. That having been said, CMAQ-funded projects support the goals of the area's long-range plan, which are compatible with clean air.

Decision-Making Procedures

From a federal perspective, CMAQ is a highly decentralized program; decision making is devolved to state and local governments. From a local perspective, CMAQ is a state program. The states certainly play an important role in the program. They control the way CMAQ funds are suballocated, subject to the restriction, of course, that the funds must be spent within nonattainment and maintenance areas. States are also accountable for how CMAQ funds are spent and must report annually to FHWA on project obligations and estimated emission reductions. States may also reserve a portion of the funds for special projects. For example, the New York State DOT reserved $30 million of the state's CMAQ apportionments of $129 million and

$138 million in fiscal years 1998 and 1999, respectively, for high-speed rail projects in nonattainment areas throughout the state.

State involvement in the program at the local level differs by state. In all the case study sites, the state DOT, usually the local district office, nominates projects for CMAQ funding, as do many other local agencies. Typically, the area MPO has the lead responsibility for developing a consensus list of projects for funding and programming.[21] However, in two of the five case study sites—Houston and Washington, D.C. (Maryland)—the state DOTs take a more proactive role in the program at the local level. For example, the Texas DOT (TxDOT) plays a major role in the management and administration of CMAQ funds in Houston. Once projects have been selected and programmed for CMAQ funding in the TIP, TxDOT allocates the funds to its Houston District Office, which then lets the contracts for individual projects and administers the program locally, with the exception of transit projects.[22] In Maryland, responsibility for highways and mass transit rests with the state. The Maryland DOT (MDOT) has primary responsibility for the CMAQ program. After reviewing the input of county staff and elected officials, MDOT makes the final project programming and funding decisions.

One notable difference among the case study sites is the extent to which special consideration is given to the identification and selection of projects for CMAQ funding. For example, the Chicago Area Transportation Study (CATS), the MPO for the area, puts out a regional call for projects for CMAQ each year, distributes the notification widely, and provides staff support to those who need assistance in preparing project proposals.[23] In the Washington, D.C.,

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[21] In the Los Angeles region, this responsibility is further devolved to the county transportation commissions, which act as councils of government for their respective counties.

[22] METRO, the major transit provider in the region, is responsible for managing and administering its own CMAQ-funded projects.

[23] Approximately 7,000–8,000 mailings are sent to all relevant constituencies, private citizens, and all pertinent governmental bodies. In addition, CATS provides staff support to 11 subregional councils in an effort to assist local governments in proposal development. Nongovernmental entities are also encouraged to participate in the process, although they are required to obtain a government sponsor for their projects before submitting a proposal.

metropolitan area, Northern Virginia has a special call for projects for the CMAQ program, but there is no regionwide call. In the Los Angeles region, where responsibility for selecting and programming CMAQ funds has been devolved to the counties, Ventura, Riverside, and San Bernardino counties have separate processes for soliciting CMAQ project proposals. In some cases, the process is open to the full range of CMAQ-eligible projects. In others, proposals are restricted to certain categories of projects that have been preselected by the lead agency as particularly effective in addressing the specific pollution problems of the area.[24] Finally, in other regions, no distinction is made between CMAQ and other transportation improvement programs; nomination and selection of projects are handled as part of the regular TIP process. The decision about which funds to use frequently comes after project selection. (Of course, pollution problems are so severe in many of these regions that effects on emission levels and air quality are considered in evaluating all transportation projects for inclusion in the TIP.) In all cases, the flexibility offered by CMAQ funds—which can be used for a broad range of activities, in contrast to the funds provided by many other transportation programs, which are restricted to specific programmatic uses—makes them highly desirable to local governments.

The breadth of participation by government agencies and nongovernmental groups in the CMAQ program differs widely across the case study sites, making generalizations difficult. Those regions that make a special effort to notify potential applicants of the availability of CMAQ funds, hold technical workshops, and provide staff support to assist with proposal preparation generally have a broad range of project sponsors. This approach can provide an opportunity for nonprofit groups to become involved at an early stage in the process, but the extent of their involvement also depends on how well they are organized and what staff resources they have available to devote to the program. In the Chicago region, for example, several well-organized and -funded area interest groups formed an environmental

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[24] For example, in Ventura County, California, the county transportation commission worked with the local air district to develop a priority list of candidate project categories for CMAQ funding and selection criteria tailored to local air quality problems.

coalition that was instrumental in helping to shape the development of the CMAQ program, including the development of project evaluation criteria.[25] In most case study sites, the air agencies have been neither consulted nor heavily involved in the development or evaluation of CMAQ projects, despite federal guidance encouraging this type of interaction.[26]

Another notable difference among the case study sites is the presence (or absence) of procedures for ranking and evaluating CMAQ projects and the rigor of this process. Several regions have developed a separate process for evaluating candidate CMAQ proposals, with explicit criteria for ranking projects by cost-effectiveness of expected trip, travel, and emission reductions.[27] Typically projects are scored within categories; for example, bicycle projects are evaluated separately from transit projects.[28] Most of those interviewed believe this is the fairest way of comparing projects. The idea is to identify and select the most cost-effective projects within each category. Of course, the amount of funding allocated to each project category is not determined on the basis of technical merit alone; practical considerations, such as project readiness, and political factors, such as geographic distribution of projects, also come into play. Secondary factors, such as mobility, economic development, safety, and community livability, are sometimes considered in project selection, frequently as tie breakers for projects that rank equivalently.

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[25] Coalition members include the American Lung Association, Business and Professional People in the Public Interest, the Sierra Club, the Center for Neighborhood Technology, and the Chicagoland Bicycle Federation.

[26] Notable exceptions are Ventura County and its air district (already discussed); the San Bernardino Associated Governments and one of its air districts; and the Chicago region, where the Illinois EPA is part of the CATS CMAQ project selection team.

[27] See the discussion of the Chicago, Houston, and Los Angeles site visits in Appendix D for examples of such criteria and ranking systems.

[28] The Riverside County Transportation Commission (RCTC) and the San Bernardino Associated Governments (SANBAG) in the Los Angeles area are an exception. They have adopted scoring systems that rank all proposed projects on similar criteria. In both cases, however, projects have been selected outside of the ranking process. From time to time, SANBAG has funded some transit projects that have not ranked high on their cost-effectiveness criteria. The RCTC has set aside a certain share of CMAQ funds for ready-to-obligate projects, specifically HOV projects.

The extent of federal oversight of determinations of project eligibility depends largely on the projects involved. For example, certain bottleneck removal projects received close scrutiny by FHWA division offices to ensure that they did not conflict with the program's prohibition against projects to provide new highway capacity. Some regions—Chicago is a good example—have memorandums of understanding with FHWA, FTA, and EPA regarding project eligibility determination that provide preclearance for certain categories of projects (e.g., TCMs and other projects directly focused on CAAA requirements in an EPA-approved SIP), thus streamlining the review process.

As noted earlier, at a minimum, all regions that receive CMAQ funds are required by FHWA to report annually on the cost and emission reduction potential of all funded projects, information that is then collected in the national CMAQ database. The area MPO often takes the lead in this activity in a region. The state is responsible for combining all the regional data and reporting the state summary to FHWA. With some exceptions, most of those interviewed noted that little guidance is provided about appropriate methods for evaluating projects, particularly those that involve behavioral as well as environmental effects.[29] Hence methods vary widely from "back-of-the-envelope" to modeled estimates, depending on the technical sophistication of the agency and the complexity of the project.

Few retrospective analyses of projects are conducted to determine whether estimated changes in travel behavior and emission benefits have actually occurred. Local agency staff cite the small size and large numbers of projects as a deterrent to conducting such evaluations cost-effectively. Nor is it easy to conduct such evaluations in a methodologically sound way.

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[29] One exception is California, where the California Air Resources Board (ARB) has developed a methods handbook in cooperation with the California DOT for evaluating the cost-effectiveness of several of the most widely implemented transportation-related projects funded by the CMAQ and Motor Vehicle Registration Fee programs. The most recent edition (ARB 1999) can be accessed on the ARB website at www.arb.ca.gov. FHWA has also recently published a sampling of emission analysis techniques for a wide range of TCMs that represents an attempt to match methods and modeling tools with specific project categories (Louis Berger Associates 2000). This report can be found on the FHWA website at www.fhwa.dot.gov/environment.

SUMMARY AND FINDINGS

CMAQ is a modest program relative to many other federal-aid highway and mass transportation programs, and also as a share of regional transportation budgets. However, the funds are well targeted to regions with the most serious ozone and CO air quality problems. That having been said, large differences in regional spending priorities are evident, reflecting the decentralized nature of the program and differing local conditions. In the spirit of ISTEA, the CMAQ program allows spending for a diverse range of eligible activities and provides regions with considerable latitude in determining spending priorities and selecting appropriate projects.

The highest funding priority is given to TCMs identified in area SIPs; the TCMs included in the CAAA, except for vehicle scrappage programs, are eligible spending categories. CMAQ funds are intended primarily for new facilities, equipment, and services—with limited funding for operations—to generate new sources of emission reductions. The CMAQ legislation explicitly prohibits construction projects that add new capacity for SOV travel.

An analysis of program obligations for the first 8 program years drawn from FHWA's CMAQ database reveals that funding has been concentrated in two relatively traditional areas: transit and traffic flow improvements accounted for approximately three-quarters of CMAQ obligations during fiscal years 1992 through 1999. This pattern holds whether numbers or dollar values of projects are considered, although the former perspective reduces spending on these two categories to nearly two-thirds of the total. These spending categories are broad, however, and include nontraditional projects (e.g., alternatively fueled transit buses, intelligent transportation systems, suburban transit services), as well as more traditional activities.

An analysis of CMAQ spending trends at the national level reveals large year-to-year variations. An effort was made to determine whether the CMAQ program had resulted in any change in transportation funding priorities, but the lack of sufficiently detailed pre- and post-ISTEA data and the difficulty of separating the effects of the CMAQ program from the larger changes in funding arrangements that were ushered in with ISTEA made it impossible to pursue this line of analysis. Not unexpectedly, large variations were evident in the way

CMAQ funds are obligated in different geographic areas. For example, spending on transit dominates in regions with large metropolitan transit systems.

Results from the committee's five in-depth case studies—four in large metropolitan areas with serious air quality problems and high usage of CMAQ funds—reveal that the program is viewed as an important funding source to help nonattainment areas comply with conformity requirements. Individual projects, particularly TCMs, often have small effects on emissions, but as a package, a program of CMAQ projects can help keep a region in conformity and within SIP emission budgets.

CMAQ projects are proposed by a range of public agencies that include cities, counties, transit agencies, transportation authorities, and state DOTs through their local district offices. The MPOs typically take the lead in helping to develop a consensus list of projects for funding and programming. The extent of the state's involvement depends on historical arrangements, as well as the degree of state control over transportation programming and funding. Despite the federal exhortation for state DOTs and MPOs to consult with state and local air agencies in identifying CMAQ projects with high potential for emission reductions, with few exceptions the role of the air agencies, at least in the case study sites, has been limited.

One notable difference among the case study sites is the extent to which regions give special consideration to the identification and selection of projects for CMAQ funding. Some areas have a separate call for CMAQ projects, advertise widely, and provide staff support to encourage project proposals. At the other extreme, some regions treat CMAQ projects like any other transportation improvement projects; they are all handled through the normal TIP process. Sometimes funding choices are made after the projects have been selected. In all cases, CMAQ funds are highly valued by local governments because, in contrast with many transportation programs in which funds are restricted to specific programmatic areas, CMAQ funds can be used for a broad range of activities within certain eligibility requirements.

Several of the regions visited for the case studies have separate processes for evaluating and ranking candidate CMAQ projects, which range from applying multiple criteria and weighting schemes to using more general criteria. With a few exceptions, the norm is to compare projects within rather than across project categories to reflect inherent differences in project types. At a minimum, all regions that receive CMAQ funding must attempt to estimate the emission effects of individual projects. The state compiles the regional results and reports them to FHWA for inclusion in the national database. Again with some exceptions, most areas visited noted a lack of guidance on how to quantify these effects. Highly limited postimplementation evaluations of projects are conducted because of the cost involved (given the large numbers of relatively small projects) and, in some cases, the methodological complexity of undertaking such studies.

The focus of this chapter has been on providing an overview of the CMAQ program and how it currently operates in a selected group of metropolitan areas. The next chapter concentrates on an assessment of the program and the projects it funds.

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Abbreviations

ARB	California Air Resources Board
DOT	U.S. Department of Transportation
FHWA	Federal Highway Administration
FTA	Federal Transit Administration

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ASSESSMENT

The central task of this study was to provide a critical evaluation of the CMAQ program. The committee was charged to investigate whether projects funded under the program are effective and cost-effective, how they compare with alternative strategies for achieving the program's air quality goals, and whether the program offers other benefits that cannot be quantified. The results of this assessment are described in this chapter. In the first section, what is known about the cost-effectiveness of CMAQ-eligible projects and alternative strategies for pollution reduction is reviewed; a discussion of how the results of this review should be interpreted is included. This section draws heavily on the two papers commissioned for this study—one that reviews the literature on the cost-effectiveness of transportation-related strategies eligible for CMAQ funding (Appendix E) and another that examines the literature on the cost-effectiveness of non-CMAQ-eligible control strategies, particularly new-vehicle emission and fuel standards (Appendix F). In the second section, an assessment of some of the more difficult-to-measure, qualitative outcomes of the program is presented, drawing primarily on the case studies and briefings provided to the committee. The chapter ends with a summary of key findings drawn from this assessment.

COST-EFFECTIVENESS OF CMAQ PROJECTS AND ALTERNATIVE POLLUTION CONTROL STRATEGIES

In theory, it would be desirable to examine both the effectiveness and cost-effectiveness of projects funded under the CMAQ program. Effectiveness is a measure of the scale or magnitude of project impacts, whereas cost-effectiveness is an efficiency measure that quantifies the cost of achieving a unit of project effectiveness.[1]

Measuring the relative effectiveness of actual CMAQ projects did not prove feasible. The available data on the effectiveness of CMAQ projects are location specific; project data are valid only for the particular context and strategy involved. Sufficient data were not available on the effectiveness of similar strategies in several regions, making it difficult to generalize from particular project results or to compare types of projects systematically.

The committee decided to examine the literature for data on similar types of projects—primarily transportation control measures (TCMs)—and focused its review on project cost-effectiveness as requested in its charge. The committee selected cost per ton of emissions reduced as the primary cost-effectiveness measure by which to compare the pollution reduction potential of various strategies. The committee would have preferred as an effectiveness measure an indicator of the exposure of affected populations to various pollutant concentrations, and as a cost measure the total tangible and intangible costs to all segments of society, including both government agencies and users. A simple illustration explains why. Moving the position of exhaust stacks on public buses could reduce the exposure of affected populations, particularly those inside the bus, to particulate emissions, even though it would not change emission levels (Rodes et al. 1998). Thus, the project would show a positive impact if reducing exposure were used as the effectiveness measure, but it would have a neutral impact if reducing emissions were used. Unfortunately, the necessary data on neither exposure nor social costs were available. Moreover, the data on emissions were limited. Most of the studies report emission reductions for volatile organic compounds (VOCs) and nitrogen oxides

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[1] Cost-effectiveness analysis should not be confused with cost-benefit analysis, which requires that all costs and benefits be measured in monetary units so that each strategy can be compared on its own merits (i.e., whether the benefits are in excess of the costs) to answer the question of whether this strategy is the most worthwhile (from an efficiency perspective) that could be undertaken. Cost-effectiveness analysis normalizes effectiveness data—costs are expressed per unit of effectiveness—so that projects can be ranked to show which provide the greatest return for the investment made. For a more complete discussion of these analysis techniques, see Levin (1993).

(NO_x), but not for carbon monoxide (CO) or particulate matter (PM_{10}). The inclusion of these pollutants could change the relative ranking of projects on cost-effectiveness, as discussed later in the chapter. In addition, most of the results of the project evaluations are based on modeled estimates of emission reductions instead of on reductions measured after project implementation.

The literature was also examined for data on the cost-effectiveness of reducing congestion, using decreased hours of delay as a measure of effectiveness. However, the effects of CMAQ projects on travel delay have rarely been measured, so it was not possible to determine their cost-effectiveness in reducing congestion. CMAQ projects may have effects other than pollution and congestion reduction (e.g., mitigating adverse ecological effects of pollution, stimulating economic development), but a lack of well-developed performance measures and the data needed to quantify them precluded attempts to analyze such effects.

Analysis Approach

The papers commissioned for this study review the literature on the cost-effectiveness of a wide range of mobile source pollution control strategies (see Table 4-1). For CMAQ-eligible measures, the national CMAQ database was consulted to identify the primary strategies for which funds have been obligated over the life of the program. Particular attention was paid to transit and traffic flow improvement projects because the majority of CMAQ funds have been obligated in these two categories (see Chapter 3). Project subcategories were identified, and to the extent possible, similar strategies were grouped for analysis. The database was also explored as a source of information on the cost-effectiveness of CMAQ projects. As discussed earlier, states are required to report annually on the funds obligated and the estimated emissions reduced for each relevant pollutant for each CMAQ-funded project. However, given the lack of consistency in methods for estimating either project costs or emission reductions, the database was not deemed suitable for use in cost-effectiveness analyses.[2]

The non-CMAQ-eligible pollution control strategies reviewed were focused primarily on mobile source measures, mainly new-vehicle

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[2] See more detailed discussion in Appendix C.

TABLE 4-1 Mobile Source Pollution Control Strategies and Potential Impacts Analyzed for This Study

Pollution Control Strategy	Potential Impacts: Travel Response	Potential Impacts: Emission Reduction
CMAQ-eligible		
Transit improvements	Yes	Yes
Traffic flow improvements	Yes	Yes
Ridesharing programs	Yes	Yes
Travel demand management programs	Yes	Yes
Telecommute/telework programs	Yes	Yes
Bicycle and pedestrian improvements	Yes	Yes
Vehicle inspection and maintenance programs	No	Yes
Conventional- and alternative-fuel vehicle programs[a]	No	Yes
Pricing measures[b]	Yes	Yes
Non-CMAQ-eligible		
New-vehicle emission standards	No	Yes
Clean conventional and alternative fuels	No	Yes
Vehicle scrappage programs	No	Yes
Remote sensing	No	Yes

[a] The purchase of publicly owned alternative-fuel vehicles and related fueling facilities and the incremental cost of upgrading privately owned vehicle fleets to alternative fuels are the only CMAQ-eligible expenditures in this category (FHWA 1999, 13).

[b] Some pricing strategies are not CMAQ-eligible.

emission and fuel standards.[3] The cost-effectiveness of stationary source emission control measures, such as controls on electric power plants, was also reviewed in response to the congressional request.

The committee recognized the need for as much consistency as possible between the two papers in the treatment of cost-effectiveness calculations. Thus, similar methods were adopted by the authors for addressing such issues as the handling of multiple pollutants and related weighting factors and the treatment of emissions and costs for multiyear projects. Several rounds of revisions were undertaken to make the methods as comparable as possible. Both authors were

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[3] There was a small overlap with the first commissioned paper, however, because two of the control strategies reviewed—inspection and maintenance (I&M) programs and alternative-fuel buses—are CMAQ-eligible.

also charged with discussing the sources and extent of uncertainty for each class of strategy reviewed.

The methodological adjustments made are discussed in detail in the papers; only the highlights are mentioned here. One important issue is the selection of a baseline from which the emission reductions are estimated. For example, older studies that report on strategies designed to reduce hydrocarbons tend to show larger emission reductions because recent federal engine and fuel standards have greatly reduced emissions of these pollutants, as reflected in the lower emission rates of the current vehicle fleet. Combining the results of recent and more dated studies thus distorts cost-effectiveness estimates. The authors tried to minimize this problem by selecting more recent studies that cover roughly comparable time frames.

Another important issue relates to the handling of multiple pollutants. Although some mobile source emission control measures are focused on a particular pollutant, many affect multiple pollutants. To improve comparability among control measures, the authors adopted a uniform approach for combining and weighting pollutants for which data were available—VOCs and NO_x—in deriving a single cost-effectiveness estimate.[4] Sensitivity analyses were then conducted using different weighting schemes to test the stability of the results.

Virtually all the studies reviewed rely on emissions models or model inputs to estimate emission reductions.[5] Although emissions models have been improved, they have generally tended to overestimate emission reductions. For example, a recent evaluation of inspection and maintenance (I&M) programs (NRC 2001) revealed that many of the programs have not been structured to meet their potential; the actual emission reductions attributable to them range from zero to about one-half of the reductions predicted

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[4] For the base case results, the pollutants were weighted as follows—VOCs (1) + NO_x (4)—on the basis of a damage-value method, which assigns a weight to each pollutant depending on the estimated damage it inflicts on affected populations. Other weights were used for the sensitivity analysis. Further details on the weighting rationale are provided in the two papers.

[5] They use either the Environmental Protection Agency's Mobile Source Emissions Factor (MOBILE) model or the California alternative, the Emissions Factor (EMFAC) model of the California Air Resources Board.

by the models.[6] There was no way of addressing the problem of uncertainties introduced by the models except to acknowledge them.

The committee was aware of the shortcomings of cost-effectiveness analysis. Therefore, as discussed later in the chapter, its response to the congressional request for such an analysis includes explanations of the many uncertainties and qualifications associated with the results.

Results

Cost-Effectiveness of CMAQ-Eligible Strategies

As noted earlier, the majority of CMAQ-eligible strategies reviewed for this study were TCMs, measures that affect vehicle emissions indirectly by changing travel behavior. The two exceptions are vehicle I&M programs and alternative-fuel vehicle projects.[7] Both of these strategies affect vehicle emissions directly—the former through identification and repair of vehicles that do not meet a threshold level of emission control, and the latter through replacement of conventional-fuel vehicles with those burning cleaner fuels. Introduced in the early 1970s, TCMs include both supply-side strategies designed to improve traffic management and demand-side strategies intended to manage travel demand through such measures as encouraging higher vehicle occupancies; reducing trips and travel, at least during peak hours; and providing nonmotorized forms of transportation (Apogee Research, Inc. 1994, 1; Meyer 1999, 576).

Unfortunately, the long history of TCM implementation is not matched by a strong track record of evaluating the effectiveness or cost-effectiveness of the strategies employed. After considerable research in the late 1970s and early 1980s, little work was done until interest in TCMs as a way of controlling mobile source emissions was renewed by the 1990 Clean Air Act Amendments (CAAA), the 1991 Intermodal Surface Transportation Efficiency Act (ISTEA), and the CMAQ program in particular (GAO 1993, 7). Since that time,

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[6] The revised figures were derived by employing in-use vehicle emission data from such sources as remote sensing, random roadside vehicle testing, and I&M emission testing (NRC 2001, 2).

[7] The purchase of publicly owned alternative-fuel vehicles and related fueling facilities and the incremental cost of upgrading privately owned vehicle fleets to alternative fuels as part of a public–private partnership are all CMAQ-eligible (FHWA 1999, 13).

evaluation studies have been conducted, ranging from assessments of individual strategies to more comprehensive literature reviews, but the state of the art is not well suited to measuring the effects of TCMs, particularly those on emissions and air quality.[8] With some exceptions, the effects of TCMs are highly localized; many tend to have modest impacts—on the order of 1 percent or less—when examined from a regional perspective or over long time periods (Cambridge Systematics, Inc. 2000, xx; Ferguson 2000, 288). Most analysis tools, such as travel demand models and emissions models, are not well suited to analysis of subregional effects (Ferguson 2000, 289). As a result, the imprecision of current models is apt to be larger than the effects of the TCMs they are used to estimate (Cambridge Systematics, Inc. 2000, xx).[9] Finally, there has been little postimplementation evaluation of TCMs to ascertain whether model-predicted travel and emission effects have actually been realized.

The studies selected for this review are recent and methodologically sound and have complete data; only a modest number of studies meet these criteria. The range of results, from the lowest to the highest cost per ton of emissions reduced as reported in the literature and adjusted by the author for consistency, is presented for each strategy in Figure 4-1 and Table 4-2. To make it possible for the cost-effectiveness information to be matched with program expenditures for each strategy, Table 4-2 also indicates the amount of CMAQ obligations expended to date for each strategy analyzed, drawing on data collected from the FHWA CMAQ database (see Appendix C)

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[8] See Ferguson (2000, Chapter 16) for a review of many key studies since 1978, and also the bibliography in Appendix E, which cites many of the more recent studies.

[9] Difficulties involved in detecting the emissions effects of many TCMs also help explain why it was not possible for this study to take the next step of analyzing the ambient air quality effects of most TCMs. A recent review (Cambridge Systematics, Inc. 2000, xx) notes that control measures must reach a threshold level of emission reduction—generally greater than about 10 percent—before statistical approaches can successfully discern effects on ambient air quality levels, a threshold well beyond most CMAQ-eligible TCMs. In addition, even if controls meet the higher threshold, detecting the effects on secondary pollutants, such as ozone or fine particulates, is considerably more difficult than detecting changes in primary pollutants, such as CO.

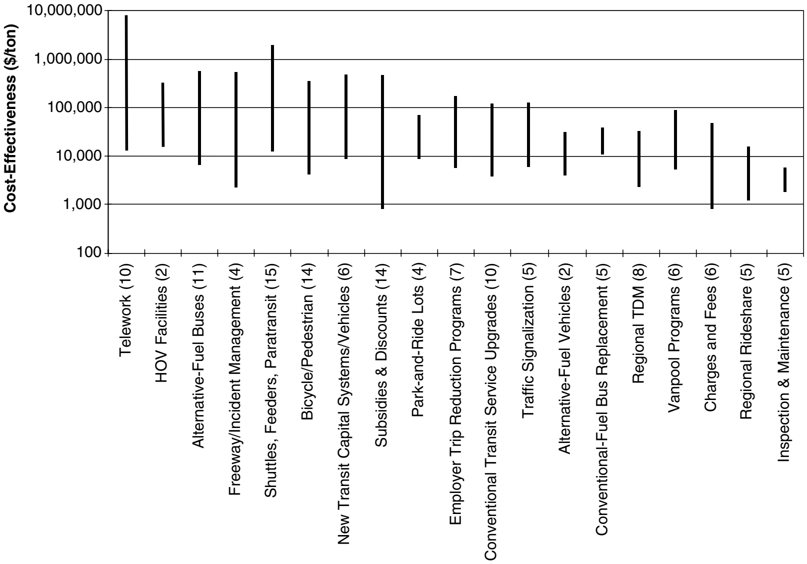

FIGURE 4-1 Range of cost-effectiveness results (dollars per ton) for CMAQ-eligible strategies (in 2000$, VOC-equivalent emission reductions). Note: HOV = high-occupancy vehicle; TDM = travel demand management. (Source: Appendix E.)

TABLE 4-2 Summary of Cost-Effectiveness of CMAQ-Eligible Projects by Strategy (VOC-equivalent emission reductions)

CMAQ Project Category	Number of Projects	Cost-per-Ton Range (2000$)		Fiscal Year 1992–1999 CMAQ Obligations (%)
		Low	High	
Traffic flow improvements				**33.1**
Traffic signalization	5	6,000	128,000	8.5
Freeway/incident management	4	2,300	544,000	8.1
HOV facilities	2	15,700	337,000	4.6
Intersections, traveler info., other	0	NA	NA	11.9
Ridesharing				**3.8**
Regional rideshare	5	1,200	16,000	2.4
Vanpool programs	6	5,200	89,000	
Park-and-ride lots	4	8,600	70,700	1.4
Travel demand management				**2.9**
Regional TDM	8	2,300	33,200	2.1
Employer trip reduction programs	7	5,800	176,000	0.8
Telework	10	13,300	8,230,000	**0.0**
Bicycle/pedestrian	14	4,200	345,000	**3.2**
Transit improvements				**28.3**
Shuttles, feeders, paratransit	15	12,300	1,970,000	7.4
New capital systems/vehicles	6	8,500	471,000	12.0
Conventional service upgrades	10	3,800	120,000	7.4
Park-and-ride lots	1	56,000	56,000	1.5
Fuels and technology				**20.6**
Conventional-fuel bus replacements[a]	5	11,000	39,900	12.7
Alternative-fuel buses[b]	11	6,700	569,000	3.1
Alternative-fuel vehicles[c]	2	4,000	31,600	0.6
Inspection and maintenance[d]	5	1,800	5,800	4.2
Other				**2.8**
Rail freight	0	NA	NA	0.4
Paving and sweeping (PM)	0	NA	NA	0.9
All other improvements	0	NA	NA	1.5
STP/CMAQ[e]				**5.4**
Pricing				**0.0**
Subsidies and discounts	14	800	471,000	0.0
Charges and fees	6	800	49,400	0.0
Total				**100.0**

Note: The following pollutant weighting scheme was assumed: 1:4 for VOC:NO_x. NA = not available; HOV = high-occupancy vehicle; TDM = travel demand management.

[a] Replacement of diesel buses with newer-vintage diesel buses.

[b] Replacement of diesel buses with alternative-fuel buses.

[c] Non-transit-vehicle fleet conversions to alternative fuels.

[d] A recent report (NRC 2001) reveals that the actual effectiveness of many I&M programs fell short of model predictions.

[e] CMAQ funds that can be used for either CMAQ or Surface Transportation Program projects; project categories are undefined.

Source: Appendix E.

from the inception of the program to fiscal year 1999, the most recent year for which national data were available. Table 4-3 displays the results by cost-per-ton increments to illustrate the dispersion (or concentration) of results by strategy.

Using a threshold of approximately $10,000 per ton of emissions reduced[10]—the cutoff point used for selecting control measures under many regulatory approaches to emission reductions (E. H. Pechan and Associates 1997)—results for only one of the 19 strategies reviewed—I&M—lie entirely below the $10,000-per-ton cutoff (see Figure 4-1).[11] Half or more of the results lie below the $10,000-per-ton cutoff or are fairly concentrated (i.e., less than $50,000 per ton) (see Table 4-3) for the following five strategies:

- Regional ridesharing programs (areawide programs that provide information, promotion, and assistance in matching potential car poolers);[12]
- Regional travel demand management programs (areawide programs that are generally aimed at commute travel);[13]
- Replacement of conventional-fuel buses;
- Alternative-fuel vehicle programs (e.g., conversion of public and private nontransit vehicle fleets to alternative fuels); and
- Charges and fees (e.g., workplace parking fees, mileage fees, congestion pricing).[14]

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[10] The $10,000-per-ton threshold should not be interpreted as a valid absolute cutoff point for cost-effectiveness comparisons. Thresholds for cost-effectiveness depend on the severity of the nonattainment problem and the pollutant(s) of concern. The $10,000-per-ton threshold, which has been used in many regulatory analyses, is used here primarily as a necessary simplification to compare the relative cost-effectiveness of CMAQ-eligible and non-CMAQ-eligible control measures.

[11] A recent study (NRC 2001), however, has shown that many current I&M programs do not achieve their potential. Modeled estimates of program effectiveness have tended to overstate potential emission reductions when compared with results from implemented programs.

[12] This is one of the few strategies for which estimates of cost-effectiveness are derived from empirical data, not solely from model predictions of travel behavior.

[13] This category covers a wide range of measures. One of the initiatives studied involved an effort by a regional transit agency to engage employers in selling and distributing transit passes.

[14] Only some of these measures are currently in use and eligible for CMAQ funding.

Table 4-3 Number of CMAQ Project Examples by Project Category and Cost-Effectiveness Level

	Cost per Ton (2000$, VOC-equivalent emission reductions)										
Project Category	**<10,000**	**$10,000–$19,999**	**$20,000–$29,999**	**$30,000–$39,999**	**$40,000–$49,999**	**$50,000–$59,999**	**$60,000–$69,999**	**$70,000–$99,000**	**$100,000–$249,999**	**$250,000+**	**Total**
Traffic signalization	2		2						1		5
Freeway/incident management	2								1	1	4
HOV facilities		1								1	2
Regional rideshare	3	2									5
Vanpool programs	2	2	1					1			6
Park-and-ride lots	1	1					1	1			4
Regional TDM	4	1	2	1							8
Employer trip reduction programs	1	2	1		1	1			1		7
Telework	1							1	3	5	10
Bicycle/pedestrian	1	1	1				2	5	2	2	14
Shuttles, feeders, paratransit		1	1	1	1	2		2	1	6	15
New capital systems/vehicles	1	1		1					2	1	6
Conventional service upgrades	1	2	4	1				1	1		10
Alternative-fuel buses	3			1	1				2	4	11
Conventional-fuel bus replacements		3	1	1							5
Alternative-fuel vehicles	1			1							2
Inspection and maintenance	5										5
Subsidies and discounts	5		1	1		1	2		3	1	14
Charges and fees	3	1	1		1						6
Total	**36**	**18**	**15**	**8**	**4**	**4**	**5**	**11**	**17**	**21**	**139**
Percent	**26**	**13**	**11**	**6**	**3**	**3**	**4**	**8**	**12**	**15**	**100**

Note: The following pollutant weighting scheme was assumed: 1:4 for VOC:NO_x. HOV = high-occupancy vehicle; TDM = travel demand management.

Source: Appendix E.

At the other extreme, results for two strategies—telework facilities and new transit shuttle and feeder services—exceed $1 million per ton.[15] Results for the remaining 11 strategies lie between these extremes, in several cases being widely dispersed (see Figure 4-1 and Table 4-3). It is important to note that there is no way to be sure that implementing these strategies would result in cost-effectiveness values similar to those found in the studies. Nevertheless, the study results offer the only guidance available at this time.

As noted previously, the majority of CMAQ funds provided since the program's inception has been spent on traffic flow and transit improvements. Yet with the exception of conventional-fuel bus replacements, which could be categorized under transit instead of under fuels and technology as shown, transit and traffic flow improvements are not among the most cost-effective strategies listed above. However, $10,000 is near the lower end of the range of cost-effectiveness estimates for many transit and traffic flow improvement projects; other results range across the cost intervals, suggesting that performance depends on where and how a particular strategy is implemented.

A sensitivity analysis was conducted using different weighting schemes for VOCs and NO_x.[16] The ranking of strategies was relatively invariant with respect to the different scenarios (see Appendix E). However, had data been available on particulate reductions, for example, and included in the cost-effectiveness calculations, the ranking of strategies focused on sources of particulate emissions, such as alternative-fuel buses, would likely have shown more promising cost-effectiveness results.

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[15] Results for two of the nine telework projects reviewed exceeded $1 million per ton; those for three more projects exceeded $250,000 per ton. Results for 1 of the 15 transit shuttle and feeder service projects exceeded $1 million per ton; those for 5 exceeded $250,000 per ton. The poor cost-effectiveness results for some of the telecommuting projects reflect the inclusion of the capital cost of telework facilities, which results in very high costs relative to emission reductions. The capital costs of constructing telework facilities are not CMAQ-eligible; hence these projects are not as comparable as they could be to telecommuting activities funded under the CMAQ program.

[16] Two alternative weighting schemes were used. The first weighted NO_x equivalently with VOCs [i.e., VOCs (1) + NO_x (1)]. The second weighted NO_x much more heavily than VOCs [i.e., VOCs (1) + NO_x (8)], in part as a surrogate for particulates, for which data were unavailable; NO_x is one component of secondary particulate formation (see Appendix E).

In sum, for only one of the 19 strategies reviewed—I&M programs—is the entire range of results below the $10,000 cutoff. The majority of the strategies (11), for which the bulk of CMAQ funds has been spent show a wide range of cost-effectiveness results. That having been said, many of these strategies are exemplified by one or more projects that fall below the $10,000-per-ton threshold and thus may have the potential to demonstrate more positive results.

Cost-Effectiveness of Non-CMAQ-Eligible Pollution Control Strategies

Figure 4-2 and Table 4-4 summarize the cost-effectiveness results for mobile source strategies that for the most part are ineligible for CMAQ funding.[17] This analysis, too, was constrained by a limited number of usable studies, as well as by a wide range of results for some strategies. Nevertheless, using the same threshold of $10,000 per ton of emissions reduced, the range of cost-effectiveness estimates was well below the threshold (see Figure 4-2) for half of the 16 strategies reviewed:

- Passenger and heavy-duty vehicle emission standards,
- California's Phase 3 reformulated gasoline program,
- I&M programs,
- Use of remote sensing,[18] and
- Vehicle scrappage programs.

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[17] The exceptions are I&M programs and alternative-fuel buses, which were included in both reviews. In the case of the former, the results from the two papers are quite similar. In the latter case, the opposite is true. The estimates in Appendix F, which show that compressed natural gas (CNG) buses are highly cost-effective (i.e., below $10,000 per ton), are based on two studies, which are engineering estimates. The results in Appendix E are based on 11 studies that include other fuel options and represent bus replacement programs in metropolitan areas. The results show poor cost-effectiveness for this strategy; however, the range is wide, from $6,700 to $568,700 per ton.

[18] Remote sensing refers to a method for measuring pollution levels in a vehicle's exhaust while the vehicle is in use (NRC 2001, 192).

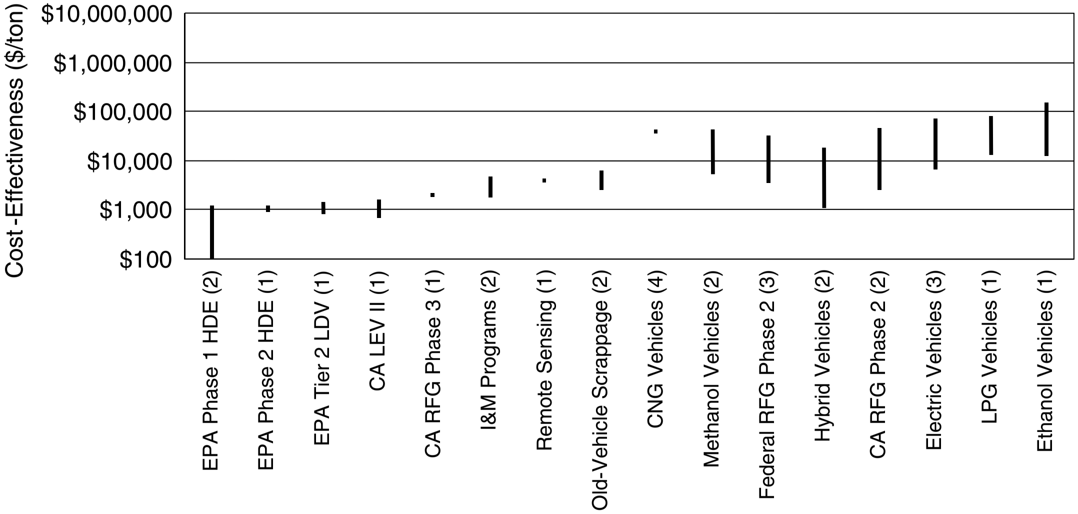

FIGURE 4-2 Range of cost-effectiveness results (dollars per ton) for non-CMAQ-eligible mobile source control measures (in 2000$, VOC-equivalent emission reductions). Note: two of the strategies are CMAQ-eligible: I&M programs and CNG buses. CA = California; CNG = compressed natural gas; EPA= Environmental Protection Agency; HDE = heavy-duty engine; I&M = inspection and maintenance; LDV = light-duty vehicle; LEV = low-emission vehicle; LPG = liquid petroleum gas; RFG = reformulated gasoline. (Source: Appendix F.)

TABLE 4-4 Summary of Cost-Effectiveness of Non-CMAQ-Eligible Mobile Source Control Measures (VOC-equivalent emission reductions)

Control Measure	Number of Studies	Cost-per-Ton Range (2000$) Low	Cost-per-Ton Range (2000$) High
Vehicle emission standards			
EPA Phase 1 HDE standards	2	100	1,200
EPA Phase 2 HDE standards	1	900	1,200
EPA Tier 2 LDV standards	1	800	1,400
CA LEV II program	1	700	1,600
Reformulated gasoline			
CA Phase 3 RFG	1	2,000	2,000
Federal Phase 2 RFG	3	3,600	83,500
CA Phase 2 RFG	2	2,600	45,000
In-use vehicle emission reductions			
I&M programs[a]	2	1,800	4,600
Remote sensing programs	1	4,100	4,100
Old-vehicle scrappage	2	2,500	6,400
Alternative-fuel vehicles			
CNG vehicles	4	0	36,000
Methanol vehicles	2	5,300	43,600
Hybrid electric vehicles	2	1,100	18,900
Electric vehicles	3	6,600	72,400
LPG vehicles	1	13,000	80,000
Ethanol vehicles	1	12,600	152,200

Note: A single study may have several scenarios. The following weighting scheme was assumed: 1:4 for VOC:NO_x. CA = California; CNG = compressed natural gas; EPA = Environmental Protection Agency; HDE = heavy-duty engine; I&M = inspection and maintenance; LDV = light-duty vehicle; LEV = low-emission vehicle; LPG = liquefied petroleum gas; RFG = reformulated gasoline.

[a] A recent report (NRC 2001) reveals that the actual effectiveness of many I&M programs fell short of model predictions.

Source: Appendix F.

The least cost-effective strategies are federal and earlier California (Phase 2) reformulated gasoline programs[19] and vehicle fleet conversions to alternative fuels (i.e., liquefied petroleum gas, compressed natural gas, electricity, ethanol, and fuel cells) (see Figure 4-2).[20] However, with one exception—fleet conversion to ethanol vehicles—the top of the range for even the least cost-effective strategies falls below $100,000 per ton.

The results also tend to be more clustered than those found in the review of CMAQ-eligible strategies (see Table 4-5).[21] This might be because fewer studies were reviewed. Nevertheless, many of the evaluations are comprehensive analyses of large programs, such as new-vehicle emission and fuel standards, that include several different scenarios, so the clustering probably indicates less variation among measures than in the case of CMAQ-eligible projects—exactly what one would expect given that CMAQ intentionally encourages experimental strategies.

The committee was also charged with analyzing the cost-effectiveness of stationary source control measures. A recent comprehensive analysis of stationary source control measures and a limited number of mobile source control strategies (E. H. Pechan and Associates 1997) conducted for the Environmental Protection Agency (EPA 1997a; EPA 1997b) was used to address this task. Most of the stationary source measures controlled for a single pollutant only and thus could not be directly compared with the previous results for mobile source strategies that affected multiple pollutants. Where comparisons were possible—primarily for VOC control measures—mobile source non-CMAQ-eligible control measures (e.g., new-vehicle emission and fuel standards) appeared to be competitive with stationary source VOC control measures.[22] Many

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[19] The cost-effectiveness of such other fuel measures as the low-sulfur diesel fuel standards was evaluated as part of the heavy-duty vehicle emission standards (Table 4-4, first two rows), which were found to be highly cost-effective.

[20] Table 4-2 also includes a high and low cost-effectiveness result for alternative-fuel vehicles, both within the range shown in Table 4-4.

[21] Note that studies may have multiple observations or scenarios, which accounts for the larger numbers of measures included in Table 4-5 than in Table 4-4 and Figure 4-2.

[22] For this comparison, the cost-effectiveness of mobile source control strategies is expressed in VOC-equivalent emission reductions (see Appendix F).

TABLE 4-5 Number of Non-CMAQ-Eligible Mobile Source Control Measures by Project Category and Cost-Effectiveness Level

	Cost per Ton (2000$, VOC-equivalent emission reductions)										
	<10,000	$10,000–$19,999	$20,000–$29,999	$30,000–$39,999	$40,000–$49,999	$50,000–$59,999	$60,000–$69,999	$70,000–$99,000	$100,000–$249,999	$250,000+	Total
CA LEV II Program	2										2
EPA Tier 2 LDV standards	1										1
EPA Phase 1 HDE standards	3										3
EPA Phase 2 HDE standards	1										1
CA Phase 2 RFG	1			1							2
Federal Phase 2 RFG	1		1		1						3
CA Phase 3 RFG	1										1
I&M programs[a]	2										2
Old-vehicle scrappage	3										3
Remote sensing programs	1										1
Methanol vehicles	1		1								2
Ethanol vehicles								1			1
LPG vehicles					1						1
CNG vehicles[a]	3			1							4
Electric vehicles			1	1		1					3
Hybrid electric vehicles	1	1									2
Total	**21**	**1**	**3**	**3**	**2**	**1**	**0**	**1**	**0**	**0**	**32**
Percent	**66**	**3**	**9**	**9**	**6**	**3**	**0**	**3**	**0**	**0**	**100**

Note: The following pollutant weighting scheme was assumed: 1:4 for VOC:NO_x. Some studies have more than one scenario. This is true for the CA LEV II Program, EPA Phase 1 HDE standards, and old-vehicle scrappage programs. CA = California; CNG = compressed natural gas; EPA = Environmental Protection Agency; HDE = heavy-duty engine; I&M = inspection and maintenance; LDV = light-duty vehicle; LEV = low-emission vehicle; LPG = liquefied petroleum gas; RFG = reformulated gasoline.

[a] These strategies are exceptions. I&M programs and CNG buses are CMAQ-eligible.

Source: Appendix F.

mobile source emissions occur in populated areas, whereas stationary sources are often located outside of population centers. The higher health-related damages from greater population exposure could justify implementation of some higher-cost mobile source control measures.

Interpreting the Results

The limited evidence available from the papers commissioned for this study suggests that control strategies aimed directly at emission reductions (e.g., new-vehicle emission and fuel standards, I&M programs, remote sensing programs, vehicle scrappage programs) have generally been more cost-effective than behaviorally oriented CMAQ-funded TCMs. Results of a few TCMs, however—those involving regional ridesharing, regional transportation demand management, and some CMAQ-eligible charges and fees—compare favorably with those of strategies aimed directly at emission reductions, suggesting that the former may have the potential to yield more cost-effective results.

There is considerable uncertainty about these conclusions, especially regarding their applicability to emission control measures that may be implemented in the future. First, the wide range of cost-effectiveness results for many TCMs, even within the same project category, suggests that performance depends largely on context, that is, on where and how projects are executed (see Table 4-3). Regional differences affect both the choice of projects for CMAQ funding and their effectiveness in reducing emissions. Project costs and effects can vary greatly within one metropolitan area, as well as among areas. Project performance depends on the transportation systems already in place, the air quality and congestion mitigation measures already implemented, and the projects (CMAQ-funded and others) carried out together with any CMAQ projects.

Second, the cost-effectiveness comparisons reported here were limited to ranking strategies on the basis of their cost per ton of VOC and NO_x reduced. Many CMAQ-eligible TCMs may have other benefits, including particulate reduction, congestion relief, and other environmental and ecological benefits (e.g., reduction of greenhouse gases). It was not possible to quantify these other benefits for this study, but their absence from the cost-effectiveness calculations may have resulted in higher cost-effectiveness estimates than would have been obtained if the costs had been spread across a larger number of benefits.

Third, the estimates for nearly all strategies are affected by modeling uncertainties. Modeled estimates have generally tended to overstate emission reductions. Modeling uncertainties are compounded for TCMs, which require the prediction of travel as well as emission effects, adding to the uncertainty of the estimates.

Fourth, several of the most cost-effective strategies, such as federally mandated new-vehicle emission and fuel standards, have already been implemented. Other cost-effective strategies, such as I&M and regional ridesharing programs, have been applied in particular nonattainment areas, but these areas may require additional measures to reach or maintain conformity. Adopting more stringent versions of these strategies would probably be possible only at much higher cost. Thus, as vehicles become cleaner and the most cost-effective strategies are put in place, obtaining further emission reductions will likely require TCMs and other control strategies that may be less cost-effective than measures already implemented.

Finally, one may question whether it is appropriate to compare CMAQ-eligible TCMs with many of the other pollution control strategies reviewed here. One could argue that, at least in the short run, if the CMAQ program were not reauthorized, the funds, which come from Highway Trust Fund revenues, would more likely be folded into the Surface Transportation Program and the federal transit program than used to support these other pollution control measures. Thus, the relevant comparison would be with more traditional highway and transit expansion and rehabilitation projects that are currently ineligible for CMAQ funding. Although an in-depth review of these projects from the perspective of the goals of the CMAQ program, particularly their effect on emissions, was beyond the scope of this study, there is some evidence to suggest that they would generally not represent a cost-effective way of reducing emissions. For example, an assessment of the effects of highway capacity improvements on air quality (TRB 1995, 8) indicated that many of these projects would have negligible or adverse effects on emission levels.[23] Another review of expanding capacity through the use of intelligent transportation system technologies on highways (e.g., highly automated freeway and HOV lanes) and expanded light rail transit (Johnston and Rodier 1997) showed that each of these strategies increased emissions as compared with a no-build option.[24] Of course, as noted earlier, traditional highway and transit rehabilitation and maintenance projects are not eligible for CMAQ funding precisely because they maintain existing levels of highway and transit service and thus are not expected to result in further progress toward reducing emissions.

PERSPECTIVES FROM THE CASE STUDIES

Several of the more difficult-to-measure, qualitative aspects of the CMAQ program were investigated as part of the five case studies conducted by the committee. In particular, respondents were asked to comment on such issues as value added by the CMAQ program, impact on local spending priorities, consideration of objectives in addition to air quality improvement and congestion mitigation in project selection, and incentives to innovate. In this section, the views of the agencies interviewed at each case study site regarding these and other program strengths, weaknesses, and suggested areas for improvement are summarized; material from briefings presented to the committee is also brought to bear.

Program Goals

To provide some perspective on how the case study respondents viewed the effectiveness of the CMAQ program, this section begins with a summary of their thoughts on what the program is attempting to accomplish.

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[23] The study revealed at least one exception in traffic flow improvements within developed areas. In such areas, better traffic signal timing and left-turn lanes that alleviate bottlenecks may reduce some emissions by reducing speed variations and smoothing traffic flows without risking large offsetting increases from new development and related traffic growth (TRB 1995, 7).

[24] When pricing or land use strategies were added to the light rail transit scenario, however, this option had the best results in terms of emission reductions. Adding pricing measures (e.g., congestion pricing on freeways, new parking charges, fuel tax increases) to some of the scenarios—HOV facilities, light rail transit—had a major positive influence on reducing emissions (Johnston and Rodier 1997).

The vast majority of agencies interviewed were in agreement that the primary objective of the CMAQ program is and should be to improve air quality. There was less agreement about the legitimacy of the congestion mitigation goal of the program. More specifically, transportation departments in the sites visited generally took the position that congestion relief projects, such as traffic signalization and intersection improvements, meet program goals and can result in air quality benefits. For example, the major transportation agencies in Houston and Los Angeles supported the dual goals of the program and saw no major conflict between them, particularly if projects were structured appropriately, a viewpoint that may reflect the high levels of congestion in both regions. Some transportation agencies went further, recommending that the program restriction against the use of funds to expand highway capacity for single-occupant vehicle (SOV) travel be relaxed for projects that remove bottlenecks by making small capacity additions, such as auxiliary lanes, where it could be shown that these improvements would reduce emissions.

Other respondents—mainly transit operators, environmental groups, and some air agencies—thought the program should be focused primarily on nonhighway projects or at least on alternatives to SOV travel. They argued that other funds are available for congestion relief and that many of the projects that support this goal are of dubious value or less cost-effective than others in helping reduce pollution. In a briefing to the committee, the South Coast Air Quality Management District, the local air agency for a major part of the Los Angeles region, articulated this position. According to that agency, when viewed in the context of the greatest air quality improvement per CMAQ dollar spent, projects focused directly on vehicle emission reductions, such as the replacement of fleet engines with engines that burn clean fuel and support for clean-fuel infrastructure, rank higher than many transportation congestion relief projects.

Few of the respondents mentioned other objectives, such as improved mobility and economic development, as important goals for expenditure of CMAQ funds. In some regions, however, these considerations do play a role in determining which projects should be selected for CMAQ funding. For example, the Washington Metropolitan Area Transit Authority takes into account access, affordable transit, and economic development as well as criteria relating to emission reductions in considering projects for CMAQ funding. Quality-of-life issues frequently arise in evaluating the desirability of bicycle and pedestrian projects for CMAQ funding. These factors also play a role as "tie breakers" when two projects are ranked equally.

Program Benefits and Weaknesses

According to most of those interviewed, the CMAQ program is valuable because it helps regions with air quality problems develop and fund strategies aimed at reducing pollution and related congestion. Although the program represents only a small fraction of federal transportation funding, it is one of the few examples of a funded mandate: CMAQ funds are dedicated to helping local areas comply with the stringent conformity requirements of the 1990 CAAA.

Local agencies view the restrictions imposed on the use of CMAQ funds as one of the program's most important strengths. The restrictions are seen as particularly important in large metropolitan areas where needs for transportation infrastructure preservation are numerous and would likely be given higher priority, claiming most available funds if the restrictions were lifted. In fact, when asked what would be the likely effect if the restrictions were relaxed or the program discontinued, the majority of those interviewed agreed that some projects would be delayed, while others would simply not be undertaken. Projects such as telecommuting and suburban transit shuttle services have no alternative federal funding sources. Of course, state and local funds could always be used, but competing needs for these funds reduce the attractiveness of this option. A few respondents did not agree with this assessment. They claimed that areas with severe air quality problems would be forced to spend on projects that would reduce, or at least not increase, pollution regardless of whether CMAQ funds were available.

Although restricted in purpose, the CMAQ program provides local governments with considerable flexibility and a diverse set of options in making their spending choices. Projects can readily be tailored to multimodal approaches to local pollution and congestion problems. Federal funds are often restricted to specific programmatic areas (e.g., highways, bridges). Thus, funds that can be used for a wide array of projects are highly valued. Flexible funds can also be used to support projects that encourage interagency collaboration and attract new project sponsors. For example, in the Chicago area, CMAQ funds were used to support projects in many suburban jurisdictions, helping overcome a history of divisive city–suburban relations. In Chicago as well as in other cities, CMAQ funds support transportation management associations (TMAs), groups of individuals and employers who organize to address local transportation issues. CMAQ funds have been used both to establish TMAs and to support such activities as suburban shuttle and express bus services.[25] The CMAQ program complements ISTEA in its effort to include a broad range of participants in planning and executing transportation solutions to local problems.

On the other hand, to the extent that flexibility encourages widespread use of CMAQ funds to ensure that everyone gets a "slice of the pie," it can lead to an unfocused program and failure to concentrate on projects that are likely to yield the largest air quality benefits. This dilemma was voiced during the Chicago site visit. Although the process for allocating funds in the northeastern Illinois region is noted for having involved many new groups and ensured a fair and equitable distribution of funds, a frequently heard complaint of case study participants was the lack of a strategic program focus and scattering of projects.

The CMAQ program is also viewed as a source of funds to encourage innovation by developing new strategies for controlling emissions from transportation sources (Farrell et al. 1998, ii). Both the Federal Highway Administration (FHWA) and the Environmental Protection Agency (EPA) have documented projects that local officials have identified as nontraditional, either because of the type of project (e.g., a daycare center near a transit hub, a taxicab alternative-fuel program) or because of the process (e.g., involvement of nontraditional partners, such as business or community groups) (FHWA 1996; EPA 1999). During the site visits, many respondents acknowledged

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[25] CMAQ-eligible activities include coordinating and marketing rideshare programs, providing shuttle services, and developing parking programs. Reimbursement of expenses associated with TMA start-up is limited to 3 years (FHWA 1999, 17).

the positive incentives provided by the program to consider innovative transportation strategies for which there are few traditional funding sources. The program is focused on new services and offers the ability to fund small pilot demonstration projects. According to the Houston–Galveston Area Council, the metropolitan planning agency for the Houston area, an important role of the CMAQ program has been to "buy down the risk of pilot projects." Furthermore, the program offers the opportunity to involve a wide range of nontraditional participants, including nonprofit and private-sector organizations, and leverage other funds in support of these projects. Box 4-1 describes four projects that local officials in the case study sites identified as innovative and that FHWA and EPA have showcased as CMAQ success stories (EPA 1999; FHWA 1996). They include a shuttle service in suburban Chicago to connect a commuter rail transit line with a major suburban employment center, creating a viable suburban transit alternative to drive-alone commuting; a public education and month-long reduced transit fare program in Houston to reduce emissions during August, typically the month with the highest number of ozone exceedance days; an employer outreach effort in the Washington, D.C., metropolitan area in support of an areawide integrated program of ridesharing services; and a high-tech facility to allow real-time traffic monitoring and coordinated rapid response to incidents on Houston's congested freeways.

Nontraditional projects typically represent a small fraction of a region's CMAQ program in any given year. The extent of innovation depends in large part on the willingness and capacity of local agencies to support new activities. A recent report on CMAQ-funded demonstration projects[26] in the Chicago area (Jackson and Murtha 2001) provides a sense of the challenges faced by local agencies undertaking nontraditional projects. Of the 17 projects covered in that report, 4 were considered successful, 5 were failures (were cancelled or had disappointing results), and 8 had unknown outcomes.

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[26] Demonstration projects are defined as projects that are innovative (i.e., not yet having been done in the region); have regional applications beyond the specific project; and have potential emission benefits that can be measured, at least conceptually (Jackson and Murtha 2001, 2).

BOX 4-1. CMAQ Success Stories

Suburban Transit: Lake Cook (Chicago) Shuttle Bug

Shuttle Bug service was started in 1996 as a CMAQ demonstration project. The Transportation Management Association of Lake Cook, representing several major area employers, acted as a catalyst for establishing a free shuttle service to connect commuters from a new commuter rail train station to a major suburban center with some 30,000 employees along a 6-mile corridor on Lake Cook Road (EPA 1999, 23–24). Riders who commute out of Chicago were targeted, but significant ridership also comes from suburban residents. CMAQ funds were used to defray the cost of operating the shuttles, with additional support provided by employer contributions and Metra, the Chicago region's commuter rail service provider. Pace, which is responsible for Chicago's suburban bus service, operates the Shuttle Bug.

Demand for the shuttle service has grown steadily—from 110 trips per day in 1996 to more than 800 daily trips in 2001; buses have replaced vans (Jackson and Murtha 2001, 5–6). The most recent survey of users indicated that prior to the shuttle service, approximately 55 percent of users drove alone to work. Thus, an estimated 2.7 tons of VOCs has been eliminated through a reduction of 1.8 million vehicle-miles traveled (VMT) each year (Jackson and Murtha 2001, 20). Preliminary estimates of project costs relative to pollution reduction benefits alone are high (between $165,000 and $200,000 per ton of VOCs eliminated), but continuing ridership gains and calculation of other uncounted benefits (e.g., congestion reduction) should improve this performance.

Encouraging Transit Use on High-Ozone Days: Clean Air Action Program, Houston

The Clean Air Action Program, sponsored by the Houston–Galveston Area Council and the Metropolitan Transit Authority of Harris County (METRO), is designed to educate the public

(*continued*)

BOX 4-1. *(continued)* **CMAQ Success Stories**

about the region's ozone problem and encourage voluntary actions to reduce motor vehicle emissions through proper vehicle maintenance, reduced vehicle trips, and combining of trips (EPA 1999, 7–8). One of the most successful elements of the program is the "August Is Clean Air Month" transit fare subsidy campaign. CMAQ funds were used in 1997 through 1999 to subsidize transit fares by 50 percent during August, which typically has the highest number of ozone exceedance days.

An evaluation of the program by METRO revealed that 13 percent of the 36 percent increase in transit ridership over the 3-year period could be attributed to the program, although the evaluation showed diminishing returns in the third year (METRO 2000, 1). One of the benefits of the program has been an increase in year-round ridership, resulting in an estimated annual reduction of 27 million VMT (assuming 50 percent retention of August ridership) and elimination of 18 tons of VOCs annually (EPA 1999, 8; METRO 2000, 16). Program costs are high [nearly $300,00 per ton of VOCs eliminated (EPA 1999, 8)], but do not include the benefits of increased transit ridership and reduced highway congestion.

Commuter Connections Employer Outreach Program: Washington, D.C., Metropolitan Area

The Washington, D.C., region's Commuter Connections program was developed to reduce drive-alone commuter travel. It includes a telework resources center, a guaranteed ride home and ride matching services, and an employer outreach program. With the help of CMAQ funds, the program now includes a dedicated sales force that promotes transportation demand strategies directly to region employers (EPA 1999, 11–12). Employers can access Commuter Connection services by simply dialing an easy-to-remember 800 number. In 1997, the first year of operations, the program resulted in 15 employers establishing new

(*continued*)

BOX 4-1. *(continued)* **CMAQ Success Stories**

transit benefit programs (i.e., subsidized transit passes for employees), 12 commuter information displays at employer work sites, and 43 on-site commuter information fairs.

An evaluation of the employer outreach program from 1997 through mid-1999 showed 415 participating employers with estimated daily trip reductions of 7300 and daily VMT reductions of 90,000 attributable to the outreach effort (Ramfos et al. 1999, 21). Together these reductions were estimated to have eliminated 23 tons of VOCs and 39 tons of NO_X annually at a cost of approximately $18,000 per ton of VOCs eliminated, not counting the benefits of NO_X reductions or other nonenvironmental benefits (e.g., congestion reduction) (Ramfos et al. 1999, 21).

TranStar: Houston's Traffic Control and Incident Management Center

Local agencies in the Houston area combined resources to open a TranStar Management Center in 1996 to manage Houston's highly congested freeway traffic using the latest transportation management technologies. Under a single roof and a unified management structure, the city of Houston, Harris County, the Metropolitan Transit Agency, the Texas Department of Transportation, and law enforcement authorities monitor traffic conditions in real time, detect incidents, and coordinate rapid response to traffic crashes and vehicle breakdowns (FHWA 1996, 18–19).

Funded originally as part of an intelligent transportation system demonstration corridor, the center recently sought CMAQ funds to finance projects that benefit multiple agencies; the local match is provided by contributions from agency members. For example, CMAQ funding was used to fund the TranStar computer facility. Cost-effectiveness estimates are not available, but response time to incidents by authorities has been reduced by one-third, resulting in more rapid clearance of incidents, reducing congestion, and enabling motorists to maintain higher and more constant travel speeds (FHWA 1996, 18).

The high risk of failure inherent in any innovation and the lack of experience of many project sponsors in implementing federally assisted projects were cited as the primary reasons for the relatively low success rate (Jackson and Murtha 2001, 2). Nevertheless, local agency staff noted that both failures and successes add to the body of knowledge about which strategies work better and why (Jackson and Murtha 2001, 2).

Public–private partnerships, encouraged by the program, were evident in many of the case study sites. For example, in Southern California, the San Bernardino Associated Governments is working with a private utility in a pilot project to convert forklifts to clean-fuel operation. The Riverside County Transportation Commission was also engaged with a private utility, California Edison, to electrify truck stops to eliminate idling emissions, but the project was canceled because of the energy crisis in California. The Ventura County Transportation Commission is working with the Southern California Gas Company to provide compressed natural gas (CNG) fueling facilities to ensure long-term fueling capabilities and price stability for local CNG transit buses and other vehicles. In Chicago, the CMAQ program is supporting a partnership between the City of Chicago and the Wendella Sightseeing Company, Inc., to improve ferry service along the Chicago River to better serve commuter rail lines (see Box 4-2). As with demonstration projects, however, these arrangements can pose large administrative burdens on the public partner, particularly when they include not-for-profit agencies or private-sector partners that have little experience with regulations and requirements of federal programs. Moreover, because these projects are often one-of-a-kind, they can require the development of new or modified administrative procedures, a time-consuming process for the lead public agency. For example, the Wendella Boat project required a special ordinance between the city and the boat company authorizing the execution of the CMAQ grant agreement, which resulted in a significant delay in the project (Poska et al. 2001, 13).

Many of those interviewed noted the lack of ex-post project evaluations as an important program weakness. They stressed that the focus should be not on individual project assessments, such as the effects of a single traffic signalization improvement, but on how

BOX 4-2. Wendella RiverBus Service, Chicago

Wendella Boats has operated a commuter ferry service along the Chicago River since 1962. In 1999 the Chicago Area Transportation Study, the metropolitan planning organization for the Chicago region, conducted a survey to determine whether the service was eligible to receive CMAQ funds for the purchase of additional boats to improve commuter service. The RiverBus operates from April to early November on docks along the Chicago River, strategically located to efficiently serve many Metra commuter rail customers. For example, the Madison Street dock is one block from the Ogilvie Transportation Center, which serves Union Pacific rail lines, and is linked to the dock by an enclosed pedestrianway (Poska et al. 2001, 2, 5).

The survey revealed that the vast majority of RiverBus users are Metra riders, who were diverted from either taxi service or a commute by passenger vehicle because of the ferry service (Poska et al. 2001, 6, 8). A small but positive effect on reducing VMT and vehicle emissions was identified, signaling the go-ahead for the city to engage in a contractual arrangement with the boat service. The cost per ton of VOCs eliminated over the 20-year life of the project was estimated at $16,850 (Poska et al. 2001, 13).

groups of similar projects affect the system. Suggestions for encouraging more evaluation ranged from a federal set-aside of CMAQ funds for evaluation activities (although many did not want to see funds taken away from projects) to a more active federal role in project evaluation and sharing of best practices (e.g., using samples of similar projects across nonattainment areas to analyze which projects are most effective and most cost-effective and which factors most influence these outcomes).

Another important program weakness from the local perspective is the lack of provision for operation and maintenance of new CMAQ-funded facilities and services. Several of those interviewed thought the CMAQ program encourages short-term solutions. In their view, CMAQ provides startup funds for new facilities, equipment, and services, but leaves local governments with the burden of financing equipment replacement and operating expenses because of program restrictions on funding for operations.[27] Suggested changes ranged from relaxing the current 3-year limit for most projects to enable local areas to locate alternative funding sources, to doing away with the restrictions altogether.

Future Program Scope and Activities

A broad range of regional transportation planners, operating agency staff, air quality officials, and interest groups who were interviewed for the case studies or briefed the committee at its meetings supported reauthorization of the CMAQ program. This is not surprising because the program offers local agencies a targeted source of federal funds to address the stringent CAAA requirements in areas with poor air quality. However, program funding is modest by transportation standards, and some regions have a backlog of unfunded projects. Thus, many respondents were hesitant about the advisability of broadening the scope of the program to cover additional pollutants unless funding levels are also expanded. They suggested that the focus should be on making the current program better. Those interviewed in Chicago perhaps expressed the reservation best: "We barely understand VOCs; we need to stay focused." Others thought the program should keep pace with whatever pollutants come to be regulated, even if this means spreading the funds more widely as new regions become noncompliant. They also recommended that newly regulated pollutants be added to the CMAQ apportionment formula as a basis for future allocation of funds.

Despite the flexibility of the current program, there were numerous suggestions for expanding project eligibility—too numerous to catalogue fully here. Those who were favorably disposed toward expanding the scope of the program to include other pollutants had

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[27] Some urban transit operators made the further point that projects that support existing transit services and ridership should be an eligible expenditure. In their view, restricting funds to new transit services and operations prejudices the program in favor of suburban areas.

several suggestions for new activities. For example, some suggested that as greater attention is focused on fine particulates and air toxics, such as those from diesel fuel, projects directed toward emissions of heavy-duty vehicles and even off-road vehicles should be made eligible because these vehicles are large contributors to pollution from these sources. Others went a step further and recommended that any project that can demonstrate the potential to reduce mobile source emissions should be eligible. The other most frequently suggested area for expanding project eligibility was land use. Smart-growth measures (e.g., sidewalks and other pedestrian-friendly strategies) were among those most frequently mentioned.

COMMITTEE ASSESSMENT AND FINDINGS

In this chapter, the available evidence has been assembled to address the key evaluation issues raised in the committee's charge. Early in its review, the committee concluded that it could not provide a scientifically grounded, quantitative evaluation of the cost-effectiveness of the CMAQ program as a whole at the national level. Program funds represent a relatively small fraction of any given region's transportation budget, and they are often broadly distributed within an area for diverse projects. In the spirit of ISTEA and TEA-21, decisions about project spending priorities have been devolved to the states, and within the states to local agencies in nonattainment and maintenance areas. The regional and sometimes more localized character of pollution and congestion problems means that regions differ in their spending priorities and selection of individual strategies. Thus, it is more sensible and feasible to evaluate individual strategies funded by the program as they have been implemented in different regions.

Two in-depth literature reviews were commissioned to examine the effectiveness of strategies similar to those funded by the program in relation to their cost and to other strategies for achieving the CMAQ program goals. The limited available evidence presented in these papers suggests that, when compared on the sole criterion of emissions reduced per dollar spent, strategies aimed directly at emission reductions (e.g., new-vehicle emission and fuel standards, well-structured I&M programs, remote sensing programs, vehicle scrappage programs)—some of which are eligible for CMAQ funding, but most of which are not—generally have been more successful in reducing emissions than most CMAQ-eligible TCMs that rely on changes in travel behavior.[28]

The committee agreed with this finding, but found the evidence inadequate to address fully the questions posed under its charge. First, nearly all the results are based on modeled estimates and thus are susceptible to modeling uncertainties. The results for I&M programs illustrate the problem. Modeled results show I&M as a highly cost-effective strategy, but a recent study (NRC 2001) revealed that the emission benefits are overestimated for many I&M programs. TCMs are particularly affected by modeling uncertainties because travel behavior as well as vehicle emissions must be estimated, and the available models are not suited to analyzing small-scale projects typical of many TCMs. Second, emission data were available only for VOCs and NO_x; if data on particulates had been available, the ranking of projects that address particulates (e.g., alternative-fuel buses) would likely have been higher. Third, as the wide range of TCM cost-effectiveness results shows, the performance of individual strategies is context specific even for projects in the same category. Fourth, many TCMs have benefits other than emission reductions (e.g., congestion mitigation), which were not captured in the analyses. Finally, several of the most cost-effective strategies have been implemented, but nonattainment areas still require additional emission reductions to reach or stay in conformity. Thus, TCMs are likely to be employed in meeting the next round of required reductions even if they are less cost-effective than other strategies. For all these reasons, the committee concluded that the evidence on project cost-effectiveness was not sufficient for a definitive evaluation of the program.

The strongest evidence for the program is qualitative. The information gathered by the committee during the site visits and the briefings conducted for this study offered strong support for continuation of the program. First, the CMAQ program helps fund the

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[28] The necessary data were simply not available to investigate how well the program is meeting its other goal of congestion mitigation.

strict mandates and regulations required of nonattainment areas by the 1990 CAAA. The committee supports funding of federal mandates and recognizes the CMAQ program as the only transportation program explicitly targeted to meeting the transportation-related air quality goals of the CAAA. Second, the committee sees value in a program limited to expenditures on projects with demonstrable potential air quality benefits. If CMAQ projects had to compete with the large backlog of infrastructure preservation projects in most large metropolitan areas, the air quality focus of these funds likely would not be a priority. Third, the program provides an incentive to encourage nontraditional approaches to solving air quality and congestion problems. By focusing on new facilities and services and providing funds for projects that have limited alternative funding sources, the program has enabled areas to experiment with what they believe are innovative strategies. The fact that these projects are not numerous and are often small should not be surprising. By its nature, innovation is risky, with high failure rates, and thus only a limited number of such projects can be undertaken at any given time. Finally, the CMAQ program gives local areas great flexibility in tailoring funds to projects that address specific air quality and congestion problems. Deployed in this way, CMAQ funds can also foster interagency cooperation and encourage participation of new groups in project planning and selection—all desirable outcomes.

On the basis of the evidence just described, the committee concludes that the program should be reauthorized, but several modifications are in order. First, a more strategic approach may be needed in some nonattainment areas to link CMAQ-funded projects more closely to local air quality and congestion problems, and to identify measurable objectives so that project performance can be monitored more closely and strategies altered as new information becomes available. Second, project cost-effectiveness could be enhanced if the program recognized emerging knowledge about the health hazards of various pollutants (e.g., particulates) and directed more funds toward these problems (e.g., heavy-duty vehicle projects). Finally, perhaps the greatest potential benefit of the CMAQ program is the development of new strategies for pollution reduction. However, this benefit is now mostly lost because there is no reliable way to tell how successful different strategies are and no mechanism for sharing the information among program recipients. The committee believes more extensive evaluation, at both the local and national levels, should be undertaken, using CMAQ funds to help ensure that the wealth of accumulated experience can be examined and shared more systematically in the future.

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Abbreviations

EPA	U.S. Environmental Protection Agency
FHWA	Federal Highway Administration
GAO	General Accounting Office
METRO	Metropolitan Transit Authority of Harris County
NRC	National Research Council
TRB	Transportation Research Board

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FINDINGS AND RECOMMENDATIONS

A summary of the key findings resulting from the committee's assessment of the CMAQ program is presented in this chapter, and the committee's recommendations for improving the program are provided. As discussed in Chapter 4, the supporting evidence for these findings and recommendations is largely qualitative, drawn from the committee's review of program operations to date, the papers commissioned for this study, the case studies conducted by and briefings provided to the committee, and the committee's understanding of the changing air quality and travel context in which the program operates.

SUMMARY OF FINDINGS

It is not possible to undertake a credible scientific quantitative evaluation of the cost-effectiveness of the CMAQ program at the national level. An evaluation of the CMAQ program must take into account the magnitude of the air quality problem in the United States and must also provide a realistic expectation of the influence one relatively small program can have on improving air quality. Pollution from transportation is only one of many sources of emissions; industry is also a major polluter. The CMAQ program is modestly funded and accounts for a small portion of any region's transportation budget. Thus, evaluation of the effectiveness of the CMAQ program even at the local level is difficult because the effects of most CMAQ projects are small compared with those of other sources of variation in emissions and air quality. In addition, methods for measuring the effects of many CMAQ-funded projects on emissions and air quality are limited at present. The available models are not suited to estimating the emissions effects of small projects or linking these effects with air quality. Moreover, few evaluations have been conducted following the completion of CMAQ projects to determine whether modeled estimates have been realized. Thus, the basic data needed to carry out a cost-effectiveness analysis are not available.

Even if better data and analytic methods were available, it would be unrealistic to attempt a nationwide cost-effectiveness analysis of the CMAQ program. Regions have differing priorities for their use of CMAQ funds; some are more interested in congestion mitigation, others in air quality. Hence finding a common basis on which to measure program effectiveness is difficult. Moreover, the costs and effects of CMAQ-funded projects are highly location specific. They can vary greatly within one metropolitan area, not to mention among areas. The performance of a project in a given region depends on the transportation systems already in place, the air quality and congestion mitigation measures already implemented, and the projects (CMAQ-funded and others) implemented together with any CMAQ projects. Therefore, an infeasible number of local studies would have to be conducted to aggregate local results credibly into a national total.

A broad range of regional transportation planners, operating agency staff, air quality officials, and interest groups consulted for this study see value in the CMAQ program and support its continuation. This conclusion is not surprising because the CMAQ program helps finance the mandates imposed on the transportation sector by the 1990 Clean Air Act Amendments (CAAA). It provides funds specifically to assist regions with poor air quality in reaching and maintaining conformity. Without this restriction, the money likely would go to other uses, such as the backlog of infrastructure rehabilitation and expansion needs. For many regions that have implemented most available pollution reduction strategies, CMAQ-funded transportation control measures (TCMs) offer an additional source of reductions that can help keep an area in conformity and within state implementation plan (SIP) emission budget targets.

The CMAQ program also provides funds that can be used for a wide range of activities, enabling areas to tailor their projects and programs to address specific local air quality and congestion problems and priorities. The program affords great flexibility in comparison with many other transportation programs whose funds are restricted to specific programmatic areas (e.g., highways, bridges).

The complexity of transportation funding in general creates an incentive to try to tailor investment programs to available funds, instead of establishing funding priorities based on investment worthiness. Flexible funds are therefore of great value to regions.

The CMAQ program provides regions with the incentives and opportunity to experiment with nontraditional transportation projects, particularly alternatives to highway projects that are popular among elected officials and citizens. Given the scarcity of available funding, this focus would probably not have occurred without the CMAQ program.

The committee was unable to determine whether the CMAQ program had resulted in any measurable change in transportation funding priorities at the national level. The Intermodal Surface Transportation Efficiency Act (ISTEA), which authorized the CMAQ program in 1991, introduced major changes in transportation and funding arrangements. For example, ISTEA imposed the transportation planning requirements that complemented the conformity provisions of the 1990 CAAA and also ended the practice of including unfunded projects in transportation plans. It was not possible to segregate the impact of the CMAQ program from that of other elements of ISTEA because the program was one of many changes in funding policy made simultaneously. Thus, the committee was forced to conclude that the shifts in funding priorities since 1991 have had as much to do with these other changes as with CMAQ, a relatively small element of the ISTEA legislation.

The CMAQ program has helped foster the participation of new groups in the transportation planning and project selection process, building partnerships among diverse groups and expanding the number of stakeholders involved in transportation. CMAQ has complemented other elements of ISTEA in this emphasis on a more participatory and inclusive transportation planning process. The CMAQ program has also encouraged more interagency consultation and cooperation as local transportation agencies have been forced to think seriously about strategies for reducing pollution and congestion in their regions.

The CMAQ program provides an opportunity to measure the cost-effectiveness of individual projects or groups of projects at the local

level. Because of the variety and sometimes innovative nature of the projects funded, the CMAQ program constitutes a valuable laboratory for learning how well different types of projects perform in improving air quality and reducing congestion. To date, however, the evaluations that have been conducted have been of limited use. One reason for this is that none of the evaluations provide direct measurements of the primary final program outcomes—changes in pollutant concentrations and congestion levels. Another is that even the more sophisticated evaluations of necessity involve estimating such crucial effects as changes in traffic volumes or trips using models or inputs derived from models that were developed for regional analysis, and hence are too aggregate to capture the effects of highly location-specific projects. Some of these models, particularly emissions models, also have untested accuracy. Yet another problem is that most of the evaluations of TCMs are based on projected rather than actual outcomes. As a result of these problems, the levels of uncertainty of modeled estimates of project effects in some cases probably exceed the magnitude of the effects. Even when individual studies are reliable, it is difficult to make meaningful comparisons across projects because of differences in assumptions and methods. All these problems can be ameliorated with more attention to evaluation procedures. Thus, it is possible to make great improvements in the present ability to track the effectiveness of CMAQ projects.

The limited evidence available suggests that, when compared on the sole criterion of emissions reduced per dollar spent, approaches aimed directly at emission reductions (e.g., new-vehicle emission and fuel standards, well-structured inspection and maintenance programs, and vehicle scrappage programs) have generally been more successful than most CMAQ strategies relying on changes in travel behavior (i.e., TCMs). The past record indicates that broad regulatory control strategies, such as new-vehicle emission and fuel standards, and other measures directly targeting vehicle emission reductions have generally been more cost-effective than attempts under the CMAQ program to change travel behavior. Nonetheless, the cost-effectiveness of some TCMs—those involving regional ridesharing, regional transportation demand management, and some pricing strategies—

compares favorably with that of non-CMAQ-eligible control strategies. There is considerable uncertainty about these conclusions, however. First, the comparisons are based on estimates of emission reductions for the ozone precursors only—volatile organic compounds (VOCs) and oxides of nitrogen (NO_x)—because the data were generally not available for other pollutants. Had estimates of emission reductions for particulates and carbon monoxide (CO) been available, strategies focused on these pollutant sources (e.g., alternative-fuel buses) might have ranked more favorably. Second, the wide range of cost-effectiveness results for TCMs, even for the same type of CMAQ strategy, suggests that performance depends largely on context, that is, on where and how projects are executed. Third, many TCMs have benefits other than emission reductions (e.g., congestion mitigation, ecological effects). Finally, the estimates for nearly all strategies are affected by modeling uncertainties. Modeled estimates have generally tended to overestimate emission reductions. Inspection and maintenance programs provide a good illustration. Modeled results show such programs to be highly cost-effective, but a recent study (NRC 2001) revealed that the emission benefits are overestimated for many of these programs. Modeling uncertainties are compounded for TCMs, which require the prediction of travel as well as emission effects, adding to the uncertainty of the estimates.

The CMAQ program encourages innovation and experimentation that can lead to the development of cost-effective projects. The program provides incentives and resources for local agencies to think seriously about new strategies for improving air quality and reducing congestion. With its focus on new facilities and services and its breadth of eligible nontraditional transportation projects, the program encourages local areas to experiment and provides the opportunity to fund small demonstration projects. If local areas can learn from the successes and failures of these efforts and share this learning widely, some of these projects may in time warrant broader implementation and leverage more traditional funding sources.

The historical performance of CMAQ projects does not provide a basis for confident projections about the future cost-effectiveness of these projects. Since the CMAQ program was enacted in 1991, the vehicle fleet has gradually become cleaner as newer vehicles meeting more stringent emission regulations have come to make up a larger share of the fleet, and alternative-fuel vehicles have become more common. These changes will alter the relative desirability and cost-effectiveness of different strategies. For example, they will probably make it increasingly difficult in the future to find projects that address both congestion and air quality. Traffic flow improvements undoubtedly had greater impacts when cars were "dirtier." Automobile emissions are increasingly a function of the small number of dirty cars and of certain types of driving (e.g., hard accelerations, grades), a fact that enhances the value of such strategies as use of remote sensing and well-structured inspection and maintenance programs to detect and possibly repair heavily polluting vehicles, and vehicle scrappage programs designed to take these vehicles off the roads. Once cost-effective strategies have been applied in a nonattainment area, more stringent versions of these programs (e.g., enhanced inspection and maintenance, regional ridesharing) to achieve further emission reductions would probably be adopted only at much higher cost. Finally, new knowledge is emerging about the adverse health effects of pollutants, such as particulates and air toxics, that are not currently a program emphasis. Focusing more attention on strategies that address the primary transportation sources of these pollutants—heavy-duty diesel vehicles—may have important benefits.

RECOMMENDATIONS

The quantitative evidence reviewed by the committee on the benefits of the CMAQ program did not provide a strong basis for either supporting or opposing continuation of the program. Nonetheless, on the basis of its review of the available qualitative as well as quantitative evidence on program effectiveness, the committee reached consensus on the following recommendations.

1. **The CMAQ program has value and should be reauthorized with the modifications recommended below.** The potential benefits of the CMAQ program are sufficiently great, in the collective judgment of the committee, to warrant its continuation. This judgment is made despite the inadequacy of the data to support an overall quantitative cost-effectiveness evaluation, for the following reasons.

First, CMAQ is the only federally funded transportation program explicitly targeting air quality improvement. Arguably the most important benefits of the CMAQ program are the incentives and resources provided to local agencies to think seriously about strategies for improving air quality and reducing congestion. Second, the funds provided are restricted to these purposes, offering an opportunity for local nonattainment areas to experiment with nontraditional transportation approaches to pollution control, and to forge new partnerships and greater interagency cooperation in the development of such approaches. Third, some of the most promising TCMs in terms of cost-effectiveness (according to admittedly uncertain data) receive limited if any support from traditional transportation funding sources, and thus depend on CMAQ for a full exploration of that promise. Fourth, the program helps nonattainment and maintenance areas fund the strict mandates and pollution control schedules required by the 1990 CAAA. Finally, CMAQ provides a flexible source of funds that can be used for a wide range of activities tailored to local pollution and congestion problems.

2. **Air quality improvement should continue to receive high priority in the CMAQ program.** Although the formal justification for the program gives equal weight to congestion management and air quality goals, in fact the latter have been given higher priority. It is desirable to maintain this focus on air quality because congestion management is already addressed by the much larger share of highway funds spent on infrastructure. At the same time, congestion management projects may in many instances make important contributions to the improvement of air quality, and such projects should be supported by the program. However, the primary criteria by which the cost-effectiveness of these projects and more generally that of all CMAQ-eligible projects are judged should relate to the reduction of air pollution. The CMAQ program's legislative restriction on projects involving construction of new capacity for single-occupant vehicle travel should also be maintained, given the uncertain effects of such projects on air quality and the availability of other funds for this purpose.

3. **Consistent with maintaining a focus on the air quality dimensions of the program, state and local air quality agencies should be involved more directly in the evaluation of proposals for**

the expenditure of CMAQ funds. Program regulations encourage consultation with state and local air quality agencies in the development of appropriate project selection criteria and the agencies' involvement in project and program funding decisions. The case studies conducted by the committee suggest that some regions do involve air quality agencies in these ways, but often the agencies have a more limited role. Air quality agencies are expressly charged with reducing emissions of air pollutants and meeting national air quality standards. Moreover, at least in some regions (e.g., Southern California), air quality agencies have generally greater technical expertise than transportation agencies concerning current understanding of air pollution phenomena, emission control technologies, and the cost-effectiveness of various control approaches. Thus in many regions, the role of air quality agencies should be strengthened so they can become more meaningful participants in the CMAQ project review process.

4. **The components of air quality addressed by the CMAQ program should be broadened to include, at a minimum, all pollutants regulated under Title I of the Clean Air Act.** The CMAQ program is focused primarily on VOCs, NO_x, and CO. This focus is too narrow in view of emerging knowledge of other pollutants and their adverse health effects. For example, it is incongruous that particulate matter (PM), now believed to pose a greater health hazard than any of the other criteria pollutants, is included in CMAQ only for project eligibility, not as part of the funding allocation formula. At a minimum, the eligibility criteria and allocation formula should include all pollutants regulated under the Clean Air Act, which would cover PM_{10}, as well as sulfur dioxide and air toxics.

Any changes to regulated pollutants, such as implementation of new standards for fine particulates ($PM_{2.5}$), should automatically be reflected in the CMAQ eligibility criteria and funding formula. Inclusion of $PM_{2.5}$ would encourage regions to use CMAQ funds to a greater extent for the support of projects involving heavy-duty diesel vehicles. Moreover, when U.S. policies are put in place to address carbon dioxide and other greenhouse gas emissions, projects focused on these emissions should also be considered for eligibility for CMAQ funding. The issues are sufficiently important and complex, however, that a separate funding program may be required.

5. **Any local project that can demonstrate the potential to reduce mobile source emissions should be eligible for CMAQ funds.** The CMAQ program should encourage metropolitan planning organizations (MPOs) to select and approve the most cost-effective local strategies available for reducing mobile source emissions. For example, on the basis of the review of vehicle scrappage programs provided in Appendix F and summarized in Chapter 4, these programs, which appear to be more cost-effective than many other types of projects routinely approved under the CMAQ program, should be eligible for CMAQ funding.[1] Current restrictions on the use of public funds for private purposes should be reviewed to permit such programs. Regions should also consider wider use of CMAQ funds for projects focused on heavy-duty diesel vehicles and freight transport that can demonstrate the potential to reduce particulate emissions.

6. **Restrictions on the use of CMAQ funds for operating assistance should be relaxed if it can be demonstrated that using the funds for this purpose continues to be cost-effective.** The restriction on using CMAQ funds for operating expenses of newly initiated CMAQ projects for more than 3 years creates an incentive for making capital expenditures that may not be efficient, and may arbitrarily eliminate some cost-effective operating expenditures. For example, the best way to increase transit ridership may often be to reduce fares. At the margin, this measure could reduce trip making in old cars. The use of CMAQ funds to expand bus service generally results in highly subsidized service. When the operating subsidies are removed, the service often cannot be continued.

The committee recognizes that not all operating subsidies are cost-effective or will continue to be so. Moreover, once projects have commenced, local pressures to continue them could increase if restrictions on the use of CMAQ funds for project operations are

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[1] A recently published dissertation on travel behavior, older vehicles, and vehicle scrappage programs (Dill 2001) provides a comprehensive assessment of such programs, including consideration of the roles and use of older vehicles in U.S. households. Dill finds that most vehicle scrappage programs reduce emissions significantly, particularly emissions of VOCs. It should be noted, however, that as vehicles become cleaner, it remains to be seen what emission reductions will be achieved and thus whether vehicle scrappage programs will continue to be cost-effective.

eliminated. Thus, the committee recommends that all proposed CMAQ projects—capital or operating—be evaluated through a process, outlined below, that should help establish the cost-effectiveness of proposed and funded projects. The use of CMAQ funds for operations should not be an entitlement and should be reviewed in competition with applications for other projects.

7. **The use of CMAQ funds should be considered for land use actions designed to establish the conditions for long-term reductions in future mobile source emissions.** The potential of land use strategies to reduce congestion or vehicle emissions is complex and unclear. There appears to be some evidence to support the link between urban design (i.e., the relative location of activity and housing, mixed-use design) and encouragement of travel modes other than the automobile (EPA 2001; Ewing and Cervero undated). Thus with further study, projects that support transit- and pedestrian-oriented development might be made eligible for CMAQ funding.[2] Other land use actions—such as Portland, Oregon's, revolving capital fund, which has been used to aggregate land in appropriate locations for sale to developers—could also be considered.

8. **The agency responsible for CMAQ project selection in each nonattainment area should develop a process by which projects can be identified, selected, and evaluated in the context of the specific air quality and congestion problems of that region. In turn, the federal project approval process should be streamlined.** The committee believes many nonattainment areas could do a better job of selecting projects for CMAQ funding that are linked more closely to the specific air quality and congestion problems of the region, and of developing the information needed to determine whether project and program objectives have been accomplished. For example, the lead agency responsible for the CMAQ program in a region could seek the advice of air quality agencies and public health

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[2] The Environmental Protection Agency (EPA) has prepared a guidance document (EPA 2001) that provides recommendations regarding the kinds of land use activities that can be accounted for in SIPs and conformity determinations. The document also presents a sketch planning model—EPA's Smart Growth Index—that can be used to determine whether a particular land use activity may have air quality benefits (EPA 2001, 65).

experts in identifying the most effective pollution control strategies. It could also review the recommendations of the ISTEA-required congestion management plans that most urbanized areas larger than 200,000 in population must prepare to identify proposed strategies and steps already taken to address regional congestion problems. Once this context-setting effort has been completed, the lead agency could define objectives for its CMAQ program and develop measurable performance indicators so that individual project outcomes could be quantified. At a minimum, these indicators should include measures to estimate emission reductions, but it would also be desirable to define and measure other effects, such as congestion mitigation and, where appropriate, effects on ecosystems or economic development.

The intent of this structure is not to add a new layer of regulatory requirements, but to build on and strengthen the existing transportation planning and certification process. With greater ability to measure program performance against objectives, responsible local agencies should be in a better position to document the effects of CMAQ projects, report on those effects to their constituencies, and provide more complete input to FHWA's national CMAQ database that could be used for evaluation purposes.

Once a nonattainment area has implemented a process along the lines just described, determinations of project eligibility by federal program sponsors should no longer be required. Projects should be precertified as long as a region can demonstrate that they are consistent with the program objectives outlined above. Of course, all National Environmental Policy Act requirements would still need to be addressed if applicable to specific projects.

9. **Recipients of CMAQ funds should be given incentives to conduct more evaluations of funded projects, and federal program sponsors should provide guidance on best practices for these evaluations.** One of the greatest benefits of the CMAQ program may well be the development of new strategies that can be adopted by other localities or incorporated into subsequent federal legislation. This benefit is now largely lost because there is no reliable way to gauge the success of different strategies. Local agencies are currently required to provide information on the expected emission reduction potential of

funded projects for the FHWA database, but evaluation of the effects of implemented projects is not required.

Recipients of CMAQ funds should be expected to conduct more follow-up to determine whether the anticipated reductions have been realized and examine the factors that have made a project successful. The committee realizes it would be impractical for a region to evaluate all its CMAQ projects. Likely candidates include individual projects that are expensive or controversial and groups of small projects (e.g., bicycle projects or traffic signal improvements) that together have measurable effects. For example, the Chicago MPO—the Chicago Area Transportation Study (CATS)—undertook an evaluation of CMAQ-funded bicycle projects that proved quite beneficial in evaluating and selecting among bicycle projects for future CMAQ funding. The evaluation consisted of a survey conducted by CATS staff of bicycle riders on bicycle paths that had been funded by CMAQ. Riders were asked (*a*) the purpose of their trip (e.g., commuting, recreation), (*b*) the length and destination of the trip, and (*c*) the alternative mode of transportation that would have been taken, if any, had the bicycle path not been built. The results of the survey helped CATS staff identify bicycle path locations that attracted commuters rather than recreational bikers, determine whether bicycle trips replaced trips by car, and develop estimates of the emission reductions attributable to those trips. FHWA, in consultation with EPA, should provide program recipients with guidance on best practices for conducting such evaluations, including examples and contacts for additional information. Two recent initiatives by FHWA are a start in the right direction—the primer describing modeling tools and other analytic methods that can be used to assess the potential emission benefits of CMAQ project applications (Louis Berger Associates 2000) and the development of a 2-day course on the CMAQ program for state and local program recipients. The latter course includes treatment of evaluation methods such as before-and-after analysis, estimation of emission reductions and other performance measures for candidate projects, and case studies (FHWA 2001).

Although program recipients might prefer that all CMAQ funds be reserved for projects, evaluation is in the interest of both federal sponsors and local recipients, and thus is an entirely appropriate use of CMAQ funds. The best incentive to encourage more local project evaluation would be to provide additional funds for this purpose.

10. **A more targeted program of evaluation should be undertaken at the national level, to include in-depth evaluation studies, synthesis and dissemination of results, research on appropriate analysis methods, and monitoring.** The CMAQ program offers a rare opportunity to evaluate a diverse group of implemented projects whose primary purpose is to improve air quality and reduce congestion. Little systematic evaluation has been undertaken, even though TCMs were widely employed well before the CMAQ program was established. This lack of evaluation is partly the result of the intrinsic difficulty of predicting or measuring the effects of strategies that cause only small changes in emissions, air quality, and travel costs. Models are under development that should provide for more accurate assessments of the travel variables and emission levels affected by TCMs, and methods are being devised to measure changes in emissions and pollutant concentrations at the tailpipe directly.

FHWA, in consultation with EPA, should take the lead in initiating a well-focused national program of evaluation financed by CMAQ funds set aside for this purpose. The program would fund a selected group of studies—perhaps drawing on a representative sample of CMAQ projects both within and across regions—in which competitively selected researchers would work with local agencies to collect baseline data and track project performance using credible evaluation criteria. FHWA or EPA should synthesize the results of these studies and maintain a cumulative database for their broad dissemination.

Appropriate research designs, methods, and models for conducting evaluations of difficult-to-measure TCMs are also appropriate topics for study, but CMAQ should not be the sole funding source for this purpose because the results will have application well beyond the program. For example, the appropriate geographic or programmatic scale at which measurements should be carried out is not always evident. Such questions must be addressed as what geographic boundaries are appropriate for measuring the impacts of a traffic flow improvement project that include the effects of induced travel, and whether it would be better to group small projects for analysis instead of evaluating their effects separately.

The program should also include a monitoring component to help program sponsors remain abreast of the relevant science. Topics addressed might include, for example, human health effects and exposure assessment research concerned with in-vehicle and near-roadway exposure, as well as ecological effects of vehicle emissions and other secondary impacts.

Concluding Comments

Since its inception, the CMAQ program has provided nonattainment areas with a modest but valuable source of funds dedicated to addressing their air quality and related congestion problems. The program has offered incentives for regions to develop effective local pollution control strategies, drawing from a wide range of eligible projects. It has also encouraged broad participation by local agencies and public interest groups in strategy development, and has enabled them to experiment with nontraditional and innovative approaches. If the program is reauthorized in line with the above recommendations, the committee believes its sponsors should be in a better position in the future to account for the cost-effectiveness of implemented projects, evaluate the success of different strategies, monitor advances in scientific knowledge, and share this information widely among program recipients and the general public.

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Abbreviations

EPA	U.S. Environmental Protection Agency
FHWA	Federal Highway Administration
NRC	National Research Council

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APPENDIX A

TEXT OF CONGRESSIONAL REQUEST

Conference Report for H.R. 2400, Transportation Equity Act for the 21st Century (TEA-21), May 22, 1998.

SEC. 1110. CONGESTION MITIGATION AND AIR QUALITY IMPROVEMENT PROGRAM.

(e) Study of CMAQ Program.—

(1) Study.—The Secretary and the Administrator of the Environmental Protection Agency shall enter into arrangements with the National Academy of Sciences to complete, but not later than January 1, 2001, a study of the congestion mitigation and air quality improvement program under section 149 of title 23, United States Code. The study shall, at a minimum—

(A) evaluate the air quality impacts of emissions from motor vehicles;

(B) evaluate the negative effects of traffic congestion, including the economic effects of time lost due to congestion;

(C) determine the amount of funds obligated under the program and make a comprehensive analysis of the types of projects funded under the program;

(D) evaluate the emissions reductions attributable to projects of various types that have been funded under the program;

(E) assess the effectiveness, including the quantitative and non-quantitative benefits, of projects funded under the program and include, in the assessment, an estimate of the cost per ton of pollution reduction;

(F) assess the cost effectiveness of projects funded under the program with respect to congestion mitigation;

(G) compare—
  (i) the costs of achieving the air pollutant emissions reductions achieved under the program; to
  (ii) the costs that would be incurred if similar reductions were achieved by other measures, including pollution controls on stationary sources;

(H) include recommendations on improvements, including other types of projects, that will increase the overall effectiveness of the program;

(I) include recommendations on expanding the scope of the program to address traffic-related pollutants that, as of the date of the study, are not addressed by the program.

(2) REPORT.—Not later than January 1, 2000 [sic], the National Academy of Sciences shall transmit to the Secretary, the Committee on Transportation and Infrastructure and the Committee on Commerce of the House of Representatives, and the Committee on Environment and Public Works of the Senate a report on the results of the study with recommendations for modifications to the congestion mitigation and air quality improvement program in light of the results of the study.

(3) FUNDING.—Before making the apportionment of funds under section 104(b) (2) of title 23, United States Code, for each of fiscal years 1999 and 2000, the Secretary shall deduct from the amount to be apportioned under such section for such fiscal year, and make available, $500,000 for such fiscal year to carry out this subsection.

APPENDIX B

NOTE ON THE FORMATION OF OZONE AND SECONDARY FINE PARTICULATE MATTER

OZONE FORMATION

Ozone is formed by the reaction of atomic and molecular oxygen. The only significant oxygen atom production in the troposphere is from photodissociation of nitrogen dioxide (NO_2) into nitric oxide (NO) and oxygen atoms, Reaction 1. The oxygen atoms react with molecular oxygen to produce O_3, Reaction 2. When nitrogen oxides are present, O_3 reacts rapidly with NO to regenerate NO_2, Reaction 3. The first and third reactions occur rapidly, establishing a steady-state equilibrium ozone concentration, which is proportional to the NO_2/NO ratio. Because these reactions only recycle O_3 and NO_x, they are insufficient, by themselves, to create excessive ozone levels.

When volatile organic compounds (VOCs) are present, their oxidation produces the hydroperoxy radical (HO_2) and organic peroxy radicals (RO_2), which react with NO to form NO_2 without destruction of ozone, thereby allowing ozone to accumulate. For the majority of VOCs emitted from anthropogenic and natural sources, the reaction with the hydroxyl radical (HO) initiates the oxidation sequence. However, there is a competition between VOCs and NO_x for the HO radicals. VOCs are consumed in the sequence of ozone formation, while both NO_x and HO and HO_2 radicals act as catalysts. Termination occurs when HO_2 combines to form hydrogen peroxide (H_2O_2) or by reaction of HO with NO_2 to form HNO_3. O_3 production is related to the number of NO to NO_2 conversions effected by VOCs and their decomposition products over the entire photooxidation cycle. The ozone production efficiency (OPE) is defined as the number of O_3 molecules produced per NO_x molecule emitted. This parameter is relevant for the development of regional ozone-mitigation strategies because it provides an indication of the reduction in O_3 that might be expected for a given reduction in regional NO_x emissions. OPE also provides a basis for weighting NO_x emission reductions in the calculations of cost-effectiveness of control measures (i.e., cost of the control measure in dollars divided by the expected emission reductions in tons).

Estimates of OPE, ranging from 7 to 10, were initially derived on the basis of linear relationships between O_3 and the oxidation products of NO_x at rural sites (Trainer et al. 1993). Chin et al. (1994) derived a lower limit for OPE of 1.7 and argued that the earlier estimates overstated OPE because NO_x is removed from the atmosphere more rapidly than is O_3. More recent studies involving direct, airborne measurements within power plant and urban plumes (Ryerson et al. 1998) and regional analyses of rural O_3 monitoring data (Kasibhatla et al. 1998) yield OPE values in the range of one to three molecules of O_3 per molecule of NO_x.

The concentration of NO_x and VOC/NO_x ratios are the two main factors affecting the OPE. At low VOC/NO_x ratios, HO reacts predominantly with NO_2 to form HNO_3, removing radicals and NO_x from the photochemical cycle and retarding O_3 formation. Under these conditions, a decrease in NO_x concentration favors O_3 formation (ozone formation is hydrocarbon limited). High VOC/NO_x ratios favor HO reaction with VOCs that generate new radicals that accelerate O_3 production. However, at a sufficiently low concentration of NO_x, or a sufficiently high VOC/NO_x ratio, a further decrease in NO_x favors peroxy-peroxy reactions, which retard O_3 formation by removing free radicals from the system (ozone formation is NO_x limited). At a given level of VOC, there exists a NO_x mixing ratio at which a maximum amount of ozone is produced. This optimum VOC/NO_x ratio depends on the reactivity of HO to the particular mix of VOCs present. Because NO_x is removed faster than hydrocarbons, VOC/NO_x ratios tend to increase during transport, and ozone formation can change from hydrocarbon limited in the urban core to NO_x limited in downwind suburban and rural locations. Accordingly, NO_x reductions could lead to higher peak 1-hour average O_3 levels in the urban locations that are currently hydrocarbon limited, but to lower 8-hour average O_3 levels in downwind locations. Ozone formation is complex, and a thorough understanding of the response of ozone levels to specific changes in VOC or NO_x emissions is the fundamental prerequisite to developing cost-effective ozone abatement strategies.

FORMATION OF SECONDARY FINE PARTICULATES

The gaseous precursors of most particulate sulfates and nitrates are SO_2 and NO_x, respectively. Ambient concentrations of sulfate and nitrate are not necessarily proportional to quantities of emissions because the rates at which they form may be limited by factors other than the concentration of the precursor gases. The majority of secondary sulfates are found as a combination of sulfuric acid, ammonium bisulfate, and ammonium sulfate. The majority of secondary nitrates in PM_{10} are found as ammonium nitrate, though a portion of the nitrate is also found in the coarse particle fraction, usually in association with sodium (this is presumed to be sodium nitrate derived from the reaction of nitric acid with the sodium chloride in sea salt).

Sulfur dioxide changes to particulate sulfate through gas- and aqueous-phase transformation pathways. In the gas-phase pathway, sulfur dioxide reacts with hydroxyl radicals in the atmosphere to form hydrogen sulfite. This species rapidly reacts with oxygen and small amounts of water vapor to become sulfuric acid gas. Sulfuric acid gas has a low vapor pressure. It condenses on existing particles and nucleates at high relative humidities to form a sulfuric acid droplet or, in the presence of ammonia gas, becomes neutralized as ammonium bisulfate or ammonium sulfate. When fogs or clouds are present, sulfur dioxide can be dissolved in a droplet, where it experiences aqueous reactions that are much faster than gas-phase reactions. If ozone and hydrogen peroxide are dissolved in the droplet, the sulfur dioxide is quickly oxidized to sulfuric acid. If ammonia is also dissolved in the droplet, the sulfuric acid is neutralized to ammonium sulfate. The major pathway to nitric acid is reaction with hydroxyl radicals. Nitric acid leaves the atmosphere fairly rapidly, but in the presence of ammonia it is neutralized to particulate ammonium nitrate.

Sulfur dioxide to particulate sulfate and nitrogen oxide to particulate nitrate reactions compete with each other for available hydroxyl radicals and ammonia. Ammonia is preferentially scavenged by sulfate to form ammonium sulfate and ammonium bisulfate, and the amount of ammonium nitrate formed is only significant when the total ammonia exceeds the sulfate by a factor of two or more on a mole basis. In an ammonia-limited environment, reducing ammonium sulfate concentrations by one molecule would increase ammonium nitrate concentrations by two molecules. This implies that reducing SO_2 emissions might actually result in ammonium nitrate increases that exceed the reductions in ammonium sulfate where the availability of ammonia is limited.

While the mechanisms and pathways for inorganic secondary particles are fairly well known, those for secondary organic aerosols are not well understood. Hundreds of precursors are involved in these reactions, and the rates at which these particles form are highly dependent on the concentrations of other pollutants and meteorological variables. Organic compounds present in the gas phase undergo atmospheric transformation through reactions with reactive gaseous species such as OH radicals, NO_3 radicals, or O_3. Secondary organic compounds in particulate matter include aliphatic acids, aromatic acids, nitro aromatics, carbonyls, esters, phenols, and aliphatic nitrates (Grosjean 1992; Grosjean and Seinfeld 1989). However, these compounds can also be present in primary emissions [see, for example, Rogge (1991)]; thus they are not unique tracers for atmospheric transformation processes. Particles are formed when gaseous reaction products achieve concentrations that exceed their saturation concentrations. Fraction conversion factors, based on experimental data taken in smog chamber experiments, relate the aerosol products of selected precursors to the original quantities of those precursors. Applying these factors to chemically speciated emission inventories provides an approximate estimate of the equivalent emissions of secondary organic particles. Grosjean (1992) shows that these equivalent emissions are comparable with primary emissions from other carbon-containing sources, such as motor vehicle exhaust in the Los Angeles area. While this empirical model provides an order-of-magnitude estimate of the VOC impacts on PM_{10}, quantitative estimates are very imprecise.

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APPENDIX C

ANALYSIS OF THE CMAQ DATABASE

Harry S. Cohen, *Ellicott City, Maryland*

The Federal Highway Administration (FHWA) maintains a database on all projects funded under the Congestion Mitigation and Air Quality (CMAQ) program. The database provides information on type of project, location, funding level, and estimated emission reductions. Currently, the database covers the first 8 years of the CMAQ program (FY 1992–1999).

The following are provided in this appendix:

- A description of the database,
- A summary of what the data show about the types of projects funded and emission reductions,
- An assessment of the usefulness of the database for this study, and
- Recommendations for improvements to the database.

The FHWA CMAQ database for each fiscal year provides the following information on individual projects in each state:

- A brief text description of the project;
- Project type;
- Amount obligated for the project in the fiscal year; and
- Estimated emission reductions in kilograms per day for volatile organic compounds (VOCs), nitrogen oxides (NO_x), carbon monoxide (CO), and particulates (PM_{10}).

Text descriptions, project type, and amount obligated are provided for all projects in the database. As discussed in more detail below, estimates of emission reductions are provided for many, but not all, projects.

The text descriptions in the database usually provide an indication of where in the state the project was located and the type of work involved. The locations may be specified in terms of a route designation, city, or county. Examples of these descriptions, selected at random from the database, are provided in the accompanying text box.

Examples of Project Descriptions from the CMAQ Database

Employee commute options—Bridgeport
Land use ordinance demo
Hawthorn Bridge—sidewalk improvement (CONSTR)
Construction funding for park-and-ride lot at MD108/MD32
Hillsborough County video surveillance system
Additional design cost for grade-separated interchange
Roadway/geometric/signal improvements
City of Wilmington signals
US-17N in Myrtle Beach, closed-loop signal system
Purchase of 40 large passenger buses
SORTA FY 1995 Clean Air Fare Subsidy

With regard to project type classifications, the program guidance document (FHWA 1992, 12–13)[1] asks states to classify CMAQ projects as follows:

- Transit: construction, equipment, or operating expenses for new and improved services and parking for transit services.
- Other shared-ride: vanpool and carpool programs, parking for shared-ride services.
- Highway/road (traffic flow):[2] traffic management and control services, signalization projects, intersection improvements, and construction or dedication of high-occupancy vehicle (HOV) lanes.

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[1] The most recent program guidance (FHWA 1999, 22) adds two new project categories—public–private partnerships and experimental pilot projects.

[2] In the FY 1992 database, these projects are referred to as "highway/road"; in subsequent years, they are referred to as "traffic flow."

- Demand management: employer trip reduction programs, transportation management plans, flexible work schedule programs, vehicle restriction programs.
- Pedestrian/bike: trails, storage facilities, promotional activities.
- Inspection and maintenance and other transportation control measures (not covered by the above categories).

The CMAQ project categories listed above are broad. For example, "traffic flow" includes both the construction of HOV lanes and the retiming of traffic signals. Similarly, "transit" includes both the purchase of alternative-fuel buses and the addition of parking spaces at a transit station.

States that have no nonattainment or maintenance areas are allowed to use their CMAQ funds for any project eligible for federal funding under the Surface Transportation Program (STP) or CMAQ. Also, other states receiving the minimum apportionment may use a portion of their CMAQ funds for any project eligible for federal funding under the Surface Transportation or CMAQ programs under certain circumstances.[3] In the CMAQ database, these projects are designated as "STP/CMAQ."

States are required to provide the amount of CMAQ funds obligated for each project (or project category where groups of projects are analyzed together) for the year, disaggregated by the categories of projects listed above. However, it appears that obligations in the CMAQ database are not reconciled with the CMAQ program obligations from the Federal Management Information System (FMIS). For example, according to FMIS, total obligations for CMAQ in FY 1997 were $807 million. Total FY 1997 obligations for all projects in the CMAQ database were $773 million. While the difference is small

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[3] CMAQ funds are apportioned to the states on the basis of the population in nonattainment and maintenance areas multiplied by a weighting factor. The weighting factor is based on the pollutant for which the area is in nonattainment and its severity. All states get a minimum apportionment whether or not they have nonattainment or maintenance areas. Those states without nonattainment or maintenance areas may use their minimum apportionment for any projects eligible under either the CMAQ program or the STP. In those minimum allocation states with nonattainment or maintenance areas where the CMAQ formula results in less than the minimum apportionment, the funds may be used in addition to the formula amount for any CMAQ- or STP-eligible project.

(less than 5 percent in FY 1997), it would nonetheless be desirable to avoid publishing two different estimates of CMAQ obligations for a fiscal year.

The committee investigated the desirability of using the FMIS database to obtain information about CMAQ projects, particularly programmatic detail. Limitations of that database, however, precluded this option.[4]

CLASSIFICATION OF PROJECTS

The project classification scheme used in the CMAQ database was expanded to examine the composition of the CMAQ program in more detail and to link program expenditures with specific types of projects for which data on cost-effectiveness are available in the literature. The categories and subcategories are as follows:

- Transit
  - Alternative-fuel vehicles
  - Conventional fuel transit vehicles
  - Park-and-ride facilities
  - Station and bus stop improvements
  - Transit service expansion
  - Other transit improvements
- Traffic flow
  - Congestion and incident management
  - HOV lanes
  - Traffic signal improvements
  - Traveler information
  - Turn lanes and other intersection improvements
  - Other traffic flow improvements

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[4] A comparison of CMAQ data compiled from FMIS by the Surface Transportation Policy Project for FY 1992–1997 and FHWA's CMAQ database for the same years showed a significant undercount for many project categories. For example, in FMIS, bicycle and pedestrian projects that are part of larger improvements never appear as separate projects in the database. Hence FMIS represents a serious undercount of CMAQ-funded bicycle and pedestrian projects. Similarly, transit projects are undercounted—43 percent for FY 1992–1997 in the FHWA CMAQ database versus 32 percent in the FMIS database for the same period. Moreover, since the Transportation Equity Act for the 21st Century, no data are collected on transit projects in FMIS, a critical omission for one of the most important CMAQ spending categories.

- Shared ride
  - Park-and-ride facilities
  - Other shared ride
- Pedestrian/bicycle (no subcategories)
- Demand management
  - Employee trip reduction
  - Other demand management
- STP/CMAQ (no subcategories)
- Other (and unclassifiable)
  - Alternative-fuel vehicles
  - Paving and sweeping to reduce PM
  - Rail freight
  - Vehicle inspection and maintenance
  - All other improvements

The project descriptions in the CMAQ database were used to assign projects to the above subcategories. Also, in cases where projects appear to have been misclassified, they were switched from one major category to another.[5]

In many cases, it was difficult to determine appropriate subcategories on the basis of project descriptions. For example, many of the project descriptions under "transit" were just the name of a transit agency or line. These were classified as "other transit improvements." Similarly, many of the project descriptions under "traffic flow" were just the name of an intersection or highway. These were classified as "turn lanes and other intersection improvements," even though it was possible that only traffic signal improvements were made at these intersections.

COMPOSITION OF THE CMAQ PROGRAM

Using the categories and subcategories listed above, Figure C-1 and Table C-1 show the composition of the CMAQ program for the 8-year period from FY 1992 to FY 1999.

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[5] Less than 1 percent of the project amounts that were originally classified as "transit," "traffic flow," and "pedestrian/bicycle" appear to have been misclassified. However, about 25 percent of the project amounts originally assigned as "demand management" were reassigned to other categories on the basis of the project description. Also, about 20 percent of the projects originally assigned as "STP/CMAQ" were reassigned to categories that were more descriptive of project type (mostly to "traffic flow" and "transit").

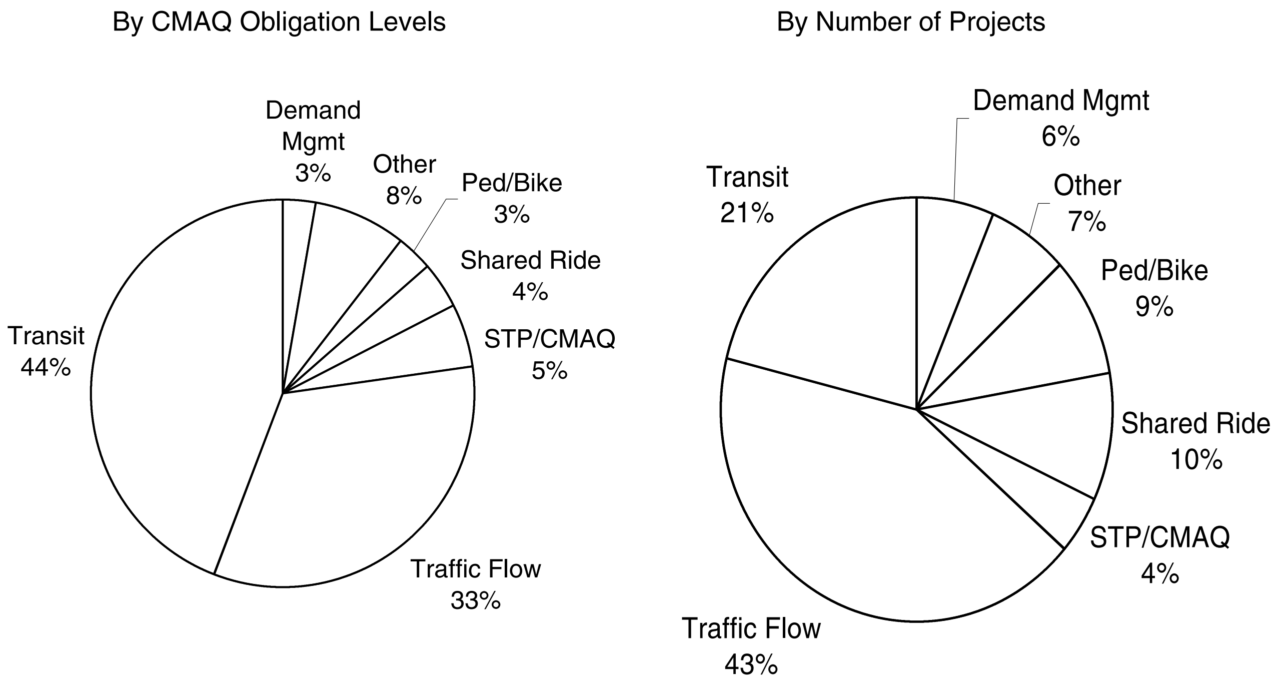

Figure C-1 CMAQ spending priorities, FY 1992–1999. (Source: FHWA CMAQ database.)

TABLE C-1 CMAQ Obligations by Type of Project (FY 1992–1999)

Project Category and Subcategory	FY 1992–1999 Obligations	
	Millions of Dollars	Percent
Transit		
Alternative-fuel vehicles	193	3.1
Conventional-fuel transit vehicles	800	12.7
Park-and-ride facilities	91	1.5
Station and bus stop improvements	302	4.8
Transit service expansions	456	7.2
Other transit improvements	937	14.9
Subtotal	2,780	44.1
Traffic flow		
Congestion and incident management	508	8.1
HOV lanes	291	4.6
Traffic signal improvements	536	8.5
Traveler information	84	1.3
Turn lanes and other intersection improvements	295	4.7
Other traffic flow improvements	371	5.9
Subtotal	2,086	33.1
Shared ride		
Park-and-ride facilities	85	1.4
Other shared ride	152	2.4
Subtotal	238	3.8
Pedestrian and bicycle	199	3.2
Demand management		
Employee trip reduction	51	0.8
Other demand management	133	2.1
Subtotal	184	2.9
STP/CMAQ	338	5.4
Other (and unclassifiable)		
Alternative-fuel vehicles	40	0.6
Paving and sweeping to reduce PM	55	0.9
Rail freight	23	0.4
Vehicle inspection and maintenance	264	4.2
All other improvements	94	1.5
Subtotal	476	7.6
Grand total	**6,300**	**100.0**

Together, transit and traffic flow improvement projects accounted for slightly more than three-fourths (77 percent) of CMAQ obligations during the first 8 years of the program. These types of projects provide benefits in addition to emission reductions, such as time savings to highway and transit users. Types of projects for which most of the benefits are emission reductions or energy savings—alternative-fuel vehicles, paving and sweeping to reduce PM, and vehicle inspection and maintenance—account for only about 8 percent of CMAQ obligations.

Figure C-1 also shows the number of projects funded between FY 1992 and FY 1999 by project type. Slightly more than two-fifths (43 percent) of the projects were traffic flow improvements, but only one-fifth (21 percent) of the projects were transit related, compared with 44 percent when project value is the analysis criterion. The differences arise because the amount of obligations per project is not the same for each category. For example, in comparison with other CMAQ project categories, transit projects have relatively higher dollar obligations per project. Hence, transit represents a larger share of the CMAQ program when the program is analyzed by value of projects than when analyzed by numbers of projects.

Trends over Time

Table C-2 shows the composition of the CMAQ program by type of project for each fiscal year. This information is provided in graphical form in Figures C-2 through C-8. As suggested by the following observations, the composition of the CMAQ program has been changing over time.

Transit Projects (Figure C-2)

CMAQ obligations for all transit projects range from 34 percent in FY 1997 and FY 1998 to more than 50 percent in FY 1995 and FY 1999. These variations are due to the effects of a few large projects. In FY 1995, $76 million was obligated for the construction of a busway from downtown Pittsburgh to the airport and another $76 million for the purchase of rail cars for the Southeastern Pennsylvania Transportation Authority's Market-Frankfort line. In FY 1999, $124 mil-

TABLE C-2 CMAQ Obligations by Type of Project for Each Fiscal Year

Project Category and Subcategory	Percentage for Fiscal Year								
	FY 1992	FY 1993	FY 1994	FY 1995	FY 1996	FY 1997	FY 1998	FY 1999	Total
Transit									
Alternative-fuel vehicles	0.3	6.9	2.9	3.5	2.6	4.3	1.5	1.9	3.1
Conventional-fuel transit vehicles	17.8	11.1	17.1	15.5	9.5	9.3	8.7	14.2	12.7
Park-and-ride facilities	1.4	2.5	1.5	1.2	1.3	0.8	0.7	2.1	1.5
Station and bus stop improvements	9.4	3.6	2.3	4.6	5.4	4.5	5.2	5.5	4.8
Transit service expansions	0.0	6.4	4.3	13.3	6.8	2.2	1.8	13.5	7.2
Other transit improvements	20.9	18.1	12.6	13.1	14.2	13.1	15.9	15.4	14.9
Subtotal	49.8	48.6	40.6	51.2	39.8	34.1	33.8	52.6	44.1
Traffic flow									
Congestion and incident management	1.9	5.3	10.8	9.9	7.7	8.0	4.6	10.5	8.1
HOV lanes	23.5	0.8	0.8	2.4	8.7	7.8	1.8	1.8	4.6
Traffic signal improvements	5.7	7.4	9.6	8.5	12.0	10.7	8.8	4.7	8.5
Traveler information	0.8	6.4	1.8	0.7	0.2	0.6	1.1	0.4	1.3
Turn lanes and other intersection improvements	4.0	2.9	2.6	3.2	7.0	11.4	3.6	2.8	4.7
Other traffic flow improvements	0.1	4.5	9.8	4.6	2.6	4.8	15.0	4.9	5.9
Subtotal	36.0	27.2	35.3	29.4	38.2	43.3	35.0	25.2	33.1

Shared ride									
Park-and-ride facilities	0.8	1.6	1.1	3.0	1.2	1.3	1.0	0.5	1.4
Other shared ride	2.1	4.0	3.1	2.0	1.6	1.7	2.7	2.5	2.4
Subtotal	2.9	5.6	4.2	5.0	2.8	3.1	3.7	2.9	3.8
Pedestrian and bicycle	3.0	3.0	2.2	1.5	4.0	4.9	4.4	2.7	3.2
Demand management									
Employee trip reduction	0.0	0.2	1.1	0.8	1.8	0.2	1.2	0.6	0.8
Other demand management	1.2	1.7	3.1	1.9	2.5	2.3	2.4	1.5	2.1
Subtotal	1.2	2.0	4.3	2.7	4.2	2.4	3.5	2.1	2.9
STP/CMAQ	6.6	6.8	6.3	3.5	5.2	6.1	7.9	3.3	5.4
Other (and unclassifiable)									
Alternative-fuel vehicles	0.0	0.5	0.8	1.5	0.0	1.3	0.6	0.0	0.6
Paving and sweeping to reduce PM	0.3	0.7	2.5	0.8	0.1	0.4	1.1	0.9	0.9
Rail freight	0.0	0.5	0.2	0.9	0.0	0.8	0.3	0.1	0.4
Vehicle inspection and maintenance	0.1	0.1	2.5	2.6	2.8	2.3	8.9	9.9	4.2
All other improvements	0.1	4.9	1.1	0.9	2.9	1.2	0.8	0.2	1.5
Subtotal	0.5	6.8	7.1	6.7	5.9	6.0	11.7	11.1	7.6
Grand total	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**

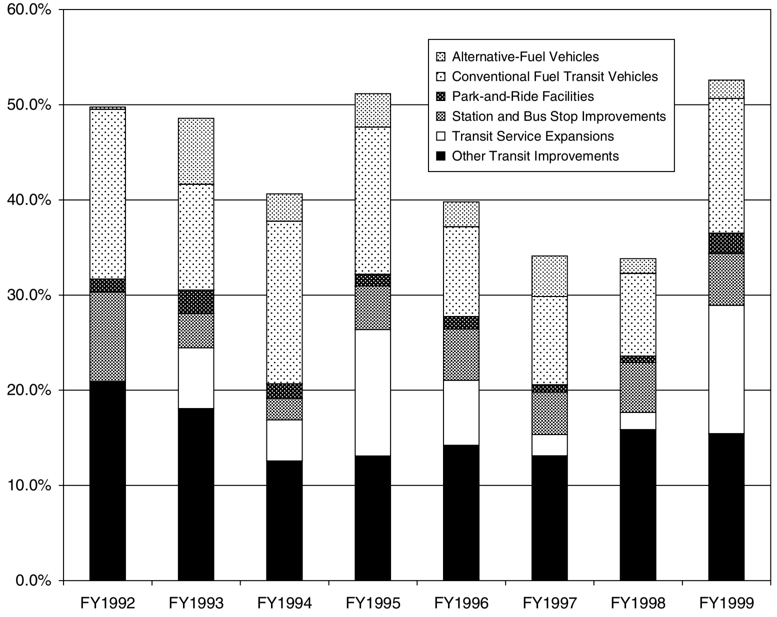

FIGURE C-2 Transit projects as percent of all CMAQ obligations, by fiscal year.

lion was obligated for the Red Line in Los Angeles and $46 million for advanced automatic train control from Daly City to downtown Oakland.

Traffic Flow Projects (Figure C-3)

- CMAQ obligations for all traffic flow projects exhibit no clear trend. They range from 25 percent of total CMAQ obligations in FY 1999 to 43 percent in FY 1997.
- HOV lanes accounted for nearly 24 percent of all CMAQ obligations in FY 1992, when $74 million was obligated to California for this purpose. Over the next 7 years, HOV lanes accounted for less than 10 percent of all CMAQ obligations. In FY 1998 and FY 1999, they accounted for only about 2 percent of all CMAQ obligations.

Shared Ride Projects (Figure C-4)

Obligations for shared ride projects have ranged between about 3 and 6 percent of all CMAQ obligations from FY 1992 to FY 1999. During the last 4 years, obligations were near the low end of the range.

Pedestrian and Bicycle Projects (Figure C-5)

CMAQ obligations for pedestrian and bicycle projects range from 1.5 percent (in FY 1995) to 5 percent (in FY 1997), with no clear trend over time.

Demand Management Projects (Figure C-6)

Demand management projects have accounted for between 2 and 4 percent of total CMAQ obligations since FY 1993.

STP/CMAQ Projects (Figure C-7)

STP/CMAQ projects have accounted for between 3 and 8 percent of total CMAQ obligations, with no clear trend over time.

Other Projects (Figure C-8)

Obligations for vehicle inspection and maintenance projects have been increasing over time. In FY 1992 and FY 1993, these projects accounted for just 0.1 percent of all CMAQ obligations. In the next 4 years, they accounted for 2 to 3 percent of total CMAQ obligations.

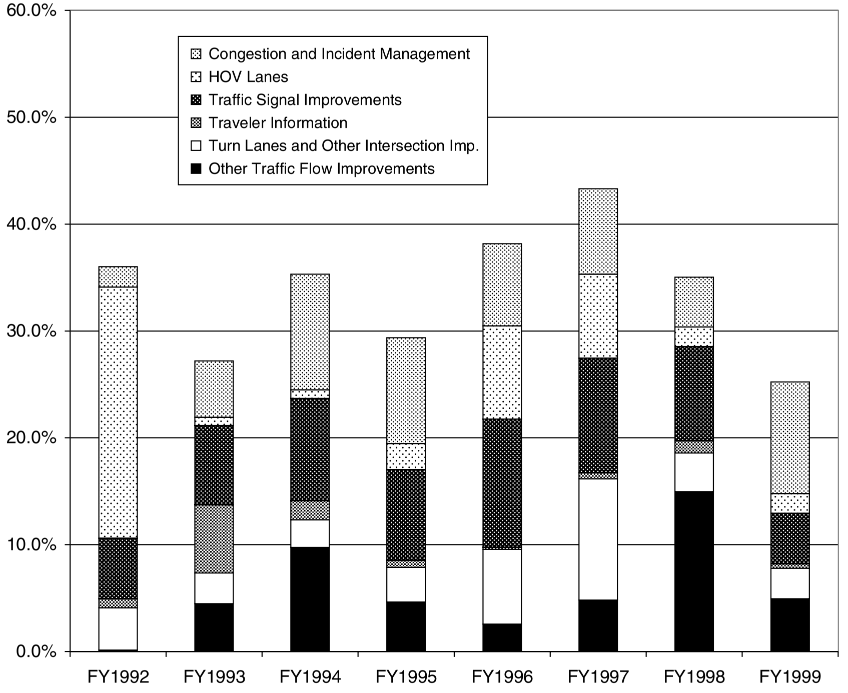

Figure C-3 Traffic flow projects as percent of all CMAQ obligations, by fiscal year.

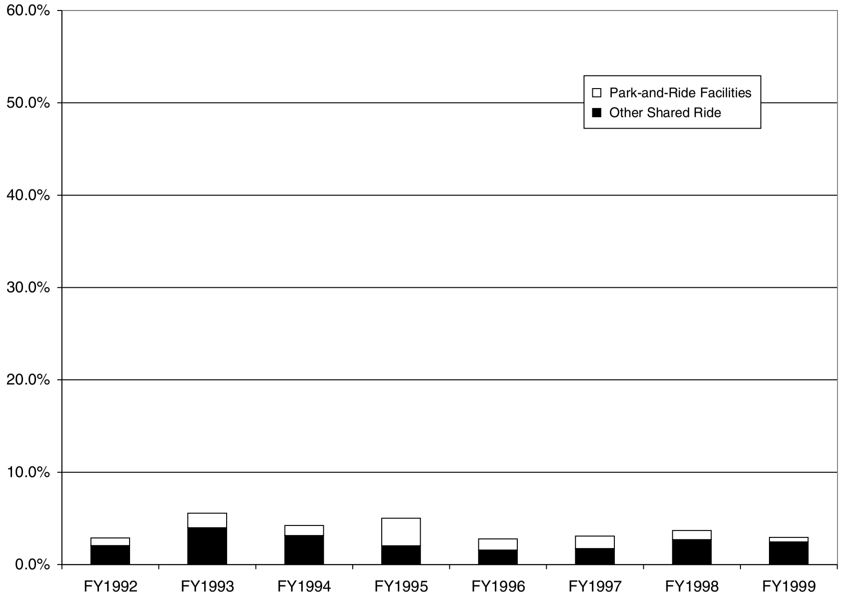

Figure C-4 Shared ride projects as percent of all CMAQ obligations, by fiscal year.

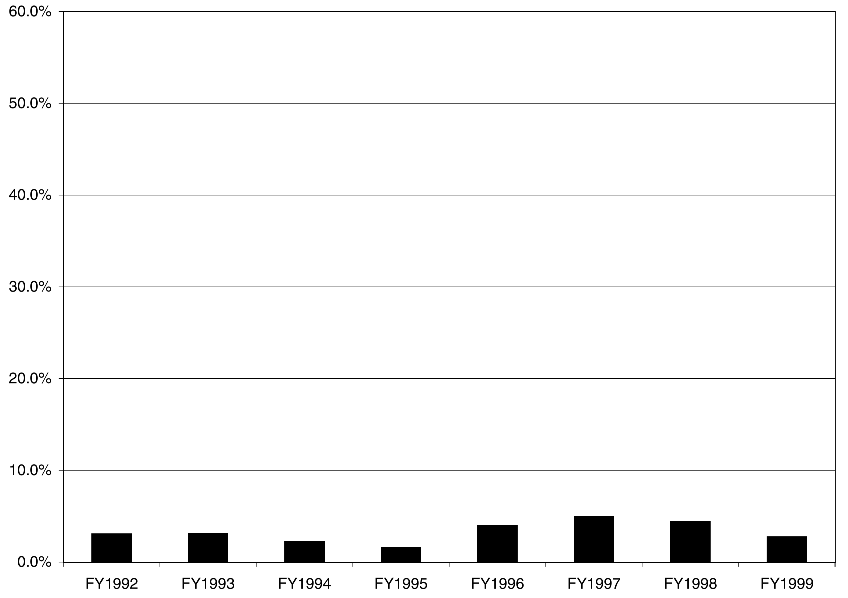

FIGURE C-5 Pedestrian and bicycle projects as percent of all CMAQ obligations, by fiscal year.

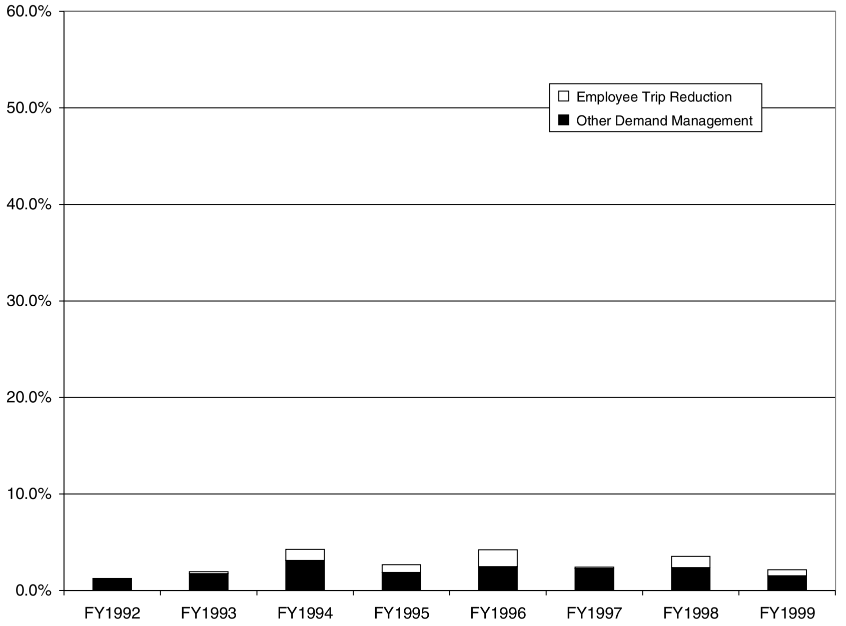

FIGURE C-6 Demand management projects as percent of all CMAQ obligations, by fiscal year.

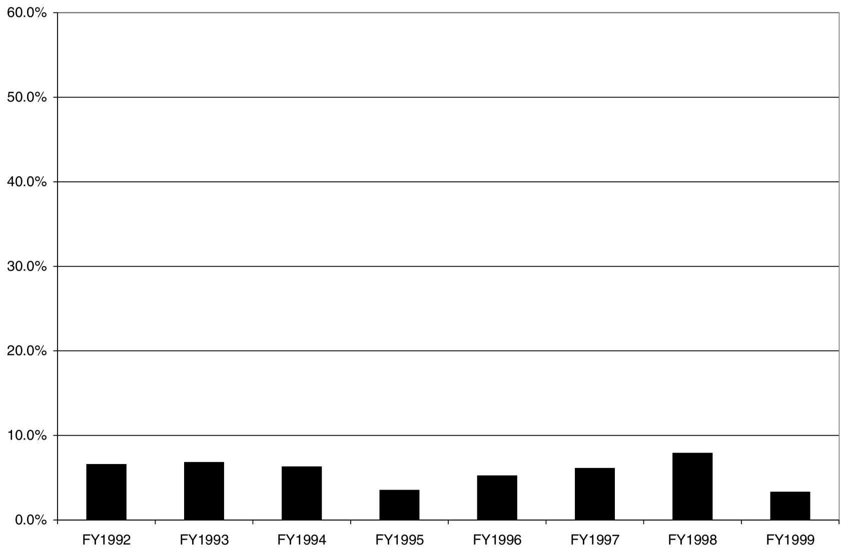

Figure C-7 STP/CMAQ projects as percent of all CMAQ obligations, by fiscal year.

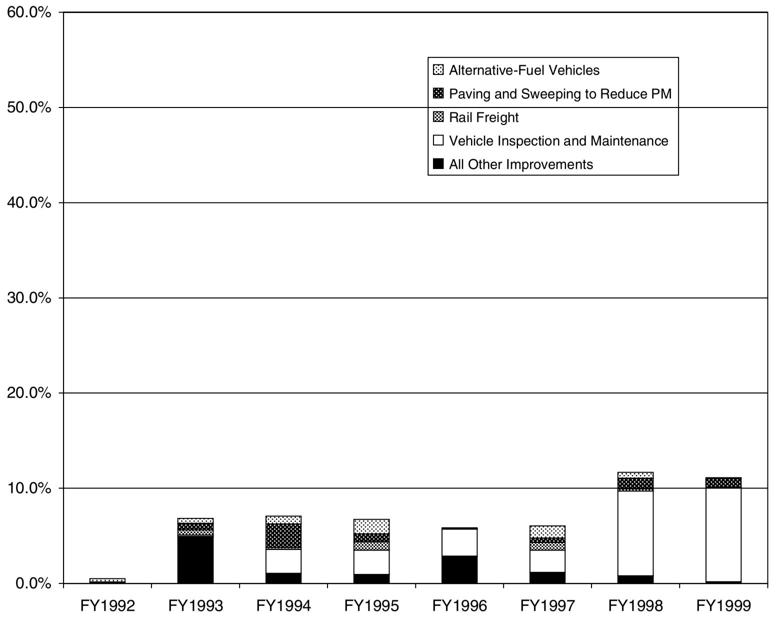

FIGURE C-8 Other projects as percent of all CMAQ obligations, by fiscal year.

In FY 1998 and FY 1999, they jumped to almost 10 percent of total CMAQ obligations.

Trends by DOT Region[6]

Table C-3 and Figures C-10 to C-16 show the composition of the CMAQ program for each of the 10 U.S. Department of Transportation regions. These data indicate that there are large differences across regions in how CMAQ funds are spent.

Transit Projects (Figure C-10)

- Transit projects account for more than 44 percent of all CMAQ obligations in Regions 1, 2, 3, 5, 9, and 10. In the other four regions, transit projects account for less than 25 percent of all CMAQ obligations.
- Projects involving conventional fuel transit vehicles range from less than 2 percent of total CMAQ obligations in Regions 6 and 8 to 26 percent of total CMAQ obligations in Region 3.
- Transit park-and-ride projects range from less than 0.1 percent of total CMAQ obligations in Regions 4, 8, and 9 to 5 percent in Regions 1 and 10.
- Transit station and bus stop improvements range from less than 1 percent of all CMAQ obligations in Regions 7 and 8 to 9 percent in Regions 1 and 2.
- Transit service expansions range from less than 3 percent of total CMAQ obligations in Regions 2, 6, 7, 8, and 10 to 16 percent in Region 1.

Traffic Flow Projects (Figure C-11)

- Traffic flow projects range from about 10 percent of total CMAQ obligations in Region 10 and 19 percent in Region 1 to 52 percent in Region 4 and 57 percent in Region 6.

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[6] Figure C-9 is a map showing the states in each of the 10 U.S. Department of Transportation regions.

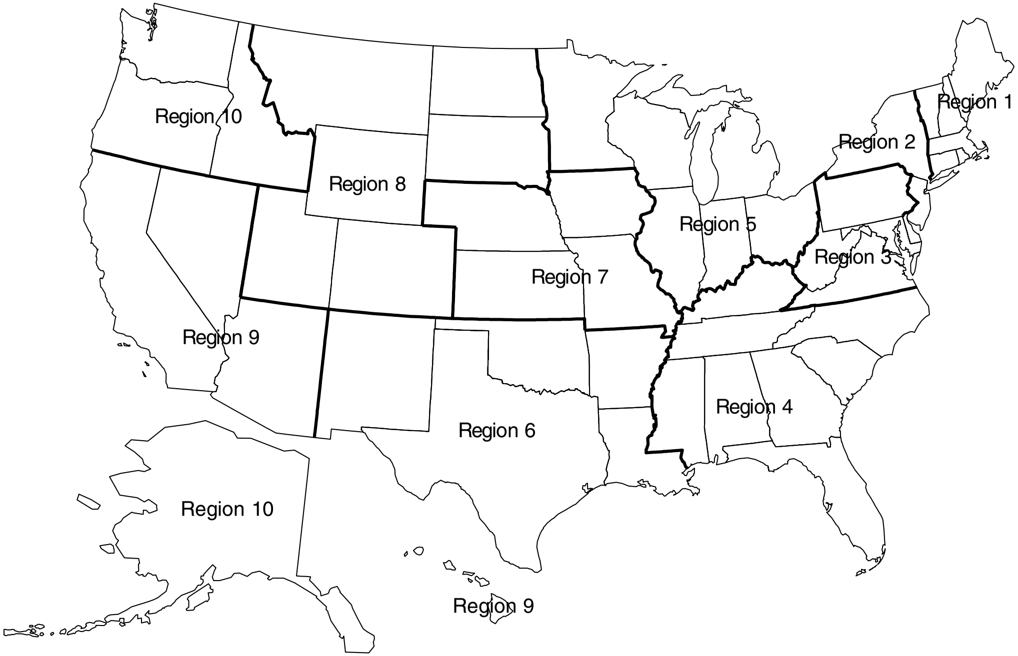

FIGURE C-9 U.S. Department of Transportation regions.

TABLE C-3 CMAQ Obligations by Type of Project for Each Region (FY 1992–1999)

Project Category and Subcategory	**Percentage for Region**										
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**Total**
Transit											
Alternative-fuel vehicles	1.0	2.0	1.7	1.6	4.6	2.6	0.0	0.3	5.9	4.1	3.1
Conventional-fuel transit vehicles	9.7	8.7	26.2	5.6	13.3	1.3	9.3	1.6	19.7	13.1	12.7
Park-and-ride facilities	4.9	0.4	2.3	0.0	3.4	0.5	0.4	0.0	0.0	5.2	1.5
Station and bus stop improvements	9.5	9.4	1.6	1.9	8.1	4.1	0.8	0.4	1.8	1.9	4.8
Transit service expansions	16.5	1.1	11.4	6.3	5.1	2.1	0.0	0.6	13.3	2.3	7.2
Other transit improvements	14.7	25.1	9.2	9.4	10.0	11.2	11.6	1.8	18.3	20.1	14.9
Subtotal	56.3	46.7	52.4	24.8	44.4	21.8	22.0	4.7	59.0	46.6	44.1
Traffic flow											
Congestion and incident management	3.1	5.9	4.8	13.7	7.9	22.8	9.0	4.6	6.4	0.8	8.1
HOV lanes	3.0	0.5	0.5	1.4	0.4	3.9	0.0	3.6	16.4	1.2	4.6
Traffic signal improvements	7.2	5.3	8.3	14.5	12.4	8.3	7.0	13.4	6.8	4.1	8.5
Traveler information	0.4	3.7	0.6	3.4	0.3	2.0	0.0	0.0	0.2	0.0	1.3
Turn lanes and other intersection improvements	3.5	5.3	4.4	12.5	4.5	8.0	7.4	3.5	0.8	0.4	4.7
Other traffic flow improvements	1.8	4.3	13.4	6.8	8.3	12.0	3.6	1.1	1.7	3.2	5.9
Subtotal	19.0	25.1	32.0	52.5	33.8	57.1	27.0	26.1	32.4	9.7	33.1

Shared ride											
Park-and-ride facilities	2.0	0.9	5.4	0.2	0.6	1.8	0.5	2.0	0.3	1.2	1.4
Other shared ride	4.4	1.5	1.8	3.7	1.9	2.1	1.7	6.2	2.1	2.4	2.4
Subtotal	6.4	2.4	7.1	3.9	2.5	3.9	2.2	8.3	2.4	3.6	3.8
Pedestrian and bicycle	1.7	4.6	0.6	2.7	3.3	2.1	0.1	4.6	2.3	18.7	3.2
Demand management											
Employee trip reduction	4.3	0.9	0.6	0.1	0.1	0.6	0.2	0.1	0.6	0.5	0.8
Other demand management	2.4	4.3	0.9	3.8	1.6	1.4	1.0	1.3	0.7	4.3	2.1
Subtotal	6.7	5.2	1.6	3.9	1.7	2.0	1.2	1.5	1.3	4.8	2.9
STP/CMAQ	2.6	2.5	2.7	8.6	0.0	10.2	29.5	48.2	0.9	2.5	5.4
Other (and unclassifiable)											
Alternative-fuel vehicles	1.1	1.1	0.5	0.4	0.2	2.1	0.0	0.0	0.1	0.3	0.6
Paving and sweeping to reduce PM	0.0	0.0	0.0	0.0	0.0	0.2	10.3	4.5	0.6	8.8	0.9
Rail freight	1.2	1.5	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.4
Vehicle inspection and maintenance	3.2	10.4	1.4	1.6	11.8	0.1	0.6	0.6	0.0	2.0	4.2
All other improvements	1.8	0.6	1.8	1.6	2.2	0.4	7.1	1.5	0.9	2.9	1.5
Subtotal	7.3	13.6	3.7	3.6	14.3	2.9	18.0	6.6	1.7	14.1	7.6
Grand total	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**

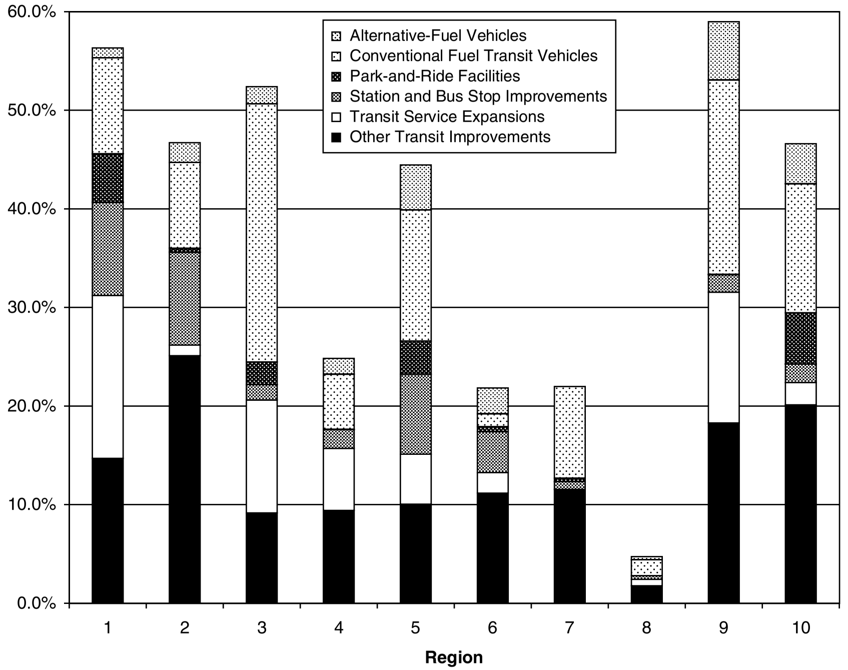

FIGURE C-10 Transit projects as percent of all CMAQ obligations, by region.

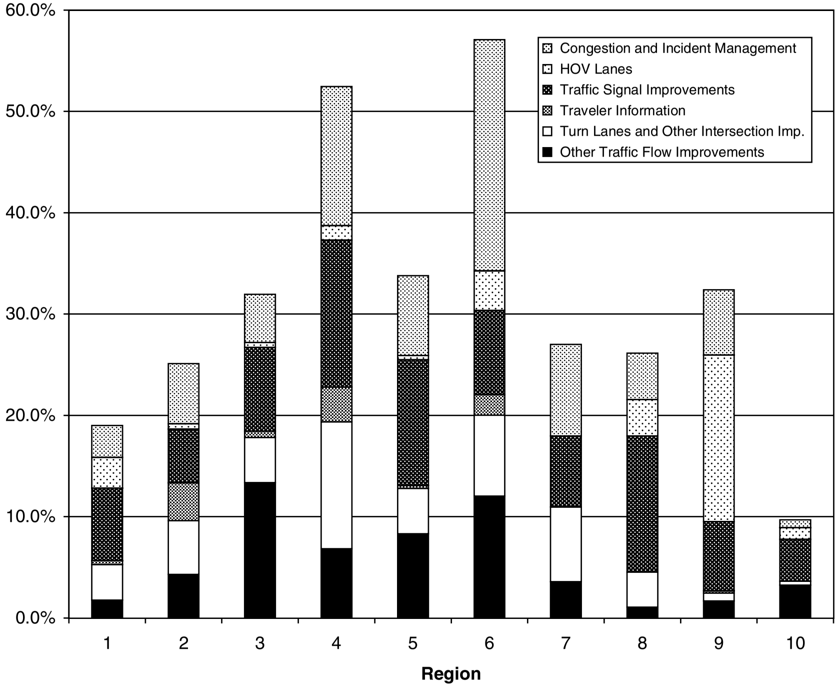

FIGURE C-11 Traffic flow projects as percent of all CMAQ obligations, by region.

- Turn lanes and other intersection improvements range from less than 0.5 percent of total CMAQ obligations in Region 10 to 12 percent in Region 4.
- Traffic signal improvement projects range from 4 percent of total CMAQ obligations in Region 10 to 12 to 15 percent in Regions 4, 5, and 8.
- Region 6 spends 23 percent of total CMAQ obligations on congestion and incident management projects. In most other regions, these projects account for less than 10 percent of total CMAQ obligations.
- HOV lanes account for 16 percent of total CMAQ obligations in Region 9. In other regions, these projects account for less than 5 percent of total CMAQ obligations.

Shared Ride Projects (Figure C-12)
Regions 1, 3, and 8 spend 6 to 8 percent of total CMAQ obligations on shared ride projects. Other regions spend 2 to 4 percent of total CMAQ funds on these projects.

Pedestrian and Bicycle (Figure C-13)
Regions 3 and 7 spend less than 1 percent of total CMAQ obligations on pedestrian and bicycle projects. Region 10 spends 19 percent of total CMAQ obligations on these projects.

Demand Management (Figure C-14)
Demand management projects range from about 1 percent of total CMAQ obligations in Regions 7 and 9 to 7 percent in Region 1.

STP/CMAQ Projects (Figure C-15)
Regions 7 and 8 spend 30 and 48 percent, respectively, of CMAQ obligations on STP/CMAQ projects. In most other regions, these projects account for less than 3 percent of CMAQ obligations.

Other Projects (Figure C-16)

- CMAQ obligations for paving and sweeping projects (to control PM_{10}) are 10 percent in Region 7, 5 percent in Region 8, and 9 percent in Region 10. In all other regions, expenditures on these projects are less than 1 percent of CMAQ total obligations.
- Regions 6, 7, 8, and 9 spend less than 1 percent of total CMAQ obligations on vehicle inspection and maintenance projects. Region 2 spends 10 percent of total CMAQ obligations on these projects.

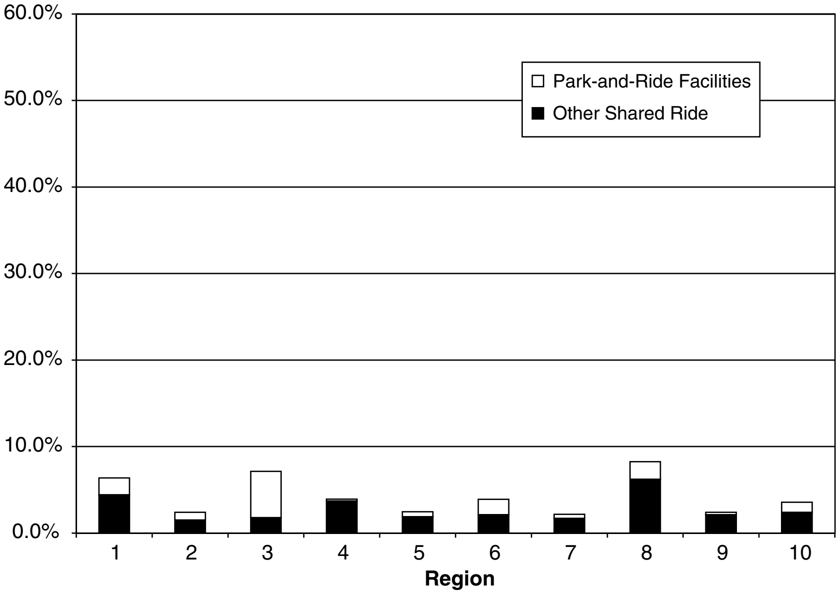

FIGURE C-12 Shared ride projects as percent of all CMAQ obligations, by region.

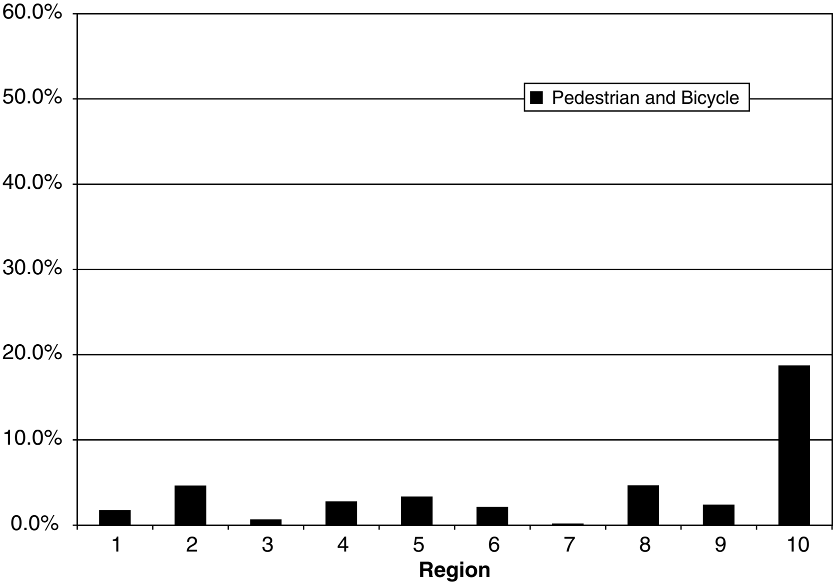

FIGURE C-13 Pedestrian and bicycle projects as percent of all CMAQ obligations, by region.

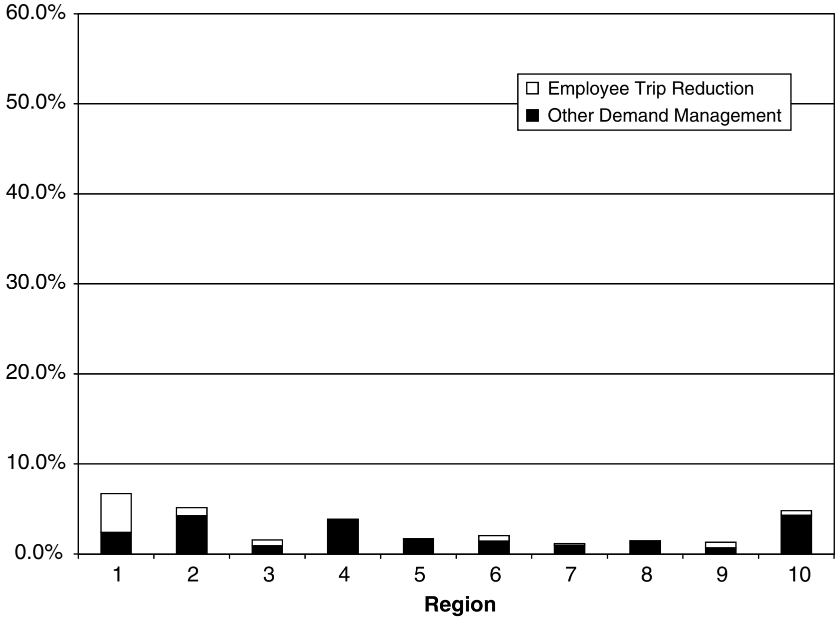

FIGURE C-14 Demand management projects as percent of all CMAQ obligations, by region.

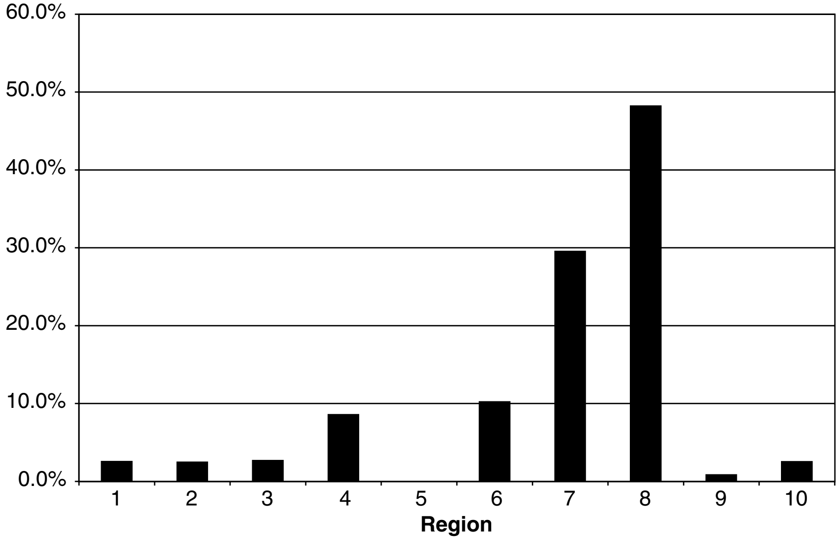

FIGURE C-15 STP/CMAQ projects as percent of all CMAQ obligations, by region.

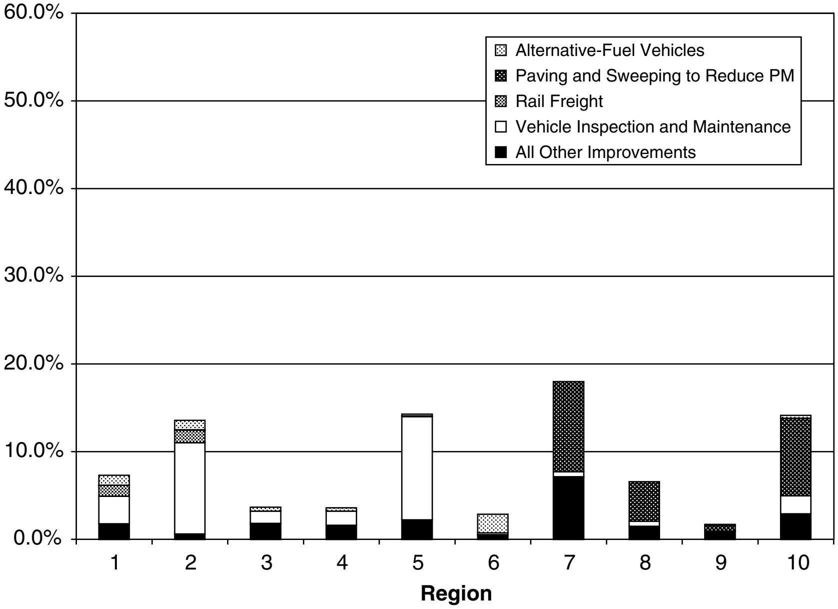

FIGURE C-16 **Other projects as percent of all CMAQ obligations, by region.**

EMISSION REDUCTIONS AND COST-EFFECTIVENESS OF CMAQ PROJECTS

The CMAQ program guidance document (FHWA 1992, 13) also requires states to provide estimates of emission reductions in kilograms per day for VOCs, NO_x, CO, and PM_{10}. Table C-4 shows the number of FY 1992–1999 projects with estimates of emission reductions for each project type. Excluding STP/CMAQ projects, which are in states that receive the minimum apportionment, emission estimates for at least one of the four pollutants are provided for almost 70 percent of all projects. Table C-5 shows percentages of FY 1992–1999 projects with estimates for each of the four pollutants. Almost 60 percent of the projects in the database have estimates of emission reductions for VOCs; however, only 5 percent have estimates for PM_{10}.

Table C-6 shows percentages of projects with estimates for each of the four pollutants by fiscal year. In FY 1992, fewer than 20 percent of projects had estimates for VOCs. In the next year, this percentage jumped to almost 60 percent, and it remained at about this level for the next 5 years. Similar though somewhat more erratic patterns are seen for estimates of the other pollutants.

The units for reporting emission reductions in the CMAQ database—kilograms per day—present a problem in evaluating the cost-effectiveness of CMAQ projects. The cost-effectiveness of air quality improvement strategies is usually expressed in terms of cost per ton (or some other unit of weight) reduction in emissions. In fact, in the legislation calling for this study, Congress asked the committee to "assess the effectiveness, including the quantitative and nonquantitative benefits, of projects funded under the [CMAQ] program and include, in the assessment, an estimate of the cost per ton of pollution reduction." Since project life (the period over which the emission reductions are expected to occur) is not given in the database, it is not possible to determine cost per ton reduced for the projects in the CMAQ database. To eliminate this problem in the future, it would be useful to ask states either to (*a*) report total emission reductions for a project rather than emission reductions per day, or (*b*) add information on project life to the database, so that total emission reductions can be calculated as the product of project life (in days) and emission reductions per day.[7]

Some problems were found in the treatment of those projects for which obligations in a given fiscal year did not cover the total cost of the project. For some of these projects, the estimated emission reductions were for the entire project, even though the obligations for that project in a given fiscal year accounted for only a small part

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[7] The second option may be more desirable because state implementation plans (SIPs) require information on estimated emission reductions in kilograms or tons per day. Thus, if an area wants to include a CMAQ-funded transportation control measure in a SIP and get credit, these data must be provided.

TABLE C-4 Projects with Any Estimates of Emission Reductions (FY 1992–1999)

Type of Project	**Quantitative Estimates of Emission Reductions for One or More Pollutants** **Yes**	**No**	**Total Projects**
Transit	1,119	490	1,609
Traffic flow	2,207	999	3,206
Shared ride	550	190	740
Pedestrian/bicycle	469	231	700
Demand management	319	165	484
STP/CMAQ	–	336	336
Other	265	234	499
Grand total	**4,929**	**2,645**	**7,574**
Percentage	65	35	100
Total without STP/CMAQ	**4,929**	**2,309**	**7,238**
Percentage	68	32	100

TABLE C-5 Projects with Estimates for Each Pollutant by Project Type (FY 1992–1999)

		Percent of Projects with Quantitative Estimates of			
Type of Project	**Total Projects**	**VOCs**	**CO**	**NO_x**	**PM_{10}**
Transit	1,609	62.5	38.2	51.5	7.5
Traffic flow	3,206	65.6	35.7	40.0	1.1
Shared ride	740	66.2	38.6	52.7	6.1
Pedestrian/bicycle	700	56.7	40.3	46.0	7.7
Demand management	484	63.0	35.7	52.1	5.8
STP/CMAQ	336	0.0	0.0	0.0	0.0
Other	499	34.5	19.4	26.1	18.2
Grand total	**7,574**	**59.0**	**34.3**	**42.3**	**4.9**

TABLE C-6 Projects with Estimates for Each Pollutant by Fiscal Year

Fiscal Year	Total Projects	Percent of Projects with Quantitative Estimates of			
		VOCs	CO	NO_x	PM_{10}
1992	182	19.2	18.7	14.8	3.3
1993	778	59.3	33.3	27.8	5.9
1994	980	63.3	36.5	42.7	4.4
1995	1,072	61.8	41.1	44.9	5.0
1996	1,258	56.7	29.7	35.1	4.0
1997	1,178	63.2	37.0	50.4	5.6
1998	1,052	58.2	33.6	45.3	5.5
1999	1,074	58.1	31.8	51.3	4.7
All Years	7,574	59.0	34.3	42.3	4.9

of the cost of the project.[8] This problem can lead to an underestimate of cost per ton of pollution reduced. To eliminate this problem in the future, it would be useful if the total cost of a project were included in the database (including costs in all years whether covered by CMAQ or other funding sources), along with CMAQ obligations for the project in the fiscal year.

The analysis requirements in the CMAQ program guidance for projecting emission reductions are very flexible. States are not required to use a specific methodology in estimating emission reductions. Further, states are not required to provide documentation of key input factors (e.g., reductions of vehicle miles or changes in emission rates) used in developing estimates of emission reductions. As a result, users of the CMAQ database have difficulty evaluating the basis for estimates of emission reductions. Also, the lack of a standard methodology decreases the level of confidence for comparisons of emission reductions and cost-effectiveness across project types and states.

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[8] Many projects are implemented using CMAQ funds from more than one fiscal year. Frequently, these projects appear in the CMAQ databases for different years with identical estimates of emission reductions, even when the amount of funds in each year differs greatly.

SUMMARY AND AUTHOR'S RECOMMENDATIONS

The following are the key findings from the review of the composition of the CMAQ program:

- Slightly more than 75 percent of obligations during the first 8 years of the CMAQ program have been for traffic flow and transit improvement projects. These types of projects provide benefits beyond emission reductions, such as time savings to highway and transit users. Types of projects for which most of the benefits are emission reductions or energy savings—alternative-fuel vehicles, paving and sweeping to reduce PM, and vehicle inspection and maintenance—account for only about 8 percent of CMAQ obligations.
- There are large year-to-year changes in the distribution of CMAQ obligations among different types of projects. The patterns of these changes do not indicate any clear trends. However, it appears that obligations for HOV projects are decreasing while obligations for vehicle inspection and maintenance projects are increasing.
- There are large differences across regions in the composition of the CMAQ program. For example, transit project obligations range from about 5 to nearly 60 percent of total CMAQ obligations, depending on the region. Traffic flow projects range from about 10 to nearly 60 percent of total CMAQ obligations, also depending on the region.

Three problems limit the usefulness of the database in estimating the cost-effectiveness of CMAQ projects in providing emission reductions:

- Emission reductions are stated in kilograms per day, and project lives are not given. Accordingly, it is not possible to determine the total amount of emission reductions attributable to a project.
- For some projects in the database, it appears that emission reductions are reported for the entire project, whereas obligations in a given fiscal year account for only a part of the cost of the project. This problem can lead to an underestimate of the cost per ton of achieving emission reductions.
- Little is known about the data, methods, and assumptions used in estimating emission reductions. As a result, it is difficult to

compare the cost-effectiveness of different types of CMAQ projects in different states.

To address these problems, it is the author's recommendation that FHWA ask states to

1. Add information on project life to the database, so that total emission reductions can be calculated for project cost-effectiveness analyses; and
2. Report total cost for a project (including costs in all years whether covered by CMAQ or other funding sources), along with CMAQ obligations for the project in the fiscal year.

FHWA also should consider ways of addressing problems due to inconsistent data, methods, and assumptions in estimating emission reductions, without imposing unreasonable reporting burdens on states.

REFERENCES

Abbreviation

FHWA	Federal Highway Administration

FHWA. 1992. *Further Guidance on the Congestion Mitigation and Air Quality Improvement Program (CMAQ Program).* U.S. Department of Transportation, Oct. 16.

FHWA. 1999. *The Congestion Mitigation and Air Quality Improvement (CMAQ) Program Under the Transportation Equity Act for the 21st Century (TEA-21): Program Guidance.* U.S. Department of Transportation, April.

APPENDIX D

INTERVIEW GUIDE AND SITE VISIT RESULTS

INTERVIEW GUIDE

Introductory Questions

Please describe in general terms your involvement with the CMAQ program and how that involvement may have changed over time.

Note: Please provide contextual information on the nonattainment area, including population, employment growth, travel trends (VMT growth), nature of the air quality problem (i.e., nonattainment or maintenance area for which criteria pollutants).

CMAQ Program Process and Decision-Making Procedures

1. Who has the primary responsibility for the CMAQ program in your area?

2. What role do the following entities play in project initiation, selection, or evaluation—state transportation department? MPO? state or local transit agency? state or local air agency? local interest groups? FHWA regional/divisional office? EPA divisional office? FHWA headquarters? FTA headquarters? EPA headquarters?

3. How are projects nominated as candidates for CMAQ funding? Is guidance provided regarding project initiation? Where do CMAQ projects come from (e.g., previously programmed but unfunded, especially designed to meet CMAQ program goals)?

4. How are projects selected for CMAQ funding? Is there a formal project selection process? If so, please describe. How is public input obtained? (Please provide written documentation if available.)

5. To what extent does conformity (the need for projects that provide conformity credits) have a bearing on CMAQ project selection? Please elaborate.

6. How are projects evaluated and who conducts the evaluation?

   a. Are project-level data collected on changes in travel behavior (e.g., trips, VMT, congestion effects, such as travel time delays)? Who collects these data? (Please provide written documentation if available.)

b. Are models and modeling techniques used to estimate travel effects and emission reductions for CMAQ projects? Is this true for all project categories? If not, what other methods are being used? Please describe. Who performs these analyses? (Please provide written documentation if available.)

c. To what extent are secondary project outcomes considered in project selection and evaluation [e.g., factors such as effects on greenhouse gases, ecology, economic development, equity (welfare-to-work initiatives), community livability]? How are these effects measured? Who does the analysis? (Please provide written documentation if available.)

d. How are project costs determined? Who determines them?

e. Who uses the project evaluation information? Have changes been made—for example, in project design or selection—as a result of project evaluations?

7. Reporting requirements

a. Which agency is responsible for reporting information on CMAQ projects to FHWA?

b. What role does your agency play, if any, in collecting this information?

c. What information, if any, is gathered in addition to the reporting data required by FHWA?

d. Should additional information be gathered? reported to FHWA?

e. Would you recommend any changes in the FHWA reporting process? If so, please elaborate.

8. Are ex-post project evaluations undertaken to determine whether desired travel changes and emission reductions and other project outcomes have been achieved? (Please provide copies of any such studies or analyses.)

CMAQ Program Objectives

1. What do you see as the primary goal of the CMAQ program?

2. Are there other objectives addressed by the program (e.g., mobility enhancement, community livability)? Please describe.

3. What role does the CMAQ program play in the area's air quality planning process and conformity requirements for meeting regional air quality goals?

4. How does the CMAQ program fit into local transportation plans and objectives?

5. If CMAQ program funding were not available, would these types of projects be undertaken?

    a. If so, what funding sources would be used?

    b. Would project delays be likely?

    c. If not, why not?

    d. Are there particular types of projects that would not likely be funded without the CMAQ program? What would be the impact on regional air quality or other program objectives if these projects were not undertaken? Please explain.

6. In your opinion, which types of CMAQ projects come closest to achieving program goals of reducing mobile source emissions and improving air quality? Why?

7. In your opinion, which projects are most effective in reducing congestion? Why?

8. Is cost-effectiveness a criterion in selecting CMAQ projects for funding? How important a criterion relative to the others?

9. In your opinion, which types of CMAQ projects are most cost-effective? Why?

10. Please comment on the cost-effectiveness of CMAQ projects relative to other control strategies for reducing pollution (e.g., vehicle technology improvements).

CMAQ Program Evaluation

1. What do you see as the main strengths of the CMAQ program?

2. What do you see as the main program weaknesses?

3. What effects, if any, has the program had on agency or interagency decision making? What changes, if any, should be made in program implementation? Please elaborate.

4. Do you think the CMAQ program should be continued in the next reauthorization of TEA-21? If so, please elaborate on the reasons.

5. Do you think the scope of the program should be broadened to include additional types of projects? additional pollutants of concern

(e.g., air toxics)? If so, please elaborate. If CMAQ funding were to remain constant at current levels, would you still support broadening the program scope? Please explain.

6. If you could change the program, what are the two or three key changes you would make?

ALBANY SITE VISIT

Introduction

The Capital District area includes the metropolitan areas of Albany, Rensselaer, Saratoga, and Schenectady Counties. The region is designated a marginal nonattainment area for ozone, although it has not been in violation of the ozone standard for several years now. Formal redesignation as a maintenance area will be sought, but contingency measures to include in a maintenance plan have not yet been identified.

The Capital District area is a midsized metropolitan area, with a current population of approximately 800,000 according to the Capital District Regional Planning Commission (CDTC 2000, 8). Population, number of households, and employment are estimated to increase by approximately 4, 7, and 2 percent, respectively, between 2000 and 2015, indicating a slow-growth area (CDTC 2000, 8). Travel growth is expected to increase somewhat more rapidly, with average daily vehicle miles traveled (VMT) and peak-hour VMT both rising by 17 percent between 2000 and 2015 (CDTC 2000, 17). Transit accounts for 2 percent of total travel and 4 percent of work travel in the region. Transit ridership increased 4 percent in 1999, reversing a history of declining ridership. It is too early to tell whether the upswing in ridership will continue.

CMAQ Program Process and Decision-Making Procedures

The Capital District Transportation Committee (CDTC)—the metropolitan planning organization (MPO)—has the primary responsibility for programming CMAQ funds in the Albany area. New York State (NYS) has a decentralized process for managing the CMAQ program. The NYS Department of Transportation (NYSDOT) allocates funds to eligible nonattainment and maintenance areas by NYSDOT region using the same formula by which national-level

CMAQ funds are allocated to the state. By this metric, the Capital District Area typically receives about 4 percent of NYS's annual CMAQ allocation—between $4 million and $5 million each year.[1]

CDTC does not have a separate process for identifying, selecting, and programming CMAQ projects. CMAQ is one funding source among several [e.g., National Highway System funds, Surface Transportation Program (STP) flexible and urban funds] that are used to fund projects included in the area's 5-year Transportation Improvement Program (TIP). That being said, the area has a rigorous process for identifying programming priorities and selecting individual projects for inclusion in the TIP—the outgrowth of an exhaustive long-range planning process that resulted in the adoption of a long-range Regional Transportation Plan (RTP) in March 1997 (CDTC 1999, 21–25). The "New Visions Plan," as it is known, calls for a balanced transportation system that emphasizes preservation over new capacity, links transportation with land use, and provides for modes other than cars. Budgets for some 17 project categories are defined, and individual projects are selected within categories for inclusion in the TIP on the basis of merit (with a heavy emphasis on cost–benefit analyses), adjusted by other considerations, such as essentiality of facilities and geographic balance (CDTC 1999, 27). CMAQ eligibility and emission reduction estimates are noted for relevant projects, but air quality is not an explicit project selection criterion. That being said, projects that are eligible for and use CMAQ funds must demonstrate emission reduction potential.

The CDTC Policy Board, composed of the chief elected officials of each of the region's eight cities and four counties, at-large members of the area's towns and villages, representatives of NYSDOT, the Capital District Transportation Authority (CDTA), the Capital District Regional Planning Commission, the New York State Thruway Authority, the Albany County Airport Authority, the Albany Port District Commission, and advisory members from the Federal Highway Administration (FHWA) and the Federal Transit

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[1] In each of federal fiscal years 1998 and 1999, NYSDOT reserved $30 million in CMAQ apportionments for high-speed rail projects throughout the state (NYSDOT 1998; NYSDOT 1999).

Administration (FTA), selects projects for inclusion in the TIP by unanimous consent. In addition to CDTC, the major players involved in proposing and programming CMAQ projects are NYSDOT (Region 1 Office) and CDTA.

CDTC conducts the analytical work for all projects, including CMAQ-eligible projects. In the latter case, for projects that can be modeled, travel forecasts are made on the basis of the CDTC travel demand model [Systematic Traffic Evaluation and Planning (STEP) Model]. Emission reductions for hydrocarbons and nitrogen oxides are then estimated using a postprocessor, which links emission rates from the Environmental Protection Agency (EPA) MOBILE model to the travel model output.[2] NYSDOT and CDTA often provide the raw data or preliminary estimates for the travel analysis. NYSDOT collects the project information, including the emission estimates, from all CMAQ-eligible areas in the state and prepares a summary for FHWA.

CMAQ Program Objectives

The primary role of the CMAQ program in the Capital District area, according to those interviewed, is to provide a flexible funding source that enables more projects to be funded in categories that match New Visions priorities. Without CMAQ, the TIP would be even more heavily weighted toward infrastructure renewal projects. Another and related role of CMAQ funds is to enable more experimental projects to be funded (e.g., the on-demand shuttle bus service).

Conformity appears to play a less direct role in programming CMAQ funds, largely because the Capital District area does not have a severe air quality problem. In addition, the New Visions goals, which many CMAQ projects support, are largely compatible with clean air goals.

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[2] The STEP Model calculates total operating speeds for each link in the network on the basis of estimated link delay and estimated node delay. The postprocessor then looks up an emission rate per VMT for that link on the basis of operating speed and functional class. The emission rates were developed by NYSDOT and the NYS Department of Environmental Conservation for the Capital District using the EPA MOBILE model. The total emissions for each link are then calculated by multiplying the emission rate per VMT by the STEP Model VMT on the link. Link emissions are then added for all links in the system (personal communication with Chris O'Neill, CDTC, Sept. 21, 2000).

CDTC has programmed three major types of CMAQ projects between federal fiscal years (FFY) 1995 and 1999, the most recent years of data available (Table D-1). Traffic flow improvements are the major spending category, specifically Intelligent Transportation System (ITS) projects such as the Traffic Management Center and supporting operations (e.g., highway loop detectors, police support for incident management). Shared-ride projects are the next-largest spending category, including park-and-ride lots and a regionwide guaranteed ride home program to support carpool, vanpool, and transit riders. Transit projects are the other major spending category, supporting new on-demand shuttle bus services on major corridors, a transit pass subsidy program, and a bus signal preemption system on a major corridor (Route 5). Bicycle paths, pedestrian improvements (e.g., sidewalks), and support for employer rideshare programs are among the other types of projects funded by CMAQ in the last 5 years.

If CMAQ funds had not been available during this period, many projects would not have gone forward, in the judgment of those interviewed. For example, ITS projects would not likely have been funded or would have been significantly delayed; the priority given to area infrastructure renewal would have dominated highway programming decisions had only traditional funding sources been available. More traditional transit projects might have been funded from other funding sources or delayed, but experimental projects like the on-demand

TABLE D-1 CMAQ Program Obligations by Project Category, Capital District Area, Albany, New York, FFY 1995–1999

Project Category	CMAQ Obligations ($)	Percent of Total Obligations
Traffic flow improvements	5,652,000	53.0
Shared ride	3,123,000	29.3
Transit	1,249,000	11.7
Pedestrian/bicycle	366,000	3.4
I&M and other	240,000	2.2
Demand management	40,000	0.4
Total	**10,670,000**	**100.0**

Source: NYSDOT (1996–2000).

shuttle bus service and new suburban ridership projects would probably not have gone forward in the absence of funding for equipment and operations. Stand-alone bicycle and pedestrian projects probably would not have been undertaken without CMAQ funds, but some could have been funded as part of larger projects using STP funds.

When asked which types of projects were most effective in achieving CMAQ program goals of emission reductions and air quality improvement, traffic operations projects that reduced travel delays, transit projects that supported new ridership, and transportation demand management projects that included pricing incentives were mentioned. Bicycle and pedestrian projects were not as strong from an emission reduction perspective, but they served other goals, such as improved community livability. ITS projects that reduced delays on the system were rated highly from a congestion mitigation perspective, but transit projects were not. From a cost-effectiveness perspective, traffic improvements on congested corridors again ranked highly, but transit projects did not, mainly because of the expense of providing transit service (traditional transit service costs about $3 per passenger trip, shuttle service about $5 per trip, and paratransit service about $16 per trip). In making these judgments, all of the respondents noted the uncertainty of emission estimates, particularly for smaller projects, and the absence of postproject evaluations to determine whether emission forecasts had been realized.[3]

NYSDOT believes that the most cost-effective strategies for reducing emissions are those that affect large numbers of highway vehicles, such as vehicle technology improvements, inspection and maintenance programs, and changes in fuel composition.

CMAQ Program Evaluation

The main strengths of the CMAQ program are its flexibility and its innovative focus. The availability of flexible funds has enabled the Capital District to achieve its planning goals for a balanced transportation system with small shifts in spending priorities. The extra

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[3] CDTA does collect information on ridership for new transit services.

funding and the specific focus areas of CMAQ, which do not compete with infrastructure renewal and maintenance projects that tend to dominate older areas like the Capital District, have enabled the area to experiment and undertake innovative projects.

One of the primary weaknesses of the CMAQ program is the uncertainty regarding the effects of projects, particularly small projects, on area emissions and air quality. This problem is magnified in an ozone nonattainment area, because the nature of the ozone problem and hence its solutions tend to be regional rather than local. More follow-up and evaluation of projects are needed. Given the methodological complexity and expense of such evaluations, however, the respondents recommended that FHWA take a more proactive role in determining project effectiveness and cost-effectiveness. On the basis of national experience, FHWA could even predetermine categories of projects from the perspective of their emission reduction potential and cost-effectiveness rather than require local justification for every project.

All those interviewed thought that the CMAQ program should be continued, and funding increased if possible, when the Transportation Equity Act for the 21st Century (TEA-21) is reauthorized. The scope of the program should be broadened to include whatever pollutants are regulated at the time. With regard to project eligibility, NYSDOT staff believed that all projects that can demonstrate emission reductions should be eligible for CMAQ funding. CDTA supported keeping current eligibility requirements and only expanding them if a clear air quality benefit is evident.

In summary, the respondents' major suggestion for change, in addition to more program funding, was increased guidance from FHWA, drawing on national experience concerning which projects are most effective and most cost-effective. One process-related change was mentioned—electronic reporting—to ease data collection by the state and summary reporting to FHWA.

Organizations and Persons Interviewed—July 10, 2000

Capital District Transportation Commission
  John Poorman, Staff Director
  Chris O'Neill, Senior Transportation Planner

New York State Department of Transportation
  John Zamurs, Head, Air Quality Section, Environmental Analysis Bureau
New York State Department of Transportation, Region 1 Office
  Jeffrey Marko, P.E., Associate Transportation Analyst
  Robert Hansen, P.E., Regional Capital Program Coordinator
  Robert Falcone, Senior Transportation Analyst
Capital District Transportation Authority
  Kristina Younger, Manager for Planning

CHICAGO SITE VISIT

Introduction

The Chicago Area Transportation Study (CATS) is the designated MPO responsible for transportation planning in Northeastern Illinois. The counties served by CATS include Cook, DuPage, Kane, Lake, McHenry, Will, and parts of Kendall. According to the 1990 census, 7.3 million people reside in the region, 3.8 million of whom are employed, and 33 Fortune 500 companies have located their headquarters there. By 2020, the region's population is expected to grow by nearly 25 percent to 9.0 million; 1.5 million additional people will be employed in the region; and the number of households is expected to increase by 31 percent to 3.4 million (CATS 2000a). Most of this growth is expected to occur in suburban areas, though the city of Chicago is slowly reversing a declining population trend.

The transportation system in the region comprises 23,903 miles of streets and highways, including 4,264 miles of Interstates, freeways, and principal and minor arterials. The region houses the second-largest transit system in the country and the third-largest bus system. CATS estimates that 22 million trips are made every day in the region and that 1,100 freight trains and 36,000 rail cars move 2.5 million tons of freight through the area on a daily basis (CATS 2000a). Automobile person trips are expected to increase by about 46 percent between 1996 and 2020, while transit trips are expected to increase by nearly 15 percent. Total network VMT is projected to increase by more than 26 percent between 1999 and 2020.

The Northeastern Illinois region is classified as a severe nonattainment area for ozone and receives approximately $70 million annually in CMAQ funding under TEA-21. In FY 2001, CATS considered 170 project proposals for a projected total cost of nearly $200 million.

CMAQ Program Process and Decision-Making Procedures

The first step in the CMAQ programming process in Illinois is for the Illinois Department of Transportation (IDOT) to allocate CMAQ funding to the designated MPOs in the state. The state allocates CMAQ funding to the MPOs in nonattainment areas by using the same apportionment formula that FHWA uses to apportion CMAQ funds to the states, that is, on the basis of population and severity of the air quality problem. Approximately 97 percent of the allocated funding is provided to CATS in the Northeastern Illinois region, with the remaining funds allocated to the East-West Gateway Coordinating Council in the East St. Louis area.

There is one exception to the process. Under the Intermodal Surface Transportation Efficiency Act (ISTEA) and TEA-21, prior to the distribution of CMAQ funds to the MPOs, IDOT had reserved funds to finance an inspection and maintenance (I&M) program in the state's nonattainment areas. Under ISTEA, IDOT programmed $45 million in CMAQ funds for development of the Illinois Environmental Protection Agency's (IEPA) enhanced I&M program. Under TEA-21, it programmed an additional $80 million for operation of the enhanced I&M program.[4]

CATS has primary responsibility for programming CMAQ projects in the Northeastern Illinois area.[5] IDOT administers the implementation of programmed projects. The staff of CATS begins the CMAQ process in January of each year by issuing a call for projects. Between

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[4] The majority of those interviewed did not object to this practice, though some did note that it contributes to the general encouragement of automobile usage by defraying the cost of the automotive inspection program to the state rather than to individual automobile owners.

[5] IDOT is responsible for financing and administering the operating budget of CATS. The staff of CATS are technically state employees but are governed by the operating procedures of the CATS Policy Committee. None of the representatives interviewed expressed concern with this arrangement because the Policy Committee operates by consensus and IDOT constitutes only 1 of 20 votes. This arrangement is unique to the Northeastern Illinois region.

7,000 and 8,000 mailings are distributed to all relevant constituencies, private citizens, and all pertinent governmental bodies. The primary governmental operating agencies that participate in the CMAQ process and propose projects are IDOT, IEPA, the Chicago Transit Authority (CTA), Metra (commuter rail), Pace (suburban bus), the city of Chicago, counties, and 270 municipalities. CATS has made a concerted effort to ensure that all eligible parties are able to participate in the process. For example, CATS routinely provides staff support to 11 subregional councils in an effort to assist local governments in project development.

Nongovernmental entities are also encouraged to participate in the process, although they are required to obtain a government sponsor for their project before submitting a proposal to CATS. Neither CATS nor the interest groups interviewed for this case study felt that this provision inhibited project submittals. In fact, the Chicagoland Bicycle Federation has made partnering with government agencies a key tenet of its organizational strategy.

The most common types of CMAQ projects implemented over the years in the Northeastern Illinois region include transit improvements (commuter rail, rapid transit, and bus projects), commuter parking, traffic flow improvements, signal interconnects, and the enhanced I&M program. (Table D-2 shows CMAQ obligations since the inception of the program, and Table D-3 shows CMAQ obligations for the most recent 5 years.) All federally eligible projects, including transit improvements, commuter parking, traffic flow improvements, signal interconnects, bike and pedestrian facility projects, bike parking and bike encouragement projects, and other projects designed to meet regional congestion and air quality goals, are considered by the CMAQ Project Selection Committee.

The CMAQ Project Selection Committee has also approved a number of demonstration projects (CATS 2000b). Demonstration projects are typically characterized as innovative projects for which the data are unavailable to estimate emission reductions. As a requirement for approving a demonstration project, CATS typically requires that a study be conducted in conjunction with the project to help ascertain emission reductions in the future. The car-sharing project, sponsored

TABLE D-2 CMAQ Program Obligations, Northeastern Illinois, FFY 1992–2000

Program Category	Federal ($)	Total ($)	Program (%)
Signals/congestion improvements	42,766,369	56,405,103	11.59
Transit improvements (total)	193,045,686	244,818,067	50.28
Rapid transit improvements	70,150,400	87,188,000	17.91
Rapid transit expansion	5,360,000	6,700,000	1.38
Bus route improvements	9,663,560	12,079,500	2.48
Bus replacements	26,499,033	33,123,791	6.80
Transit transfer improvements	2,392,845	2,991,056	0.61
Commuter rail/parking	49,723,848	66,165,720	13.59
Metra/North Central service	29,256,000	36,570,000	7.51
Vanpools	12,300,000	12,425,000	2.55
Intermodal improvements	2,100,000	5,201,500	1.07
Demonstrations	8,168,379	11,304,873	2.32
Bike/pedway improvements	16,627,821	21,085,786	4.33
Enhanced I&M	102,126,000	127,657,500	26.22
Regional programs	6,345,400	7,892,750	1.62
Total	**383,479,655**	**486,790,579**	**100.00**

Source: Data compiled by CATS.

TABLE D-3 CMAQ Program Obligations, Northeastern Illinois, FFY 1996–2000

Program Category	Federal ($)	Total ($)	Program (%)
Signals/congestion improvements	29,624,656	39,166,784	13.82
Transit improvements (total)	101,232,953	130,606,215	46.09
Rapid transit improvements	57,083,200	71,354,000	25.18
Bus route improvements	6,448,100	8,050,150	2.84
Transit transfer improvements	140,845	176,056	0.06
Commuter rail/parking	37,560,808	51,026,009	18.01
Vanpools	8,300,000	8,425,000	2.97
Bike/pedway improvements	4,270,910	5,193,861	1.83
Enhanced I&M	72,126,000	90,157,500	31.82
Demonstrations	2,050,000	3,089,000	1.09
Regional programs	5,398,400	6,709,000	2.37
Total	**223,002,919**	**283,347,360**	**100.00**

Source: Data compiled by CATS.

by the city of Chicago and the Center for Neighborhood Technology, is an example of such a demonstration project.[6]

Completed project proposals are submitted to CATS in March of the same year. Before finalizing proposals, all applicants are encouraged to scope the project thoroughly (i.e., engineer the project in accordance with federal design standards). In addition, all project submittals (except demonstrations) must include data on anticipated changes in travel conditions or traveler behavior (e.g., changes in intersection delay, or expected trips eliminated or diverted to nonhighway modes). All project submittals must include project costs; detailed estimates are requested. The cost estimates of local agencies submitting project proposals are reviewed by IDOT engineers for reasonableness. A mechanism has been established to assist projects that require additional funding in subsequent years. However, to be eligible for these funds and to discourage deliberate "lowballing," a project will be reranked and selected for additional funding only if the project ranks (at the new cost level) higher than the projects not previously selected. Finally, a local match of 20 percent of the project total is required for most projects. Some sponsors provide more than the required match.

Between March and August, the staff of CATS reviews and ranks all projects. Sponsors are contacted as needed for additional information. Projects are ranked by dollars per ton of volatile organic compounds (VOCs) reduced, dollars per 1,000 VMT reduced, dollars per 1,000 single-occupant vehicle (SOV) trips eliminated, and dollars per ton of nitrogen oxides (NO_x) eliminated. Project Selection Committee members and staff agreed that the primary factor in ranking CMAQ projects is and should be the ability of a project to reduce VOCs.[7]

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[6] Car-sharing originated in Europe and has quickly spread to Canada and several cities in the United States. Essentially, individuals forgo automobile ownership in favor of paying a nominal fee for the right to use an automobile as necessary. A study by the Swiss Office for Energy Affairs indicates that car owners who switch to car-sharing reduce their driving by more than 70 percent. (See website—http://www/carsharing/net—for more information.)

[7] The Chicagoland Bicycle Federation suggested that in the future both dollars per ton of VOCs reduced and dollars per 1,000 SOV trips eliminated be the primary criteria for evaluating CMAQ projects.

Projects are ranked within their project category; projects are not ranked across categories. All interviewed felt that this was a fair and acceptable method for ranking projects. This method does not ensure that the most cost-effective projects will be implemented; rather it ensures that the most cost-effective projects within a particular category will be implemented. CATS staff holds that it is not possible to compare the results of different methodologies employed for different project categories to arrive at a valid cost-effectiveness ranking across all projects.

Project evaluation methodologies are reviewed and approved by the CMAQ Project Selection Committee. CATS has received considerable input on methodology development, particularly from area interest groups, who formed an environmental coalition to help shape the development of the CMAQ program in the Northeastern Illinois region.[8] The Chicagoland Bicycle Federation noted that evaluation methodologies used to rank projects in other states frequently are biased against bicycle and pedestrian projects and recommended that the U.S. Department of Transportation provide guidance on appropriate and equitable methodologies for quantifying emission reductions for this project category.

After the staff of CATS has reviewed and ranked the proposals, this information is submitted to the CMAQ Project Selection Committee, which reviews the package. Six organizations are represented on the CMAQ Project Selection Committee: IDOT, IEPA, the Council of Mayors, the Regional Transportation Authority (RTA),[9] the counties (the seven counties select one representative), and the Chicago Department of Transportation. CATS serves as the chair of the committee, voting only to break a tie vote (to date, CATS's vote has not been required since the committee operates on a consensus basis). At this point in the process, additional factors such as geography, mix of projects, and project

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[8] Coalition members include the American Lung Association, the Business and Professional People in the Public Interest, the Sierra Club, the Center for Neighborhood Technology, and the Chicagoland Bicycle Federation.

[9] RTA was created in 1973 as the policy and financial oversight public transit agency for the three public transit operators in the Chicago area—CTA, Metra, and Pace.

readiness are considered as the committee develops a list of recommended projects.

Using the rankings and the other information available, the staff develops a recommended program in consultation with the CMAQ Project Selection Committee. The CATS Work Program Committee then releases the program for a public comment period, typically extending 30 days. In addition to soliciting input on the current year's package, the release serves as a public education tool for the next year's submittals.

After comments are considered, the package is forwarded to the CATS Work Program Committee, which, together with the CATS Policy Committee, must approve the recommended CMAQ program. The Work Program Committee is composed of a representative from each of the 20 agencies on the Policy Committee and six additional members. It is charged with resolving any disputes and formulating funding recommendations before review of the proposed package by the Policy Committee.

The Policy Committee is officially vested by the governor of Illinois and local elected officials with authority for all decisions concerning regional transportation plans and programs for Northeastern Illinois. Generally, the Policy Committee approves the proposed program in December. FHWA must then find programmed projects eligible for CMAQ funding. The process from start to finish is completed on a 12-month calendar year cycle.

While it is the policy of CATS not to predetermine a quota of projects for each category, many participants interviewed for the case study noted that the process works because everyone is assured a "slice of the pie." The CMAQ Project Selection Committee attempts to balance the program by type of project and geography. All eligible projects with a governmental sponsor are considered. However, the year-to-year program has varied widely by geography and project type. Bicycle and pedestrian projects, for example, have historically received approximately 7 percent of the allocated funding, but have varied from having only cost increases approved for previously funded projects to making up more than 10 percent of the program. Although interest groups are not formally represented on the CMAQ Project Selection or CATS Work Program or Policy Committees, they are actively involved in the various task forces. The coalition of interest groups, for example, strongly advocated and were successful in ensuring that dollars per ton of VOCs eliminated, dollars per 1,000 trips eliminated, and dollars per 1,000 VMT eliminated be considered as the CMAQ project evaluation criteria. The coalition also encouraged the inclusion of IEPA in the membership of the CMAQ Project Selection Committee. In sum, those interviewed generally found the CMAQ project selection process inclusive and the results satisfactory, despite annual variations in project selection.

Conformity requirements drive the project selection process, insofar as high-ranking projects are more likely to be selected than low-ranking projects, taking into account project readiness, feasibility, and coordination requirements. In addition, the CMAQ program has provided funding critical to meeting mobile source emission budgets through the enhanced I&M program. The CMAQ-funded I&M program allowed approximately a 30 ton per day credit for the region's 1999 Rate of Progress State Implementation Plan (SIP) mobile source emissions budget of 200 tons per day. Other transportation control measures (TCMs), largely CMAQ-funded, provided another 2 tons per day in credits. As more CMAQ-funded projects are added to the SIP, the TCM contribution will grow.[10] However, during the project selection process, there are few projects—the I&M program being the major exception—that can be regarded individually as critical to conformity. Thus, the impact of the CMAQ program as a whole on conformity is important, but the impact of individual TCM projects is usually minimal.

Secondary criteria, such as community livability and economic development, generally receive only cursory consideration in the project selection process. In fact, several of the representatives interviewed questioned whether a project's ability to serve as a catalyst for economic development should weigh positively or negatively in ranking the project. In some cases secondary effects are important in building stakeholder support for particular projects.

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[10] CMAQ projects are put in the SIP to get credit only when the funds are fully committed. Individual projects are not identified; rather, IEPA records categories of projects with the individual project list attached as documentation.

However, the overarching theme emerging from those interviewed is that the region's primary criterion for CMAQ project selection remains elimination of VOCs.

Postproject evaluations are conducted for certain categories of projects, and the information obtained is factored into the decision-making process for selecting and evaluating the merits of projects in subsequent years. Postproject evaluations are the weakest area of the process, however, because attributing reductions in emissions to a particular source or project is difficult. The methods sometimes require complex statistical analyses and often must accommodate rapidly changing travel patterns.

IDOT is responsible for reporting the results of the CMAQ program to FHWA. All information reported by the state is received directly from CATS. Neither CATS nor IDOT thought that the current reporting requirements should be modified.

CMAQ Program Objectives

When asked whether congestion mitigation or air quality was the primary goal of the CMAQ program, there was a slight divergence in the respondent's answers. The representatives from the American Lung Association, the Chicagoland Bicycle Federation, and IEPA all stated that the objective of the program is to improve air quality, whereas the representatives from RTA tended to focus on congestion mitigation. Staff from CATS, IDOT, the city of Chicago, and the Council of Mayors' Executive Committee noted that while the goal of the program is to reduce emissions, the most viable means for achieving air quality is through congestion mitigation. Participants also agreed that an indirect benefit of the CMAQ program is the ability to heighten the public's awareness regarding air quality through education and focused campaigns.

As with many areas, the availability of CMAQ funds provides the region with the ability to enhance its transportation system and to develop alternatives to SOV travel. It was the general consensus of those interviewed that if CMAQ funding were no longer available, some projects would be maintained and funded via alternative sources of funding, others would be substantially delayed in implementation, and still others would be terminated (e.g., marketing/education campaigns). It should be noted that in cases where alternative funding sources exist, particularly for transit and traffic flow improvements, the demands for rehabilitation needs in the area are and will continue to be significant, making it unlikely that many of the improvement projects would be funded. Projects that use CMAQ funding as leverage to obtain additional sources of funding could also be jeopardized. For example, CMAQ funding was a critical component of the Metra North-Central rail line, a new commuter rail line serving Chicago's northern suburbs; many have questioned the viability of this project if CMAQ funding had not been available. It is also worth noting that the majority of participants interviewed believed that bicycle and pedestrian projects would be maintained, albeit slightly reduced in number, if CMAQ funding were not available. However, the Chicagoland Bicycle Federation representative reiterated that CMAQ funding was and is crucial to the development and implementation of bicycle and pedestrian projects.

CMAQ Program Evaluation

Interestingly, the two primary strengths of the CMAQ program identified by case study participants appear also to contribute significantly to the program's chief weaknesses. Specifically, case study participants lauded the consensus process used by CATS in selecting projects and the ability to implement diverse and innovative projects using CMAQ funding as the primary benefits of the program. On the other hand, the most frequent complaint cited by case study participants was the resulting "scattering of projects" and seeming lack of a central plan or long-term vision for the Northeastern Illinois region. Several implementing agency representatives also cited the desire to have the opportunity to fund larger, long-term projects, while representatives from interest groups argued that for the region to be truly effective in achieving air quality goals, land use considerations must be incorporated into the CMAQ process. All participants, however, agreed that the process created and used by CATs was effective in fostering interagency partnerships, bringing "new players to the table," and ensuring an equitable distribution of funds. In addition, the city of Chicago noted that CMAQ served as a catalyst for improving cooperation between the city and the suburbs in what formerly was often characterized as a divisive relationship.

In conclusion, it is apparent that all participants in the CMAQ process in Northeastern Illinois remain cognizant of the region's designation as a severe nonattainment area for ozone and consequently are focused and fairly united in using CMAQ funds to help achieve the region's air quality goals. All participants endorsed the inclusion of the CMAQ program in the reauthorization of TEA-21, and most responded with skepticism to the notion of broadening the scope of the program to include new projects or additional pollutants of concern. As one participant stated, "We barely understand VOCs; we need to stay focused."

Several of the case study participants did, however, have suggestions for improving and refining the current CMAQ program. While additional funding topped everyone's list, other suggestions ranged from expanding the ability to fund operating expenditures from 3 years to 6 years, particularly for the I&M program, to barring the state's ability to use CMAQ funding for the I&M program. Some participants wished to insert additional flexibility into the program to allow for the funding of bottleneck relief projects that could result in slight increases in capacity (e.g., auxiliary lanes), while others suggested making these improvements ineligible for CMAQ funds. RTA recommended strengthening the role of FTA in the program so that CMAQ-funded highway and transit projects would complement rather than compete with each other. They recommended structuring the program along the lines of the ITS program, that is, having FHWA and FTA jointly administer the program in a cooperative manner. The city of Chicago expressed a desire for Congress to reconsider the need for nonprofits and private entities to obtain government sponsors to be eligible to apply for CMAQ funds. Specifically, the city has experienced a significant administrative burden associated with overseeing nongovernmental agency projects and has questioned whether the current process was cost-effective.[11]

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[11] The city of Chicago is the public agency sponsor of the Wendella Boat Company's commuter ferry project and the Center for Neighborhood Technology's car-sharing project.

Organizations and Persons Interviewed August 16–17, 2000

Members of the CMAQ Project Selection Committee are indicated with asterisks.

Chicago Area Transportation Study
  Martin Johnson, Associate Executive Director*
  Donald Kopec, Deputy for Programming
  Patricia Berry, Director of the Transportation Improvement Program
  Tom Murtha, Chief of the CMAQ Program
Regional Transportation Authority
  Richard Bacigalupo, Executive Director
  John DeLaurentiis, Director of Planning
  Mark Pitstick, Manager, Program Support*
  Sidney Weseman, Manager, Systems Planning
Illinois Department of Transportation
  Carla Berroyer, Chief, Bureau of Urban Program Planning*
Illinois Environmental Protection Agency
  Mike Rogers, Environmental Specialist (by telephone)
American Lung Association
  Brian Urbaszewski, Director, Environmental Health Programs
Chicagoland Bicycle Federation
  Randy Neufeld, Executive Director

Organizations and Persons Interviewed Via Conference Call August 21–22, 2000

Members of the CMAQ Project Selection Committee are indicated with asterisks.

Council of Mayors Executive Committee
  The Honorable Jeffery Schielke, Mayor of the City of Batavia*
City of Chicago
  John Tomczyk, Director of Planning and Programming Division
  Luann Hamilton, Director of Transportation Planning*

WASHINGTON, D.C., SITE VISIT

Introduction

The Washington metropolitan nonattainment area is a complex group of jurisdictions, including several cities, 10 counties, 2 states—

Virginia and Maryland—and the District of Columbia (the District).[12] The region is currently designated a serious nonattainment area for ozone, with mobile source emission budgets for both VOCs and NO_x. The 2000 update to the area's long-range plan and the FY 2001–2006 TIP conform to the requirements of the 1990 Clean Air Act Amendments (CAAA). The attainment year is 2005.[13] However, recent updates in the vehicle data inputs to the conformity determination indicate that area NO_x emissions will exceed emission budgets in 2005. Amendments to the long-range plan and the FY 2002–2007 TIP have been put on hold as the area attempts to identify measures to close the gap.

The Washington metropolitan area is experiencing rapid growth. From 2001 to 2025, population is expected to increase by 31 percent from its current level of 4.2 million, and the number of households is expected to increase by 31 percent, on the basis of forecasts developed through a Cooperative Forecasting Program administered by the Metropolitan Washington Council of Governments (COG) (COG 2000b).[14] By 2025 regional employment is expected to grow by 41 percent from the 2000 employment base of 2.7 million, with the greatest growth during the 2000 to 2005 period, when 55,000 new jobs per year on the average are anticipated (COG 2000b). Travel projections to 2025 indicate that travel will increase much more rapidly. Vehicle trips are estimated to increase by 38 percent, VMT by 46 percent, number of vehicles by 38 percent, and transit work trips by 18 percent (COG 2000a).

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[12] The counties in Maryland are Frederick, Montgomery, Prince George's, Calvert, and Charles; in Virginia the counties are Arlington, Fairfax, Loudoun, Prince William, and Stafford.

[13] The region originally had a 1999 attainment year but was unable to reach attainment largely because of ozone transport issues over which the area had no control (i.e., emissions from power plants in the Midwest). EPA has extended the attainment year to 2005 and has approved the region's new air quality plan and mobile emission budgets. However, the Earthjustice Legal Defense Fund filed a court challenge on behalf of the Sierra Club on February 14, 2001, to the EPA-approved deadline extension, which, if upheld, could result in a reclassification of the region as a severe nonattainment area for ozone.

[14] The Cooperative Forecasting Program was established in 1975. It enables local and regional planning to be coordinated through the use of common assumptions about future growth and development. The forecasts cited in the text are for the intermediate growth scenario.

CMAQ Program Process and Decision-Making Procedures

CMAQ funds come to the Washington metropolitan area from Virginia, Maryland, and the District. Virginia suballocates its CMAQ funds to in-state nonattainment and maintenance areas using the same formula by which national-level CMAQ funds are allocated to the state. Maryland does not suballocate its CMAQ funds by any specific formula. Rather, statewide project needs are reviewed annually before any CMAQ funding allocation. The District, which operates as a state with respect to the CMAQ program, retains all the funds it receives. Currently, the Washington metropolitan area receives $20 million to $25 million annually in CMAQ funds.

There is no regional CMAQ program or process as such in the Washington metropolitan area in the sense that CMAQ funds are pooled and projects identified, selected, and programmed regionwide for CMAQ funding. In fact, each of the three jurisdictions that receive CMAQ funding—Virginia, Maryland, and the District—has its own process for deciding which projects to fund with CMAQ dollars. Virginia has the most decentralized process. In 1992 the state created the Transportation Coordinating Council (TCC) of Northern Virginia to program CMAQ and Regional STP funds.[15] TCC of Northern Virginia, which programs CMAQ funds, has an annual solicitation for the CMAQ program. A technical committee reviews project proposals, and public input is sought through a Citizens Advisory Committee before the annual program is finalized.

In comparison, Maryland has a very centralized approach, mirroring the strong state role in funding and programming both highway and transit projects. The state has adopted a unified trust fund approach, whereby all federal funds are pooled in a trust fund; CMAQ is one of many funding sources. The Maryland Department of Transportation (MDOT) has the primary responsibility for the CMAQ program. The

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[15] TCC consists of elected officials of all towns, cities, and counties in Northern Virginia plus local transit authorities. (Washington Metropolitan Area Transit Authority staff sit on the TCC Technical Committee but are not directly represented on TCC itself.) Although TCC programs CMAQ and STP funds for Northern Virginia, the Commonwealth Transportation Board, whose members are nominated by the governor from the nine state transportation districts and whose chair is the Secretary of Transportation in Virginia, has the primary responsibility for appropriating and allocating the funds to the area and for final approval of the programs that TCC recommends.

state's selection process for CMAQ projects is the same as that for all other transportation projects. MDOT in conjunction with its modal agencies, the State Highway Administration and the State Mass Transit Administration, selects projects for CMAQ funding after two reviews—the first with the county staff and the second with elected officials and the public—before final project programming. After review of the input of county staff and elected officials, MDOT makes the final project selection. The District determines its funding priorities for CMAQ largely in-house through the Department of Public Works, District Division of Transportation.

The three jurisdictions forward their recommended lists of CMAQ and other transportation projects to the MPO for the Washington metropolitan area—the National Capital Region Transportation Planning Board (TPB). Designated by the governors of Maryland and Virginia and the mayor of the District of Columbia as the area MPO, TPB is staffed by the Department of Transportation Planning of COG.[16] TPB programs the recommended projects for inclusion in the TIP.

A major exception to this general process is the treatment of a group of largely CMAQ-funded projects called Transportation Emission Reduction Measures (TERMS). In the 1990s the major jurisdictions and interest groups in the Washington metropolitan area embarked on a collaborative process to identify and fund projects to help the area meet the conformity requirements of the CAAA. A technical committee conducted a rigorous review of possible regional TCMs from the perspective of VMT and trip reduction potential, related emission reduction potential, and cost-effectiveness (FHWA 1995). A funding mechanism was also established. When TERMS are needed to meet conformity requirements for the area to stay within SIP budgets, projects are selected that rank highest on the list on the basis of their emission reduction potential and cost-effectiveness, and each state commits the necessary funds. Virginia and the

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[16] The jurisdiction of COG is somewhat smaller than the Washington nonattainment area. COG's membership includes the District of Columbia; the Virginia counties of Arlington, Fairfax, Loudoun, and Prince William and cities of Alexandria, Fairfax, and Falls Church; and the Maryland counties of Frederick, Montgomery, and Prince George's and cities of Bowie, College Park, Frederick, Gaithersburg, Greenbelt, Rockville, and Takoma Park.

District have chosen to use CMAQ funds to finance their share; Maryland uses state funds, because its CMAQ funds typically are already programmed for other purposes.

The area jurisdictions do not have formal ranking systems for selecting among and evaluating projects for CMAQ funding, with the exception of the TERMS. For example, the technical staff of the TCC of Northern Virginia considers such criteria as emission reduction potential, project continuations, and the seven ISTEA planning factors (e.g., intermodalism) in evaluating projects, but the criteria are not used to rank individual projects. The District considers emission reduction potential and project readiness in its selection and evaluation of CMAQ projects, but there is no formal rating scheme. Maryland considers project acceptability by elected officials and the public and emission reduction potential in selecting and evaluating projects for CMAQ funding, but there is no formal project ranking system. The Washington Metropolitan Area Transit Authority (WMATA), the major transit provider in the region, also has an informal process for recommending projects for CMAQ funding. Its primary concerns are capital needs identified in its own capital budget and service amenities, which may be CMAQ-eligible, that support transit ridership in the region. WMATA is involved in the process of project selection only through TCC in Northern Virginia; it has little or no contact with the District or MDOT concerning their selection and evaluation of transit projects for CMAQ funding.

Conformity plays a major role in selecting projects for CMAQ funding. When additional mobile source measures are needed to keep the area in conformity, the highest-ranking TERMS are selected from a candidate list and, as preagreed in Virginia and the District, CMAQ is used to fund these projects. Maryland finances its TERMS using state funds.[17]

Air quality improvement is the primary criterion for selecting among TERMS and other TCMs, but secondary considerations are also taken into account, at least in an informal way. For example, the

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[17] COG/TPB staff made the additional point that all emission-reducing projects are quantified and counted toward conformity irrespective of funding source or purpose. TERMS represent just a few of these projects.

District examines how projects fit into the long-range transportation vision developed for the Washington metropolitan area (COG 1999).[18] Northern Virginia takes into account quality-of-life issues in its project selection. Maryland considers social and economic as well as environmental aspects of CMAQ projects, as it does for any transportation project the state is developing. The state also looks at the benefits of CMAQ projects in reducing congestion. Finally, WMATA considers economic development, access, and affordable transit as important factors in evaluating projects for CMAQ funding.

Generally, the jurisdictions that recommend projects for CMAQ funding provide the initial information to TPB on projected effects on trips and VMT, project costs, and emission reductions.[19] With regard to the latter, the jurisdictions use a consistent methodology, developed at COG/TPB, to evaluate the pollution reduction potential of the TERMS. COG/TPB handles both the travel and emission estimates for the evaluation of the TERMS. A regional demand model is used to estimate travel effects and emission factors from the MOBILE model (employing postprocessing techniques) to project pollutant reductions. Each of the jurisdictions is responsible for providing FHWA with the required annual information on CMAQ-funded projects, including estimates of emission reductions. The survey respondents did not recommend any changes in the reporting process, with the exception of Maryland, which recommended that project emission reductions be reported in tons per day rather than in kilograms per day, as is now required.

Some ex-post evaluations of CMAQ-funded projects have been conducted by COG/TPB. These are typically the large TERMS, such as the Regional Commuter Connection program, which involves employer outreach, guaranteed ride home, telework resource centers, integrated rideshare, and a commuter operations center. WMATA is planning to conduct an evaluation of a bus signalization project on

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[18] The National Capital Region TPB unanimously adopted its long-range transportation vision in October 1998.

[19] There are some exceptions. For example, COG/TPB conducts the analysis of estimated ridership and emission effects of new transit services in Northern Virginia. COG also conducts much of the required analysis for the District, particularly the estimated emission reduction potential of individual projects.

Columbia Pike; ITS funds will be used to fund the evaluation. The small scale of many CMAQ projects (with emission reductions on the order of 0.001 tons per day), however, raises concerns about the cost-effectiveness of conducting extensive ex-post project evaluations.

CMAQ Program Objectives

Those interviewed saw the CMAQ program mainly as an air quality program. Its primary role is to help the Washington metropolitan area stay in conformity and, by so doing, help improve regional air quality. The respondents differed, however, in terms of how this could be accomplished. Some viewed congestion mitigation and highway projects that remove bottlenecks or improve the efficiency of traffic flow [e.g., traffic signalization projects, high-occupancy vehicle (HOV) lanes to reduce SOV travel] as effective ways of reducing pollution. Others thought that the benefits of such projects are short term; freer-flowing highways will simply fill up again with traffic. They saw the goal of the program as providing alternatives to highway travel, such as better transit. Their perception was that the CMAQ program should not be used for highways and congestion relief. Most of those interviewed sought more federal guidance on what is an appropriate program balance between highway and nonhighway projects.

Over the past 5 years (FY 1995–1999), the Washington metropolitan area has used its CMAQ funds primarily to support transit projects (e.g., bus replacements) and traffic flow improvements (e.g., traffic signalization projects, HOV lanes) (see Table D-4). Priorities, however, differ by jurisdiction. The District spends the largest share of its CMAQ funding on transit (69 percent), followed by demand management projects (10 percent) and the I&M program and other projects (11 percent). Virginia spreads its funds among several different project categories with the largest expenditures for transit (64 percent) followed by traffic flow improvements (e.g., signalization projects) (23 percent). Maryland has concentrated its CMAQ spending in three main project categories. Traffic flow improvements (e.g., signalization projects, HOV lanes, and ITS projects) and transit accounted for 46 percent and 42 percent of spending, respectively, over the past 5 years. Shared-ride projects accounted for another 12 percent.

TABLE D-4 CMAQ Program Obligations in the Washington Metropolitan Area by Jurisdiction and Spending Category, FY 1995–1999

	Jurisdiction (%)			
Project Category	**District**	**Maryland**	**Virginia**	**Regional Total (%)**
Traffic flow improvement	0	46	23	26
Transit	69	42	64	59
Shared ride	7	12	3	6
Demand management	10	0	5	4
Pedestrian/bike	3	0	4	3
Other	11	0	1	2
Total	**100**	**100**	**100**	**100**

Sources: Data provided by the District of Columbia Department of Public Works, the TCC of Northern Virginia, and MDOT.

According to those interviewed, if CMAQ funds had not been available during this period, projects that were necessary to meet conformity requirements would have gone forward using other funding sources. However, this could have delayed other highway and transit projects.[20] Other projects that were required by the CAAA, such as the District's I&M program, and certain bicycle and pedestrian projects that had strong public interest group and community support, also would probably have gone forward using other funds. In the judgment of many of those interviewed, projects without obvious alternative funding sources, such as the Commuter Connections program and regional integrated ridesharing, probably would not have been undertaken.[21]

When asked which types of projects were most effective in achieving CMAQ program goals of emission reductions and air quality

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[20] The Greater Washington Board of Trade questioned whether the absence of CMAQ funding, which is a "drop in the bucket" relative to the region's capital needs (identified as $2.5 billion for FY 2000 alone in the TIP for FY 2000–2005), would make a noticeable difference.

[21] It should be noted, however, that Maryland does not fund the Commuter Connections program with CMAQ funds.

improvement, the following types of projects were mentioned: the TERMS, the District's I&M program, the telecommuting project,[22] projects that reduce SOV travel or get people out of their cars entirely, clean vehicle purchases, new buses and rail cars, park-and-ride lots, and traffic signalization projects (with the exception of increases in NO_x emissions from increased vehicle speeds). Projects that would get high-emitting vehicles off the road, such as vehicle scrappage programs, were also viewed as having high emission reduction potential but are not currently eligible for CMAQ funding.

The best projects for congestion relief were telecommuting, traffic signalization projects, projects that use ITS technologies to improve highway efficiency, and projects that encourage use of transit or reduce SOV travel. The Greater Washington Board of Trade also mentioned improving suburb-to-suburb connectivity in the Washington metropolitan area as a key to congestion relief and recommended that CMAQ restrictions on capacity enhancements be lifted to finance such connectors, supported by tolls and buffered by parklands and limited interchanges to reduce public expenditures and potential for sprawl. The Coalition for Smarter Growth, however, feared that such capacity enhancements would lead to sprawl and questioned the longer-term value of projects that improve the capacity of existing roadways from both a congestion and an air quality perspective.

Cost-effectiveness is only considered as a formal selection criterion for the TERMS. However, area jurisdictions do consider cost as one factor in selecting projects for CMAQ funding. In the opinion of those interviewed, the most cost-effective projects were the I&M program, demand management measures such as telecommuting and ridesharing, park-and-ride lots, clean vehicle and clean fuel technologies, and ITS technologies.[23] Transit projects were perceived by the staff of the TCC of Northern Virginia to be among the least cost-effective from an air quality perspective but cost-effective from a

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[22] A survey conducted for COG showed that 12 percent of the Washington area residents telecommute at least 1 day per month.

[23] Maryland thought that transit bus fleet replacement projects were cost-effective. WMATA staff disagreed. In their opinion, transit clean fuel technology projects were far more cost-effective from an air quality perspective.

congestion mitigation perspective. Of course, when compared with other strategies for reducing pollution, improvements in vehicle technology and fuels were thought to yield the greatest benefits and to be the most cost-effective because all vehicles are affected.

CMAQ Program Evaluation

The main strength of the CMAQ program lies in its provision of a dedicated funding source for transportation projects that improve air quality. Without such a restriction, CMAQ funds would probably be used to finance the region's large infrastructure preservation needs. Flexibility was also noted as a program strength, and several respondents recommended areas in which the program could be made even more flexible (see below for more details). Some thought that the CMAQ program has encouraged innovative projects. Others, however, did not see CMAQ as a mechanism for stimulating innovation, mainly because the area has so many traditional needs that are CMAQ-eligible.

In the opinion of several of those interviewed, Maryland being a key exception, a critical weakness of the CMAQ program is the significant state role in the program. There is no assurance, for example, that funds will be suballocated to the Washington metropolitan area on the basis of the same criteria—population and air quality status—that were used to allocate the funds to the states in the region. This lack of a regional funding approach is magnified by the lack of a regional process for identifying CMAQ project priorities that uses regional criteria for emission reductions and congestion relief. Finally, Maryland noted as a weakness that there is not enough emphasis on the congestion management part of the CMAQ program.

Because there is no regional CMAQ program as such, many of those interviewed did not think that the program has had much effect on interagency decision making. The exception is the TCC of Northern Virginia, where the state has delegated decision making to the local area. Most of the respondents thought that the federal government should mandate a regional cooperative process as a CMAQ program requirement. The perception is that the CMAQ program can provide a forum for broader involvement of groups, such as air agencies and bicycle and pedestrian interests, in making area transportation choices. However, this has not happened in the Washington area. The interest groups indicated that opportunities for input into the CMAQ decision-making process come too late for them to make any meaningful contribution. Maryland strongly disagreed with both the characterization of the current process and the recommendation for a federal mandate. According to MDOT, the state reviews and receives input directly on CMAQ and other transportation projects from local government staff and elected officials as well as transit agencies during the programming process. Maryland believes that states should be allowed to self-certify their coordination process with local governments.

All of those interviewed thought that the CMAQ program should be continued when TEA-21 is reauthorized and that the funding should continue to be protected, that is, the focus should continue to be on transportation projects that improve air quality. In fact some of the respondents (COG/TPB, the Coalition for Smarter Growth) thought that the program should be more targeted at projects that reduce VMT and emissions. Others, like WMATA, thought that the regulations should allow projects, such as new station improvements, that may not show new emission reductions but help maintain transit ridership. Restrictions on highway capacity improvements should be kept. The Greater Washington Board of Trade disagreed on the latter point and recommended expanding project eligibility to include capacity enhancement projects, such as the suburban connectors previously discussed.

The majority thought that the program should not be broadened to cover other pollutants, with the possible exception of $PM_{2.5}$, and then only if funding were increased.[24] Maryland thought that other types of pollutants should not qualify for CMAQ funding until the current 1-hour ozone attainment standard is met, but the state supports CMAQ eligibility for any project that measurably reduces ozone precursor emissions. The consensus was that the focus should

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[24] There was some discussion of whether the program scope should be broadened to focus on other environmental problems, such as noise and storm water, but the general consensus was that this would dilute the air quality focus of the program. Moreover, other funding sources are available to tackle these problems.

be on making the current program better. COG/TPB suggested that, rather than earmarking CMAQ funds for a broad range of pollutants, the federal government ought to be looking at individual pollutant sources and the most cost-effective ways of obtaining emission reductions.

The respondents made several suggestions for changing the program, although not all of the respondents agreed with all of the suggestions. First, many recommended that CMAQ funds be suballocated to nonattainment and maintenance areas within states using the same federal formula that determined the state allocation. Second, many recommended that the federal government require a cooperative regional process for identifying, selecting, and evaluating projects for CMAQ funding. The process should enable air agencies and interest groups to have a greater role in the program.[25] Third, program flexibility should be increased. For example, staff of the Northern Virginia TCC thought that limits on the use of CMAQ funds for transit operations should be relaxed.[26] Use of funds to support a CMAQ grants manager at the state level should also be considered (a suggestion of the District). Fourth, greater flexibility should come with more extensive and intensive project evaluations to make sure that the funds are being well spent, presumably with federal guidance and funding to prevent burdensome new requirements on local governments. Finally, the federal role in managing the program could be strengthened in the following areas: sharing of information on best practices, ex-post evaluation of projects, guidance on program balance issues (i.e., to what extent the program is an air quality program versus a congestion mitigation program), clear statement of project matching ratios, and an up-to-date national database.

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[25] Maryland did not support this or the prior suggested program change.

[26] WMATA staff strongly disagreed with this position. In their view, CMAQ restrictions on the use of funds for transit operations help provide funding for new transit services that otherwise might not be started and give time for those services to build up ridership before local support is needed. Lifting these restrictions, in their opinion, would encourage jurisdictions to substitute CMAQ funds for existing transit operations, removing the incentive to use them for starting up new services.

Organizations and Persons Interviewed—September 7–8, 2000

Metropolitan Washington Council of Governments
  Ronald Kirby, Director, Transportation Planning
  Gerald Miller, Chief, Program Coordination
  Mark Pfoutz, Transportation Planner
Government of the District of Columbia, Department of Public Works
  Ken Laden, Administrator, Intermodal Planning
  Michelle Pourciau, Chief of Transportation and Public Space Planning
  Maurice Keyes, Environmental Program Coordinator
Virginia Department of Transportation
  Kanathur Srikanth, Senior Transportation Engineer
Maryland Department of Transportation (written response)
  Marsha J. Kaiser, Director, Office of Planning and Capital Programming
Washington Metropolitan Area Transit Authority
  Richard Stevens, Director, Office of Business Planning and Development
  Kathleen Donodeo, Associate Director, Office of Business Planning and Development
Greater Washington Board of Trade
  Robert Grow, Staff Director, Transportation and Environmental Committee
Coalition for Smarter Growth
  Stewart Schwartz, Executive Director
  James Clarke, Consultant, Environment and Transportation Policy

HOUSTON SITE VISIT

Introduction

The Houston-Galveston metropolitan area is designated a Severe-II nonattainment area for ozone, with mobile source emission budgets both for VOCs and NO_x. In December 2000, the state air agency, the Texas Natural Resource Conservation Commission, approved the Houston-Galveston SIP, which is designed to bring the eight-county nonattainment area into compliance by 2007. The plan was approved by EPA in October 2001. The area's long-range Metropolitan Transportation Plan (MTP) and current 2000–2002 TIP conform with the SIP's rate-of-progress requirements for the region.

The Houston-Galveston metropolitan area is experiencing rapid growth, with substantial projected population and employment increases. From 2000 to 2022, population is expected to grow by 36 percent from its current level of 4.5 million and employment by 29 percent from its current level of 2.4 million, according to forecasts of the Houston-Galveston Area Council (H-GAC) (H-GAC 2000b, 6).[27] This projected growth will affect transportation use in the region. Vehicle trips are expected to increase by nearly 40 percent and VMT by nearly 47 percent between 2000 and 2022 (H-GAC 2000b, 11, 14). The major transit provider in the region, the Metropolitan Transit Authority of Harris County (METRO), carries about 5 percent of work trips in the region (METRO 2000b, ES-9). Current estimates show that the mode share is closer to 10 percent of work trips in Harris County, where METRO provides the majority of its service. Transit ridership levels have been increasing since 1997 (H-GAC 2000b, 13).

CMAQ Program Process and Decision-Making Procedures

The Texas Department of Transportation (TxDOT) suballocates CMAQ funds to nonattainment and maintenance areas in the state using the same formula by which national-level CMAQ funds are allocated to Texas. Currently, the Houston-Galveston nonattainment area receives about $32.5 million in CMAQ funds annually,[28] which represents about 2 percent of the $1.6 billion annual TIP.[29]

The H-GAC Transportation Policy Council, the designated MPO for the eight-county Houston-Galveston Transportation Management Area,[30] is responsible for the selection and programming of CMAQ projects as well as other transportation projects in the region.

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[27] The forecasts were developed by H-GAC in a process begun in 1997. After examining alternative regional forecasts from two scenarios, H-GAC selected the "aggressive" scenario as the basis for developing the new forecasts (H-GAC 2000b, 5–6).

[28] This level of funding under TEA-21 represents a reduction from prior levels of $40 million to $42 million annually under ISTEA. Release of caps on CMAQ funding to large states such as New York and California accounts for the reduced funding to Texas and, by extension, to the Houston-Galveston area.

[29] Only about 40 percent of the TIP funding comes from federal and state sources.

[30] The eight counties are Brazoria, Chambers, Fort Bend, Galveston, Harris, Liberty, Montgomery, and Waller.

TxDOT also nominates projects for CMAQ funding and is a major user of CMAQ funds in the Houston-Galveston area. In addition, TxDOT plays a major role in the management and administration of CMAQ funds in Houston and other nonattainment areas in the state—a role it has taken on because the agency is ultimately accountable to the U.S. Department of Transportation for the use of CMAQ program funds. More specifically, once projects have been selected and programmed for CMAQ funding in the TIP, TxDOT allocates the funds to the Houston District Office of TxDOT, which then lets the contracts for individual projects and administers the program locally.[31] METRO is an exception to this process. For most of METRO's CMAQ-funded transit projects, the funds are transferred from FHWA to FTA for inclusion in METRO's annual formula fund grant.[32] METRO is responsible for managing and administering its own CMAQ-funded projects.

CMAQ-eligible projects must first be incorporated into H-GAC's regional transportation plan. This may occur when projects are nominated for inclusion in the regional plan every 2 to 3 years or through staff analysis of transportation needs during plan reevaluation. Except for the initial introduction of the CMAQ funding category with the passage of ISTEA, H-GAC has not conducted a separate solicitation for nominating projects for CMAQ funding. The vast majority of projects are recommended by TxDOT and METRO, and to a lesser extent, by the city of Houston and Harris County. However, projects have been successfully sponsored by several other groups.[33] Involvement of

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[31] The district office lets contracts for typical CMAQ highway projects such as traffic signalization and grade separation projects and for such projects as bicycle paths that have traditionally not been an area of state highway interest.

[32] For some transit projects, such as the Clean Air Month project, the U-Pass project, and projects involving alternative fuel systems on transit support vehicles, H-GAC acts as the funding conduit, working through interagency agreements.

[33] For example, every transit provider in the eight-county region and many other local governments have successfully sponsored CMAQ projects. In addition, the Port of Houston has developed several intermodal projects with CMAQ funds. Lastly, H-GAC administers programs supporting the use of alternative fuels and the start-up of small transit projects for which proposals are solicited annually. Using interlocal agreements, these projects vary from a few thousand to several hundred thousand dollars.

public interest groups in the identification of projects as candidates for CMAQ funding is limited.

A separate process has been established for the evaluation and ranking of CMAQ-eligible projects in the RTP that may be candidates for inclusion in the TIP. This process has resulted in a broader range of agency and public involvement in project review. In the mid-1990s, desired categories of CMAQ-eligible projects were identified, and target levels of funding were established, to ensure that regional goals identified in the MTP were not lost in the process of individual project evaluation, comparison, and selection (H-GAC 2000a, B-1–B-5). The six categories identified and their targeted percentages of CMAQ funding are as follows: bicycle/pedestrian, 7 percent; air quality/environmental (e.g., engine replacements), 7 percent; travel demand management (e.g., rideshare/vanpool), 9 percent; transit, 26 percent; intermodal, 6 percent; and transportation system management/traffic operations, 44 percent.[34] Within each category, projects are rated on two criteria: (*a*) cost-effectiveness [i.e., cost (net of local contributions) per expected total annual pounds reduction of VOCs and NO_x] and (*b*) readiness.[35] This system allows CMAQ funds to be allocated to a relatively wide range of projects, reflecting locally agreed-upon priorities. It also enables like projects to be compared and ranked within each category. The targeting system has not been used for the FY 2002–2004 TIP currently in development because the reduction in CMAQ funding to the area has created a substantial backlog of projects. In addition, $35 million of CMAQ funding has been set aside for CMAQ-eligible projects that support a major freeway reconstruction project, the Katy Freeway.[36]

Once candidate projects for CMAQ funding have been identified for a particular TIP, they are reviewed by the Technical Advisory Committee (TAC) of H-GAC. TAC membership is broad. It includes

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[34] Because of rounding, the category percentages do not add up to 100 percent.

[35] Four factors are examined to determine project readiness: basis for cost estimates, completeness of environmental analyses, availability of right-of-way, and local government financial commitment (H-GAC 2000a, B-3).

[36] The backlog could grow even more in the future. In anticipation of the 8-hour ozone standard, TxDOT is already planning to set aside a certain amount of future CMAQ funds for allocation to newly designated nonattainment areas.

member governments and citizen interest groups with expertise in transportation planning who are appointed by the Transportation Policy Council (TPC) to assist in the coordination of the TIP, MTP, and other transportation planning activities. Because of the size of the TIP, TAC is assisted by a standing subcommittee that reviews and recommends project readiness, ranking, and programming. Membership in the TIP subcommittee is open to all TAC members. Several of the nongovernmental members of TAC, however, noted that they had little understanding of the CMAQ project evaluation and ranking process and limited opportunity to discuss individual CMAQ projects at the TAC meetings. TPC, which consists of 3 at-large members appointed by the H-GAC Board of Directors and 24 members who represent cities and counties, TxDOT, and METRO, provides overall policy guidance and approves the final TIPs and MTPs.

H-GAC has assumed the primary role of preparing the information needed to evaluate CMAQ projects. Typically, project sponsors provide activity-level data (i.e., project inputs such as vehicle speeds, trip, and VMT data) and project costs. H-GAC then determines whether the project is eligible for CMAQ funding, whether it is compatible with the MTP, and how it ranks on the basis of cost-effectiveness and readiness. Emission evaluations are conducted using methodologies developed by H-GAC (H-GAC 2000b, Appendix B).[37] The exception again is METRO, which prepares its own emission estimates in consultation with H-GAC for the projects it sponsors. Secondary factors, such as safety, are not directly considered in evaluating CMAQ projects, but they can play a role in determining the final project ranking within project categories.[38]

Conformity requirements have become an increasingly important factor in the selection of CMAQ projects. For example, in prior years CMAQ funds were used to finance grade separation projects, which

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[37] H-GAC has developed different methodologies and assumptions for each project subcategory. In general, travel data (e.g., changes in trips or VMT) are linked with appropriate emission factors from the MOBILE model in off-model calculations that estimate the net emission benefits of various types of projects.

[38] For example, safety was a consideration in selecting among grade separation projects for CMAQ funding, and economic development was a consideration in selecting the intermodal port project for CMAQ funding.

were found to be beneficial for VOC reduction. However, as the area has had to pay increasing attention to the issue of reducing NO_x (previously the region received a NO_x waiver), many grade separation projects, which increase vehicle speed and thus NO_x emissions, are no longer desirable from an air quality perspective.

Many CMAQ projects as well as other TCMs are included in the area SIP for emission credit. Such projects include regional computerized traffic signal systems, arterial traffic management systems, intersection improvements, park-and-ride lots, HOV lanes, and transit service projects (H-GAC 2000b, 23). Other mobile emission programs (e.g., employer-sponsored commute programs, alternative-fueled railroad vehicles) are included in the SIP as voluntary programs rather than TCM commitments. They are evaluated for credit in the conformity analysis, and off-model credits are taken as appropriate. Although the contribution of these projects is small relative to estimates of area emission levels, they help demonstrate the region's commitment to achieving SIP targets.[39]

The TxDOT Houston District Office is responsible for reporting information on CMAQ-funded projects to TxDOT's state planning office, which, in turn, provides the required data to FHWA. H-GAC helps coordinate the collection of this information from the relevant local agencies. The survey respondents did not recommend any changes in the reporting process, although some questioned the level of detail required and wondered whether the information was useful to program sponsors for program design and modification.

A few ex-post evaluations of CMAQ-funded projects have been conducted. METRO has conducted an evaluation of a 3-year, CMAQ-funded transit subsidy program during the high-ozone month of August, known as Clean Air Month. The evaluation found that 13 per-

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[39] For example, in 2000 the SIP VOC emission budget was 132.68 tons per day and projected highway VOC emissions for that year were 114.30 tons per day. CMAQ and other TCMs were expected to reduce VOC emissions by 0.71 tons per day for a net highway emission total of 113.59 tons per day relative to the VOC budget (H-GAC 2000b, 22). Similarly, in 2000 the SIP NO_x emission budget was 283.01 tons per day and projected highway NO_x emissions for that year were 268.76 tons per day. CMAQ and other TCMs were expected to reduce NO_x emissions by 1.41 tons per day for a net highway emission total of 267.35 tons per day relative to the NO_x budget (H-GAC 2000b, 23).

cent of the 36 percent increase in boardings from August 1996 to August 1999 could be attributed to the program, although the evaluation showed diminishing returns in the third year (METRO 2000a). Two other evaluation efforts are under way. H-GAC is conducting a "before and after" study of the regional bicycle plan, which is being funded in part by the CMAQ program. In addition, H-GAC is collecting traffic data to capture "before" conditions for subsequent analysis and evaluation of regional computerized traffic signalization projects that will soon be implemented, also using CMAQ funds.

H-GAC staff suggested that more comprehensive evaluations of CMAQ-funded activities are needed. Currently each project is expected to contribute to reductions in congestion and emissions. The focus should be on the combined systems effects of individual projects rather than on project-by-project evaluations. H-GAC, at least, would be sympathetic to using some CMAQ funds for such comprehensive evaluations. TxDOT, however, does not think that funding for evaluation should come from project funds.

CMAQ Program Objectives

The majority of those interviewed supported the dual goals of the CMAQ program—air quality improvement and congestion mitigation—and saw no major conflict between them. Representatives from the Houston Area Bicycle Alliance and the Gulf Coast Institute, however, did not agree with this perspective. In their view, congestion mitigation measures that improve highway travel are at odds with the program goal of pollution reduction.

The area's strong focus on congestion mitigation can perhaps be explained by the high level of congestion in Houston,[40] by the major role played by TxDOT in the CMAQ program, and by METRO's role in improving regional mobility, not just operating transit services. Whatever the reasons, the area spent nearly 60 percent of its CMAQ funds in the last 5 years (FY 1996–2000) on traffic flow improvements for such projects as a regional computerized traffic signalization

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[40] According to a congestion index developed by the Texas Transportation Institute, Houston ranks 12th out of 86 urban areas and 4th in terms of annual person delays (Schrank and Lomax 2001, 38).

TABLE D-5 CMAQ Projects Let to Contract, Houston Metropolitan Area, FY 1996–2000

Project Category	Total Cost ($)	CMAQ Share ($)	Percent CMAQ
Traffic flow improvements	147,842,724	113,474,179	57.8
Shared ride	32,117,994	26,023,184	13.3
Transit	29,958,278	23,966,622	12.2
Bicycle/pedestrian	16,308,256	11,198,444	5.7
Demand management	697,045	567,636	0.3
Other	40,141,901	20,956,665	10.7
Total	**267,066,198**	**196,186,730**	**100.0**

Note: Spending is reported by state fiscal year, which runs from September 1 through August 31.

Source: TxDOT, Houston District, Jan. 2001.

system, a traffic incident and management facility,[41] and HOV lanes (Table D-5).[42] The next-largest spending categories are shared ride (e.g., regional commute programs, vanpool programs), which accounted for 13 percent of contracts let in this period, and transit (e.g., fare subsidy program, new shuttle and bus service), which accounted for 12 percent of contracts let (Table D-5). Bicycle and pedestrian projects accounted for another 6 percent. Of the remainder,

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[41] Houston has a demonstration corridor under the ITS Program. TRANSTAR is a local partnership formed and operated through the agreement and funding of TxDOT, METRO, the city of Houston, and Harris County. It was established to coordinate and fund projects of regional benefit that support ITS solutions to traffic and incident management. CMAQ funds were used to finance building a TRANSTAR command post and are being used for ITS project support now that ITS demo funds are drying up.

[42] These spending percentages cannot be directly compared with the target percentages established by H-GAC. When adjustments are made to equate the federal project classification system with the H-GAC classification scheme, actual spending for FY 1996–2000 was higher than targeted for traffic flow improvement projects (50 percent versus the 44 percent target) and transportation demand management projects (13.5 percent versus the 9 percent target). Spending on transit projects was lower than targeted (20 percent versus the 26 percent target); intermodal projects also fell short (4.4 percent versus the 6 percent target). Bicycle and pedestrian projects and air quality/environmental projects were close to target (5.7 percent versus the 7 percent target for the former, and 6.3 percent versus the 7 percent target for the latter).

the largest project is the CMAQ-funded intermodal project involving the Port of Houston categorized under "other."[43]

According to many of those interviewed, if CMAQ funds had not been available during this period, certain projects, such as vanpooling, telecommuting, technology projects (e.g., bus engine replacements with cleaner engines), and clean air educational initiatives for which there are no obvious alternative funding sources, probably would not have been undertaken. In addition, there probably would have been fewer bicycle and pedestrian projects, and there probably would have been delays in implementation of new transit services and traffic signalization improvement projects if these projects had to rely on other funding sources. TxDOT thought that most projects probably would be undertaken even if CMAQ funds were not available, but implementation schedules would slip considerably. Moreover, in TxDOT's judgment, if CMAQ funds were unavailable, more projects would have been focused on infrastructure and operations than on air quality improvement. Finally, according to H-GAC, one important role of CMAQ has been to "buy down the risk of pilot projects," such as transit services focused on suburban employment centers and METRO's Clean Air Month.

When asked which types of projects were most effective in achieving CMAQ program goals of emission reductions and air quality improvement, the following types of projects were mentioned: traffic signalization and ITS projects, transit (transit service start-up and expansion and vehicle engine replacements), and projects that help reduce the number of SOV trips or eliminate vehicle trips entirely, such as the intermodal port project, vanpooling projects, park-and-ride, HOV lanes, and bicycle, teleworking, and pedestrian projects.

The best projects for congestion relief fell into the category of traffic flow improvements—projects such as intersection improvements, grade separations, computerized traffic signalization and coordination, and bottleneck reductions. The most cost-effective projects included many of the same projects that were mentioned as

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[43] The $3.6 million project involved adding queuing lanes and traffic crossovers to reduce truck congestion at a major terminal and adding rail spurs near two cargo transit sheds.

effective for emission reductions—traffic signalization and bottleneck removal projects (although the benefits are relatively short term), HOV lanes (mainly because they are built on existing state facilities and thus require no right-of-way costs), park-and-ride lots and vanpool programs, and engine replacements.

Of course, when CMAQ projects are compared with other strategies for reducing pollution, improvements in vehicle technology and fuels were thought to be the most cost-effective strategies because they are applied fleetwide.

CMAQ Program Evaluation

Viewed in the context of other transportation programs, the main strengths of the CMAQ program are its focus on air quality (the only transportation program that is so focused), its multimodal scope, and its encouragement of some nontraditional demonstration projects (e.g., METRO's Clean Air Month Program). As a funded mandate, the CMAQ program is an effective tool for leveraging other funds. Its availability also helps accelerate certain projects, which might have been delayed had CMAQ funding not been available.

Not all who were interviewed saw the CMAQ program as innovative, at least not with respect to how the program has been implemented in the Houston area. In the view of the Gulf Coast Institute staff, for example, it appeared that the majority of CMAQ funding has supported traditional highway and transit projects in the region. Even when more innovative projects have been funded, others noted that the program encourages short-term solutions. CMAQ provides start-up funds but leaves local governments with the burden of financing equipment replacement and operating expenses because of CMAQ program limits on operating funding and its focus on investments in new facilities, equipment, and services. Finally, inadequate evaluation of CMAQ projects, particularly evaluations that are focused at the system rather than the individual project level, was noted as a program weakness.

Agencies with a major role in the CMAQ program—H-GAC, TxDOT—believe that the program has improved interagency cooperation and increased agency awareness of air quality problems. The program has also leveraged the participation of new players (e.g., the

Port of Houston) and broadened the activities handled by H-GAC (e.g., its involvement through the CMAQ program in transportation management organizations). However, with the exception of the bicycle interests, CMAQ is not viewed by public interest groups as having increased their involvement in area transportation planning and decision making.

Despite these differences of opinion, all of those interviewed thought that the CMAQ program should be continued when TEA-21 is reauthorized. When new air quality regulations are implemented (e.g., the 8-hour ozone standard) or standards are established for other pollutants (e.g., air toxics), CMAQ eligibility should be expanded accordingly, but only if more program funding is provided; otherwise, the current program will be diluted.[44] Others, like the Houston Area Bicycle Alliance and the Gulf Coast Institute, thought that CMAQ eligibility should be expanded to include more "Smart Growth" and land use projects (e.g., sidewalks). Concern was expressed, however, about implementation of more nontraditional projects, particularly if TxDOT continues its current program management role.

Several suggestions were made for changing the program, although not all of those interviewed agreed with all the suggestions. First, more CMAQ funding should be available for project planning and development as well as for operations. Second, nearly all agreed on the need for better evaluation of the benefits of CMAQ projects. However, the focus should not be on individual project assessments so much as on how groups of similar projects affect the system. H-GAC and TxDOT differed on whether existing CMAQ funds should be used to sponsor such evaluations (H-GAC was in favor of and TxDOT against taking some project funds for this purpose). Third, METRO thought that more CMAQ funds should be spent on demonstration projects selected on the basis of their benefits for air quality. Several of the interest groups—Gulf Coast Institute, the Houston Area Bicycle Association—would also like to see more innovation in

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[44] The Bay Area Transportation partnership—a transportation management organization—thought that the program scope should be broadened to cover additional pollutants of concern whether or not program funding is increased.

CMAQ projects. Finally, several recommendations were made for improvements in program implementation that may only be applicable to the way the CMAQ program is handled in Texas. In the opinion of TxDOT and the city of Houston, some of the funding should be passed through directly to local governments in a small block grant, along with the responsibility and accountability for how the money is spent. In addition, the process needs to be streamlined, particularly for those projects that are suggested by a local government but implemented by TxDOT.

Organizations and Persons Interviewed—January 31–February 1, 2001

Houston-Galveston Area Council
  Alan Clark, MPO Director, Transportation Department
  Rick Beverlin, Senior Transportation Planner
  Cynthia Adamson, Senior Planner
Metropolitan Transit Authority
  Edith L. Lowery, Director, Grant Programs, Finance
  Larry Badon, Transportation Systems Planner, Planning, Engineering and Construction
  Lynda C. Mifsud, Manager of Environmental Planning, Planning, Engineering and Construction
Texas Department of Transportation, Houston District
  Gabriel Y. Johnson, P.E., Director of Transportation Planning and Development
  Carol W. Nixon, P.E., Director of District Transportation Planning
Texas Department of Transportation, Headquarters (by telephone)
  Timothy Juarez, Metropolitan Planning Supervisor, Transportation Planning and Programming Division, Transportation Systems Planning Section
City of Houston
  Douglas Wiersig, Senior Assistant Director, Traffic Management
Houston TranStar
  John R. Whaley, P.E., Director
Houston Area Bicycle Alliance
  Dan Lundeen, President
Gulf Coast Institute
  David Crossley, President

Bayou Preservation Association
  Mary Ellen Whitworth, P.E., Executive Director
Texas Natural Resource Conservation Commission (by conference call)
  Michael Magee, Program Specialist, Office of Environmental Policy, Analysis, and Assessment
  Kim Herndon, Program Specialist, Technical Analysis Division
  Roland Castaneda, Planner 1, Office of Environmental Policy, Analysis, and Assessment
Bay Area Transportation Partnership (by telephone)
  Connie Elston, President

LOS ANGELES SITE VISIT

Introduction

The Southern California region, which contains 13 nonattainment and maintenance areas, 4 air basins, 5 local air districts, and 6 counties (Los Angeles, Orange, Riverside, San Bernardino, Ventura, and Imperial), has some of the most serious air quality problems in the nation. The South Coast Air Basin (SCAB), which includes the urbanized portions of Los Angeles, San Bernardino, and Riverside Counties, and all of Orange County, is designated "extreme" for ozone—the only such area in the nation; "serious" for carbon monoxide (CO)—the only such area in California and the largest in the nation; and "serious" for particulates (PM_{10}). SCAB must reach attainment by 2010 for ozone and by 2006 for PM_{10}; it has already passed its attainment year, 2000, for CO. Portions of the three other air basins are also in nonattainment for ozone and PM_{10}, with differing designations and attainment deadlines.[45] The Southern California region is nearing completion of a new RTP (2001 RTP Update) for 2001–2025, including

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[45] The air basins cover the remainder of Los Angeles, San Bernardino, and Riverside Counties, as well as Ventura and Imperial Counties. In the Mojave Desert Air Basin, portions of San Bernardino and Riverside Counties are designated severe nonattainment areas for ozone; San Bernardino County is designated moderate for PM_{10}. In the South Central Coast Air Basin, Ventura County is designated severe for ozone. In the Salton Sea Air Basin, the Riverside portion is designated severe for ozone and serious for PM_{10}. The Imperial County portion is designated moderate and transitional for PM_{10} and ozone, respectively (Keynejad 2001, 2–3).

its conformity findings.[46] The 2001 RTP Update shows positive conformity findings relative to emission budgets and timely implementation of TCMs. The regional emission budgets and TCMs are contained in the applicable SIPs approved by EPA.

The six-county region, which includes nearly half the population of California and a gross national product equivalent of 12th-highest in the world, is expected to continue its rapid growth during the first quarter of the 21st century, according to the Southern California Association of Governments (SCAG), the MPO for the region (SCAG 2000, 29).[47] From 2000 to 2025, population is expected to grow by 34 percent to 22.6 million; households, by 37 percent to 7.4 million; and employment, by 7 percent to 10 million jobs (SCAG 2000, 29). This high level of projected growth will put further pressure on a transportation system that has been rated the most congested in America (Schrank and Lomax 2001, 38).[48] Person trips are expected to increase by nearly 40 percent and VMT by nearly 41 percent between the 1997 base projection year and 2025, with a projected doubling in vehicle hours of delay (SCAG 2000, Appendix J, J-7).[49] Nearly constant levels of drive-alone and carpool person trips and slight increases in transit person trips (from 2 percent in 1997 to 2.1 percent in 2025) and nonmotorized person trips (9.4 percent in 1997 to 9.6 percent in 2025) are assumed in the projections (SCAG 2000, Appendix J, J-8).

CMAQ Program Process and Decision-Making Procedures

The California Department of Transportation (Caltrans) suballocates CMAQ funds to nonattainment and maintenance areas in the state using the same formula by which national-level CMAQ funds

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[46] The conformity status of the 1998 RTP expired on June 9, 2001. The 2001 RTP Update was approved by the Regional Council of the area's MPO, the Southern California Association of Governments, on April 12, 2001.

[47] The draft 2001 RTP Update actually projects a slightly lower population and employment growth rate than did the earlier 1998 RTP (SCAG 2000, 29).

[48] The Los Angeles urban area ranks first on a congestion index developed by the Texas Transportation Institute and on annual delays per person.

[49] The travel forecasts are based on SCAG's enhanced regional transportation demand model. The figures quoted are based on the assumption that RTP programs and projects will be fully implemented.

are allocated to California. State legislation and the federal government require that CMAQ and other federal transportation funds be obligated within 3 years in a "use it or lose it" provision designed to help the state retain federal funds.

Because of the severity of its air quality problems, the six-county region receives nearly 60 percent of the statewide CMAQ apportionment.[50] In FY 2000–2001, the apportionment was nearly $220 million for the region, with about 62 percent going to Los Angeles County, 34 percent to Orange, Riverside, and San Bernardino Counties, and the remaining 4 percent to Ventura County. Imperial County, which is thinly populated, does not receive CMAQ funds (Keynejad 2001, 8).

Although the Southern California region receives the major share of CMAQ funds in the state, the FY 2000–2001 apportionment represents only 5.5 percent of the region's federal transportation funds and 2.3 percent of the region's transportation funds from all sources.[51] The region receives substantial assistance in addition to CMAQ to fund projects that help improve air quality, such as funding from the California Motor Vehicle Registration Fee Program. For example, the Southern California region receives about $10 million to $13 million annually from motor vehicle registration fees to support the Clean Fuels Fund that finances transit and other fleet engine replacements. Moreover, Los Angeles, Orange, Riverside, and San Bernardino Counties have a local sales tax, which is often reserved for investments in transit and HOV lanes that may help reduce vehicle emissions.

In contrast to other regions in California, the primary responsibility for programming CMAQ and other transportation funds within the Southern California region rests at the county and subcounty level.[52] Each county in the region is a designated council of governments, and each has a transportation commission or authority

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[50] The actual amount of obligation authority, however, typically is lower—about 80 to 90 percent of the apportionment.

[51] State and local sources make up 58 percent of total annual transportation funds to the six-county Los Angeles area.

[52] A history and overview of transportation planning in Southern California and its implications for decision making are given by Giuliano (2001).

charged with countywide transportation planning, allocation of locally generated revenues, and in some cases, operation of transit services (SCAG 2000, 25).[53] SCAG's role is to integrate the county and subregional TIPs of the councils of government, ensuring consistency and brokering disagreements, into the RTP and the associated short-range Regional Transportation Improvement Program (RTIP). SCAG is also responsible for the associated conformity analyses and findings and has veto power over any project that does not meet conformity requirements (Giuliano 2001). This highly decentralized decision-making structure, enacted by state law after passage of ISTEA, has meant that there is no regional process for the selection and evaluation of CMAQ projects. Each county has its own process.[54]

The Los Angeles County Metropolitan Transportation Authority (MTA), the largest user of CMAQ funds in the region, does not have a separate call for projects for CMAQ. All transportation projects are handled through a call for projects for the TIP, which is sent to Los Angeles County, Caltrans, 88 cities including the city of Los Angeles, and numerous transit and paratransit operators. Through the use of evaluation criteria, which are weighted to achieve a potentially perfect score of 100 percent, all proposed projects are evaluated against others in the same category.[55] The most weight is given to "regional significance, project benefit, and intermodal integration," although

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[53] The exception is Imperial County, where the Imperial Valley Association of Governments serves as the countywide transportation agency. In addition, there are 14 subregional councils of government (e.g., city of Los Angeles, Orange County Council of Governments, San Bernardino Associated Governments, Ventura County Council of Governments), comprising groups of cities and geographically clustered communities, which identify, prioritize, and seek transportation funding for needed investments in their respective areas (SCAG 2000, 25).

[54] To facilitate the work of the counties and the subregional councils of government and to ensure that conformity requirements are met, SCAG provides guidelines before preparing the RTIP, which outline all federal, state, and MPO requirements for CMAQ programming.

[55] There are eight project categories—freeways/HOV lanes, regional surface transportation improvements (mainly arterial highway improvements), signal synchronization and bus speed improvements, transportation demand management, bikeway improvements, pedestrian improvements, transit capital, and transportation enhancement activities (MTA 2000).

"land use and environmental compatibility" are also considered for certain project categories (MTA 2000, 11).[56] The objective of the process is to identify the best regionally significant projects without regard to funding sources (MTA 2000, 14). MTA staff work with Transportation Advisory Committee subcommittees to rank projects for each modal category, which are then scheduled for review and adoption by the MTA board. Once projects are approved for funding, specific funds such as CMAQ are assigned to each project on the basis of eligibility requirements and availability of funds. Project commitments are made for several years into the future. For example, the most recent call for projects in 1999 has committed CMAQ funds for the county through FY 2004. From time to time, the MTA board has earmarked CMAQ funds directly, outside the call process, primarily to fund transit projects, such as an all compressed natural gas (CNG) bus fleet, which the board has deemed to be critical for the county and for the basin's air quality.

Like MTA, the Orange County Transportation Authority (OCTA) does not have a separate call for projects for CMAQ funds. Appropriate projects are drawn from the county's long-range plan—entitled FastForward—and are approved by the OCTA Board of Directors. The choice of projects for CMAQ funding is also influenced by project readiness. Currently, the board of directors has earmarked all of the CMAQ funds remaining under TEA-21 for a single project, the urban rail Centerline project, which serves central Orange County. Weak support from the cities in Orange County, however, has stalled the Centerline project and may require reprogramming CMAQ funds to a different use.

In contrast to the process in Los Angeles and Orange Counties, the San Bernardino Associated Governments (SANBAG), the Riverside County Transportation Commission (RCTC), and the Ventura County Transportation Commission (VCTC) have separate calls for projects for CMAQ in San Bernardino, Riverside, and Ventura Counties, respectively. Since TEA-21 was enacted, SANBAG has had three

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[56] Other criteria include cost-effectiveness and local match, benefit to transit system, project need, and project readiness (MTA 2000, 11). The weights given to each criterion vary by project category.

calls for projects for CMAQ. The first allocated funds through board-approved set-asides for a truck climbing lane, transit capital, rideshare, and HOV projects. The second and most recent calls were directed to SANBAG's member agencies in a request for proposal–like format, and a scoring process was developed to rank proposed projects that places a priority on a project's cost-effectiveness in reducing emissions and travel delay. A board-approved subcommittee, consisting of representatives of SANBAG staff, a technical consultant, SCAG, the relevant air district, and Caltrans, reviews and scores each project proposal, making recommendations for final approval by the SANBAG board. CMAQ funds, however, continue to be set aside outside this process. For example, in the most recent call for projects, approximately 30 percent of the available CMAQ funds for San Bernardino County were earmarked for ready-to-obligate HOV projects to ensure meeting the state and federal use-it-or-lose-it requirement. Some transit projects that have not ranked high on cost-effectiveness ratings have also been funded outside the ranking process.

RCTC also had three calls for projects under TEA-21 that were sent to its member agencies.[57] The first call covered the first 2 years of CMAQ funding under TEA-21; the second call covered the remaining 4 years; and the third call was directed toward programming a $2 million set-aside for clean fuels projects. Project selection criteria were established, and the Transportation Advisory Committee evaluated all proposals using the criteria, with the assistance of a consultant who helped estimate project emission reductions and prepare other technical calculations.[58] A prioritized list of projects was developed

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[57] These calls cover only those CMAQ funds—about 80 percent of the total—available to SCAB, which covers the western part of the county. The remaining funds available in the Salton Sea Air Basin, which covers the eastern part of the county, were handled by the Coachella Valley Association of Governments, the council of governments for that area, who coordinated the programming of these funds.

[58] Proposed projects for the second call were evaluated on the basis of eight criteria: (*a*) emphasis on Measure A (the sales tax program), (*b*) economic development, (*c*) project readiness, (*d*) areas not included in Measure A, (*e*) air quality, (*f*) geographic balance, (*g*) safety, and (*h*) congestion mitigation. No priority order or weight was placed on the selection criteria in evaluating projects.

for consideration by the Budget and Implementation Committee. Following its review, a recommended list of projects was forwarded for final approval by RCTC. RCTC, like SANBAG, has used CMAQ funds for ready-to-obligate HOV projects—nearly three-fifths of the second call for projects were recommended for this purpose. Funds have also been earmarked outside the process (e.g., the $2 million Clean Fuels Opportunity Fund).

VCTC also has a separate call for projects for the CMAQ program and the STP. Following passage of TEA-21, a call for projects programmed CMAQ (and STP) funds for the 6-year authorization period.[59] VCTC has identified a priority list of project categories for CMAQ funding, which was developed in conjunction with its air district—the Ventura County Air Pollution Control District—when the CMAQ program was first authorized.[60] There are no target percentages by category, but criteria and weights have been established for ranking project submittals within each project category.[61] VCTC project staff perform the initial project scoring, with the assistance of the Air Pollution Control District for air quality benefit assessments. Then the projects are reviewed by a subcommittee of the Transportation Advisory Committee consisting of representatives from the Transportation Technical Advisory Committee, the Transit Operators Committee, the Citizens Transportation Advisory Committee/Social Services Transportation Advisory Council, and the Air Pollution Control District. The Managers Policy Advisory Committee also reviews the recommended list for final action by VCTC.

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[59] Receipt of additional funds from higher-than-projected federal gas tax receipts and funds made available from revisions to existing projects resulted in a new call for projects to allocate $3.9 million in CMAQ funds in February 2000.

[60] The six project categories are (*a*) clean fuel bus fleets and support facilities, (*b*) improved public transit, (*c*) bicycle facilities, (*d*) traffic management congestion relief strategies, (*e*) clean fuel fleet subsidy programs, and (*f*) other projects as appropriate.

[61] Project ranking criteria include improving mobility (up to 20 points); improving air quality (up to 20 points); providing multijurisdictional benefits (up to 10 points); addressing multimodal or HOV needs (up to 5 points); meeting one of the top three priority categories for CMAQ funding—clean fuel bus fleets/facilities, improved public transit, bicycle and pedestrian facilities and programs (up to 10 points); leveraging local funds (up to 5 points); meeting a local priority (up to 10 points); and providing a jurisdiction an equitable share of the funds (up to 20 points). The highest potential score is 100 points.

Caltrans, primarily through its local district office, also recommends projects for CMAQ funding. With some counties experiencing difficulty in meeting funding obligation deadlines, ready-to-fund state projects, such as HOV lanes, are often selected for CMAQ funding. Caltrans has no formal project ranking procedures; projects are simply screened to make sure they meet CMAQ eligibility requirements.

According to the Coalition for Clean Air (CCA) and other public interest and advocacy groups in the region, neither the air agencies nor the public interest and advocacy groups have been heavily involved in identifying or evaluating CMAQ projects. A combination of long programming time frames and poorly organized interest groups in some areas contributes to the limited level of participation. Counties with smaller CMAQ programs and separate calls for projects for CMAQ tend to provide more opportunities for public interest group involvement early in the process.

In San Bernardino, Riverside, and Ventura Counties, the private sector has been involved in a few small CMAQ projects funded through public-private partnerships. SANBAG has a partnership arrangement with a private utility in a pilot project to convert forklifts to clean fuel operation. RCTC was also engaged in a project with a utility, California Edison, to electrify truck stops to eliminate idling emissions, but the utility had to cancel the project because of the current energy crisis in California. Finally, Ventura County has a partnership arrangement with a private company to provide CNG infrastructure support for the county's CNG-fueled transit buses.

Because of the severity of the Southern California region's air quality problems, the transportation policies, programs, and projects contained in the RTP and the RTIP are primarily focused on pollution reduction and compliance with federal transportation conformity requirements. In addition, the California Air Resources Board and the local air agencies have developed emission control strategies, incorporated into local air basin air quality management plans and SIPs, to help meet air quality attainment deadlines. CMAQ funds have been used extensively to fund TCMs and other emission control strategies, such as replacement of diesel with alternative fuel buses. For example, a significant portion of projects in the SCAG RTIP are TCMs. They are included in the Air Quality Management Plan of SCAB, listed by category rather than individual project (MTA 2000, 17).[62]

Each county is responsible for pulling together needed information from project sponsors to evaluate CMAQ project proposals. In Los Angeles County, MTA uses its own transportation and emission models to estimate the travel and emission effects of large projects. Many of the counties use the methodology developed by the California Air Resources Board to estimate emission reductions of projects, and some use it to estimate travel effects as well.[63] Staff prepare the estimates in Los Angeles, Orange, and Ventura Counties—in the latter, with the assistance of the Air Pollution Control District. Consultants help prepare the technical assessments in Riverside and San Bernardino Counties, in the latter case in conjunction with SANBAG staff, Caltrans, the relevant air district, and SCAG. Several of the counties, such as Los Angeles, Riverside, and Ventura, explicitly take into account secondary factors, such as economic development, multimodal and multijurisdictional effects, geographic balance, and project readiness, in evaluating CMAQ projects. However, because of the area's problems, improvement of air quality and congestion mitigation are generally the primary considerations in selecting among projects; according to many, CMAQ funding is insufficient for meeting these primary goals.

The counties are also responsible for annual reporting to Caltrans on projects funded by the CMAQ program and their projected emission reductions. Caltrans, in turn, is responsible for reporting this information to FHWA. Some survey respondents suggested that more time was needed to prepare the information. SCAG recommended a biennial report. Others questioned how the report is being used and by whom.

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[62] For many TCMs, credit is not taken separately in the SIP. Rather, the emission reduction effects of these projects are modeled and credit taken when conformity analyses are conducted. Credit for TCMs not covered by modeling can be taken via "off-model" emission calculations.

[63] The California Air Resources Board has prepared a methods handbook in cooperation with Caltrans for evaluating the cost-effectiveness of the most widely implemented transportation-related air quality projects funded by the CMAQ and Motor Vehicle Registration Fee Programs. The most recent (1999) edition can be accessed on the Air Resources Board website at www.arb.ca.gov.

Few ex-post evaluations of CMAQ projects are conducted, although the Southern California region must continually monitor and report on its progress in meeting air quality requirements. For example, SCAG must redetermine the conformity of the RTP and the RTIP at least every 3 years. Similarly, the air agencies must report on the rate of progress toward meeting attainment, also at least every 3 years. In addition, the counties must report to SCAG every 2 years on timely implementation of TCMs, including CMAQ-funded projects. Staff of VCTC suggested that there was little incentive for local agencies to monitor and evaluate CMAQ projects, particularly if it would take away from project funding. SANBAG staff suggested that ex-post evaluation is not necessary for straightforward projects, like vehicle engine replacements, for which the emission reduction benefits are clear. Nevertheless, CCA recommended a program set-aside for CMAQ project evaluation.

CMAQ Program Objectives

The majority of those interviewed believe that the primary goal of the CMAQ program is air quality improvement. In view of the air quality problems of the region, a high priority is given to funding CMAQ projects that have the potential for reducing emissions. That said, many view congestion mitigation as another important program goal and see no major conflict between the twin goals of the program. Transportation agency staff of SCAG, several of the county transportation commissions, and the city of Los Angeles believe that the region must accommodate growth and that congestion relief projects appropriately attempt to address the reality that most Los Angeles residents drive. If properly structured, such projects should help reduce emissions as well as congestion. Not surprisingly, this view is not held by the South Coast Air Quality Management District or CCA, who believe that more emphasis should be placed on projects with air quality benefits and that, with the possible exception of some HOV projects, congestion mitigation projects are not likely to have this outcome.

A review of CMAQ obligations in the Southern California region for the last 5 years, FY 1996–2000, shows that more than 60 percent of the funds have gone for transit, including many projects to replace buses and bus engines with nondiesel alternatives—a requirement of the air districts in Southern California (Table D-6). The next-largest spending category—nearly one-quarter of the total—is for traffic flow improvements, including HOV projects. The third-largest category is "all other," a catchall category that represents nearly 10 percent of total spending. Shared-ride, bicycle and pedestrian, and demand management projects represent a small fraction (i.e., between 1 and 2 percent) of areawide spending.

CMAQ obligations for the region are dominated by the priorities of Los Angeles County, which accounted for nearly 70 percent of area CMAQ obligations in the past 5 years. The priorities of the four other counties that receive CMAQ funds differ widely (Figure D-1). For example, San Bernardino and Riverside Counties have obligated large amounts of CMAQ funds for traffic flow improvements, including HOV projects. Orange County has focused heavily on transit in recent years,[64] and Ventura County has obligated nearly three-fourths of its CMAQ funds for transit improvements (Figure D-1).

According to many of those interviewed, if CMAQ funds were not available or were folded into existing transportation programs, the area would lose funding generally because the CMAQ apportionment formula targets areas with serious air quality problems, like Los Angeles. Moreover, spending priorities would likely change, with less emphasis on projects that improve air quality. The shift in priorities could be greater in suburban areas, where, without CMAQ, more highway projects would probably be undertaken. Many acknowledged that the area would have no choice but to find alternative funding sources for many projects to meet conformity requirements if the CMAQ program were ended. In their view, the projects for which this would be most difficult or for which delays would be likely include new transit services and operations, transit fleet conversions to alternative fuels and supporting infrastructure (e.g., refueling stations), and some HOV and bicycle projects.

When asked which types of projects were most effective in achieving CMAQ program goals of emission reductions and air quality

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[64] Orange County focused heavily on HOV projects in the early program years, but the county's HOV network is largely complete.

TABLE D-6 CMAQ Program Obligations, Greater Los Angeles Area, FFY 1996–2000

Project Category	Total Cost ($)	CMAQ Share ($)	Percentage of CMAQ Total
Five-County Total			
Traffic flow improvements	180,641,170	139,224,012	23.9
Shared ride	17,559,561	11,353,295	1.9
Transit	455,042,865	368,832,984	63.3
Bicycle/pedestrian	8,521,636	7,526,601	1.3
Demand management	2,304,799	2,076,729	0.4
Other	79,179,782	53,994,452	9.2
Total	**743,249,813**	**583,008,073**	**100.0**
Los Angeles County			
Traffic flow improvements	67,755,489	57,051,954	14.6
Shared ride	10,660,830	5,142,621	1.3
Transit	385,013,257	307,680,926	78.6
Bicycle/pedestrian	768,119	673,642	0.2
Demand management	345,896	342,512	0.1
Other	22,738,033	20,302,595	5.2
Subtotal	487,281,624	391,194,250	100.0
Riverside County			
Traffic flow improvements	50,795,887	41,288,526	54.0
Shared ride	1,630,976	1,443,902	1.9
Transit	21,305,778	18,861,438	24.7
Bicycle/pedestrian	3,800,000	3,364,000	4.4
Demand management	54,000	47,806	0.1
Other	21,901,958	11,431,713	14.9
Subtotal	99,488,599	76,437,385	100.0
San Bernardino County			
Traffic flow improvements	61,134,339	40,037,668	73.3
Shared ride	3,362,562	2,976,875	5.5
Transit	7,789,216	6,051,208	11.1
Bicycle/pedestrian	158,000	128,788	0.2
Demand management	–	–	–
Other	6,279,673	5,396,843	9.9
Subtotal	78,723,790	54,591,382	100.0
Orange County			
Traffic flow improvements	–	–	–
Shared ride	900,000	900,000	2.8
Transit	17,600,179	15,581,437	47.7
Bicycle/pedestrian	–	–	–
Demand management	–	–	–
Other	27,454,997	16,150,527	49.5
Subtotal	45,955,176	32,631,964	100.0

(*continued*)

TABLE D-6 (*continued*) **CMAQ Program Obligations, Greater Los Angeles Area, FFY 1996–2000**

Project Category	Total Cost ($)	CMAQ Share ($)	Percentage of CMAQ Total
Ventura County			
Traffic flow improvements	955,455	845,864	3.0
Shared ride	1,005,193	889,897	3.2
Transit	23,334,435	20,657,975	73.4
Bicycle/pedestrian	3,795,517	3,360,171	11.9
Demand management	1,904,903	1,686,411	6.0
Other	805,121	712,774	2.5
Subtotal	31,800,624	28,153,092	100.0

Source: Caltrans Office of Local Programs.

improvement, nearly all of the respondents mentioned technology-oriented projects, particularly transit vehicle and engine replacements with clean fuel alternatives. Other transit projects as well as ridesharing and HOV projects, which are focused on reducing vehicle trips and the numbers of vehicles on the road, were also mentioned as the most effective from an emission reduction perspective.

The best strategies for congestion relief include projects that fall under the category of traffic flow improvements—signal system synchronization, intersection improvements, and HOV projects. To the extent that transit services, including shuttles, move riders in high-capacity vehicles or remove vehicles from the highway entirely, these projects were also viewed as being effective for congestion relief.

When asked which projects are most cost-effective, several respondents noted that cost-effectiveness is only one of several criteria that should be taken into account in determining CMAQ spending priorities. Only a few agencies, such as SANBAG, focus on cost-effectiveness as a primary CMAQ project selection criterion. When asked which projects are most cost-effective, SANBAG staff mentioned replacement of bus engines with clean fuel–burning engines.[65]

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[65] Replacing the bus is not always cost-effective. Moreover, operating an alternative-fueled transit fleet can be more expensive than buying and operating new cleaner diesel buses because of transitional infrastructure costs of moving to a nondiesel fleet.

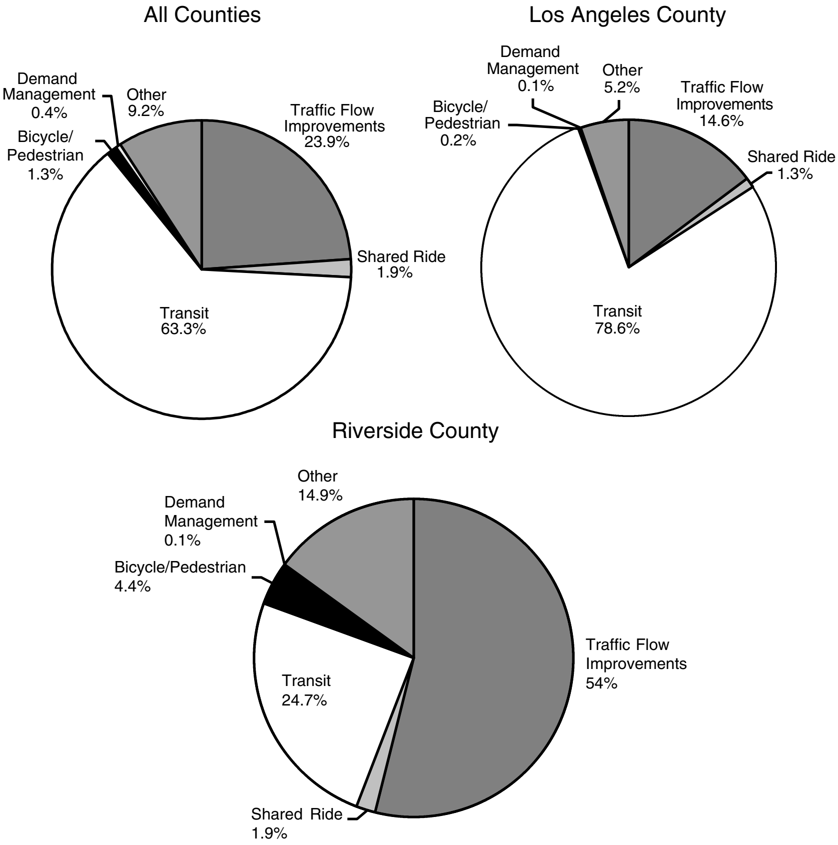

FIGURE D-1 **CMAQ program obligations by project category, Greater Los Angeles area, FFY 1996–2000 (data from Caltrans Office of Local Programs).** *(continued)*

Some ridesharing projects are low in cost and have tangible benefits. Finally, paving of dirt roads—projects directed toward PM_{10} emission reductions—is also thought to be cost-effective, although FHWA and Caltrans view many of these projects as capacity enhancing and thus ineligible for CMAQ funding. The California Air Resources Board provides guidance on assessing project cost-effectiveness, but some agen-

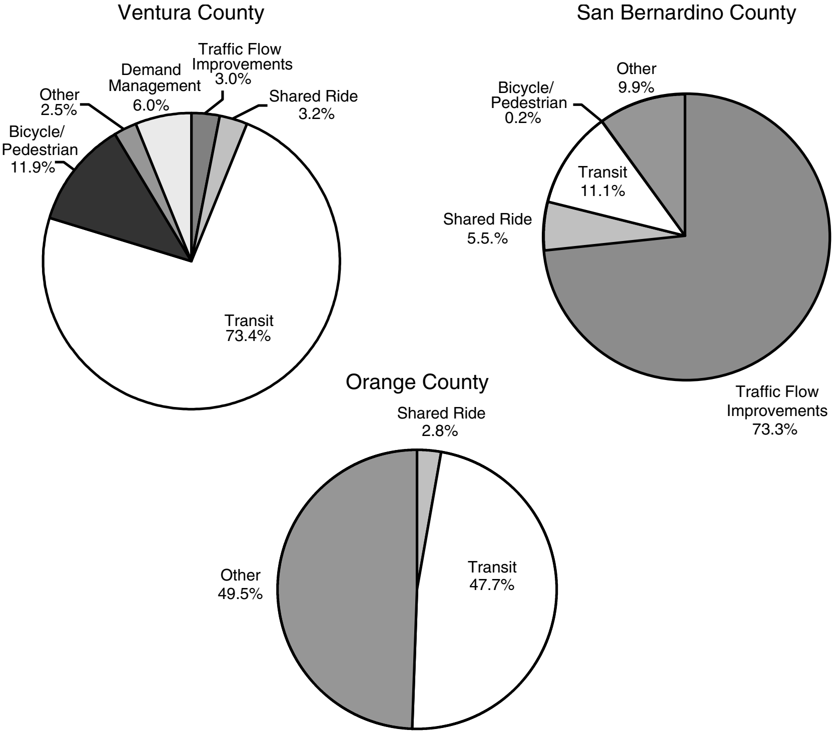

FIGURE D-1. *(continued)* **CMAQ program obligations by project category, Greater Los Angeles area, FFY 1996–2000 (data from Caltrans Office of Local Programs).**

cies use this methodology after the fact to justify project selection rather than before the fact as a project selection tool.[66]

CMAQ Program Evaluation

The key strength of the CMAQ program, according to those interviewed, is its role as a dedicated source of federal transportation

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[66] At least one reason for this, according to VCTC staff, is the lack of data to make the necessary assessments before the project is implemented.

funds for air quality improvement targeting the areas of greatest need (i.e., nonattainment and maintenance areas) to help meet mandated federal air quality requirements. Many of the restrictions on the program are considered to be its greatest benefits. For example, the CMAQ program requires agencies to consider transportation strategies that reduce emissions and provide alternatives to SOV highway travel, hence encouraging a more multimodal focus. It also requires spending on new facilities and operations, which can enable local agencies to experiment with new services. The extent of innovation, however, was questioned by RCTC staff and CCA, who noted that there were "not that many innovative CMAQ projects," although they deemed spending on more traditional projects "worthwhile."

Some program restrictions were viewed as weaknesses. For example, MTA staff believe that restricting funds to new services and operations, particularly for transit projects, can bias the program in favor of suburban areas; in their view, CMAQ funds should be eligible for use in projects that support existing transit services and ridership in urban areas. In addition, more attention should be paid to providing a transition period lengthier than the current 3 years for local governments that use CMAQ funds to support operations so that alternative funding sources can be found to continue newly started-up services. Others (RCTC staff and CCA) thought that the program is not restrictive enough in terms of its focus on air quality; within this objective, however, some (OCTA staff, in particular) thought that any project that reduces emissions should be eligible for CMAQ funding. Others (primarily the South Coast Air Quality Management District) noted that there is insufficient accountability about where program funds are going and how program funds are being spent.

Most of those interviewed did not see much change in interagency cooperation and decision making that could be attributed specifically to the CMAQ program, an unsurprising outcome in view of the lack of a regional approach to the program. With some notable exceptions (e.g., Ventura and San Bernardino Counties), the air agencies are viewed as having an arms-length role in the program; MTA staff suggested that the program could be better coordinated with the air agencies. Public interest groups in the Los Angeles area also have limited involvement, particularly early in the process of determining appropriate projects for CMAQ funding. The highly decentralized decision-making structure has also resulted in program funds being spread widely among a large number of local jurisdictions in many counties. With some notable exceptions (e.g., clean fuels projects, HOV projects), the current structure provides few incentives for focusing CMAQ funds on regional strategies for improving air quality.

All of those interviewed thought that the CMAQ program should be continued when TEA-21 is reauthorized. Some (i.e., SCAG, city of Los Angeles, Caltrans) were hesitant about expanding the scope of the program unless funding was increased accordingly. Present levels of funding are insufficient, in their view, to meet the current air quality standards. Others (MTA, OCTA, SANBAG, RCTC) strongly urged that the program be extended to cover other pollutants (e.g., fine particulate matter, air toxics). If these other pollutants were included in the CMAQ apportionment formula, the area would likely receive even more funds. Some (RCTC, CCA) recommended broadening project eligibility to include strategies that address these new pollutants, such as projects focused on heavy vehicles and off-road vehicles. Others (SANBAG, in particular) thought there was sufficient flexibility within current eligibility requirements to address most of these problems now.

Several suggestions were made for changing the program, although not all of those interviewed agreed with all the suggestions. First, more incentives should be provided for a regional program focus to encourage more coordinated strategies for pollution reduction in the region (Caltrans, CCA), but local differences within the region should also be recognized (RCTC). Second, state and local air agencies should have an ex officio or advisory role in programming CMAQ funds at the county level (RCTC). Greater public participation would also be desirable, particularly early in the project selection and evaluation process. Third, 3-year restrictions on the use of CMAQ funds for operations should be lengthened if it can be demonstrated that the project continues to provide new emission reductions. Fourth, more project evaluation would be desirable, including restricted funds for this purpose (city of Los Angeles), but these funds should not come at the expense of project funds (South Coast Air Quality Management District). Finally, looking ahead, the pollutants covered under the CMAQ program should be expanded to include fine particulate matter and air toxics, particularly diesel, and added to the CMAQ apportionment formula as a basis for future funds allocation (SANBAG).

Organizations and Persons Interviewed—March 5–7, 2001

Southern California Association of Governments
  Charles Keynejad, Senior Transportation Analyst
  Sylvia Patsaouras, Regional Planner
Los Angeles County Metropolitan Transportation Authority
  Keith L. Killough, Deputy Executive Officer, Countywide Planning
  Frank Flores, Deputy Executive Officer, Capital Development and Programming
  David E. Yale, Director, Regional Programming and Policy Analysis
  Ronald L. Smith, Transportation Funding Manager, Capital Planning
  Douglas Kim, Program Manager, Regional Planning—Air Quality Programs
  Herman S. J. Cheng, Manager, Transportation Improvement Programming
  John Asuncion, Transportation Planner
State of California, Department of Transportation, District 7—Office of Local Programs
  Satish Chander, P.E., Chief, Office of Local Programs and Alameda Corridor
  Norma Ortega, Chief, Office of Resource Management, Local Assistance Division (by telephone)
City of Los Angeles
  Jaime De La Vega, Assistant Deputy Mayor, Office of the Mayor
Orange County Transportation Authority
  James Ortner, Manager, Transit Technical Services
  Dean Delgado, Principal Transportation Analyst
  William J. Dineen, Manager, Financial Plans, Financial Planning and Analysis
Ventura County Transportation Commission
  Ginger Gherardi, Executive Director (by telephone)
  Christopher Stephens, Deputy Director

Peter De Haan, Director of Transportation Programming, Legislation, and Grants
San Bernardino Associated Governments (by conference call)
Norman King, Executive Director
Ty Schuiling, Director of Planning and Programming
Deborah Barmack, Director of Management Services
Riverside County Transportation Commission (by conference call)
Eric Haley, Executive Director
Cathy Bechtel, Director of Planning and Programming
South Coast Air Quality Management District
Connie Day, Program Supervisor
Eyvonne V. Sells, Regional Transportation Programs, Transportation Specialist
Coalition for Clean Air
Tim Carmichael, Executive Director

REFERENCES

Abbreviations

CATS	Chicago Area Transportation Study
CDTC	Capital District Transportation Committee
COG	Metropolitan Washington Council of Governments
FHWA	Federal Highway Administration
H-GAC	Houston-Galveston Area Council
METRO	Metropolitan Transit Authority of Harris County
MTA	Los Angeles County Metropolitan Transportation Authority
NYSDOT	New York State Department of Transportation
SCAG	Southern California Association of Governments
TPB	National Capital Region Transportation Planning Board

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APPENDIX E

COST-EFFECTIVENESS OF CONGESTION MITIGATION AND AIR QUALITY STRATEGIES

J. Richard Kuzmyak, *Transportation Consultant, LLC*

INTRODUCTION AND BACKGROUND

Purpose

The results of a commissioned review of the cost-effectiveness of transportation-related strategies as funded under the Congestion Mitigation and Air Quality Improvement (CMAQ) program are summarized in this paper. The review was performed under contract to the Transportation Research Board's Committee for Evaluation of the CMAQ Improvement Program to support its deliberations and development of recommendations to Congress as to whether and how the CMAQ program should be continued when the federal transportation funding act is reauthorized in 2003.

At issue in this review is whether the types of strategies funded under CMAQ represent cost-effective approaches for achieving the objectives of the program to reduce emissions from mobile sources through congestion relief or other methods of improving transportation efficiency. This raises questions as to the effectiveness of individual types of projects and strategies funded, as well as the overall effectiveness of the body and mix of projects and strategies that CMAQ funds have purchased to date. Comparisons of the cost-effectiveness of the types of strategies eligible for CMAQ funding with the cost-effectiveness of strategies that have not been eligible for CMAQ funding, such as the construction of new highway capacity, roadway or other travel pricing schemes, new vehicle/fuel technology, and emission controls for nonmobile sources, were also made. The highway capacity, travel pricing, and selected (mainly transit-oriented) technology approaches are addressed in this paper, but the detailed investigation of vehicle standards, fuels, and non–mobile source approaches are explored in a second commissioned paper authored by Michael Wang of Argonne National Laboratories. Both papers have been produced under the guidance of the CMAQ committee, and efforts have been made to coordinate methodologies and assumptions to maximize the comparability of findings.

Overview of CMAQ Program and Eligible Strategies

The CMAQ program is a special funding provision established under the 1991 Intermodal Surface Transportation Efficiency Act (ISTEA) that earmarks resources to help states and local areas achieve compliance with National Ambient Air Quality Standards (NAAQS). Over the first 6 years of the program, beginning in 1992, $6 billion was authorized under the program, and funding levels were subsequently continued under the 1998 reauthorization (the Transportation Equity Act for the 21st Century). The original purpose of the CMAQ program was to fund transportation programs or projects that would contribute to attainment of standards for ozone [hydrocarbon (HC) and oxides of nitrogen (NO_x) precursors] and carbon monoxide (CO) in *nonattainment* areas. However, provisions were subsequently modified to permit use of the funds by areas that had reached attainment (transforming to "maintenance areas") and in mitigating particulate matter (PM_{10}) pollution under certain circumstances.

Title 21, Section 149 of ISTEA stipulates in detail the types of strategies that are eligible for CMAQ funding.[1] These include the following:

- Improvements to public transit service, including new and replacement vehicles (but not operating costs that do not arise out of new or expanded service, nor transit-oriented private development);
- New transit stations, terminals, transit centers or malls, intermodal transfer facilities, and park-and-ride facilities;
- Short-term promotional subsidies of transit/paratransit fares;
- Construction or designation of roads or lanes for exclusive use of buses or high-occupancy vehicles (HOVs);

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[1] Congestion Mitigation and Air Quality Improvement Program (CMAQ) Guidance Update, FHWA website: http://www.fhwa.dot.gov/environment/cmaqguid.htm (Sept. 2000).

- Employer-based transportation management plans, including incentives (but excluding employer-sponsored flexible work schedules);
- Telecommuting programs, including studies, training, coordination, and promotion (but excluding capital equipment and facilities);
- Trip reduction ordinances or programs to facilitate nonautomobile travel or reduce the need for single-occupant vehicle travel, including programs or ordinances applicable to new shopping centers, special events, and other centers of vehicle activity;
- Traffic flow improvements, such as signal improvements and freeway management systems (provided they can be demonstrated to improve air quality), traveler information programs, and electronic toll/fare payment systems;
- Fringe and corridor parking facilities serving transit or multi-occupant vehicle use;
- Peak-period or area-specific vehicle use restrictions;
- Programs for provision of ridesharing services;
- Construction or redesignation of facilities for exclusive use by nonmotorized vehicles or pedestrians, and bicycle storage/protective facilities;
- Nonconstruction projects related to safe bicycle use, establishment of bike/pedestrian coordinators, and public education programs;
- Project planning or development activities that lead directly to construction of facilities or new services with air quality benefits (i.e., the projects themselves have air quality benefits);
- Alternative-fuel vehicle (AFV) conversions or on-site fueling facilities/infrastructure, provided the fleet is publicly owned or leased and centrally fueled and the primary motivation is air quality attainment; and
- Intermodal freight facilities/improvements (provided air quality benefits can be demonstrated and facilities are not solely owned/operated/managed by private interests).

In the language of the act, CMAQ funds are specifically not authorized for highway or transit maintenance or reconstruction projects or for new single-occupant vehicle capacity projects.

Organization of Paper

This paper is structured into the following sections:

- In this Introduction and Background section, the purpose and scope of the study are described, a brief background description of the CMAQ program and its objectives is given, and strategies that are eligible for funding are listed.
- In the next section, Methodology, an overview of the general approach used to conduct the study, the literature identification and review process, and templates used to store and compile data is given. All analytic approaches and assumptions used to address key methodological issues are described, including the following:
  - Parameters and considerations in compiling transportation and travel impact data;
  - Emission criteria, including pollutants considered, baseline assumptions, computational assumptions and factors, weighting and summation, and emission discounting; and
  - Cost and cost-effectiveness calculation procedures, detailing assumptions regarding capital versus operating costs, cost annualization, public versus private costs, consumer versus manufacturer costs, societal and external costs, and transfer payments.
- The Cost-Effectiveness Findings section is the most substantial section of the report, given its purpose of presenting and describing the nature and range of impacts for each strategy category and subcategory:
  - Traffic flow improvements, including subcategories of traffic signalization, freeway management, and HOV lanes;
  - Ridesharing programs, including general regional outreach and matching programs, vanpool and buspool programs, and park-and-ride lots;
  - Travel demand management, including regional or areawide approaches and employer trip reduction programs;
  - Telecommute/telework programs, including employer-based, nonworksite, and nonwork approaches;
  - Bicycle/pedestrian facilities and programs, either site-based or areawide;
  - Transit improvements, including new shuttle or feeder services, new rail transit services or equipment, and conventional transit service improvements;

- Technology and fuel programs, including conventional bus replacements, alternative-fuel buses, and AFV fueling facilities; and
- Vehicle inspection and maintenance programs.

The section also provides limited cost-effectiveness information on two non-CMAQ-eligible strategies:

- Pricing strategies, including subsidies and discounts and charges and fees, and
- New roadway capacity.

- An Analysis of Findings section follows the individual strategy review. In that section, the cost-effectiveness performance of the 19 separate strategy groups is ranked and compared. The importance of various assumptions is discussed, in particular the pollutant weighting ratios that were used. The important differences between strategies in the same group are explored, and finally an estimate of the overall effectiveness of the CMAQ program with respect to strategy performance and how funds have been allocated across strategies is offered.
- In a Final Thoughts and Closing section, the author's views of the key findings from the research are provided.
- An Annotated Bibliography is provided at the end of the paper, citing (along with the source) the strategies that are addressed and giving a general assessment of the quality, value, and eventual use (or reasons for nonuse) of the source in the review.
- An annex contains analysis tables, which summarize the travel impacts, emissions, and cost-effectiveness for each individual strategy included in the analysis, organized by major category (as listed above).

METHODOLOGY

Overview of Study Approach

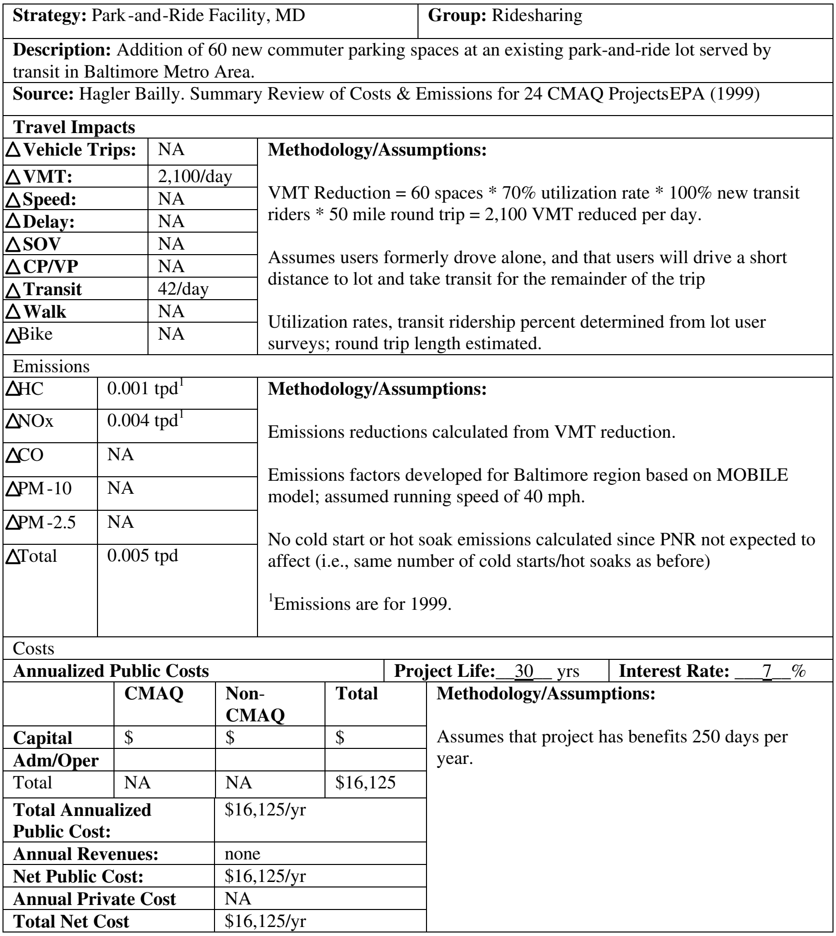
The findings in this paper are primarily the result of an extensive literature review and synthesis. Original modeling approaches were not used. Rather, the CMAQ committee desired as broad a sampling of findings from existing experience as possible, with emphasis on measured empirical results as opposed to synthetic results derived through forecasts. Estimates of cost or emission reductions associated with CMAQ funding applications were avoided, by direction of the committee, since these data were earlier found to be variable in quality and supporting analysis. Also, the purpose of the review was to obtain an objective assessment of CMAQ effectiveness independent of the program.

Various mathematical procedures were used to process and adjust information from the sources that were selected. However, these procedures were strictly for the purpose of filling in blanks (where such an estimate could be reliably made from other information supplied), placing costs and benefits on a common lifetime basis, or updating emissions or costs to current/common levels. As will be discussed later, however, even with some flexibility to control for missing information, the majority of the original source studies reviewed were rejected for critical weaknesses of one type or another.

Once a candidate example was identified in the research phase, the information on that case was transcribed into an individual project "profile." Physically, this profile took the form of a one-page template (computer spreadsheet), which was designed to compile all critical facts related to the example in one place to facilitate subsequent review, screening on particular criteria, and ultimately acceptance or rejection from the analysis. As illustrated in Figure E-1, information recorded in the profile included the following (the file of these individual profiles is too voluminous to include with this paper):

- Source information: title, author, and date of the study;
- Description of critical characteristics and scope (corridor, site, areawide);
- Impacts on travel: change in vehicle trips, vehicle miles traveled (VMT), transit trips, and congestion (speed and delay);
- Emission reductions: change in emissions of HC [including volatile organic compounds (VOC) and reactive organic gases (ROG)], NO_x, CO, and PM_{10}, measured in tons per day; and
- Costs and cost-effectiveness: capital (annualized) and operating costs, from CMAQ and non-CMAQ sources (where known), as well as direct private costs.

The profiles were designed to record critical supporting information concerning the methodologies employed in any of the steps (travel, emissions, costs), critical assumptions, time frames, service



Strategy: Park-and-Ride Facility, MD	**Group:** Ridesharing
Description: Addition of 60 new commuter parking spaces at an existing park-and-ride lot served by transit in Baltimore Metro Area.	
Source: Hagler Bailly. Summary Review of Costs & Emissions for 24 CMAQ ProjectsEPA (1999)	

Travel Impacts

Δ Vehicle Trips:	NA	**Methodology/Assumptions:** VMT Reduction = 60 spaces * 70% utilization rate * 100% new transit riders * 50 mile round trip = 2,100 VMT reduced per day. Assumes users formerly drove alone, and that users will drive a short distance to lot and take transit for the remainder of the trip Utilization rates, transit ridership percent determined from lot user surveys; round trip length estimated.
Δ VMT:	2,100/day	
Δ Speed:	NA	
Δ Delay:	NA	
Δ SOV	NA	
Δ CP/VP	NA	
Δ Transit	42/day	
Δ Walk	NA	
ΔBike	NA	

Emissions

ΔHC	0.001 tpd[1]	**Methodology/Assumptions:** Emissions reductions calculated from VMT reduction. Emissions factors developed for Baltimore region based on MOBILE model; assumed running speed of 40 mph. No cold start or hot soak emissions calculated since PNR not expected to affect (i.e., same number of cold starts/hot soaks as before) [1]Emissions are for 1999.
ΔNOx	0.004 tpd[1]	
ΔCO	NA	
ΔPM-10	NA	
ΔPM-2.5	NA	
ΔTotal	0.005 tpd	

Costs

Annualized Public Costs	**Project Life:** 30 yrs	**Interest Rate:** 7 %

	CMAQ	**Non-CMAQ**	**Total**	**Methodology/Assumptions:**
Capital	$	$	$	Assumes that project has benefits 250 days per year.
Adm/Oper				
Total	NA	NA	$16,125	
Total Annualized Public Cost:	$16,125/yr			
Annual Revenues:	none			
Net Public Cost:	$16,125/yr			
Annual Private Cost	NA			
Total Net Cost	$16,125/yr			

FIGURE E-1 Sample CMAQ project profile summary sheet.

lives, discount rates, and the like. Comments were also entered to document the general quality of the study as appraised by the reviewer, for use in later evaluation and selection of cases.

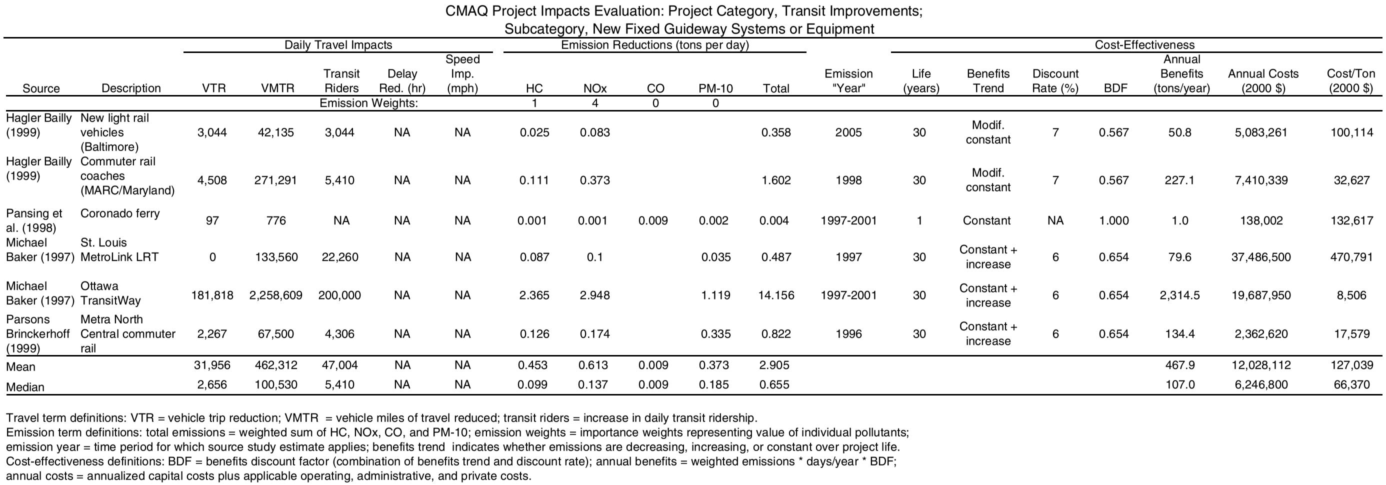
Profiled examples that were found of sufficient quality to be included in the analysis were posted to a summary table, which displayed key summary information on travel, emissions, and costs for each strategy. A separate table was prepared for each category and subcategory to permit comparison among similar strategies (sharing the same table) and to facilitate computation of "group" statistics (range, median) for comparison with other strategy groups. An example of a summary table is provided in Figure E-2, and the complete set of tables used to support the analysis in the body of the paper is provided in the annex.

Literature Review

As earlier stated, the general approach used to prepare estimates of the impact of CMAQ (and related "control") strategies was through a literature review and synthesis. More than 80 source documents were consulted for potentially usable information on travel and air quality effects of the identified strategies. The following characterizes the range of sources consulted for the review:

- State and metropolitan planning organization (MPO) studies of transportation control measures for air quality attainment and state implementation plans (SIPs);
- Modeling and simulation studies where major travel changes and air quality effects were key study parameters;
- Guidance and procedure manuals developed by the Environmental Protection Administration (EPA), the California Air Resources Board (CARB), and various National Cooperative Highway Research Program projects or special studies;
- Formal evaluation studies of actual CMAQ transportation demand management (TDM) and other innovative project implementations;
- Transportation and air quality model guides and applications test results;
- Synthesis documents on transportation and air quality impacts;
- A wide variety of published research papers and reports by individuals or university research departments; and
- More fundamental research documents or guides on travel behavior changes.

The following particular qualities and minimum requirements were desired in searching for the most useful sources:



CMAQ Project Impacts Evaluation: Project Category, Transit Improvements;
Subcategory, New Fixed Guideway Systems or Equipment

		Daily Travel Impacts					Emission Reductions (tons per day)						Cost-Effectiveness						
Source	Description	VTR	VMTR	Transit Riders	Delay Red. (hr)	Speed Imp. (mph)	HC	NOx	CO	PM-10	Total	Emission "Year"	Life (years)	Benefits Trend	Discount Rate (%)	BDF	Annual Benefits (tons/year)	Annual Costs (2000 $)	Cost/Ton (2000 $)
				Emission Weights:			1	4	0	0									
Hagler Bailly (1999)	New light rail vehicles (Baltimore)	3,044	42,135	3,044	NA	NA	0.025	0.083			0.358	2005	30	Modif. constant	7	0.567	50.8	5,083,261	100,114
Hagler Bailly (1999)	Commuter rail coaches (MARC/Maryland)	4,508	271,291	5,410	NA	NA	0.111	0.373			1.602	1998	30	Modif. constant	7	0.567	227.1	7,410,339	32,627
Pansing et al. (1998)	Coronado ferry	97	776	NA	NA	NA	0.001	0.001	0.009	0.002	0.004	1997-2001	1	Constant	NA	1.000	1.0	138,002	132,617
Michael Baker (1997)	St. Louis MetroLink LRT	0	133,560	22,260	NA	NA	0.087	0.1		0.035	0.487	1997	30	Constant + increase	6	0.654	79.6	37,486,500	470,791
Michael Baker (1997)	Ottawa TransitWay	181,818	2,258,609	200,000	NA	NA	2.365	2.948		1.119	14.156	1997-2001	30	Constant + increase	6	0.654	2,314.5	19,687,950	8,506
Parsons Brinckerhoff (1999)	Metra North Central commuter rail	2,267	67,500	4,306	NA	NA	0.126	0.174		0.335	0.822	1996	30	Constant + increase	6	0.654	134.4	2,362,620	17,579
Mean		31,956	462,312	47,004	NA	NA	0.453	0.613	0.009	0.373	2.905						467.9	12,028,112	127,039
Median		2,656	100,530	5,410	NA	NA	0.099	0.137	0.009	0.185	0.655						107.0	6,246,800	66,370

Travel term definitions: VTR = vehicle trip reduction; VMTR = vehicle miles of travel reduced; transit riders = increase in daily transit ridership.
Emission term definitions: total emissions = weighted sum of HC, NOx, CO, and PM-10; emission weights = importance weights representing value of individual pollutants;
emission year = time period for which source study estimate applies; benefits trend indicates whether emissions are decreasing, increasing, or constant over project life.
Cost-effectiveness definitions: BDF = benefits discount factor (combination of benefits trend and discount rate); annual benefits = weighted emissions * days/year * BDF;
annual costs = annualized capital costs plus applicable operating, administrative, and private costs.

FIGURE E-2 Sample strategy summary table.

- Time frame: In general, the sources reviewed for this study and the most likely to be selected were among the most recently prepared. The chief reason for this was that emission impacts are quite particular to the time in which they were estimated. In the early 1990s, following passage of the 1990 Clean Air Act Amendments, much of the focus in SIP attainment plans was on achieving VOC and CO reductions. As a result, most of the emphasis in studies of that period was on VOC and CO reduction, which was reflected in the types of strategies emphasized, types of analytic technique used, and types of emissions reported on. NO_x (as well as PM) was almost always absent from studies of this era. Maybe as important, steady and significant improvement of fuels and technology through this period, coupled with turnover in the light-duty vehicle fleet, resulted in major reductions in VOC and CO production. Changes in emission rates reflecting this transformation of the fleet mean that relationships between travel changes and emission impacts would be quite different if taken from a study done in the early 1990s as opposed to one done today.
- Type of analysis: In general, the preferred source of impact information would be from an empirical assessment (i.e., where a project had been implemented and its before-and-after effects carefully documented). Not surprisingly, these types of studies were not plentiful, and an even smaller percentage had provided all of the relevant information needed to prepare a cost-effectiveness assessment. Modeling studies, in which impacts were forecast with the aid of analytic tools, were generally less preferable because of their whole or partial reliance on simulation versus actual events. However, for certain types of applications, particularly corridor- or system-level actions that would have complex impacts on network travel and speeds, model approaches were deemed acceptable and even necessary to determine what particular strategies would accomplish.
- Diversity: An effort was made to uncover information on all types of strategies and to represent as many types of settings and locations as possible. This may have resulted in being more lenient with the selection criteria for certain studies, given their uniqueness, and more stringent with others, given that they were heavily studied.

- CMAQ files not to be used: A clear working rule issued by the CMAQ committee was that project examples should not be taken from the CMAQ project application files at the Federal Highway Administration (FHWA). An earlier independent review (Cohen 2000, included as Appendix C), determined that the documentation to support the impacts for many of these project submissions was too limited to support an acceptable evaluation of the project. For purposes of this review, an independent assessment of CMAQ project effectiveness was expected, without drawing on these internal results, potentially biasing the findings.

For these and other reasons, only a modest number of the reviewed studies were ultimately found to be usable as sources. Recurring problems that caused many of the studies to be rejected were as follows:

- Inappropriate study content: Many of the researched studies were not helpful in providing data on strategy impacts. These studies may have been informative on some particular aspect of the given strategy, such as how to determine its impacts, but provided no directly usable information for the assessment.
- Missing emission information: Information was sought on VOCs (hydrocarbons), NO_x, CO, and PM. A minimum requirement was for VOC and NO_x information, given the continued struggles of many areas to attain or maintain ozone standards. In this regard, and for its contribution to fine particulate matter ($PM_{2.5}$), NO_x emissions were seen as critical. If NO_x estimates were not provided, it was essential that sufficient supporting data be provided to allow their calculation, in which case the study might be retained.
- Indefensible analysis: Very few studies were ultimately rejected for this criterion, since generally there would have been other failings (missing data) that would have rendered the study unusable. In fact, the review was generally liberal in accepting methodology unless there were clearly missing steps or insupportable logic, since this helped capture the range of estimates and perceptions being applied in the field.
- Dated emission information: Studies in which the underlying analysis was acceptable but whose emissions were from a different

period were retained if sufficient background information was available to update the estimates.

- Missing cost information: A surprising number of otherwise good studies had to be disqualified because there was no accompanying information on costs. Since the ultimate measure of effectiveness for the review was cost per ton of emissions reduced, lack of cost information made it impossible to compare the strategy with others. Findings from some studies that had solid and unique information on travel (especially effects on congestion) or emission effects were retained to illustrate the range of potential impacts, though these studies could not be used in the ultimate cost-effectiveness comparisons.
- Use of percentages: Another group of otherwise solid studies could not be used because their format was to present their findings in terms of *percentage* changes in travel or emissions related to some baseline (which was not sufficiently apparent that necessary calculations could be made, nor could the changes be related to costs). Some of these studies presented estimates of emission cost-effectiveness, but the estimates were not used because they could not be substantiated from the other data provided.
- Emission time frame: Some studies were not useful because the time frame for which their emissions were to apply was not specified. Since the methodology in this review involves a conscious effort to discount both costs and benefits to a common basis, failure to include this information might eliminate a study from further use.

The unfortunate result of the application of these criteria was that a number of studies that might have served as valid examples had to be eliminated. The effects of this selection process on the overall results and conclusions of this paper obviously cannot be estimated. However, every possible effort was made to keep a good or unique study in the analysis, and most of the strategy groups have the advantage of a respectable sample size from which to draw conclusions about the category.

The following abbreviated list of studies was eventually relied on to form much of the basis for this review and synthesis:

- Hagler Bailly Services, Inc. 1999. *Summary Review of Costs and Emissions Information for 24 Congestion Mitigation and Air Quality Improvement Program Projects.* Prepared for Office of Policy, U.S. Environmental Protection Agency, Sept.
- Delaware Valley Regional Planning Commission. 1994. *Transportation Control Measures: An Analysis of Potential TCMs for Implementation in the Pennsylvania Portion of the Philadelphia Region.* Philadelphia, Pa., May.
- California Air Resources Board. 1999. *Methods to Find the Cost-Effectiveness of Funding Air Quality Projects (for Evaluating Motor Vehicle Registration Fee Projects and CMAQ Projects).* California Environmental Protection Agency, Aug.
- COMSIS Corporation et al. *MTA TDM Demonstration Program Third Party Evaluation.* 1996. Final report, prepared for Los Angeles County Metropolitan Transportation Authority, Feb.
- Zarifi, S. 1996. *Transportation Demand Management: Second Tier Evaluation.* Final report, Los Angeles County Metropolitan Transportation Authority, July.
- COMSIS Corporation and Cynthia Pansing, Transportation Consultant. 1997. *MTA Transportation Demand Management Evaluation.* Final report, prepared for Los Angeles County Metropolitan Transportation Authority, April.
- Pansing, C., E. N. Schreffler, and M. A. Sillings. 1998. Comparative Evaluation of the Cost-Effectiveness of 58 Transportation Control Measures. In *Transportation Research Record 1641,* TRB, National Research Council, Washington, D.C., pp. 97–104.
- Michael Baker Corporation et al. 1997. *The Potential of Public Transit as a Transportation Control Measure: Case Studies and Innovations.* For National Association of Regional Councils, Oct.
- Parsons Brinckerhoff et al. 1999. *CMAQ Analysis: North Central Service Impact Evaluation—Phase II.* Prepared for Metra, Chicago, Ill., June.
- Federal Highway Administration. 1995. *Transportation Control Measure Analysis for the Washington Region's 15% Rate of Progress Plan.* Metropolitan Planning Technical Report 5, Feb.
- Lachance, L. C., and E. Mierzejewski. 1998. Analysis of the Cost-Effectiveness of Motor Vehicle Inspection Programs for Reducing Air

Pollution. In *Transportation Research Record 1641,* TRB, National Research Council, Washington, D.C., pp. 105–111.

The manner in which each of these studies was used in the analyses in this paper may be seen in the Annotated Bibliography. The bibliography provides an abstract of the content of each study, as well as an assessment of why it was or was not used in the review. Source documents are generally also identified in conjunction with discussion of the respective strategies as they are presented later in the paper.

Comparability Across Examples

As noted, original analysis or technique development was not within the scope of this commissioned research. However, various adjustments were made to results taken from the studies to "fill in" for missing items where the component information permitted a reasonable estimate, to strip out superfluous information, or to ensure greater comparability across cases and studies (e.g., if emissions were from different periods). The assumptions and procedures that have been used in preparing the strategy impacts that will be presented later are described in this section.

It is also important to note that a second paper was commissioned by the CMAQ committee, dealing with the effectiveness of non-CMAQ-eligible emission control strategies, in particular, advances in vehicle technology and fuels (see Appendix F of this Special Report). These technology-based measures have been analyzed to provide a comparison of the level of impact and cost-effectiveness of strategies eligible for funding under CMAQ with other potential methods for reducing emissions. To ensure the maximum comparability between the results of the two papers, a concerted effort has been made to coordinate the methodological assumptions between the two studies. Because of inherent differences between the two types of strategies and types of studies from which their impacts have been derived, a perfect correspondence in methodologies is not possible. However, for practical purposes, they are as comparable as possible given the circumstances.

Key issues addressed in the interest of methodological parity include the following:

- Establishment of baseline emissions from which individual strategy emission reductions are measured;
- Totaling of emission reductions across multiple pollutants, particularly when individual pollutants may carry more or different weight or importance in addressing a given area's attainment needs;
- Emission benefit discounting;
- Program versus component cost-effectiveness;
- Emissions in attainment versus nonattainment areas;
- Annual versus seasonal emission adjustments;
- User costs versus societal costs;
- Manufacturer versus consumer costs;
- Estimated versus actual on-road emissions; and
- Adjustment of costs to constant dollars.

The eventual treatment or disposition of each of these issues is discussed below, either in the context of the specific methodological procedure where it was relevant, or separately where it presented a unique (or inapplicable) circumstance for this paper.

Transportation and Travel Impacts

The primary way in which CMAQ-type strategies effect emission reductions is through changes in travel: either by reducing vehicle trips or travel (VMT) through alternative modes or travel substitution, or through more efficient operation via less congested operating conditions. All CMAQ strategies, even if they are directed at managing congestion, are required to demonstrate tangible emission benefits and to contribute to attainment or maintenance of air quality standards.

Specific travel information sought for each strategy included

- Change in vehicle trips (absolute, not percentage),
- Change in VMT (absolute, not percentage),
- Change in transit trips (absolute, not percentage), and
- Change in average speed or delay (for congestion purposes).

Almost universally, information on nonmotorized trips or other modal split impacts was not found in the source literature. Transit trips were estimated by most (though not all) of the better studies, and speed/delay measures were rarely reported, even in the case of traffic flow improvements where they are critical to determining emissions.

Emissions

For a study to be included as an example, it was critical that estimates were provided for each major pollutant. Reductions of hydrocarbons (HC/ROG/VOCs), NO_x, CO, and PM_{10} were recorded. HC and NO_x emissions were regarded as most critical for the cost-effectiveness assessment given their role in the formation of ozone, which is the most compelling standard among the NAAQS that most states and regions must achieve. CO is also a regulated pollutant, but it has been largely controlled in most areas through technological advancements. Because CMAQ funds may have been expended for CO-specific strategies (various traffic flow improvements) in past years, an effort was made to document CO reductions where available. Particulate matter presents a different situation from the others. Particulate matter is classified in two primary size categories, "coarse" (PM_{10}, with particle sizes of up to 10 microns) and "fine" ($PM_{2.5}$, with particle sizes of 2.5 microns or less). Regulatory standards presently exist only for PM_{10}, although its relation to vehicular activity is incidental (i.e., it is less the result of fossil fuel combustion and more the result of road dust raised from unpaved roads). $PM_{2.5}$, because of its finer particle size, is regarded as the more serious health hazard and is much more closely linked to fuel combustion, although national standards have not yet been established for various reasons. Hence, virtually no estimates of $PM_{2.5}$ reductions are presented in the literature, and while sporadic reporting of PM_{10} is found, its importance as a vehicle "emission" is less than the others. However, estimates of PM_{10} reductions were documented where they exist.

Emission Baseline

A practical concern in comparing emission estimates from different studies relates to the assumptions on which the estimates are based, and in particular, what starting conditions are reflected in the baseline. For example, emission studies performed prior to 1995 were heavily focused on reduction of hydrocarbons (VOCs), given NAAQS attainment timetables for VOCs. In large part this was attributable to high rates of emissions of VOCs from mobile sources based on technology at that time. Federal engine and fuel standards have since greatly reduced these emissions, and these improvements are reflected in lower fleet emission rates for gasoline-powered vehicles. Thus, were one to use emission estimates from these earlier studies, comparability concerns would arise in that the same travel change would probably elicit a greater absolute or percentage change in VOC emissions than a study performed using current fleet emission factors.

To a large extent, this issue has been minimized by using literature sources that are fairly recent and hence of comparable time frame. In particular, a series of evaluation studies performed by or for the Los Angeles County Metropolitan Transportation Authority (MTA) (COMSIS et. al 1996; COMSIS et al. 1997; Zarifi 1996; Pansing et. al 1998), in conjunction with MTA's regional TDM demonstration program, provided a large number of project examples for this paper. Those evaluation studies employed common methodological procedures for travel, emissions, and cost reporting. Comparability in emission estimates for these diverse projects was achieved through use of the CARB emission calculation procedures detailed in its 1999 guidance manual. The manual provides methods with examples for determining emissions for the following types of strategies:

- On-road and off-road cleaner vehicle purchases and repowering,
- Operation of new bus service,
- Vanpools and shuttles,
- Suburban vanpool/carpool park-and-ride lots,
- Signal coordination,
- Bicycle facilities,
- Telecommunications, and
- Ridesharing and pedestrian facilities.

For studies that applied these methods, emissions correspond to baseline characteristics reflecting 1997–2001 conditions. Studies dating from the same or later time period that did not use the CARB methodology were assumed to reflect comparable baseline conditions in terms of emission factors used in the analysis. The principal caveat in using the CARB procedure is that it embodies emission factors derived from California's EMFAC emission model, which are somewhat lower than those found in EPA's MOBILE models, given the more stringent emission standards for California vehicles. However, this feature does result in a somewhat more conservative projection of the emission savings.

For studies whose emission estimates predated the 1997–2001 period, the CARB methods were used to calculate VOCs, NO_x, and PM_{10} to allow estimates to better reflect a common baseline. Emissions for most of the Washington, D.C., Council of Governments' (1995) strategies, for example, were developed in this fashion. Whereas the strategies as reported had emissions estimated, the VOC estimates were from 1996 emission factors, and the NO_x emissions were not reported at all. Since all necessary travel inputs were available, it was possible to calculate revised emissions using the CARB relationships, thus putting the emission estimates on more common ground.

The CARB procedures are not intended for calculation of CO emissions. While CARB acknowledges that FHWA requests CO reductions for CMAQ projects, its own Motor Vehicle Fee program does not request CO information, since CO is seen as a localized and not a regional problem. Most of the CMAQ and Motor Vehicle Fee projects funded are primarily to reduce regional ozone, and they have little impact on localized CO hot spots. From a more technical perspective, computation of CO emissions relies heavily on detailed speed and delay data, which are generally not provided in the source studies, thereby making after-the-fact calculation difficult. The CARB guidance manual does not even provide emission factors for CO.

For most strategies, use of the CARB procedure for calculating emissions requires knowledge of the projected change in annual vehicle trips and VMT. Annual emissions for each pollutant are then calculated through the following formulation:

$$\text{Annual emission reduction} = [(\text{annual auto trips reduced}) * (\text{auto trip end factor}) + (\text{annual auto VMT reduced}) * (\text{auto VMT factor})]/454$$

The emission factors are supplied in the following table. Different factors are provided on the basis of the analysis period that is applicable, so for strategies involving major capital investments where costs are amortized over longer time periods, the method allows for emission rates to be used that reflect gradual improvement in rates over time through technology advances. *It should be noted, however, that rates exclusively for the 1–5 year analysis period have been used in this paper, since a discounting procedure is employed in the cost-effectiveness analysis (see section on emission discounting below). This procedure is assumed to reflect the gradual improvement of emission rates over time.*

Average Automobile Emission Factors

	Analysis Period			
Pollutant	**1–5 Years (1997–2001)**	**6–10 Years (1997–2006)**	**11–15 Years (1997–2011)**	**16–20 Years (1997–2016)**
ROG				
VMT	0.55	0.44	0.36	0.30
Commute trips	4.98	4.03	3.26	2.70
Average trips	2.91	2.34	1.89	1.56
NO_x				
VMT	1.02	0.84	0.71	0.62
Commute trips	2.05	1.78	1.56	1.39
Average trips	1.49	1.33	1.20	1.11
PM_{10}				
VMT	0.45	0.45	0.45	0.45
Trips	NA	NA	NA	NA

Note: Figures are in grams per mile. NA = not applicable.

Source: *Methods to Find the Cost-Effectiveness of Funding Air Quality Projects*, California Air Resources Board, Aug. 1999, Table 3, Page 45.

Note that the vehicle trip end factors, representing the emissions associated with starts and stops, are differentiated into "commute trip" and "average trip" categories. The commute trip factors are higher, since they incorporate start emissions for a commute-type prestart soak distribution plus hot soak emissions divided by daily trips, with the distribution determined from 1991 travel survey data. The factor for average trips was determined from statewide start emissions plus hot soak emissions divided by daily trips. It should be noted that the PM_{10} factors relate exclusively to VMT and not trips, since the factor is made up of 0.422 g/mi entrained road dust, 0.008 g/mi tire wear, 0.013 g/mi brake dust, and only 0.006 g/mi exhaust emissions.

Use of these factors in the equation shown results in estimates of grams per year reduced. CARB divides the result by 454 to arrive at pounds per year. All estimates in this paper have been placed in the more universal metric of tons per day, assuming 250 days per year for strategies affecting commute travel unless otherwise specified.

For strategies involving changes to elements of travel beyond simply vehicle trips and VMT, the CARB procedure provides additional guidance and factors as follows:

- For signalization or other flow improvement strategies, emission reductions are primarily linked to changes in average speeds. Hence, emission factors are provided for different speed ranges, and guidance is provided to account for peak and off-peak travel VMT distribution.
- For bicycle, carpool, and vanpool strategies, guidelines are provided to take average trip length into account (1.8 miles for bicycle trips, 16 miles for ridesharing trips).
- For transit or carpool/vanpool strategies, allowance is made for some percentage of trips to involve automobile access at the beginning (emission reductions multiplied by 0.7 in areas with average transit use; by 0.6 in areas with high transit use).
- Clean fuel vehicle strategies are supported with emission rates for transitional low-emission, low-emission, ultra-low-emission, and zero-emission light-duty and medium-duty vehicles, as well as baseline (Tier 1) vehicles. Factors and guidelines are also provided for baseline and new or compressed natural gas (CNG) buses.

Emission Weighting

Evaluating the effectiveness of a given CMAQ strategy generally amounts to comparing the emissions reduced with the cost to implement and operate the strategy. An accounting dilemma is raised, however, in determining whether to allocate credit to reductions of individual pollutants or simply to determine the cost-effectiveness in terms of the total reduction of all pollutants. While individual pollutant cost-effectiveness is appealing, particularly when certain strategies are more effective in reducing a given pollutant (e.g., NO_x), unfortunately it is generally not possible to allocate costs to individual pollutants.

The alternative is to associate the cost of the strategy with the total net[2] reduction of all pollutants. However, this approach raises a new question as to whether reduction of each pollutant should be valued equally. An example of how this could yield misleading results is the combination of reductions of VOCs, NO_x, and CO (all considered ozone precursors) into an arithmetic sum: because quantities of CO are an order of magnitude greater than VOC or NO_x, CO reductions would dominate the cost-effectiveness determination. In this case, air quality agencies have typically directed that CO emissions be weighted at one-seventh the value of the other pollutants when assessing strategy impacts on total emissions.

In this evaluation, the CMAQ committee has considered various weighting strategies for combining individual pollutant emissions into an overall total. These deliberations considered the health impacts of particular pollutants, which pollutants are currently most crucial in attaining ozone standards, and even secondary effects, in which one pollutant contributes to the level of another that may not be well estimated. An important example of the latter is the relationship between NO_x and fine particulates ($PM_{2.5}$). $PM_{2.5}$ is generally regarded as the pollutant with the most pernicious health consequences, though to date standards have not been promulgated for its regulation for both measurement and economic reasons. $PM_{2.5}$ is a complex mixture of both directly emitted particles from the fuel combustion process and secondary particles formed through atmospheric transformation of precursor gases, primarily NO_x and oxides of sulfur. Because $PM_{2.5}$ is not regulated, its levels are not estimated in air quality studies, nor are strategies evaluated for their effects in reducing it. However, given its surrogate relationship with NO_x, its importance in emission determinations can be approximated by assigning a higher weight to NO_x emissions when computing a total.

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[2] In certain strategies, emissions of some pollutants may actually increase while others are reduced. "Net" reduction refers to the overall effect after accounting for these unintended increases.

A higher weight for NO_x than, say, HC or PM_{10} is further justified by its importance in many areas' efforts to attain or maintain ozone standards. While technology and fuel advancements have made major progress in reducing HC and CO emissions, NO_x has been much more difficult to control. Diesel engines are particularly high emitters of NO_x (and $PM_{2.5}$), control of which threatens to affect the freight industry (trucks, locomotives) and urban transit systems, which rely on diesel buses. Hence, strategies that reduce NO_x are often given greater priority in planning exercises.

For these reasons, the committee decided to apply the following weighting scheme in calculating emission reductions from CMAQ and comparative strategies:

$$\text{Total reduction} = (\text{VOC} * 1.0) + (\text{NO}_x \text{ reduction} * 4.0) + (\text{CO reduction} * 0.0) + (\text{PM}_{10} \text{ reduction} * 0.0)$$

The weights of 1:4:0:0 have been used for developing the cost-effectiveness estimates in the impact tables and discussion of strategy effectiveness that follow in the later sections. However, for the purpose of seeing how important the weighting assumptions are to the overall conclusions from this review, the strategies have also been examined under weights of HC = 1, NO_x = 1; and HC = 1, NO_x = 8. Implications of these different weighting assumptions are discussed in the Analysis of Findings section.

Emission Discounting

Best practice in economic investment analysis calls for comparing project alternatives on the basis of total net benefits. This means looking at the delivery of benefits over the lifetime of the investment and transforming that benefit stream to a net present value through use of a social discount rate. This is then compared with the net present value of the life-cycle costs for the investment, as amortized over the service life of the investment.

Emission cost-effectiveness analyses are typically not done in this rigorous fashion, however. For emission strategies whose service lives are greater than 1 year [i.e., where a capital investment is being made (such as a rail transit line or a traffic signal system)], the significant capital and operating costs are normally "annualized" by spreading the costs evenly over the life of the project and then applying a discount rate (also referred to as "social" rate of interest) that reflects the opportunity cost of taxpayer resources were they to be invested elsewhere and earn a market rate of return. This annualized cost is then compared with the estimated annual emission reduction for the strategy to ascertain cost-effectiveness. However, standard practice does not recognize that the emission "benefits" may also follow a time stream of delivery. In general, an estimate is made of the emission reduction expected in some "target" year (typically when a conformity demonstration is needed), and this is simply regarded as the "average" emissions for the life of the strategy.

In reality, emissions also follow a life cycle. Seldom does a strategy elicit its anticipated performance in the first year of operation, nor does it maintain a constant level of performance over its lifetime. For example, the effects of strategies that attempt to influence travel behavior (such as transit, ridesharing, employer commute management programs) are likely to increase over time. In contrast, strategies that attempt to improve traffic flow conditions (such as signal management or freeway incident management systems) would be expected to have a fairly powerful (if not maximum) effect shortly after implementation, but those effects are likely to diminish over time as the area and its traffic volumes grow, or as traffic is diverted from other facilities or modes to make use of a comparative advantage in capacity. In such cases, failing to compare the "lifetime" of emission benefits with the discounted lifetime of costs amounts to an "apples-and-oranges" comparison.

To maximize comparability with the non-CMAQ-eligible strategies (see Appendix F) where benefits discounting has been applied, the CMAQ project committee determined that emission estimates for CMAQ strategies—if those strategies have service lives greater than 1 or 2 years—should be treated in a fashion similar to annualized costs. This implies (*a*) forecasting the lifetime stream of benefits and (*b*) discounting the benefits to present value using a social rate of interest comparable with that used for the costs. Consequently, a procedure and a set of assumptions has been developed to accomplish the discounting, since (unlike the costs) annualized benefits are not provided by the source studies for these types of strategies.

Projecting the stream of benefits for individual strategies is the aspect of the discounting procedure requiring the most significant assumptions. None of the reviewed cases presented any indication of having forecast travel and emission impacts over the service life of the strategy. Thus, it was entirely incumbent upon this researcher to profile what those impact lifetimes would look like. As a result, simple rules of thumb were adopted to at least ensure standardized treatment across all strategies.

On the basis of the reasoning introduced previously, three generic categories of benefit lifetimes were presumed:

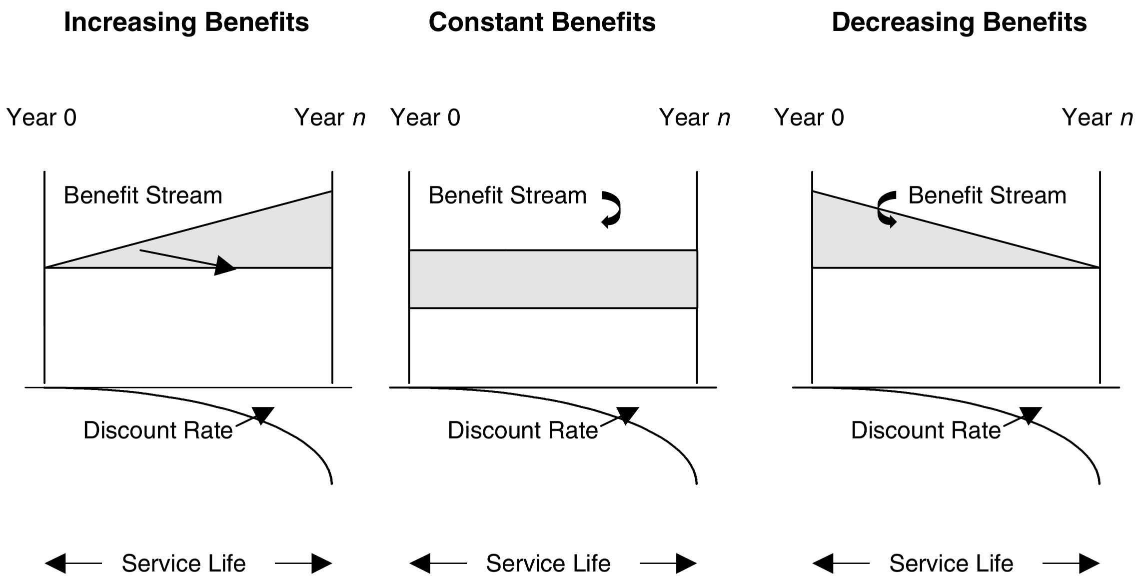
- Increasing: Travel and emission impacts would start off near zero and grow to full maturity by the end of the service life. Strategies assumed to fit this pattern include
  - New transit system elements or expansions,
  - Vanpool programs,
  - Ridesharing and travel demand management programs,
  - Employer trip reduction programs,
  - Telecommuting/telework programs,
  - Park-and-ride lots serving bus transit or as rideshare staging locations,
  - Bike/pedestrian facilities, and
  - Pricing (subsidies or fees).
- Constant: Because of either the nature of the strategy or the lack of information from which to judge a particular trend, strategies in this category were presumed to deliver a uniform stream of benefits over the course of the service life. Strategies whose service lives were only 1 to 2 years generally would also fall into this category. Strategies fitting this pattern include
  - Park-and-ride lots serving fixed-guideway transit service;
  - HOV lanes;
  - Transit shuttle services, feeder, or existing service improvements;
  - AFVs; and
  - Vehicle inspection and maintenance.

- Decreasing: Strategies in this category would start out delivering the maximum (or near maximum) impact and benefit and then gradually decline to zero by the end of the service life. Strategies treated in this manner include
  - Arterial signalization projects,
  - Freeway incident management, and
  - New highway capacity.

Of course, this is a very naïve simplification of the complex processes that shape the benefit streams of strategies in reality. Whereas it is necessary to assume that the benefits lifetime is defined by the physical project's service life and that the trend in benefits (increase or decrease) is *linear* between these end points, one would expect the actual pattern of benefits to be highly nonlinear, rising or falling at different rates as innumerable intervening factors influence the final result. Later, in the actual analysis, the definitions were amended somewhat when it was felt that a strictly increasing, decreasing, or constant benefit stream was incorrect and distorted the strategy's actual behavior.

To explain these modifications, it is necessary to describe the associated discounting procedure. As illustrated in the diagrams on the next page, the process of discounting involves reducing the benefit produced in a given year by the respective interest rate. Because of compounding, the discount rate increases at a nonlinear rate. Of course, the highest rates of discount occur in the later years of the project; hence the benefits in these out years have the least value in present time. As illustrated by the drawings, this characteristic causes discounting to have the greatest devaluing effect on strategies whose benefit streams are "increasing" (i.e., involve a long-term adaptive process before full effects are realized). In contrast, strategies with decreasing benefit streams are only modestly affected by discounting.

This result raises some interesting philosophical questions to challenge the inherent economic logic present in discounting benefits, specifically as to whether near-term rewards are always superior to long-term rewards. It suggests, for example, that traffic flow improvements, which deliver fairly immediate benefits, are more


Increasing Benefits
Constant Benefits
Decreasing Benefits
Year 0
Year *n*
Year 0
Year *n*
Year 0
Year *n*
Benefit Stream
Benefit Stream
Benefit Stream
Discount Rate
Discount Rate
Discount Rate
Service Life
Service Life
Service Life

favorable investments than, say, expansion of a transit line, which will likely not be fully utilized for several years. The former strategy offers instant relief but inevitable deterioration as traffic builds (either from secular growth or from diversion from other facilities or modes), while the latter may prove its greatest value in helping to shape long-term growth patterns and provide travel alternatives for future years when it may be more difficult to build new infrastructure. However, since the former strategy front-loads its benefits while spreading its costs over years when it ceases to provide benefits, it may appear to be a better investment than the second strategy, whose benefits are more aggressively devalued because they appear in later years.

Because of these concerns, the appropriateness of simply casting strategies into one of the above three categories was examined closely. For some strategies, such as HOV lanes, where it was not clear that the benefits would increase or decrease over time, it was assumed that the benefit stream would be constant. For other strategies, nominally classified as "increasing" but that would clearly produce benefits in early years, it seemed inappropriate to start the benefit stream at zero. For these strategies, a hybrid case was formed to combine a "constant" delivery of base year benefits with a stream of "increasing" benefits to represent the maturation of the strategy to its ultimate impact. In still another case, it was clear that whereas the costs associated with the implementation would begin in year 0, the project would not be opened for service until some subsequent year; for these, the costs and benefits were discounted in relation to their respective service lives.

To put these discounting procedures into practical use, given the large number of projects with a wide range of service lives and benefit stream characteristics, a system of discounting factors was developed. This amounted to developing tables of discount factors to reflect each encountered combination of interest rate and service life, and for each type of benefit stream (increasing, constant, and decreasing). This was done via spreadsheet to simplify the calculations given simultaneously varying benefit levels and interest rates in each year of the life of the project. The factors are shown in the table on the next page.

Benefit Discount Factors

	Interest Rate (%)		
Year	**5**	**6**	**7**
Declining Benefits			
4	0.596	0.591	0.585
5	0.563	0.557	0.550
10	0.478	0.466	0.455
12	0.457	0.444	0.431
20	0.396	0.377	0.359
30	0.341	0.319	0.299
Constant Benefits			
4	0.931	0.918	0.906
5	0.909	0.893	0.877
10	0.811	0.780	0.752
12	0.776	0.741	0.708
20	0.654	0.608	0.567
30	0.538	0.486	0.443
Increasing Benefits			
4	0.541	0.526	0.511
5	0.528	0.515	0.503
10	0.332	0.314	0.297
12	0.318	0.297	0.278
20	0.259	0.231	0.207
30	0.197	0.168	0.144

Time frame or interest combinations not shown in the table were calculated on a case-specific basis. Generally, however, the service lives and interest rates shown in the table covered most of the cases analyzed in the study.

Other Emission Adjustments

In the parallel paper on non-CMAQ-eligible control strategies (Appendix F), Wang also raised issues with the following types of adjustments to emissions, which were considered but not used as a factor in this assessment of CMAQ strategies:

- Emissions in attainment versus nonattainment areas: Wang indicates that certain emission studies attempt to control for whether the emission reductions actually occur in air quality nonattainment areas. Some analysts argue that emissions reduced in areas that already have acceptable air quality should not be included in the overall determination of cost-effectiveness, because they are less important or unimportant in those areas. Clearly, one can envision how claims of cost-effectiveness for a strategy as universal as a change in vehicle technology, under which consumers in all areas would face the cost and perhaps performance limitations of a new fuel or technology, could come under criticism as to proper definition of costs and benefits. Wang has attempted to incorporate such adjustments where possible in his review. However, in the case of CMAQ strategies, it is difficult to envision a situation where these concerns would be raised, particularly given the restriction of CMAQ funding to nonattainment or maintenance areas anyway. Hence, these adjustments have not been attempted for the CMAQ strategies.

- Seasonal adjustments: On the basis of similar arguments, some emission studies restrict or weight emissions to the season of the year when air quality conditions actually take advantage of the strategy's reductions. For example, peak ozone season falls in the summer months, calling into question the claiming of benefits that are delivered during noncritical times of year. This is often an issue in vehicle technology and fuel strategies (e.g., using more highly priced oxygenated fuels to reduce CO emissions during the winter season), and Wang has attempted to control for differences among studies by reporting all reductions on an annual, not seasonal, basis. This approach has been followed for CMAQ strategies, because all the estimates furnished from the literature are on an annual basis.

Costs and Cost-Effectiveness

Types of Costs Considered and Not Considered

Costs included in this evaluation of CMAQ strategies have been limited to the following categories:

- Annualized capital costs: These include the capital costs to construct and implement the project, reduced to an average annual dollar value based on service life and the presumed social rate of interest (generally between 5 and 7 percent). Costs include but are not limited to CMAQ-derived funding, nor have estimates been made of the effectiveness of only the CMAQ funds where there are multiple funding sources.

Capital costs have been annualized through the use of capital recovery factors (CRFs). A CRF associated with the service life and discount rate for the given strategy is multiplied by the total capital cost of the project to estimate the average annual cost. The table below shows typical project lifetimes for CMAQ-type strategies for use in cost annualization along with the respective CRFs.

Project Lifetimes for Use in Cost Annualization and Capital Recovery Factors

Service Lifespan	Types of Strategies or Facilities	CRFs at Indicated Interest Rate		
		5%	6%	7%
1–2 years	Existing transit service improvements Travel demand management programs Ridesharing programs Vanpool programs Pricing or fare strategies	0.538 (2 years)	0.545 (2 years)	0.553 (2 years)
4–5 years	Telecommunications/telework programs Paratransit vehicles	0.231 (5 years)	0.237 (5 years)	0.244 (5 years)
10–12 years	Roadway signal systems Freeway management systems (ITS) New buses or alternative-fuel buses	0.130 (10 years)	0.136 (10 years)	0.142 (10 years)
	Sidewalk or bike facilities Park-and-ride lots	0.113 (12 years)	0.119 (12 years)	0.126 (12 years)
20 years	Roadway improvements, including HOV Rail signalization systems	0.080 (20 years)	0.087 (20 years)	0.094 (20 years)
30–35 years	Rail transit systems Parking structures Locomotives or rail cars Pavements and bridges	0.065 (30 years)	0.073 (30 years)	0.081 (30 years)

- Operating and administration costs: These are included where they either constitute the strategy for which CMAQ funds are being expended or are an inextricable part of implementing, maintaining, or enforcing the strategy. These costs are almost universally reported on an average annual basis, so they were simply added to the annualized capital costs to arrive at total annual cost.

- Private costs: The above costs are typically treated as public costs, being financed from taxpayer revenues through expenditures by public agencies. However, some strategies (e.g., employer trip reduction programs or telecommuting) may require direct outlays of private resources to implement or operate the strategy. Where these costs exist and are separate from the public costs, they have been included in the total.

The following costs or cost items have not been included in the analysis:

- Incidental costs: Certain strategies, depending on their success level, may lead to associated needs for system expansion, or conversely, may reduce the level of demand for existing services or facilities. A key example would be programs, such as a fare subsidy or parking fee, that would likely increase transit ridership. Since most large city transit systems are already operating at close to capacity during peak periods, the concern is whether the increase in ridership would require additional transit vehicles and service. Similarly, if an employer were to implement a parking cash-out program that resulted in a reduction in the need for employer-provided parking spaces, the employer might be able to divest itself of some of its parking and recoup these resources. For the purposes of this analysis, however, no attempt has been made to account for these associated costs or revenues.
- Transfer payments: Certain strategies involve the exchange of resources between one societal group and another. For example, an employer implementing a trip reduction program might institute a charge for employee parking. Whereas the parking fee would furnish revenues back to the employer that could be used to defray other costs of the program (or even to provide transit subsidies to other employees), this exchange of revenues between one group and another has not been incorporated in the analysis. Similarly, revenues collected from new transit passengers or proceeds from a roadway congestion pricing project have not been factored into the analysis. This assumption should be carefully weighed when looking at the effectiveness of strategies that involve major exchanges of revenues between groups, since (*a*) many of the strategies would actually operate with net revenue (or could at least be structured to be self-

financing), (*b*) the revenues could be used to purchase additional service or capacity or turned back in productive ways to users, and (*c*) perception of cost-bearing by consumers can have major implications for political acceptability.

- Consumer versus manufacturer costs: Wang notes that pressure on manufacturers to meet new technology standards can have a multiplicative effect on consumers, since manufacturers may not only pass these costs on to consumers through higher prices, but in fact "mark-up" the price of the product to 20 to 40 percent greater than their actual production costs. Wang cites this as an important issue in judging the cost-effectiveness of a given strategy to society when consumers are obliged to shoulder an inappropriate share of the cost burden. While this concern was noted, it has not emerged as an issue in this review of CMAQ strategies.
- Societal or external costs: Interest has been increasing in finding ways to incorporate the broader costs to society of traffic congestion and air quality impacts when performing transportation planning or policy studies. Examples of these types of costs include congestion time losses, personal and property losses from accidents, noise impacts on communities, and air quality health costs. The CMAQ committee decided not to extend the current analysis to include these types of costs, given uncertainties in their valuation and general absence in the empirical literature.

Constant Dollars

All dollar costs for projects were converted to a 2000 base by using a Consumer Price Index from the U.S. Statistical Abstract. CPI values for respective years in relation to 2000 are shown below, along with the corresponding adjustment factor. The CPI for 2000 is 145.0.

Year	*CPI*	*Factor*	*Year*	*CPI*	*Factor*
1987	105.4	1.376	1994	134.3	1.080
1988	108.7	1.334	1995	139.1	1.042
1989	114.1	1.271	1996	143.0	1.014
1990	120.5	1.203	1997	144.3	1.005
1991	123.8	1.171	1998	141.6	1.024
1992	126.5	1.146	1999	144.3	1.005
1993	130.4	1.112			

COST-EFFECTIVENESS FINDINGS

In this portion of the paper, findings from the review and synthesis of CMAQ and suggested non-CMAQ control strategies are presented on a category and subcategory basis, to the extent permitted by the number of valid studies supporting the area. A summary table has been prepared for each separate category/subcategory, presenting the following information on each strategy where available:

- Name and description of strategy and location, date, and author of source study
- Travel impacts
  - Daily vehicle trip reduction
  - Daily VMT reduction
  - Increase in daily transit riders
  - Change in average speed (mph) or hours of delay associated with congestion measures, or both
- Emission impacts
  - Daily reduction in emissions by pollutant (HC, NO_x, CO, and PM_{10})
  - Weighted sum of daily tons of emissions reduced for all pollutants
  - Year or period for which emissions have been calculated
- Cost-effectiveness
  - Service lifetime of strategy
  - Assumed trend in emission benefits over time
  - Compound interest rate used for annualization of costs and discounting of emission benefits
  - Average annual (discounted) emission benefits
  - Average annual costs
  - Cost per ton for emissions reduced

Because of the number of tables (19 tables for each of the three weighting schemes), they have been treated as an annex and not incorporated in the text discussion. They are, however, referenced by table number in the text discussion for the aid of reviewers who wish to examine individual cases or details when appraising the reported findings.

An overall summary of the findings with respect to individual strategies is given in Table E-1. The table indicates the number of cases in each category/subcategory. The range of cost-effectiveness (low and high value) and the median value for each are given in the table for the selected pollutant weighting scheme (HC = 1, NO_x = 4) in the first group of columns and are given for the alternative weighting schemes (1:1 and 1:8) in the second and third groups of columns. From this information the reader can assess the importance of the weighting assumption on the overall and relative performance of each strategy group.

Traffic Flow Improvements

Traffic flow improvements reduce emissions not through reduction of vehicular travel demand, but through improved efficiency that effectively increases capacity and thus allows vehicles to travel more smoothly and at higher speeds. On arterial street systems, these improvements usually take the form of new or synchronized signal systems, potentially coupled with physical intersection improvements. On freeway/limited-access highways, improved flow is usually accomplished through management of traffic on the system versus traffic entering the system (e.g., through ramp metering) or through management of incidents.

While one would expect that traffic moving under free-flow conditions will perform more efficiently and emit less pollution, standard emission factor models do not explicitly account for the effects of stop-and-go driving. Emission factors used in the models are derived from composite drive cycles, so these uneven flow characteristics must be approximated through changes in average speed as represented in "speed correction factors." On the average, this probably underestimates the emission savings from certain flow improvements, such as signalization or incident management. However, for other types of strategies, like ramp metering, claimed emission savings may be overstated by this gap in the methodology, since vehicles accelerating rapidly from stop on a ramp into free-flowing traffic emit a substantial percentage of their total trip emissions during that single event (at high acceleration, termed "enrichment," catalytic converters may be bypassed to avoid damage and premature wear).

TABLE E-1 Cost-Effectiveness of Strategies Under Selected (1:4) and Alternative Weighting Schemes

	No. of Cases	Weights = 1:4:0:0			Weights = 1:1:0:0			Weights = 1:8:0:0		
		Low	High	Median	Low	High	Median	Low	High	Median
Traffic flow improvements										
Signalization	5	6.0	128.0	20.1	5.4	296.5	35.2	6.0	72.8	20.8
Freeway/incident management	4	2.3	543.9	102.4	5.8	732.1	240.9	1.3	672.6	52.8
HOV facilities	2	15.7	336.8	176.2	43.1	589.4	316.2	8.5	214.3	111.4
Ridesharing										
Regional rideshare	5	1.2	16.0	7.4	3.1	45.3	18.5	0.7	8.9	4.1
Vanpool programs	6	5.2	89.0	10.5	14.7	253.2	30.4	2.7	47.7	5.6
Park-and-ride lots	4	8.6	70.7	43.0	29.3	226.1	127.5	4.4	37.9	22.3
Travel demand management										
Misc. TDM	8	2.3	33.2	12.5	5.8	90.8	34.1	1.3	18.0	6.8
Employer trip reduction	7	5.7	175.5	22.7	14.2	473.8	56.9	3.2	95.4	12.6
All telework	10	13.3	8,227	251.8	34.8	21,643	742.3	7.3	4,505	133.9
All bike/pedestrian	14	4.2	344.7	84.1	11.2	893.3	206.6	2.3	189.5	47.3
Transit improvements										
Shuttles, feeder, paratransit	15	12.3	1,974	87.5	30.8	4,256	214.7	6.8	1,151	49.6
New transit capital systems/vehicles	6	8.5	470.8	66.4	22.7	1,226	208.0	4.6	258.5	34.4
Conventional service upgrades	10	3.8	120.1	24.6	9.9	336.0	64.6	2.1	64.7	13.5
Park-and-ride lots	1	56.2	56.2	56.2	149.8	149.8	149.8	30.0	30.0	30.0
Fuels and maintenance										
Conventional fuel replacement buses	5	11.0	39.9	16.1	43.2	147.5	62.3	5.5	20.2	8.1
Alternative-fuel buses	11	6.7	568.7	126.4	16.8	1,422	355.7	3.4	288.1	68.0
Alternative-fuel vehicle programs	2	4.0	31.6	17.8	9.0	97.1	53.0	2.3	16.6	9.4
Inspection and maintenance	5	1.8	5.8	1.9	3.5	10.2	4.5	1.1	5.0	1.1
Pricing measures										
Modal subsidies and vouchers	14	0.8	471.0	46.6	2.4	1,086	125.4	0.4	268.4	25.4
Charges and fees	6	0.8	49.4	10.3	2.2	132.3	27.9	0.4	26.9	5.6

Note: Figures in the “weights” columns indicate dollars per ton in thousands (2000 dollars).

A related concern in depending exclusively on speed changes for emission reduction is that not all speed improvements reduce emissions. As shown in the diagrams of Figure E-3, this is because emission rates do not change linearly with speed, but rather are high at low speeds, fall to a minimum somewhere in the middle of the speed range, and then increase again as speeds increase. Moreover, this relationship is different for each pollutant and for different settings. Pictured in Figure E-3 are speed/emission relationships for arterial/collector and freeway conditions.[3] On arterial roadways, HC and CO emissions are at a minimum at about 30 mph, while NO_x emissions do not reach a minimum until 35 mph. All pollutants then begin to increase again as speeds rise. Since many flow improvement strategies influence speeds in these ranges, it becomes very important to examine not just the change in speed, but where on the curve that change occurs.

On arterial roadways (see Figure E-3), where posted speed limits and traffic signals constrain speeds to moderate levels, improving flow at speeds up to 30 to 35 mph generally should reduce emissions, but if speeds should begin to exceed this level, emissions may increase unless the prior case involved significant delay. On freeways, the situation is different. Emission rates reach a minimum earlier, at a lower speed of 15 to 20 mph. The lower rates are then maintained until 30 to 35 mph, when once again they increase steadily with higher speeds. So on these types of facilities, where congestion is often severe and leads to stop-and-go conditions, improvements in speeds through pulsing of traffic or rapid resolution of incidents can have substantial benefits at the lower end of the speed curve. However, should conditions improve to the extent that traffic flows at speeds exceeding 35 mph, emissions then proceed to increase steadily with speed.

A final issue concerning flow improvements is their effect of diverting traffic from other facilities or modes. This not only increases traffic volumes on the improved facility, but also can reduce or eliminate the emission gains from the improvement. Everything depends on

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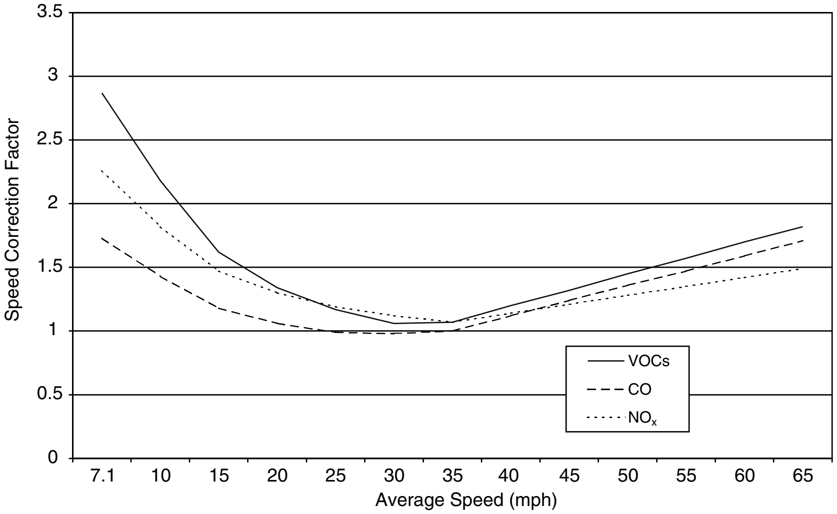
[3] The relationships depicted in Figure E-3 are speed correction factors. These are adjustment factors multiplied by the average emission rate obtained from the standard drive cycle to approximate how the average rate would change with speed.

Speed Correction Factors for Arterial and Collector Roadways by Average Speed (mph) for Tier 1 Normal Emitting Vehicles



Speed Correction Factors for Freeways by Average Speed (mph) for Tier 1 Normal Emitting Vehicles

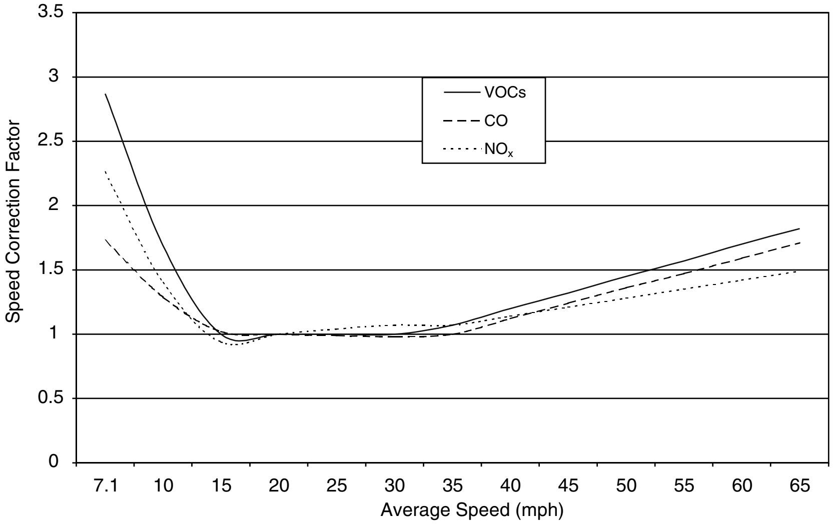


FIGURE E-3 Variation of emission rate with speed, by type of facility. Source: Brzezinski, D. J., P. Enns, and C. J. Hart. 1999. *Facility-Specific Speed Correction Factors.* Draft. M6.SPD.002. EPA420-P-99-002. U.S. Environmental Protection Agency, Aug., pp. 53–54.

how adjustments occur in the overall travel network. A good emission analysis would be expected to account for each of these effects, although the majority of those reviewed did not.

Traffic Signalization Strategies

Table E-Annex-1 contains five examples of traffic signalization projects. They range in cost from $6,300 to more than $2 million per year and have total annual emission reductions of between 0.8 and 89.6 tons. The cost-effectiveness of the five examples ranges from $7,900 to $128,000 per ton. Median cost-effectiveness is $20,100, reflecting a concentration of examples in the lower end of the cost range.

These examples are the result of fairly credible analyses using local travel models. Each accounts for whether speed will increase or decrease emissions, and some actually account for diverted traffic effects. However, all of the studies use average speeds only, and none project what traffic conditions will be in 10 to 20 years, the cited lifetimes for the respective capital investments. As a result, it has been assumed that the emission benefits for each of these projects will be realized early and then decrease over time.

Freeway Management Strategies

Strategies in this group include both incident management systems and ramp metering. Detailed results are presented in Table E-Annex-2.

There is only one example of the ramp metering strategy in the group, from the Delaware Valley Regional Planning Commission (DVRPC) (1994), and it is estimated to have an effectiveness of $5,000 per ton reduced. However, it does not appear that this analysis in any way accounted for the off-cycle emissions occurring as a result of the ramp stop-and-start activity. Hence it is reasonable to conclude that the emission savings are overestimated and that the cost-effectiveness is deceptively low.

There are three examples of freeway ITS incident management systems. They range in cost-effectiveness from $2,400 (Atlanta) to $544,000 per ton (DVRPC, Philadelphia). The middle-of-the-road estimate is for the Maryland DOT CHART program, and its results are perhaps the most reliable in terms of both emissions and costs. CHART reduces emissions at a cost of about $200,000 per ton, based mainly on an annual expense of $14 million in capital costs and $5 million in operating cost. It is not clear how much more extensive or sophisticated the Maryland system is than Atlanta's, but the annual cost of $841,309 makes Atlanta's incident management system only about 4 percent as costly as Maryland's, raising doubt as to the accuracy of the Atlanta cost. On the basis of this limited sample, the MDOT CHART system is seen as the most credible estimate of the cost of freeway ITS-based incident management.

Supplemental Traffic Flow Information

Because many of the strategies presented above did not have significant information on their traffic and congestion management benefits, for which potentially important travel time savings benefits might be presumed, the supplemental table below contains a number of examples of traffic signalization projects, incident management systems, and ramp-metering systems for which travel impacts were provided. These impacts include changes in speed, delay and travel time, and in some cases emission reductions. Unfortunately, cost information was not available from the source to permit calculation of cost-effectiveness. It should be noted also, however, that a number of the strategies—in particular, ramp metering—were also associated with increases in traffic volume.

Performance of Sample Traffic Flow Projects

Site/Project	Travel Impacts	Emission Impacts
Automobile Traffic Signal Improvements		
Los Angeles: Automated traffic signal control of 1,170 intersections	41% reduction in stops 44% reduction in delay 16% increase in speeds	14% reduction in VOC emissions (1994)
Toronto: SCOUT adaptive traffic signal control program (75 signals)	22% reduction in stops 17% reduction in delay 8% decrease in travel time	3.7% reduction in HC 5.0% reduction in CO
Garland County, TX: coordination of 127 signals	22% reduction in stops 14% reduction in delay 4% reduction in travel time	

(*continued*)

Performance of Sample Traffic Flow Projects (*continued*)

Site/Project	Travel Impacts	Emission Impacts
Transit Signal Prioritization		
"European" experience	6% to 42% reduction in travel time 40% to 80% reduction in delay	
Sapporo, Japan: Public Transportation Priority Route	6.1% reduction in travel time 20.8% reduction in delay 10% increase in transit ridership	
Portland, OR: Powell Blvd. bus priority system	5% to 8% reduction in bus travel time	
Freeway Incident Management		
San Francisco Freeway Service Patrol		0.035 tpd HC reduction 0.880 tpd NO_x reduction 0.375 tpd CO reduction
Houston: TransStar (over 127 miles of freeway)		0.1 tpd HC reduction
Boston: SmarTraveler		0.549 tpd VOC reduction 0.028 tpd NO_x reduction 5.55 tpd CO reduction
Freeway Ramp Metering		
Portland, OR (58 meters)	60% speed increase 25% volume increase	
Minneapolis (39 meters)	35% speed increase 32% volume increase	
Seattle (22 meters)	52% travel time reduction 86% volume increase	
Denver (5 meters)	19% volume increase	
Detroit (28 meters)	8% speed increase 13% volume increase	
Austin (3 meters)	60% speed increase 8% volume increase	
Long Island (70 meters)	9% speed increase	

Note: tpd = tons per day.

Source: *Intelligent Transportation Systems Benefits: 1999 Update*. ITS Joint Programs Office, FHWA, U.S. Department of Transportation, May 1999.

HOV Lanes

HOV lanes achieve their emission benefits largely in the same way as do other flow improvements, by improving flow conditions and raising average speed for vehicles traveling on congested facilities. What differentiates HOV lanes is that they also encourage change in behavior by providing higher levels of service (higher speed, reduced travel time) for persons who use transit or who rideshare, depending on the restrictions of the particular facility.

The exact extent of the emission impacts of an HOV lane depends on numerous complex and interrelated factors. If the HOV lane is "taken" from the existing roadway cross section, then the issue is whether the number of persons who travel by HOV at a noncongested speed compensates for the number who remain in the mixed-flow lanes and experience the same or worse congested speed. If the HOV lane is "added" to the existing system, then it provides less of a travel time incentive to potential HOV users but provides an across-the-board improvement to all travelers because of the increase in physical capacity. Speeds may be sufficiently improved under these conditions that either NO_x emissions rise or new vehicle trips are drawn to the facility from other routes or modes.

In the long run, the issue raised by HOV facilities where new lanes have been added is—as with new highways—whether the new capacity will encourage new trips from further locations whose accessibility has been effectively increased by the change in capacity. Few HOV studies have addressed this phenomenon in their forecasts.

HOV lanes, like other roadway projects, have service lives of about 20 years. On the basis of the above discourse on the factors that influence performance and emissions, it is difficult to know a priori whether a given system will increase or decrease in its delivery of benefits over time. Hence, for simplicity, the compromise in this analysis has been to treat the benefit stream for HOV lanes as constant.

There are only three examples of HOV facilities in Table E-Annex-3, and they reflect extremes in cost-effectiveness. The low range is represented by the Metropolitan Washington Council of Governments (MWCOG) example, which evaluates the impact of a proposed regional HOV freeway network. This system was projected (using a mode-choice model combined with a sketch planning technique) to reduce 0.6 tons of HC and 0.85 tons of NO_x per day at an annual cost of $9.5 million, resulting in a cost per ton reduced of $15,100. At the other extreme, the Hartford I-84 HOV lane extension is only a fraction of the scale of the MWCOG network and delivers only about 0.01 tons of HC per day and 0.004 tons of NO_x. Against annual costs of $1.47 million, this yields an effectiveness of $336,800 per ton reduced.

The third example in the table is Houston's Katy Freeway, for which no cost-effectiveness has been calculated. While the example has both emissions and cost data, the project is shown to *increase* NO_x emissions. The cost-effectiveness computation therefore shows a cost-per-ton *increased,* so for reasons of logic, the result is not reported.

The median for this strategy group is $176,200 per ton. However, on the basis of the large range in the examples and the complex issues discussed, there is considerable uncertainty as to the validity of this measure as indicative of performance in this category.

Ridesharing Programs

After transit, ridesharing is perhaps the most frequently applied strategy to try to manage travel demand. Effects on emissions are realized through a reduction in vehicle trips, which is accomplished by increasing the average number of persons riding in the vehicle through matching people with common travel parameters into carpools, vanpools, or even 40- to 50-passenger bus pools. Typically, the only travel and emission benefits associated with a ridesharing program have to do with the reduction of vehicle trips: the number of persons converted to ridesharing modes is not nearly enough to expect an impact on systemwide travel conditions or speeds. A concern with ridesharing is that successful campaigns may divert travelers from transit to (less efficient) carpools. However, in most cases the two modes serve very different markets, and ridesharing provides a viable alternative when transit is not available or suited.

A wide range of strategies may be associated with the ridesharing category. There are "programmatic" approaches, consisting mainly of areawide programs that provide information and assistance in matching potential poolers. Of course, individual employers may institute ridesharing programs, although this is often more in the context of a broader employer trip reduction program (discussed later). Vanpool and bus pool programs are important subsets of the ridesharing genre, not only because of their greater efficiency (persons per vehicle) but because they are to various degrees institutionalized, and hence are more formal and frequently backed by employers. Finally, there are supporting facilities such as park-and-ride lots to enable carpools and vanpools to come together at a mutually convenient location.

The absolute effects of these programs are typically modest, both in terms of costs and resultant travel and emission reductions. However, in general, the cost-effectiveness of these strategies is fairly attractive. Most of the estimates of cost-effectiveness in this category are based on empirical data from formal evaluation studies (i.e., not model simulations).

Regional Approaches

Table E-Annex-4 gives five large-scale ridesharing programs taken from the literature. Four are regional rideshare matching and information programs (Riverside, California; Los Angeles; Philadelphia; and Washington, D.C.), and one is a regional program that is focused on universities in the Atlanta area. These programs cost anywhere from \$100,000 to \$1.7 million per year and are estimated to reduce emissions by 10 to 400 tons per year. The corresponding cost-effectiveness for this group of five strategies ranges from \$1,200 to \$16,000 per ton, with a median of about \$7,400. Most of these programs are financed for operating and administrative expenses only (not capital). Hence, the service life is 1 year and both benefit and cost discounting are inapplicable.

Vanpool/Bus Pool Programs

Table E-Annex-5 lists six vanpool programs, most taken from the Los Angeles TDM evaluation studies of COMSIS, Pansing et al., and Zarifi (1996–1998). These projects are perhaps not typical of employer vanpools, but may be more like the types of publicly based strategies for which CMAQ funds can be expended. As a matter of scale, the projects range in cost from \$31,400 to \$1.7 million per year and may be capable of reducing between 3.1 and 278 tons of emissions per year. The Houston regional vanpool program is clearly an order of magnitude larger than the rest, both in annual cost (\$1.7 million) and in total emissions reduced (278 tons per year), resulting in a cost of \$6,100 per ton. The more modestly sized programs in the table, with the exception of the UCLA Vanpool Expansion project (\$89,000 per ton), are relatively cost-effective, ranging from \$5,100 to \$24,300 per ton. The median for the set of six examples is \$10,500. As with the preceding programmatic ridesharing strategies, funding for these projects is generally for operations and administration, not capital;

hence the time frame for analysis is 1 year and neither benefits nor costs are discounted/annualized.

Park-and-Ride Lots

Table E-Annex-6 lists four examples of park-and-ride lots to support ridesharing. The examples range from an individual lot to a regionwide system of lots to support an HOV network. The examples range in cost from about $16,000 to more than $5.3 million and are projected to yield between 1.9 and 75 tons of reduction per year. The group suggests a cost-effectiveness in the range of $8,600 to $70,100 per ton, with a median of about $43,000.

Because they involve construction, the costs of park-and-ride lots are generally amortized over a service life of 10 to 12 years, though one of the examples assumes a 30-year life. The benefit stream is assumed to be constant: frequently, demand for parking at park-and-ride lots hits capacity shortly after the lots are opened, after which additional usage is capacity constrained. Park-and-ride lots that serve only carpool staging may not reach capacity as rapidly as lots that serve transit, and particularly rail transit or commuter rail. One concern in using park-and-ride lots as an emission strategy is that, despite shifting travelers to a higher-occupancy mode, the shift still requires a vehicle trip to and from the lot. Thus the emissions associated with the cold start, the VMT, and soak/evaporative events must be netted from the face value of the mode shift enabled by the lot. Most of the better studies, including all of those reported here, make allowance for this automobile access element.

Travel Demand Management

TDM has come to mean a variety of actions that are typically aimed at commute travel. Frequently the employer is the medium for implementing these types of strategies, although its hand may be forced by the imposition of trip reduction ordinances or laws that require implementation of commute management programs. Depending on the type of circumstance (voluntary or mandatory) the program is created under, the types of strategies can be quite different. Voluntary programs may consist only of carpool matching assistance or transit information, while programs required to meet regulatory targets may use parking management (supply manipulation or charges), subsidies, and transportation allowances.

TDM initiatives can also be mounted by governments, public agencies, and public-private partnerships such as transportation management associations (TMAs). These efforts frequently tend to be more informational and promotional and less involved in specific travel options or pricing strategies. Both types are covered in this review.

Regional or Areawide Approaches

Table E-Annex-7 lists eight examples of TDM initiatives administered through public agencies or TMAs. These range from regional TDM programs to an effort administered by the Metropolitan Atlanta Rapid Transit Authority (MARTA) to engage employers in selling and distributing transit passes. Most of these programs are operations-type projects only and hence have service lives of only 1 or 2 years. Two programs—Atlanta's regional TMA and the Long Island TDM programs—have extended service lives (12 and 5 years), though it apparently has to do with a multiyear funding commitment and not amortization of a capital investment. For these two programs, benefits have been discounted to be compatible with the annualized costs. Atlanta was assumed to have an increasing benefit stream because of the long-term expansion objectives of the program, while the Long Island case was seen as having a constant impact.

The programs in this category span a cost range from $170,000 to more than $3.5 million per year and are estimated to reduce between 5.7 and 168 tons of emissions per year. Cost-effectiveness for these program examples ranges from $2,300 per ton (IEPA Public Outreach) to $33,200 per ton (LA County TDM). The median for the group is $12,500 per ton.

Employer-Based TDM

The employer-based trip reduction (ETR) program has attracted considerable scrutiny, given the political issues raised by California's Regulation XV program and the 1990 Clean Air Act Amendments' Employee Commute Options (ECO) requirement for severe nonattainment areas. Numerous analyses were conducted during the early to mid-1990s in attempts to either condemn or redeem the employer trip reduction program as a cost-effective way of reducing VMT and emissions. As a consequence, the range of impacts shown in Table E-Annex-8 reflects the assumptions and perspectives that emanated from these two different camps. The regional scale of these programs is reflected in the level of cost and emission reduction potential. The programs range in cost from about $20 million to more than $376 million per year (median of $115 million), and from 2,100 to 9,300 annual tons of emissions reduced. The cost-effectiveness demonstrated in the seven examples ranges from $5,700 per ton (Houston ECO program with $50 per employee assumption) to $175,500 per ton (MWCOG on-site voluntary ETR). The median for the group is about $22,700 per ton.

The major issue separating the various estimates has much to do with the composition of the individual programs. If employers implement a balanced program of measures, including transportation and work schedule options along with incentives and disincentives for their use, these programs are typically very cost-effective. This is because there is an actual change in travel behavior, and in cases where employers are using pricing strategies, the revenues or avoided costs, or both, can help finance the direct costs of the program. However, since incentives and disincentives are often regarded as a threat by employees, employers are reluctant to use such measures. Hence, they may expend substantial amounts of money on strategies that have little or no effect by themselves on changing behavior (such as guaranteed ride home, transportation coordinators, marketing and promotion, TMA membership). These latter programs were the most common among the Regulation XV experience and may be associated with the low impact/high-cost reputation that was ascribed to the program as a whole. This review is not a judgment pro or con on the ETR/ECO experience, only an observation taken from the author's own extensive work on the subject.[4]

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[4] TCRP B-4: Cost-Effectiveness of TDM Strategies (1994); FHWA/FTA: Implementing Effective TDM Measures (1993); SCAQMD: Regulation XV Analysis and Plan Review Procedure Development (1993); CARB: Survey and Development of ETR Plan Software (1993).

Telecommuting/Telework Programs

Telecommute/telework programs are frequently employer-based and incorporated within a larger TDM program. However, those analyzed in this study are more areawide than employer-based, corresponding more closely to the types of initiatives that would be funded under CMAQ. In telecommute/telework applications, CMAQ funds may not be used for capital expenditures (i.e., computer equipment). Curiously, though, no CMAQ obligations are specifically designated for telecommute/telework programs in the 1992–1999 period (see Table E-5 in Analysis of Findings section).

Emission reductions from telecommute/telework strategies derive from the ability of the participating individual to forgo travel to a formal work site 1 or more days per week. Theoretically, each day per week that the person did not travel would reduce work-related trips, VMT, and emissions by 20 percent (1 in 5 days). However, mitigating factors impinging on this emission potential include the following:

- Whether any other travel occurs on the telecommute day that would not have occurred if the person had not worked at home;
- Whether the telecommuting occurs out of the home or at a remote telework center; if the latter, it is necessary to account for the trip to access the center location;
- Whether the individual was a single-occupant vehicle commuter, or a transit, carpool, or nonmotorized mode commuter; and
- Whether the individual changes mode (e.g., from transit or carpool to single-occupant vehicle) on those days that he or she does travel to the work site.

Seven of the 10 examples of telecommute/telework programs shown in Table E-Annex-9 were taken from the Los Angeles MTA evaluation studies of Pansing et al., Schreffler, and Zarifi. Because these impacts are obtained from actual user surveys and not simulation approaches, they are more likely to account for the effects cited above and hence should be fairly realistic. The other three examples are much larger, regional programs. Their impacts are the result of a top-down regional analysis in which the employment base was categorized into groups likely to telecommute. Telecommute rates (average days per week taken from national studies) were then applied to these subpopulations to estimate an overall net effect on regional travel. The cost of the programs ranged from \$44,000 to more than \$83 million per year, and emission reductions ranged from about 0.1 ton to more than 1,000 tons per year (reflecting the gross difference between the scale of the programs depicted). Cost-effectiveness for this set of examples ranges from \$13,300 per ton (DVRPC 1994) to \$8.3 million per ton [Long Beach Telebusiness (Pansing et. al 1998)], with a median value of \$251,800 per ton. With the exception of one example (DVRPC), the cost per ton of these programs is very high compared with most other strategies reviewed in this paper.

Bicycle/Pedestrian Programs

Construction of new bicycle or pedestrian facilities, facilitation or subsidization of bicycle ownership, and education and safety programs for pedestrians and bicyclists are examples of programs in this category. Bicycle and pedestrian programs typically have modest effects on travel and emissions, particularly in the case of commute travel, because of trip length characteristics. Typically, pedestrian trips have an upper limit of 1 mile and bicycle trips a limit of 5 miles, which reduces their viability as substitutes for driving for a high percentage of commuters. They may be much more effective as strategies for reducing vehicle access trips to transit or for nonwork trips that may be made to nearby destinations (provided the land use offers such opportunities). While short bike or walk trips may not displace significant VMT, they do eliminate the cold start portion of the vehicle emission profile. Also, improving pedestrian (or bike) mobility in activity centers can help diminish the need for midday automobile travel and thus increase the possibility of switching modes for the commute trip itself.

Table E-Annex-10 lists 14 examples of these programs, taken from a fairly wide range of source studies. Travel and emission benefits are assumed to follow an increasing trend over time for discounting purposes, because of the adaptive nature of development and awareness over time. The results range from a low of \$4,300 per ton (MWCOG Bike Rack and Locker program, 1995) to \$295,600 per ton for bike lockers in Santa Clarita (Pansing et al. 1998). Median performance for the group of programs is \$84,100. Overall, it does not appear that these are among the more cost-effective CMAQ strategies, at least in their current form. Coupled with more compact land use and targeted toward their strength (access to transit, mobility in activity centers, local nonwork travel), they might be considerably more cost-effective.

Transit Improvements

This category covers a wide range of possible strategies, as seen in Tables E-1 and E-5. CMAQ funds may be expended on service expansions (involving capital investment), conventional service improvements (improved headways or speeds), innovative services (shuttles, circulators, feeders), construction of parking facilities, as well as purchase of new or replacement vehicles[5] (which may be either conventionally powered or alternative fuel).

Transit-related strategies account for 28.3 percent of CMAQ obligations between 1992 and 1999, the single largest obligation category after traffic flow improvements (33.1 percent). However, it should be noted that some substantial capital purchases are included in this total, since states and MPOs use CMAQ funds to purchase new or replacement buses, rail cars, and locomotives, as well as to construct or rehabilitate transit stations, bus stops, and parking facilities. Thus, many of these expenditures may not translate immediately into "improved service" that would attract new transit ridership.

New Transit Shuttle or Feeder Services

In Table E-Annex-11, 15 examples of transit services that consist of new shuttle or feeder services are given. Included in this group are several paratransit programs that serve broader areas than the shuttles, which tends to be reflected in their impact and costs. Because of gross scale differences among the examples, the strategies in this category range in cost from $11,300 to more than $5 million per year, and emission reductions range from 0.1 ton to 158.5 tons per

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[5] The replacement of vehicles with new diesel- or alternative-fuel-powered vehicles has been grouped under the Fuels and Maintenance section.

year. In terms of cost-effectiveness, the examples range from \$12,300 per ton (Lake Cook Shuttle Bug) to \$1.97 million per ton (West Hollywood Shuttle). This is quite a range, partially explained by the types of service. In general, the shuttle services appear to be the least cost-effective. This is shown by the various Los Angeles–based examples (Pansing et al. 1998), which reflect new specialized local transit services that have attracted relatively modest use in their reported 1 year since introduction. The 10 shuttle services alone range in cost-effectiveness from \$1.97 million per ton (West Hollywood Shuttle) to \$31,200 per ton (Hollywood Connection) and average about \$475,000 per ton. In contrast, the Lake Cook Shuttle Bug, at \$12,300 per ton, and the Pace VIP Transit Van Program, at \$24,700 per ton, are innovative services that appear to serve the characteristics of their (suburban) markets well, yielding a comparatively attractive cost per ton in reducing emissions (average of \$18,400).

New Vehicles or Capital System Expansion

As noted above, this may be the single biggest expenditure category among CMAQ projects (24.7 percent if conventional fuel vehicles and new capital systems/vehicles are included). As such, the six examples presented in Table E-Annex-12 may not do justice to the wide range of strategies and expenditures that could occur under this heading. All but one of the strategies (Coronado Ferry) have long (30-year) service lives, spreading enormous capital costs over a long period, but also allowing for growth in ridership through long-term shaping of land use and travel patterns. Thus, the benefits discounting procedure assumes a "constant plus increasing" trend, meaning that the initial design ridership is likely to be sustained and accompanied by a gradual long-term increase in ridership as the mentioned growth factors develop.

Three of the strategies in the table are new transit guideway systems, ranging from \$8,500 per ton to \$470,800 per ton. Two of these, the Ottawa TransitWay (\$8,500 per ton) and the Metra North Central commuter rail line (\$17,600 per ton) have good ridership and appear overall to be sound transportation investments as well as emission strategies. The St. Louis MetroLink light rail transit (LRT) service, however, has not attracted a ridership commensurate with its costs and hence is in a completely different league with regard to cost-effectiveness.

The Coronado Ferry is an unusual case in that it is only showing funding for a 1-year trial operation; hence, it is not clear whether the modest ridership would increase over a more realistic period of observation. It has the second-poorest cost-effectiveness in the group at $132,600 per ton.

The two examples of new rail transit vehicles are both from Maryland and range from $32,600 per ton for an investment in new commuter rail coaches to $100,100 per ton for purchase of new light rail vehicles for Baltimore's LRT system expansion.

In light of the above, while the median cost-effectiveness of the strategy group is $66,400 per ton of reduced emissions, evidence suggests that well-targeted investments can deliver benefits in the $10,000 to $30,000 per ton area. These are favorable cost ranges, indicating that context for the given strategy is a very important factor in evaluation of desirability.

Conventional Service Improvements

Table E-Annex-13 presents 10 examples of conventional transit service improvements, consisting largely of improved frequency of fixed-route bus service, though route restructuring and traveler information are also included. The service improvements range in effectiveness from $16,700 per ton (DVRPC suburban bus service improvements) to $120,100 per ton (MWCOG increased commuter rail service frequency). The median for all service improvement strategies, including the MARTA ITS Traveler Information System ($3,800 per ton), is $24,600 per ton, which appears to be reasonably attractive compared with several other categories.

Fuels and Maintenance

This category of strategies has been defined to include each of the following: conventional fuel (diesel) replacement buses for transit operators; alternative-fuel buses (either new or conversion); more general alternative-fuel programs such as refueling facilities; and inspection and maintenance programs. Each of these approaches is eligible for funding under CMAQ, and together they account for 20.6 percent of all CMAQ funding allocations between 1992 and 1999. Conventional fuel replacement buses alone have accounted for 12.7 percent of total allocations.

Replacement Conventional Fuel Buses

Diesel engines have the characteristic of being relatively efficient in terms of HC and CO emissions, but they are comparatively "dirty" in terms of NO_x and PM emissions. Heavy-duty diesel vehicles may make up only 5 to 10 percent of the VMT mix in metropolitan areas, but in 1990 they contributed between 35 and 50 percent of all mobile source NO_x emissions.[6] Several major improvements have occurred in diesel engine technology, particularly for urban transit buses since 1983, greatly reducing their rates of NO_x and PM emissions. Hence, as transit agencies have replaced fleets of aging buses, the new vehicles have also offered a significant reduction in NO_x emissions. As illustrated in the table on the next page, there have been several clear jumps in emission technology as new diesel engine standards have come on line.

Clearly, major improvements occurred across the board (HC, NO_x, and PM) when buses of the 1973–1983 vintage were replaced with 1984–1990 models, with another slight increase occurring with the introduction of the 1991–1995 vehicles (biggest improvement in PM). However, the post-1995 vehicles demonstrated the next big jump in emission reduction, especially for NO_x. Shown in the table for 1996-and-later buses are NO_x emission rates for buses in typical "urban" service, with an assumed average speed of 15 mph, and in "commuter" service, with a higher average speed of 45 mph. Emission rates are shown for engines produced under two standards: 4.0 g/bhp-hr and 2.0 g/bhp-hr. NO_x emissions for this class of engines are 43 to 79 percent lower than the 1973–1983 versions, and 20 to 72 percent lower than the 1984–1995 models.

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[6] *Air Quality Issues in Intercity Freight.* Cambridge Systematics for U.S. Department of Transportation (FHWA, FRA) and Environmental Protection Agency (July 1996), pp. 5–3 to 5–11. Metropolitan areas on which estimates are based are Philadelphia, Los Angeles, and Chicago.

Emission Rates for Transit Diesel Buses by Period of Manufacture

Year of Manufacture	VOCs (g/mi)	NO_x (g/mi)	PM_{10} (g/mi)
1973–1983	4.2	30.4	2.28
1984–1990	3.7	22.5	1.45
1991–1995	3.7	21.5	0.70
1996 and later	3.1	Urban (15 mph): 17.2 (4.0 g/bhp-hr std) 8.6 (2.0 g/bhp-hr std) Commuter (45 mph): 12.5 (4.0 g/bhp-hr std) 6.3 (2.0 g/bhp-hr std)	0.60

Source: *Methods to Find Cost-Effectiveness of Air Quality Projects*. California Air Resources Board, 1999, p. 43, as taken from MVE17G, Certification and In-Use Tests.

The service life of urban transit buses is 12 to 15 years, and they generally are used about 40,000 miles per year. At a current cost of $250,000 per bus, replacement of a pre-1984 bus with one manufactured after 1994 would result in an emission savings of between 0.7 and 2.0 tons per year, against an annualized cost of about $27,500 (12 years at 5 percent), and assuming constant delivery of benefits during this period. As shown in Table E-Annex-14A, this results in a cost per ton of between $13,800 (commuter use, 2.0 g/bhp-hr standard) and $39,900 (urban use, 4.0 g/bhp-hr standard). Obviously, if the buses being replaced were newer than the 1973–1983 vintage, the emission savings would be less and the cost per ton would be higher. The other example shown in Table E-Annex-14A, from Maryland DOT, results in the lowest cost per ton, $10,900, of the group. However, the median for the group of five examples is about $16,000 per ton.[7]

It should be noted that all of the cost-effectiveness estimates for this strategy relate solely to the difference in emission production of a replacement vehicle. They do not include any accounting for emissions saved as a result of diversions of travelers to transit, since it is assumed that the switch in buses would have a negligible effect on ridership itself.

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[7] See following section for discussion of the Schimek study, also on the list (see Table E-Annex-14A).

Alternative-Fuel Buses

Table E-Annex-14 gives 11 examples of clean (alternative) fuel vehicles acquired for transit service. The examples represent a wide range of technologies and scale. Eight of the examples are of CNG-powered buses; five of these are simply replacement services, while three are CNG buses used in new service or service expansions. As a result, the three latter examples have emission reductions based on both ridership effect and lower emission rates, while all the other examples are based only on the difference in emission rates. The final three examples consist of a CNG-powered van and two electric buses.

Again, there is quite a range of cost and effectiveness among the examples, due both to scale and type of technology, as well as to whether emission reductions were based on differences in emission rates only or included the effect of travel mode shifts. The primary advantage of switching to alternative fuels (particularly CNG) is in greatly reduced rates of NO_x emissions. Electric vehicles, obviously, are superior in regard to all pollutants.

The least cost-effective examples in the category were the CNG bus replacements. The four cases at the bottom of the table are all CNG replacements, which occurred in the Los Angeles region. The emission reductions for each are the result of simply performing the same service with CNG emission rates (i.e., no travel/ridership effects) and are very modest, ranging from 0.1 to 2.8 tons per year. As a result, the fairly substantial costs yield a cost-effectiveness of between $443,000 and $569,000 per ton. At the other extreme, the Boise CNG Bus Replacement (Baker 1997) shows a cost-effectiveness of $6,800 per ton. This example also does not claim travel-related emission benefits, but for some reason, the replacement of 28 buses of 1984 vintage with 1994 CNG vehicles was judged capable of reducing 96 tons of emissions per year, most substantially NO_x.

In contrast, the electric vans and shuttles appear to have been very cost-effective. The SCE and Laguna Beach examples (Pansing 1998) have annual emission reductions of 23 and 11.5 tons per year, respectively, and cost-effectiveness numbers of $6,700 and $7,200 per ton, making them among the most attractive strategies evaluated. The results derive only from the change in emission rates (no travel effects) and appear to be due to a much greater difference in emission rates between electric and diesel than was the case between CNG and diesel.

Four of the examples in the table involve CNG bus replacement but also account for the travel effects of these vehicles in revenue service. These examples (all Pansing) are Metropolitan Transit Development Board (MTDB) Route 904, MTDB Route 901, and MTDB Routes 933/934 in San Diego, and the CUSD Clean Air Van Purchase in Los Angeles. The range of effectiveness in reducing emissions is between 0.1 and 22.5 tons per year, while cost-effectiveness ranges from $32,800 to $212,300 per ton, with the two best-performing examples—MTDB Routes 901 and 933/934—having substantial ridership and vehicle trip reductions in comparison with the other two cases.

As a group, the 11 examples have a median annual emission reduction of 2.8 tons, a cost of $219,000, and a median cost-effectiveness of $126,400 per ton.

Schimek (2001) offers another set of cost-effectiveness numbers for comparison with the above, though they must be carefully qualified. While he calculates lifetime benefits (discounted at 7 percent) over the 15-year lifetime of a bus, he restricts his definition of costs to the incremental cost of introducing the new technology and capitalizing it over the life of the vehicle. As would be expected, this results in a more favorable set of cost-effectiveness determinations. However, its direct comparison with the other examples is inappropriate, since when CMAQ funding dollars are spent, they are not spent on just the incremental cost of a new technology, but on the entire "package" that it comes in, that is, the new vehicle and any supporting infrastructure.

Schimek's intention in performing the analysis is to demonstrate that, while alternative fuel options can produce lower emissions than new-generation diesel buses, it is at a cost that does not justify their use. His analysis compares conventional fuel diesel buses with 1998 NO_x standards with pre-1991 models, and then also with methanol-, CNG-, and hybrid-electric-powered versions. Focusing only on the incremental costs, his analysis produced the results in the following table.

Incremental Cost-Effectiveness of Alternative-Fueled Transit Buses

Technology	Lifetime Emission Benefits (tons)		Incremental Cost (2000 $)	Cost per Ton, NO_x (2000 $)	Cost per Ton, PM (2000 $)
	NO_x	PM			
1991–1998 diesel	0.545	0.267	196	360	734
Methanol	6.051	Negligible	128,534	21,242	N.A.
CNG	6.580	0.231	88,570–143,796	8,334–13,488	383,420–622,494
Hybrid-electric	4.198	0.242	35,428–172,972	8,439–41,203	146,397–714,760

Source: Schimek, Reducing Emissions from Transit Buses (2001).

Using this incremental cost approach, Schimek estimates the cost-effectiveness of new-generation diesel buses in reducing NO_x to be $360 per ton, compared with $21,200 per ton for methanol buses, $88,600 to $143,800 per ton for CNG buses, and $35,400 to $173,000 per ton for hybrid-electric. PM reductions come at an even greater advantage for the new, cleaner diesel over the AFVs.

If, on the other hand, one were to compute a full cost for the various options as Schimek's incremental cost plus the base cost of a bus (assumed to be $250,000), the rank order of the options changes dramatically. Suddenly the new conventional diesel buses (which have relatively poor NO_x emission rates compared with the AFVs) show a cost-effectiveness of $478,500, while methanol reduces NO_x at $64,300 per ton, CNG reduces at $57,200 per ton, and hybrid-electric at $86,900 per ton. From the standpoint of CMAQ funding, the full cost comparisons seem to be more appropriate and, hence, suggest that the alternative-fuel buses are more cost-effective, and certainly much more aggressive at reducing NO_x emissions, than the diesel. For PM, there appears to be no major difference among the options (except for methanol, which is described as having no benefit).

The major unresolved issue is whether CNG buses are cost-effective. On the basis of the modified Schimek analysis above, they appear to be the best option on the list of bus technologies. However, they show a range from as low as $6,700 per ton ($NO_x$ plus HC) to $570,000 per ton ($NO_x$ plus HC), while the modified Schimek example would fall somewhere on the low end of this range at $57,200.

Even at this level, the CNG buses are still among the more expensive of the strategies in the overall CMAQ list in Table E-1.

Other Alternative-Fuel Programs

Two programs listed in Table E-Annex-14B serve as examples of general-purpose alternative-fuel strategies (versus transit vehicles in the previous section). These are the Fairfax County, Virginia, Alternative Fuels Program and the Douglas County, Georgia, Alternative Fuels Refueling Station (Hagler Bailly 1999).

The Virginia program provides loans, grants, and matching funds to encourage use of alternative fuels in fleets (e.g., taxicabs, shuttle vans) by making up the difference in cost between the conventional and the alternative-fuel vehicle. This program is estimated to reduce 4.4 tons per year (on the basis of differential emission rates only, not VMT) at a cost per ton of $31,600.

The other example—Douglas County—entails construction of an alternative-fuel station at the site of a future multiuse transfer station, providing a centralized fueling site for 122 county fleet vehicles, transit vans, and buses. The primary benefit is in the centralized location of the site, which is estimated to save 50 miles of unnecessary travel per day and an estimated 6.1 tons of emissions per year. This program has a service life of 20 years, which helps bring down its average yearly cost, while benefits are assumed to remain fairly constant (they would actually increase as the fleet grows) over the period. This results in a cost per ton of about $4,000.

Vehicle Inspection and Maintenance

Table E-Annex-15 presents comparative information on five different types of vehicle inspection and maintenance (I&M) procedures, ranging from the standard idle test to the more advanced IM240 procedure, which tests vehicles in motion. The standard idle test, which is reasonably effective at detecting hydrocarbon emissions, does not do a particularly good job with NO_x. The IM240 test forces the vehicle to operate (via dynamometer) in a more realistic drive cycle, with accelerations and decelerations as well as steady-state running.

The results in Table E-Annex-15 were taken from a 1998 TRB paper by Lachance and Mierzejewski focusing on application of statewide I&M procedures in Florida. The authors compared the state's existing annual standard idle test with the same test administered biennially, and then with the more involved IM240 test. The IM240 procedure is evaluated in three forms, but all tests are conducted biennially.

The cost side of this analysis is different from other strategies discussed in the paper. The authors chose to evaluate the programs from the standpoint of costs to the vehicle owner. Thus, the estimated cost of the procedure is the sum of the cost of the inspection itself, the driver's time to reach the facility and have the test conducted, the vehicle operating cost to get to the test site, and the average expected cost of repairs.

The analysis suggests an overall range of cost-effectiveness for I&M of between $1,800 and $7,000 per ton, with a median of $1,900. The IM240 test, while more intensive, does cost the consumer slightly more than the idle test, but because it is so much more effective at reducing emissions, its cost per ton is in the $1,800 to $1,900 range, versus $5,800 to $7,000 per ton for the idle test.

Non-CMAQ Strategies: Pricing

Although pricing strategies are not explicitly named as eligible for CMAQ funding, and no funding obligations are shown for them through 1999, under certain circumstances strategies with pricing characteristics might actually be eligible for CMAQ funding. Examples would include start-up subsidies for transit or vanpooling services or for supporting employer trip reduction programs (including incentives, according to the CMAQ guidance). However, the primary purpose for including pricing strategies in this review is to compare them with the conventional strategies that have been funded under CMAQ.

Pricing strategies generally fall into two categories: subsidies (or discounts), which are designed to serve as incentives for desirable behavior (switching modes, traveling off-peak, etc.), and charges (including fees, taxes, and surcharges), which serve as disincentives for such behaviors as driving alone or traveling during peak-demand periods. Subsidies involve a direct outlay of resources to "buy" a particular result, with no return other than the objective of the strategy (e.g., to reduce vehicle travel or emissions). Fees and surcharges, on the other hand, use pricing as a way of having the "market" force choices on the basis of consumer economics; in addition to achieving the travel or emission objectives, these strategies also usually generate revenues that cover (or in many cases exceed) the direct costs of the program. What happens to this revenue influences the nature and cost-effectiveness of the strategy. If, for example, revenues from a parking fee program are used to subsidize transit passes or carpool parking, the fee levied for parking will have a multiplier effect on ultimate behavior, since the disincentive effect is strengthened by the addition of an incentive effect.

A special characteristic of pricing strategies is that they generally have an immediate effect on behavior (since they can be implemented rapidly). But, perhaps as important, they also serve as signals for long-term consumer planning and decision making (land use locations, development patterns, modal options) such that the long-term effects are likely to be even more important than the initial effects.

Tables E-Annex-16 and E-Annex-17 present examples of these incentive and disincentive strategies, respectively.

Subsidies/Financial Incentives

Table E-Annex-16 presents 14 examples of pricing strategies used as incentives. They range from discounted transit fares to vanpool subsidies, voucher systems, parking discounts, and parking cash-out. Cost-effectiveness results in the overall category range from a low of $800 per ton to $471,000 per ton, with a median of $46,600.

The wide range of differences in impacts is due to several factors, though the service life issue is not among them. Each of these strategies, by definition of the source studies, is a 1-year program based on the funds being used for operations only and not construction. The effects on travel and emissions of this short time period may be muted because the measure may not be in place long enough to gain maximum awareness or may not inspire confidence in its permanence.

Five subsidy strategies involve reductions in transit fare: the MWCOG regional fare media with discount, single-price transit service, and half-price feeder service, and the DVRPC 20 percent systemwide fare reductions and $25 TransitCheck promotion. The range for this group of strategies is $5,700 to $39,400 per ton, with a median of about $6,700. While both of these source studies estimated the travel effects using the established regional mode split model, the MWCOG strategies estimated significantly more response (transit ridership and VT/VMT) and hence emission reductions for similar levels of cost.

Five of the examples involved subsidies for taxi, vanpool, or paratransit use (Pansing et. al 1998). These examples ranged from a low of $800 per ton (Route 14 vanpool subsidy) to $471,000 per ton (Burbank flat-fare taxi), with a median of about $65,000. Apparently, the major difference among the cases is in the ridership success of the program. The lowest-cost programs were those that attracted the most riders and hence diverted the most vehicle trips.

The remaining four examples deal with some variant of travel voucher or parking fee rebate (cash-out). These programs all were demonstrated to be fairly expensive because they involve granting subsidies to a potentially large number of recipients, including those who may already be taking transit or ridesharing. Hence, the cost of these strategies ranges from $53,900 (MWCOG transit cash-out) to $238,500 (MWCOG free parking for carpools and vanpools), with a median of about $121,000.

Fees and Charges

Table E-Annex-17 presents an array of pricing strategies applied as traveler charges or fees, representing a disincentive to driving. They include workplace parking fees, pollution or mileage fees, and congestion pricing. The range of impact for these six examples is $800 to $49,400 per ton, with a median of $10,300 per ton. In practice, most of these strategies would raise enough revenue from the fees to cover their direct costs and would operate at close to zero cost per ton, or would generate net revenue that could be used for subsidies or service improvements to further enhance the effect of the base strategy. As with the subsidy strategies, each of these examples is assumed to have a service life of only 1 year, which likely diminishes an increasing long-term benefit stream.

Non-CMAQ Strategies: New Roadway Capacity

An important challenge raised by the CMAQ review process is in whether investment of the resources currently reserved for CMAQ-eligible projects would yield higher returns to air quality, mobility, and public welfare if they were invested in roadway capacity expansions. This question provokes one of the most debated topics in transportation planning: whether new highways provide temporary relief to congestion and air pollution problems but trigger long-term adjustments in development and travel patterns that eliminate the initial gains and perhaps lead to more severe long-term conditions. The big issue, therefore, in evaluating the effectiveness of new highway capacity as an air quality measure concerns the long term. A substantial body of evidence shows that new highway capacity is fairly rapidly met with new demand, since by its very nature, it enhances accessibility to areas within its service envelope.[8]

Unfortunately, the review was unable to identify any studies that comprehensively investigated the relationship between highway investment, subsequent land use and travel effects, and emissions and costs. Technically, most major urban transportation investment studies that evaluate alternatives for a corridor should generate the type of information necessary to perform such an analysis: they would need to furnish information on the expected travel utilization—volume by mode and level of service—throughout the 20- to 30-year lifetime of the improvement. From such information for a major highway system expansion alternative, one would expect to observe the following chronology of events: (*a*) disruption during the period of construction, probably with an increase in emissions resulting from traffic congestion and stoppages and diversions to alternative routes, possibly offset by the shift of some automobile traffic to transit or HOV; (*b*) in the years immediately after opening,

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[8] In Maryland, for example, Interstate 270 in Montgomery County was expanded in the early 1990s from 6 to 12 lanes. As part of its review of 23 commuter corridors for the Maryland State Highway Administration, COMSIS Corporation projected that the new highway would be operating at capacity in the inbound direction by 1995, projections that were subsequently achieved by the growth of vehicle traffic in the corridor. Substantial development from Gaithersburg north to Frederick has followed the widening of I-270, accompanied by growth in traffic congestion that extends along the entire 30 miles to the northern terminus in Frederick. It has since been necessary to widen the "spurs" that connect I-270 with the Washington Beltway, and studies to extend the widening of I-270 all the way to Frederick are under way. See COMSIS et al., *Statewide Commuter Assistance Study,* Maryland Department of Transportation, 1990.

a notable improvement in highway travel speed and congestion, most likely resulting in a reduction in emissions, provided that major diversions do not occur from alternative modes and parallel facilities and that speeds do not rise to nonoptimal levels (above 40 mph); (*c*) a long-term trend toward increased traffic because of the relative advantages for development of the area served by the corridor, resulting in increased emissions due to both higher volumes and advancing congestion; and finally (*d*) a long-term state where congestion returns but with higher volumes than before, longer trip lengths than before, and land use patterns with greater automobile dependency than before.

Thus, to properly assess the cost-effectiveness of highway capacity expansion as an air quality and congestion management strategy, it would be necessary to quantify the changes during the lifetime of the improvement, as profiled above. Unfortunately, this time stream of information is generally not developed in planning studies, such that the "crossover" points can be properly evaluated (using discounted benefits and costs) to determine what the net effect would be over the course of the project.

One study that sheds some light on the long-term consequences of highway investment on travel and emissions was performed in 1997 by Robert Johnston and Caroline Rodier of the University of California at Davis, as part of the PATH research program. The study examined various major system development plans in the Sacramento region as set forth in the Sacramento Area Council of Governments (SACOG) long-range transportation plan. These included major regional investments in light rail transit, new (automated) freeways, and an extensive HOV network, analyzed alone and in combination with concurrent pricing and land use concentration scenarios. The study estimated the travel, congestion, and emission benefits for each strategy and scenario "package" for 2015. Unfortunately, costs were not developed for any of the strategies (a consumer benefits approach was used), nor were estimates of travel or emission conditions in the intervening years leading up to 2015 developed. Hence, the primary value of the Johnston/Rodier analysis is for creating a view of the long-term effects of major investment strategies and, secondarily, for appraising the important supporting roles of pricing and land use strategies.

The particularly valuable aspect of the Johnston/Rodier analysis was the evaluation of various types of new, high-level highway capacity improvements. These improvements did not involve construction of substantial new pavement miles, but rather increased capacity and performance through ITS technology. Specific facilities were to be "automated" so that vehicles could travel at high sustained speeds (60 or 80 mph) with a very small headway (½ to 1 second of separation) between vehicles. One lane was also added to ramps in the existing network (no-build scenario) and to both sides of arterials or connector links serving the freeway access points. Also evaluated was an automated HOV network consisting of a 184.5-mile HOV lane and freeway system set to perform at either 60 or 80 mph sustained speeds, and accompanied by the ramp and arterial/connector lane additions.

Impacts for the strategies were estimated through use of SACOG's regional travel forecasting model system. The model had been recently updated and enhanced to state-of-the-art capability, including feedback throughout the model chain, the addition of choice-based formulations to modules other than modal choice (e.g., route and destination choice), and availability of microsimulation tools to more accurately estimate speed and delay conditions on facilities. The SACOG model system was used to simulate the effects of each scenario on 2015 travel conditions, with impacts gauged against the performance of a no-build scenario.

A brief description of the strategies that were tested is as follows:

- No build: All new freeways, expressways, HOV lanes, and transit projects listed in SACOG's 1993 long-range plan (LRP) and in the 2015 network were removed.
- Full automation (60 mph): All freeway lanes automated and set to 60 mph with a 1-second headway. In addition, one lane added to all ramps in no-build network and both sides of arterials or connector links to freeway lanes.
- Full automation (80 mph): Same as above, but lanes set to operate at 80 mph with ½-second headway.
- Partial automation (60 mph): Same as full automation, but only one freeway lane automated instead of all.

- HOV: Includes all new HOV lanes, freeways, and expressways listed in the 1993 LRP (184.5 lane miles).
- Automated HOV (60 mph): HOV lanes are automated and set to 60 mph with 1-second headway. Capacity of lane set to 3,600 vph to reflect the reduced headway. Base HOV network has one lane added to SR-50, where a gap exists in the planned network.
- LRT: 61.5 track miles of new LRT projects as listed in the LRP.
- Super LRT: Expanded rail network with new lines and line extensions, plus new and extended feeder bus service, and headways on all services reduced by half.
- Pricing: $0.10/mile congestion pricing on freeways, $2 parking charges in areas without current charges, and $2/gallon fuel tax (adjusted down to $0.60/gallon to account for long-term vehicle technology shifts).
- Centers: Projected growth in households and employment channeled into 45 transit-oriented centers.

The various strategies were tested individually and in select combinations, resulting in the travel and emission impacts summarized in Table E-2. The strategies are listed in order of emission reductions, from poorest to best. The following are the key findings:

- The highway capacity improvement strategies generally account for the greatest travel delay savings but the poorest emissions of all the strategies. The fully automated freeways increase emissions over the no-build case by 40 to 220 tons per day, mainly as a result of significant increases in vehicle trips and VMT, as well as higher operating speeds (60 to 80 mph) that fall in the upper range of the speed/emission curves.
- When combined with the concentrated land use (centers) strategy, the automated freeways produce even higher comparative benefits in travel delay savings while slightly improving emission performance over the basic freeway automation scenario above. They do this by reducing vehicle trips against the no-build case through greater bike/walk use, though VMT still increases significantly.
- The HOV scenarios (each of which involved addition of capacity) also acted to reduce travel delay but to increase vehicle trips, VMT,

TABLE E-2 Analysis of Sacramento Transportation System Investment Alternatives

	Daily Travel Impacts (2015)					Emission Reductions, 2015 (tons per day)				
	VTR	VMTR	Transit Riders	Walk and Bike	Delay Red. (hr)	HC	NO_x	CO	PM_{10}	Total
					Emission Weights:	1	4	0	0	
Full automation (80 mph)	(175,107)	(16,034,839)	1,213	(103,267)	183,427	(10.58)	(52.35)	(142.75)	(5.08)	(219.98)
Full automation (80 mph) and centers	115,184	(14,708,961)	1,213	19,477	187,015	(9.83)	(50.87)	(137.78)	(4.67)	(213.31)
Full automation (60 mph)	(57,892)	(3,996,231)	1,213	(37,701)	146,171	(0.09)	(9.89)	(9.48)	(1.27)	(39.65)
Automated HOV (80 mph)	(82,610)	(6,341,632)	(1,213)	(52,260)	30,311	(1.99)	(8.26)	(20.41)	(1.99)	(35.03)
Full automation (60 mph) and centers	236,697	(2,578,607)	2,436	89,864	152,645	0.71	(8.28)	(4.15)	(0.83)	(32.41)
Partial automation (60 mph)	(48,417)	(3,185,711)	1,213	(24,298)	88,467	(0.07)	(6.38)	(6.42)	(1.02)	(25.59)
Partial automation (60 mph) and centers	246,253	(1,758,822)	2,436	102,013	100,016	(0.74)	(4.92)	(1.26)	(0.59)	(20.42)
Automated HOV (60 mph)	(1,341,393)	(2,370,263)	0	(23,045)	29,568	(0.38)	(3.35)	(5.34)	(0.74)	(13.78)
HOV	(20,556)	(1,954,196)	0	(10,896)	9,857	(0.50)	(3.24)	(6.27)	(0.61)	(13.46)
Pricing and partial automation with centers	393,076	(749,679)	48,632	391,179	114,002	1.48	(3.68)	3.39	(0.25)	(13.24)
Light rail	(32,538)	(38,155)	17,023	1,253	7,146	0.07	(0.15)	(0.14)	0.01	(0.53)
Pricing and automated HOV (60 mph)	248,285	3,715,840	34,046	34,037	166,774	2.74	2.19	16.08	1.46	11.50
Super LRT and centers	(35,577)	2,912,701	92,402	136,050	22,549	1.05	3.29	8.34	1.03	14.21
Pricing and HOV	384,353	4,374,338	76,603	290,419	143,137	4.85	4.76	25.19	2.00	23.89
Pricing and LRT	425,282	6,543,725	117,937	286,755	126,764	3.18	6.23	22.15	1.99	28.10
Pricing and no build	434,701	6,515,008	77,816	289,166	120,776	3.16	6.39	22.35	1.98	28.72

Note: VTR = vehicle trip reduction; VMTR = vehicle miles of travel reduced; transit riders = increase in daily transit ridership; total emissions = weighted sum of HC, NO_x, CO, and PM_{10}; emission weights = importance value of individual pollutants.

Source: Johnston & Rodier. A Comparative Systems-Level Analysis: Automated Freeways, HOV Lanes, Transit Expansion, Pricing Policies and Land Use Intensification. California PATH Research Report (1997).

and emissions. However, the HOV approach resulted in significantly less VMT and emissions than the unrestricted automated freeways. Emissions under the HOV options ranged from 14 to 35 tons per day more than under the no-build scenario.

- The LRT option, by itself, was not particularly effective, and in fact resulted in an increase in vehicle trips, VMT, and emissions over the no-build case, while performing worst of all the scenarios in terms of travel delay reduction. When teamed with pricing or land use strategies, however, the light rail scenarios are among the best in terms of emissions and travel delay reduction. The LRT scenario teamed with land use centers results in an emission reduction of 14.2 tons per day, and LRT combined with pricing results in a reduction of 28.1 tons per day.

The general lessons from this work are that major highway capacity expansions may provide congestion relief but most probably will not result in emission reductions over the long run. HOV and transit can have positive effects on both emissions and travel delay, but those effects are marginal unless supported with pricing and land use strategies. This longer-term view suggests that the many CMAQ strategies reviewed earlier in this section should have their impact potential taken with a grain of salt. That is, it is important to look at the context in which the strategies may be implemented and the effects that they can deliver over time. Similarly, it is important to be cautious in encouraging the short-term benefits of capacity expansion in relation to long-term performance and sustainability.

ANALYSIS OF FINDINGS

Comparative Cost-Effectiveness of Strategies

If the strategies discussed above are mapped in terms of their range of cost-effectiveness and then ranked in relation to their median values, they show the comparative effectiveness illustrated in Figure E-4. The strategies demonstrating the best cost-effectiveness characteristics (least cost per ton) are seen at the right of the chart, while those with the poorest performance are located at the left of the chart. For comparison purposes, the median cost-effectiveness of all 139 strategies examined was about $66,300.

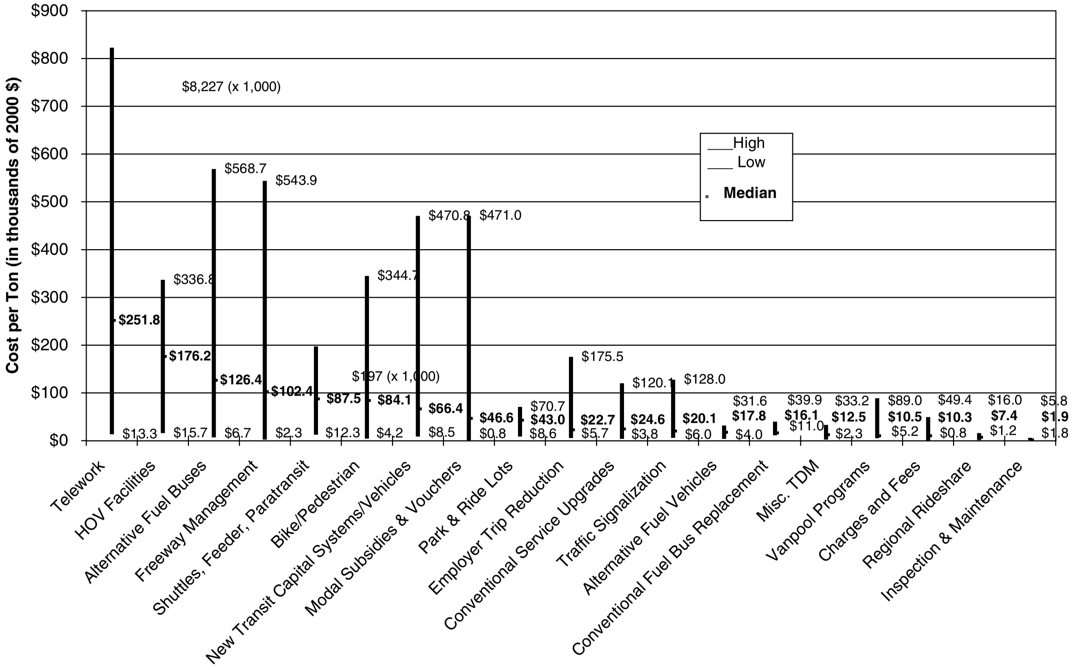

FIGURE E-4 Cost-effectiveness range of strategies (high/low range and median).

About half of the strategies displayed in the chart have median cost-effectiveness performance of between $2,000 and $23,000 per ton reduced. Moreover, the range of most of these strategies is fairly narrow, which suggests that the median is not a statistical quirk but represents performance that is fairly likely to happen when strategies of this type are implemented. In order of ranking, the strategies found in this top group are as follows:

1. I&M programs (median = $1,900 per ton),
2. Regional ridesharing programs ($7,400 per ton),
3. Charges and fees (not an eligible CMAQ strategy) ($10,300 per ton),
4. Vanpool programs ($10,500 per ton),
5. Miscellaneous travel demand management programs ($12,500 per ton),
6. Conventional fuel transit bus replacements ($16,100 per ton),
7. AFV programs (not AFV bus replacement) ($17,800 per ton),
8. Traffic signalization ($20,100 per ton),
9. Conventional transit service improvements ($24,600 per ton), and
10. Employer trip reduction programs ($22,700 per ton).

In marked contrast to the above, the following strategies did not—as a group—demonstrate favorable cost-effectiveness:

1. Telecommute/telework strategies ($251,800 per ton),
2. HOV lanes ($176,200 per ton),
3. Alternative-fuel buses ($126,400 per ton),
4. Freeway management ($102,400 per ton),
5. New transit shuttles or feeder lines ($87,500 per ton),
6. Bicycle/pedestrian facilities/programs ($84,100 per ton), and
7. New transit capital investments or vehicles ($66,400 per ton).

Importance of Pollutant Weighting Assumptions

The determination of strategy performance is, of course, dependent on the importance of the weights assigned to the various pollutants when computing total emission reductions. The cost-effectiveness calculations that result in the values and rank ordering shown in Figure E-4 are the result of assigning weights of 1 to reductions of HC and 4 to reductions of NO_x. Emissions of CO and PM_{10} are not included in this weighting scheme, for reasons that were presented in the section on methodology.

With a weighting ratio that values NO_x emissions 4 times greater than HC, clearly strategies that have a comparative advantage in reducing NO_x are going to perform much better than those that do not. To see how sensitive the study conclusions about comparative effectiveness of strategies are, each of the strategy examples was also evaluated on the basis of alternative weighting schemes that test the importance of the NO_x weighting assumptions in the standard case. The alternative weighting schemes of 1:1 and 1:8 (HC to NO_x) result in the pattern of high/low range and median cost-effectiveness displayed earlier in Table E-1. That information is presented in an alternative format in Table E-3, which shows how the ranking of the strategies would change under the two alternative weighting schemes.

Pictured in the first two columns of Table E-3 are the 19 strategy groups ranked in order of median cost-effectiveness—from best to worst—for the standard 1:4 weighting case. The adjacent sets of columns give the median cost-effectiveness values for the same strategies weighted with ratios of 1:1 and 1:8, respectively. To the right of each of those cost values is the rank that that strategy would have if the ranking were based on that particular weighting scheme. This can then be compared with the 1:4 standard case to see how much the valuation would change if only the weighting assumptions were changed.

Several interesting observations result from this analysis. First, the top five strategies do not change in rank as a result of the change in weighting assumptions. I&M remains the most cost-effective overall strategy, followed by regional rideshare in second position, charges and fees in third, vanpool programs in fourth, and miscellaneous TDM in fifth. Elsewhere in the list, strategies that do not change their order of ranking when the weighting assumptions are changed are AFV (not replacement buses) programs in 7th position, new transit shuttle and feeder services in 15th position, freeway management strategies in 16th position, and telework in last place in 19th position.

TABLE E-3 Rank Order of Strategies by Median Cost-Effectiveness and Weighting Scheme

	Weights = 1:4:0:0		Weights = 1:1:0:0		Weights = 1:8:0:0	
	Median	Rank	Median	Rank	Median	Rank
Inspection and maintenance	1.9	1	4.5	1	1.1	1
Regional rideshare	7.4	2	18.5	2	4.1	2
Charges and fees	10.3	3	27.9	3	5.6	3
Vanpool programs	10.5	4	30.4	4	5.6	4
Misc. TDM	12.5	5	34.1	5	6.8	5
Conventional fuel bus replacement	16.1	6	63.2	9	8.1	6
Alternative-fuel vehicles	17.8	7	53.0	7	9.4	7
Traffic signalization	20.1	8	35.2	6	20.8	10
Employer trip reduction	22.7	9	56.9	8	12.6	8
Conventional service upgrades	24.6	10	64.6	10	13.5	9
Park-and-ride lots	43.0	11	127.5	12	22.3	11
Modal subsidies and vouchers	46.6	12	125.4	11	25.4	12
New transit capital systems/ vehicles	66.4	13	208.0	14	34.4	13
Bike/pedestrian	84.1	14	206.6	13	47.3	14
Shuttles, feeder, paratransit	87.5	15	214.7	15	49.6	15
Freeway management	102.4	16	240.9	16	52.8	16
Alternative-fuel buses	126.4	17	355.7	18	68.0	17
HOV facilities	176.2	18	316.2	17	111.4	18
Telework	251.8	19	742.3	19	133.9	19

Note: Amounts in columns headed “median” are dollars per ton in thousands (2000 dollars).

Most of the changes in rank order that do occur are not particularly significant. The conventional transit service improvements category becomes slightly more attractive under the high (1:8) NO_x weighting, rising from 10th position to 9th. Under the low NO_x weighting (1:1), park-and-ride lots drop from 11th position to 12th, new transit capital systems and improvements drop from 13th position to 14th, and alternative-fuel buses drop from 17th position to 18th. Strategies that become more attractive when NO_x is weighted at the lower 1:1 ratio are modal subsidies and vouchers, moving from 12th position to 11th, bike/pedestrian facilities, moving from 14th to 13th, and HOV facilities, moving from 18th to 17th.

Those strategies affected the most by the different pollutant weighting assumptions are conventional fuel bus replacements and traffic signalization. Conventional fuel bus replacements offer significant reductions in NO_x over older models and hence look particularly attractive under schemes with higher NO_x weights; they drop from sixth position to ninth when the low NO_x weight ratio of 1:1 is used. Traffic signalization, on the other hand, looks better when NO_x is de-emphasized, since these strategies were frequently observed to increase NO_x emissions. These strategies improve from 8th to 6th in the rankings when the 1:1 weight ratio is used and fall from 8th to 10th when the 1:8 weight ratio is used.

Evaluating Cost-Effectiveness Within Strategy Categories

While the range, median, and ranking of the cost-effectiveness performance of the CMAQ strategies go a long way toward revealing which strategies are most or least effective, unfortunately a lot of insight is lost in the gross averaging approach. In particular, if one were to look at the strategies one by one, it would be clear that there are both extremely good and extremely poor examples in virtually all of the strategy groups. Table E-4 has been prepared to illustrate this point.

Table E-4 indicates that the experience follows a bimodal, and almost a bipolar, distribution. Of the 139 cases included in the analysis, 36 (or 26 percent) had very attractive cost-effectiveness performance of under \$10,000 per ton. If the envelope of acceptable cost-effectiveness is extended to \$19,999, 39 percent of all cases are accounted for, and if \$29,999 is the threshold, fully half of the entire sample is accounted for. However, at the other extreme, 49 cases, or 35 percent, are above the \$70,000 per ton level (sample median estimated at \$66,300), many of which are considerably above this threshold. Moreover, this dichotomy occurs across the majority of strategy groups—in other words, very successful and very poor examples can be found in each category, raising the important question of whether it is the strategy or the implementation that is responsible for the result.

Some strategies seem to rise to the top consistently despite this distributional characteristic. For example, regional rideshare (5 cases

Table E-4 Number of Project Examples by Project Category and Cost-Effectiveness Level

	Cost per Ton (in 2000 $)							
	< $10,000	$10,000–$19,999	$20,000–$29,999	$30,000–$39,999	$40,000–$49,999	$50,000–$59,999	$60,000–$69,999	$70,000+
Traffic signalization	2		2					1
Freeway management	2							2
HOV facilities		1						1
Ridesharing—programmatic	3	2						
Ridesharing—vanpool/buspool	2	2	1					1
Park-and-ride	1	1					1	1
Regional TDM	4	1	2	1				
Employer trip reduction program	1	2	1		1	1		1
Telework	1							9
Bike/pedestrian	1	1	1				2	9
Transit shuttles		1	1	1	1	2		9
Transit capital improvements	1	1		1				3
Transit service improvements	1	2	4	1				2
AFV buses	3			1	1			6
Replacement buses		3	1	1				
Other AFV programs	1			1				
Inspection and maintenance	5							
Subsidies and discounts	5		1	1		1	2	4
Charges and fees	3	1	1		1			
Total (139)	**36**	**18**	**15**	**8**	**4**	**4**	**5**	**49**
Percent	**26**	**13**	**11**	**6**	**3**	**3**	**4**	**35**

under $20,000, none over $70,000), vanpooling (4 of 6 cases under $20,000, only 1 over $70,000), miscellaneous TDM (5 of 8 cases under $20,000, none over $70,000), I&M (all 5 of 5 cases under $20,000), charges and fees (not an eligible CMAQ strategy) (4 of 6 cases under $20,000, none over $70,000), conventional fuel replacement buses (3 of 5 cases under $20,000, none over $70,000) and other AFV programs (1 of 2 cases under $20,000, none over $70,000) are almost all ranked high in the order and almost always produce attractive cost-per-ton returns.

On the other hand, some strategies almost always show poor rates of return. For example, telework (only 1 of 10 cases under $20,000, but 9 cases over $70,000), bike/pedestrian facilities (only 2 of 14 cases under $20,000, but 9 cases over $70,000), and transit shuttles (only 1 of 15 cases under $20,000, but 9 cases over $70,000) have the vast majority of their experience over $70,000 per ton. The question is, Given that there are a small number of examples that do result in acceptable performance, are there ways to learn from this experience to suggest guidelines for future applications of these strategies?

Perhaps most compelling in this regard are those strategies that reflect performance across the entire spectrum. Examples in this group include freeway management, where of the four cases, two are very effective (under $20,000) while the other two are very ineffective (over $70,000). Other such examples are employer trip reduction (3 of 7 cases under $20,000, 1 case over $70,000), park-and-ride lots (2 of 5 under $20,000, 1 over $70,000), transit capital improvements (2 of 6 under $20,000, 3 over $70,000), transit service improvements (3 of 10 under $20,000, 2 over $70,000), and subsidies and incentives (5 of 14 under $20,000, 4 of 14 over $70,000). Apparently these groups of strategies are very context sensitive—it really matters where a particular strategy is applied and how it is applied, which seems to make a great difference in the effectiveness of the same concept.

The conclusions reached from this particular analysis of the CMAQ experience is that certain strategies may be inherently more effective than others, but almost all of the strategy types that have been reviewed here have the potential to produce positive results. What seems to be of central importance is whether the right strategies are being selected and applied in the given setting. For example, the review indicates that certain areas of the country have used their CMAQ opportunities entirely on, say, traffic flow improvements, with little if any diversification into other potentially productive areas. Another example is in the use of CMAQ funds to replace transit equipment, as opposed to the use of other funding sources for the same purpose. These uses have seldom resulted in high rates of return on CMAQ dollars. This subject will be discussed in somewhat greater detail in the next section.

Overall CMAQ Program Cost-Effectiveness

By using the examples of CMAQ strategies that have been evaluated in this paper and by taking into account the manner in which CMAQ funds have been expended on the various categories of projects to date, a preliminary assessment can be made of the overall cost-effectiveness of the CMAQ program in "buying" emission reductions. To this end, Table E-5 illustrates the percentage allocation of CMAQ funds across the various types of strategies explored in this paper, from program inception in FY 1992 through FY 1999, the most recent year for which this information is available. The distribution of funding obligations illustrates the following major patterns in the types of projects that have been implemented:

- Traffic flow improvements: most heavily funded at 33.1 percent of all allocations and delivering emission reductions at a group average of $85,400 per ton.
- Transit improvements: receiving 28.3 percent of all funding allocations and delivering emission reductions at an average of $59,600 per ton.
- Fuels and technology: accounting for 20.6 percent of all allocations and delivering emission reductions at an average of $29,900 per ton.
- Ridesharing: accounting for only 3.8 percent of all funds but delivering emission reductions at an average of $20,500 per ton.
- Bike/pedestrian programs: accounting for 3.2 percent of all funds and delivering reductions at $84,100 per ton.

In general, this pattern suggests that the most funds have been allocated to the least cost-effective strategies, with the exception of

TABLE E-5 Summary of Cost-Effectiveness by Strategy (Cost-Effectiveness Results Based on HC:NO_x Weighting Ratio of 1:4)

	Number of Cases	Cost per Ton Range (2000 $)		Median (2000 $)	FY 1992–1999 CMAQ Obligations (%)	Median x Percent of Funding
		Low	High			
Traffic flow improvements					33.1	
Signalization	5	6,000	128,000	20,100	8.5	1,709
Freeway/incident management	4	2,300	543,900	102,400	8.1	8,294
HOV facilities	2	15,700	336,800	176,200	4.6	8,105
Intersections, traveler info, other	0	NA	NA	NA	11.9	NA
Allocation-weighted median				85,416		
Ridesharing					3.8	
Regional rideshare	5	1,200	16,000	7,400	2.4	89
Vanpool programs	6	5,200	89,000	10,500		126
Park-and-ride lots	4	8,600	70,700	43,000	1.4	602
Allocation-weighted median				20,516		
Travel demand management					2.9	
Misc. TDM	8	2,300	33,200	12,500	2.1	263
Employer trip reduction	7	5,799	175,500	22,700	0.8	182
Allocation-weighted median				15,314		
Telework	10	13,300	8,227,000	251,800	0.0	0
Bike/pedestrian	14	4,200	344,700	84,100	3.2	2,691

(*continued*)

TABLE E-5 (*continued*) **Summary of Cost-Effectiveness by Strategy (Cost-Effectiveness Results Based on HC:NO_x Weighting Ratio of 1:4)**

	Number of Cases	Cost per Ton Range (2000 $)		Median (2000 $)	FY 1992–1999 CMAQ Obligations (%)	Median x Percent of Funding
		Low	High			
Transit improvements					28.3	
Shuttles, feeder, paratransit	15	12,300	1,974,000	87,500	7.4	6,475
New capital systems/vehicles	6	8,500	470,800	66,400	12.0	7,968
Conventional service upgrades	10	3,800	120,100	24,600	7.4	1,820
Park-and-ride lots	1	56,200	56,200	56,200	1.5	843
Allocation-weighted median				60,447		
Fuels and technology					20.6	
Conventional fuel vehicles	5	11,000	39,900	16,100	12.7	2,045
Alternative-fuel buses	11	6,700	568,700	126,400	3.1	3,918
Alternative-fuel vehicles	2	4,000	31,600	17,800	0.6	107
Inspection and maintenance	5	1,800	5,800	1,900	4.2	80
Allocation-weighted median				29,853		
Other					2.8	
Rail freight	0	NA	NA	NA	0.4	NA
Paving and sweeping (PM)	0	NA	NA	NA	0.9	NA
All other improvements	0	NA	NA	NA	1.5	NA
Allocation-weighted median				NA		
STP/CMAQ	NA	NA	NA	NA	5.4	NA
Sum, known strategies					80.0	45,317
Allocation-weighted median, all strategies					100.0	56,646

bike/pedestrian, which has a high cost per ton, and telework, for which no funds have been officially allocated. However, as was stressed in the previous section, it can be very misleading to make such sweeping generalizations about one category being more effective than another, when some of the most significant differences in performance lie within the category (e.g., I&M, transit service upgrades, signalization) or even within the strategy group.

With these caveats in place, if one were to seek a rough estimate of the overall cost-effectiveness of the CMAQ program to date, Table E-5 provides such an estimate. The median cost-per-ton performance for each strategy (where data are available) is weighted by the percentage of CMAQ funds that have been obligated to that strategy between FY 1992 and FY 1999. The intermediate products, shown in the last column, are summed over all strategies and then divided by the respective percentage of all funding that this represents. On the basis of the projects covered in this paper review, cost-effectiveness performance has been estimated for project categories representing 80.1 percent of all funds allocated. The major missing strategy groups are

- Traffic flow improvements related to intersection improvements, traveler information systems, and so forth, accounting for 11.9 percent of all funds allocated;
- STP/CMAQ allocations, accounting for 5.4 percent of all funds allocated; and
- Other, including rail freight, paving and sweeping, and miscellaneous other, accounting for 2.8 percent of all allocations.

These missing categories are therefore not reflected in the overall program estimate, which is shown at the bottom of Table E-5 as approximately $56,600 per ton of emissions reduced.

FINAL THOUGHTS AND CLOSING

In this review, a sweeping approach has been taken toward assessing the effectiveness of the CMAQ program. It is a technical assessment, and not a policy assessment, a job that is more properly suited to the committee that has been assembled for that purpose. Hopefully, the analysis and findings contained in this review will help that executive body reach a satisfactory set of recommendations concerning the future and potential of the CMAQ program.

Clearly, the technical analysis is but one factor that will enter the committee's deliberations, as well it should be. This review, while extensive and diligent, perhaps raises as many questions or uncertainties as it provides answers. It is pointed out that the information that has been developed to document CMAQ project performance has been of generally poor quality and precision. The great majority of the almost 100 sources consulted for this evaluation were found to be insufficient to support an acceptable appraisal of the cost-effectiveness of proposed or implemented strategies. Rejected studies either failed to provide estimates of emissions or costs, or the necessary supporting data from which to estimate emissions or costs. This shortcoming extends to CMAQ proposals and even postimplementation evaluation studies.

As a prime example, many studies dealing with traffic flow enhancements raised questions in review as to whether they would be effective overall in reducing emissions, given concerns about NO_x/speed relationships, traffic diversions, or the effects of increasing traffic levels over time. Potential source studies either did not report NO_x emissions or left out critical speed/flow information from which those emissions could be calculated. Of course, as new modal emission relationships are developed, the speed/flow relationships are challenged, making it even more important to look comprehensively at speed/volume relationships across the affected network. Few if any of the reviewed studies dealt with employed system-level methods, nor did they allude to potential effects of traffic diversion, mode split changes, or secular growth in traffic on estimated benefits. This is disturbing because that category of projects represents the highest percentage of CMAQ funding obligations and is the "strategy of choice" for particular regions of the country, while its overall positive, long-term effect on travel is less than clear.

Whereas a more systematic, primary analytic approach to estimated CMAQ travel and emission impacts may have produced a more internally consistent and comparable set of findings, it was seen as important by the committee to use the literature review and synthesis to appraise the general state of the practice. In effect, these estimates reflect the tools, judgment, and perceptions that are being applied by agencies and professionals when planning, evaluating, and recommending strategies for funding. Thus, the numbers arrived at in this review, while perhaps lacking in analytic sophistication, nevertheless are useful in reflecting the processes and perceptions in the field. These norms, unless otherwise influenced by improved guidelines or methods, may well produce the same patterns of project priorities in the future.

Perhaps the most important finding of this review is that there is a great diversity in not only the types of strategies that have been deployed under CMAQ assistance but also in their effectiveness, which depends enormously on context. While some categories of strategies generally deliver high rates of return in reducing emissions, such as I&M and ridesharing programs, virtually all program categories showed examples of projects that delivered very attractive cost-effectiveness. Conversely, program categories that generally had attractive cost-effectiveness examples also included examples where the cost-effectiveness was very poor. This suggests that many strategies may be programmed for reasons other than comparative cost-effectiveness. This may be because certain strategies are popular with the public, politically attractive, a source of funding that might not otherwise exist, intuitive to planners or elected officials, or easy to implement.

This leads to the overall conclusion that the CMAQ program is capable of achieving a much higher level of performance—both total emissions reduced and cost per ton of reduction—than it has to date. Of 139 project examples reviewed, 26 percent were determined to reduce emissions at a cost of less than $10,000 per ton, another 13 percent could produce reductions at between $10,000 and $20,000 per ton, and another 11 percent could achieve reductions at a cost of between $20,000 and $30,000 per ton. In other words, about half of all examples studied delivered emission reductions for under $30,000 per ton. Why, then, do 35 percent of all projects have costs of over $70,000 per ton, with many of these substantially over $70,000 per ton? The conclusion is that this may be the result of the very flexibility that has made the CMAQ program so attractive to the audience for which it was developed, as an aid to meeting federally imposed requirements for meeting congestion and air quality targets. Given this flexibility and the general absence of supporting guidance, it seems unlikely that the CMAQ program can be expected to perform at a higher level than it has to date.

Tightening application requirements for CMAQ projects to demonstrate appropriate returns in achieving emission reductions that are commensurate with the desired funding and the needs of the particular area might be one way of achieving improved program performance. However, not only would this place increased review responsibility on the funding agency, it would also be viewed as an unacceptable break with the historic flexibility ethic of the program. It might be more effective in the long run to gather information on experience with various projects to serve as guidelines for would-be implementers of the same concept. This could be done through the introduction of an evaluation component to CMAQ grants, whereby the recipient agrees to monitor and furnish certain performance data on the project. Since not all recipients would be expected to favor such an added responsibility, nor would all eligible projects likely be of comparable interest, a selective evaluation program might be most appropriate. This could consist of first targeting specific types of projects/strategies as being of evaluation interest, and then offering additional funds to support evaluation of these projects by willing grant recipients. This technique was used successfully by the former Urban Mass Transportation Administration in the 1970s and 1980s in conjunction with its Service and Methods Demonstration program, as well as the Section 4(I) and Section 3(a)(1)(c) programs. Were such an information base to exist, it could help future proposers make more informed decisions on which strategies were most appropriate to their situation, as well as guiding them in making better estimates of the probable impact of the projects and in identifying those supporting and implementation factors that would result in the best performance.

These are but a few of the considerations that the committee has before it. This reviewer believes that the CMAQ program has been effective in defined ways and could be greatly improved in effectiveness if the positive lessons learned can be translated into future program operations.

Literature Sources Reviewed in CMAQ Evaluation Paper

Year	Title/Authorship	Abstract/Assessment	Topic Focus	Use in Paper
1998	Adler, K., M. Grant, and W. Schroeer. Emissions Reduction Potential of the Congestion Mitigation and Air Quality Improvement Program: A Preliminary Assessment. In *Transportation Research Record 1641,* TRB, National Research Council, Washington, D.C., pp. 81–88.	More of a policy/program position piece than a technical analysis. Does make point that some projects will deliver benefits into the future, beyond their lifetimes.	CMAQ.	Not used.
1994	Apogee Research, Inc. *Costs and Effectiveness of Transportation Control Measures: A Review and Analysis of the Literature.* National Association of Regional Councils, Jan.	Suggests typical impacts for comprehensive list of TCMs (per Section 108f) using findings taken/synthesized from major air quality studies performed in 1991–1993 to support CAAA requirements. Information includes change in trips and VMT, emissions, and costs. *Unfortunately, impacts on travel and emissions limited to “percentage” changes, and only HC emissions reported.*	Transit, HOV, bike/ped, TDM, pricing, technology, flow improvements.	Used in preliminary analysis, not in final because of stated shortcomings in data.
1994	Apogee Research, Inc., and Sarah Siwek & Associates. *TCM Quick Response Handbook: Tools for Local Planners.* North Jersey Transportation Planning Authority, Dec.	More of a methodology than presentation of possible outcomes. Could use methods to estimate some types of TCMs (similar to CARB CMAQ guidance, but not as complete).	TCMs.	Not used.

(*continued*)

Literature Sources Reviewed in CMAQ Evaluation Paper (*continued*)

Year	Title/Authorship	Abstract/Assessment	Topic Focus	Use in Paper
1996	Arnold. *Effectiveness of TCMs: Overview of State of the Practice.*	Includes impact estimates from TCM analyses in WASHCOG, DiRenzo's 1979 paper from TRR 714, CSI 1988, Kuzmyak & Meyer 1993; JHK/DeGang, Apogee 1994, Capital Beltway MIS 1995, SAI/EPA SIP guidance 1990.	TCMs.	A synthesis document that includes many of the other source studies used in this review. No new information added.
1994	Beaton, W. P., H. Meghdir, and K. Murty. Employer-Provided Transportation Benefits, Public Transit, and Commuter Vanpools: A Cautionary Note. In *Transportation Research Record 1433,* TRB, National Research Council, Washington, D.C., pp. 152–158.	Examines effect of tax-free employee subsidy on choice of transit or vanpool using modeling approach coupled with empirical data from NY/NJ Port Authority commuter study. *Stated preference approach deals mainly with trade-offs between transit and ridesharing, not with travel and emission impacts.*	TDM and ECO.	Not used.
1991	Bhatt, K. Review of Transportation Allowance Programs. In *Transportation Research Record 1321,* TRB, National Research Council, Washington, D.C., pp. 45–50.	Looks at transit and vanpool allowances, parking allowances for carpools, and mixed/general travel allowances. *Unfortunately, no usable travel, emission, or cost information.*	TDM and pricing.	Not used.
1999	Burbank, C., and C. Adams. *Program Guidance on the CMAQ Improvement Program.* FHWA, U.S. Department of Transportation, April.	Latest guidance from FHWA on CMAQ strategies, eligibility, evaluation. Useful for seeing what strategies are encouraged, how they will be evaluated.	All CMAQ strategies.	Not used.

Year	Title/Authorship	Abstract/Assessment	Topic Focus	Use in Paper
1999	California Air Resources Board. *Methods to Find the Cost-Effectiveness of Funding Air Quality Projects for Evaluating Motor Vehicle Registration Fee and CMAQ Projects* (1999 edition), Aug.	Provides methods/formulas for calculating emissions (ROG, NO_x, and PM_{10}) reductions and cost-effectiveness of many popular CMAQ-type projects.	All CMAQ strategies.	Used to estimate emissions where they were lacking, dated, or suspect in source study.
2000	Cambridge Systematics. *Quantifying Air Quality and Other Costs and Benefits of TCMs.* Final report, NCHRP Project 8-33, Dec.	Greatest potential value lies in results of Sacramento (HOV, ramp metering) and Portland (tour-based model application of combined auto pricing, telecommuting, transit improvements) pilot testing. *Unfortunately, only partial impact information presented, and no cost data.*	HOV lanes, ramp metering, pricing, transit.	Not used.
2000	Cambridge Systematics. NCHRP 8-33. Quantifying Air Quality Benefits of TCMs—Task 2: Improvements to Current Techniques.	Chapter 5 does simulation of pricing, transit, and telecommute policies with Portland, Oregon, tour-based model, but no statistics on individual policies, and no cost information.	TCMs.	Not used.
2000	Chang, G.-L., and Y. Point-du-Jour. *Performance Evaluation of Maryland's CHART Incident Management Program.* University of Maryland, May.	Estimates the impact of MDOT ITS incident management system on traffic flow and emissions.	Traffic flow improvements.	Used in study.

(*continued*)

Literature Sources Reviewed in CMAQ Evaluation Paper (*continued*)

Year	Title/Authorship	Abstract/Assessment	Topic Focus	Use in Paper
1994	Chicago Transit Authority. *Orange Line Travel Survey,* May.	Used CMAQ grant to market new Orange Line service. Reports on survey performed 4 months after opening. Found 6,700 new daily transit trips, reduction of 60,800 DVMT and 3,000 cold starts. *Unfortunately, cannot attribute the impacts entirely to the marketing, plus no emission or cost data provided.*	Transit improvements.	Not used.
2000	Cohen, H. S. Analysis of the CMAQ Database. (Presented as Appendix C of this Special Report.)	Assessment of types of projects funded by CMAQ, trends over time. Some information on impacts, but as taken from grantee applications (not for use in this review).	All CMAQ strategies.	Overall perspectives on program strategies, funding patterns, performance, documentation problems.
1996	COMSIS et al. *MTA TDM Demonstration Program Third Party Evaluation.* Final report, Los Angeles County Metropolitan Transportation Authority, Feb.	Detailed findings on performance of 12 TDM demonstration projects sponsored by MTA (as part of 110) in Los Angeles County.	Shuttles, telecommuting, ridesharing centers, vanpooling.	Examples used directly in study.
1997	COMSIS et al. *MTA Transportation Demand Management Evaluation.* Final report, Los Angeles County Metropolitan Transportation Authority, April.	Presents project-specific before-and-after evaluation findings for 11 TDM projects funded and evaluated under MTA's TDM Program in Los Angeles County.	Transit improvements, bike facilities, vanpooling, general TDM.	Used directly in study.

Year	Title/Authorship	Abstract/Assessment	Topic Focus	Use in Paper
1994	*Congestion Management and Air Quality Improvement Program: Indirect Benefits.* FHWA, U.S. Department of Transportation.	Describes indirect benefits associated with CMAQ program, based on surveys of MPOs, DOTs, and interest groups. Largely increased public participation, enhanced planning process, advances in evaluation methodologies, MPO empowerment, encouragement of innovation, education/outreach, quality of life. *No quantitative data or guidelines.*	All CMAQ strategies.	Background only.
1977	Crowell, W., et al. *Carpools, Vanpools and HOV Lanes: Cost-Effectiveness and Feasibility.* Office of Planning and Evaluation, U.S. Environmental Protection Agency, May.	Used empirical (but anecdotal) data on voluntary employer ridesharing programs from four metropolitan areas to establish that such programs can reduce regional VMT by 0.1% to 2–3%. Also studied transit/carpool HOV lanes, concluding that with 20-minute time savings, could reduce regional VMT by 1%.	Ridesharing and HOV lanes.	Information a little too anecdotal, conclusions a bit too simplistic for this study.
1998	Dahlgren, J. High Occupancy Vehicle Lanes: Not Always More Effective Than General Purpose Lanes. *Transportation Research A,* Vol. 32, No. 2, pp. 99–114.	Airs dilemma that HOV lanes require congestion in order to provide an advantage to attract users. Compares various add-a-lane, take-a-lane, no change scenarios. *More of an academic/policy piece, not directly useful for emissions.*	HOV lanes.	Not used.

(*continued*)

Literature Sources Reviewed in CMAQ Evaluation Paper (*continued*)

Year	Title/Authorship	Abstract/Assessment	Topic Focus	Use in Paper
1994	De Leuw, Cather & Co. *Station Renovations and Pedestrianways.* Final report, CMAQ Evaluation Method Study for City of Chicago, July.	CMAQ evaluation study that addresses transit station renovations and pedestrianways. Develops a technique for estimating effects of station and access improvements that are too small to be reflected in regional travel model. *No actual travel, emission, or cost results, however.*	Transit improvements.	Not used.
1991	Deakin, Harvey, and Skabardonis. *TCMs for San Francisco Bay Area: Analysis of Effectiveness and Costs.* Bay Area Air Quality Management District, July.	Covers full range of TCM strategies, provides estimates of cost and effectiveness, emission reductions of HC, NO_x, CO, PM_{10}. *Unfortunately, only percent reductions in VMT and emissions are reported (no control totals), and cost/ton presented for ROG only.*	TCMs.	Used in preliminary analysis only, insufficient information for final assessment.
1994	Delaware Valley Regional Planning Commission. *An Analysis of Potential TCMs for Implementation in the Pennsylvania Portion of the DVRPC (Philadelphia) Region.* May.	Travel, emissions, and cost-effectiveness for 30+ TCMs across all categories.	Transit, HOV, bike/ped, TDM, pricing, technology, flow improvements.	Used directly in study.

Year	Title/Authorship	Abstract/Assessment	Topic Focus	Use in Paper
1993	Euritt, M. A., D. B. Taylor, and H. S. Mahmassani. Cost-Effectiveness Analysis of Texas Department of Transportation Compressed Natural Gas Fleet Conversion. In *Transportation Research Record 1416,* TRB, National Research Council, Washington, D.C., pp. 95–104.	Basically a summary of detailed formal report (see below). *Good study but no emission data.*	Technology and fuels.	Not used.
1992	Euritt, M., et al. *C/E Analysis of TxDOT CNG Fleet Conversion,* Volumes 1 and 2. Research Report 983-2/1. University of Texas at Austin, Aug.	Estimates life-cycle costs and benefits of TxDOT's proposed conversion of state vehicle fleet to CNG. *Good study but no emission data.*	Technology and fuels.	Not used.
1986	Feeney. *Review of Impact of Parking Policy Measures on Travel Demand.*	Reviews empirical evidence on impact of parking policy (availability, location, price) on parking demand and travel. Assembles, compares elasticities. *Insufficient data to estimate emission or cost impacts.*	Market based.	Not used.
1990	Ferguson, E. Influence of Employer Ridesharing Programs on Employee Mode Choice. *Transportation,* Vol. 17, Aug., pp. 179–207.	Surveyed national sample of employers under National Ridesharing Demonstration Program. *Unfortunately, no information obtained on travel responses/ mode shifts.*	Ridesharing.	Not used.

(*continued*)

Literature Sources Reviewed in CMAQ Evaluation Paper (*continued*)

Year	Title/Authorship	Abstract/Assessment	Topic Focus	Use in Paper
1993	FHWA. *Implementing Effective TDM Measures.*	Provides impact information on 11 different demand management strategies, including transit, carpool, vanpool, bike/ped, economic incentives, HOV, parking pricing and management, tolls and congestion pricing, alternative work hours, telecommuting, and employer support measures. Also tied to TDM evaluation model. *No emissions estimates, and cost data limited.*	TDM and ECO.	Used for cross-checking validity of assumptions and impacts in other studies.
1992	Giuliano and Wachs. *Comparative Analysis of Regulatory and Market-Based TDM Strategies.*	Presents typology of TDM policies, focusing on differences between regulatory and market-based approaches. *Insufficient data for computation of emission cost-effectiveness.*	TDM and ECO.	Not used.
1990	Giuliano, G., et al. Impact of High Occupancy Vehicle Lanes on Carpooling Behavior. *Transportation,* Vol. 17, pp. 159–177.	Examines extent to which an HOV facility increases ridesharing using data from Route 55 in Orange County, California. *Difficult to get change in VT or VMT from presentation.*	HOV lanes.	Not used.
1992	Giuliano, G. Transportation Demand Management: Promise or Panacea? *Journal of the American Planning Association,* Vol. 58, No. 3, pp. 327–335.	Presents information from three case studies to argue that TDM has little impact on traffic conditions but big impacts on consumers. *Insufficient data for computation of emission cost-effectiveness.*	TDM and ECO.	Not used.

Year	Title/Authorship	Abstract/Assessment	Topic Focus	Use in Paper
1998	Guensler. *Increasing Vehicle Occupancy in the U.S.*	Summarizes state of practice in regional programs to increase vehicle occupancy, including regulatory trip-reduction measures, congestion pricing and other economic incentives, and education. Recommends experimenting with parking pricing and incentive-based voluntary programs before congestion pricing or privatizing roadways. *No directly usable findings for this assessment.*	TDM and ECO.	Not used.
1999	Hagler Bailly. *Summary Review of Costs and Emissions Information for 24 CMAQ Improvement Program Projects.* U.S. Environmental Protection Agency, Sept.	Reviews project impacts in six different CMAQ categories: shared ride, ped/bike, traffic flow, transit, TDM, other. Includes information on project lifetimes, costs, emissions. Emission estimates for VOC, NO_x, CO, PM_{10}.	All CMAQ strategies.	Impact estimates directly used.

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Literature Sources Reviewed in CMAQ Evaluation Paper (*continued*)

Year	Title/Authorship	Abstract/Assessment	Topic Focus	Use in Paper
1995	Harrington, W., M. A. Walls, and V. D. McConnell. Using Economic Incentives to Reduce Auto Pollution. *Issues in Science and Technology,* Vol. 11, No. 2, March.	Argues for economic incentive over regulatory approaches to achieve emission reductions. Presents cost/ton ranges for wide range of approaches, including alternative-fuel vehicles, reformulated fuels, various I&M programs and remote sensing, and a variety of economic incentives (gas tax, congestion pricing, parking cashout, emissions-based registration fees, accelerated scrappage). Argues against AFVs, and is dubious about I&M.	Market based.	Not used because results reflect cost/emission/technology relationships of 1994; emissions are only VOCs, not sure how analysis would hold up for NO_x. Economic incentive arguments seem sensible, but not much supporting information provided.
1999	ICF Inc. *Benefits Estimates for Selected TCM Programs.* U.S. Environmental Protection Agency, Office of Mobile Sources, March.	Illustrative application of EPA's TCM guidance and analysis procedures to six actual TCM programs. Estimates change in trips, VMT, speeds, and reductions in emissions (HC only). *No costs provided.*	Vanpool and shuttle programs, telecommute, bike/ped facilities.	Not used.
1999	*Intelligent Transportation Systems Benefits—1999 Update.* FHWA ITS Joint Programs Office, May.	Summarizes empirical results from field operations of deployed systems, supplemented with benefits information based on modeling and statistical studies. Distinguishes between ITS for commercial vehicles and ITS user services. *Insufficient information to derive emission cost-effectiveness.*	Traffic flow improvements.	Examples of incident management projects used in report.

Year	Title/Authorship	Abstract/Assessment	Topic Focus	Use in Paper
1992	JHK Associates and COMSIS. *Procedural Guidelines for Evaluation of TCM Impacts with Existing Tools.* For Southern California Association of Governments.	Investigates characteristics of existing tools in relation to the needs of analysts to evaluate diverse TCM strategies. *A technical review study, not a source for impacts.*	TCMs.	Not used.
1997	Johnston, R., and C. Rodier. *A Comparative Systems-Level Analysis: Automated Freeways, HOV Lanes, Transit Expansion, Pricing Policies and Land Use Intensification.* California PATH Research Report, April.	Uses advanced modeling tools to evaluate travel and emission impacts of regional LRT, HOV lanes, automated freeways, and the supportive effects of land use concentration and pricing. Setting is Sacramento, and projects as set forth in 2020 long range plan. *No cost information limited extensive use.*	Automated highways, HOV lanes, LRT, road/fuel/parking fees, land use concentration.	Used to illustrate effects of highway capacity additions, reinforcing effects of pricing and land use concentration.
1996	Johnston, R. A., and R. Ceerla. The Effects of New High-Occupancy Vehicle Lanes on Travel and Emissions. *Transportation Research A,* Vol. 30, No. 1, pp. 35–50.	Statistics presented to argue that new HOV lanes may increase travel and emissions when compared with transit alternatives. *Good analysis but no cost information.*	HOV lanes.	Examples used in preliminary analysis, but not in final report due to missing cost information.
1993	Kessler, J., and W. Schroeer. *Meeting Mobility and Air Quality Goals: Strategies That Work.* U.S. Environmental Protection Agency, Office of Policy Analysis, Jan.	Identifies/recommends strategies clearly likely to have impact on emissions. *Unfortunately, impacts reported are in gross national terms and/or percentages. Difficult to put into proper context for this paper.*	TCMs.	Not used.

(*continued*)

Literature Sources Reviewed in CMAQ Evaluation Paper (*continued*)

Year	Title/Authorship	Abstract/Assessment	Topic Focus	Use in Paper
1996	Kimley-Horn Associates. *Garland TX CMAQ Signal Timing Project.*	Four separate studies dealing with CMAQ-funded signalization projects. *Extensive raw data on vehicle movements, but no information provided on emissions or costs.*	Traffic flow improvements.	Not used.
1994	Knowles, W. *Mobile Source Emissions Impacts of HOV Facilities.* TTI Report 1353-2. Nov.	Benchmarks and compares SAI and SANDAG methods for application in estimating emission impacts of HOV lanes. Finds considerable differences between the two methods. *Unfortunately, no real quantitative value for CMAQ assessment.*	HOV lanes.	Not used.
1991	Krupnick. *Vehicle Emissions, Urban Air Quality, and Clean Air Policy.*	Focuses on reformulated fuels, high emitters, high-tech emission monitoring, congestion pricing. Standards questioned.	Technology and fuels.	Too dated for direct use.
1998	Lachance, L. C., and E. Mierzejewski. Analysis of the Cost-Effectiveness of Motor Vehicle Inspection Programs for Reducing Air Pollution. In *Transportation Research Record 1641,* TRB, National Research Council, Washington, D.C., pp. 105–111.	Examines cost-effectiveness of five types of MVIP technologies (advanced I&M) re potential application in Florida. Estimates of VOCs and NO_x reduction, associated costs.	I&M.	Used directly for I&M program estimates.

Year	Title/Authorship	Abstract/Assessment	Topic Focus	Use in Paper
1996	Lewis, J., et al. *New Commuter Railroad Stations and Station Parking Impact Evaluation Study.* Illinois Department of Transportation, June.	Develops technique to predict increase in rail ridership if parking capacity is added to existing lot or for infill station. *Unfortunately, all methodological—no change in trips/VMT, no emission or cost data.*	Transit improvements.	Not used.
1992	Loudon, W., and D. Dagang. Predicting the Impact of Transportation Control Measures on Travel Behavior and Emissions. Presented at 71st Annual Meeting of the Transportation Research Board, Washington, D.C.	Provides an overview of methodology developed for Caltrans to predict impact of TCMs. *Paper provides elasticity estimates derived from empirical studies, but no real examples for use.*	TCMs.	Not used.
1994	Lupa, M. Feasibility of Employee Trip Reduction as a Regional Transportation Control Measure. In *Transportation Research Record 1459,* TRB, National Research Council, Washington, D.C., pp. 46–52.	Compares ETR as a strategy with wide range of TCMs, using data from SCAQMD; concludes that ETR is very expensive. Comparisons show 2010 ROG and cost/cost-effectiveness for all TCMs.	TDM and ECO; TCMs.	Not used because emission data limited to ROG.
1994	Metropolitan Washington (D.C.) Council of Governments. *Transportation Control Measure Analysis.* FHWA Metropolitan Planning Technical Report, Feb.	Travel, emissions, and cost/cost-effectiveness for 60+ TCMs across all categories.	Transit, HOV, bike/ped, TDM, pricing, technology, flow improvements.	Used directly in study.

(*continued*)

Literature Sources Reviewed in CMAQ Evaluation Paper (*continued*)

Year	Title/Authorship	Abstract/Assessment	Topic Focus	Use in Paper
1997	Meyer, M. *A Toolbox for Alleviating Traffic Congestion and Enhancing Mobility.* Institute of Transportation Engineers.	Some impact information on TSM & TDM strategies for congestion relief. *Does not get into emissions or costs.*	Traffic flow improvements, TDM, transit, ITS, new capacity.	Examples of signalization and ramp metering projects used in report.
1997	Michael Baker Corporation et al. *The Potential of Public Transit as a TCM: Case Studies and Innovations.* Draft final report, National Association of Regional Councils, Oct.	Review of 10 exemplary transit or transit-related projects that demonstrate effectiveness of transit as an air quality strategy. Impacts include travel, emissions, and costs.	Transit, paratransit, subsidies, TDM.	Examples used directly in study.
1998	Mokhtarian et al. *Estimating Impacts of Telecommuting on Travel.*	Develops model for forecasting demand for telecommuting and resulting transportation impacts. Computes that only 1.5% of workforce commutes on given day, at most reducing 1% of daily household VMT. *Broad national analysis with lots of factor assumptions; no costs, no emissions.*	TDM and ECO.	Not used.
1994	National Engineering Technology Corporation. *CMAQ Special Study 1993-SCAT-OGL-009.* Final report. Illinois Department of Transportation, April.	Before/after analysis of seven signal coordination projects in Chicago area. *Emission and cost data not provided, travel speed/delay data not in format suitable for post-facto emission estimation.*	Traffic flow improvements.	Not used.

Year	Title/Authorship	Abstract/Assessment	Topic Focus	Use in Paper
2000	National Research Council. *Modeling Mobile Source Emissions* (prepublication copy).	Report of NRC committee tasked to review the MOBILE model. Insights into critical relationships, shortcomings in modeling and data, how they may influence effectiveness determinations.	Traffic flow improvements.	Reference only.
1997	*NCHRP Report 394: Improving Transportation Data for Mobile Source Emission Estimates.* TRB, National Research Council, Washington, D.C.	Focuses on importance of input data to emission calculations, especially role of speed and vehicle classification mix. Guidance on sensitivity of emissions to these factors.	Traffic flow improvements.	Reference only.
1996	NCTCOG. *TCM Effectiveness Study.*	Assessment of TCMs for 15% reduction SIP. Calculation of travel effects, VOC emissions (only). *No cost information.*	Traffic flow, HOV, incident management, rail transit, street widening.	Not used.
1993	Orski, K. ETR Programs—An Evaluation. *Transportation Quarterly,* Vol. 47, No. 3.	Critiques ineffectiveness of Southern California's Regulation XV ETR program requirement following 3 years of experience. Presents arguments based on percent reduction in VMT and emissions, and cost per reduction to employers.	TDM and ECO.	Used as data point in study.

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Literature Sources Reviewed in CMAQ Evaluation Paper (*continued*)

Year	Title/Authorship	Abstract/Assessment	Topic Focus	Use in Paper
1998	Pansing, C., E. N. Schreffler, and M. A. Sillings. Comparative Evaluation of the Cost-Effectiveness of 58 Transportation Control Measures. In *Transportation Research Record 1641,* TRB, National Research Council, Washington, D.C., pp. 97–104.	Reviews travel, emissions, and cost-effectiveness of transit, fuels, and TDM projects implemented in Los Angeles and San Diego areas. Results taken from actual before-and-after studies.	TDM, shuttles, ridesharing, transit, alternative fuels.	Used.
1999	Parsons Brinckerhoff et al. *CMAQ Analysis: North Central Service Impact Evaluation—Phase II Final Report.* Metra, Chicago, June.	Analysis of impact of new 41-mile commuter rail line in northwest Chicago on ridership and emissions.	Rail transit.	Used directly in study.
1995	Replogle, M. *Overcoming Barriers to Market-Based Transportation Reform.* Environmental Defense Fund.	Addresses broad cross section of market and pricing strategies, but more from the barriers and implementation side.	Pricing.	Not used.
1994	Replogle, M., and H. Dittmar. Integrating Travel Demand Management Strategies. In *Transportation Research Circular 433,* TRB, National Research Council, Washington, D.C., pp. 107–122.	Addresses what is strong/weak about current TDM approaches, how effectiveness can be improved through synergistic packaging, and use of correct tools/assumptions. *Impact estimates for laundry list of TCMs provided, but only VMT, though attempt is made to show short- and long-term effects.*	All TCMs.	Not used.

Year	Title/Authorship	Abstract/Assessment	Topic Focus	Use in Paper
1991	SAI. *TCM Analysis Procedures.*	Describes methodology developed for analyzing travel and emission changes resulting from individual and packaged TCMs. Shows formulations, source of information for factors/relationships.	TCMs.	Methodological only, no cost-effectiveness. Not used.
2001	Schimek, P. Reducing Emissions from Transit Buses. *Regional Science and Urban Economics,* Vol. 31, pp. 433–451.	Presents estimates of incremental cost of gaining NO_x and PM emission reductions through new-generation diesel buses versus CNG, methanol, and hybrid electric–fueled vehicles.	Conventional and alternative-fuel transit buses.	Used for comparison purposes; limited by incremental cost approach.
1996	Schreffler, E. How Costly and Cost Effective are ECO Programs? Institute of Transportation Engineers Annual Meeting.	Discusses costs per employee and per trip reduced for sample of ECO programs. *More of a policy position piece than source document for this study.*	TDM and ECO.	Not used.
1990	Shoup and Wilson. *Parking Subsidies and Travel Choices: Assessing the Evidence.*	Reviews empirical studies of how employer-paid parking affects employees' travel choices (one of many such studies). *Insufficient data to estimate emission or cost impacts.*	Market based.	Not used.
1991	Sierra Research, Inc. *Methodologies for Quantifying the Emissions Reductions of TCMs.* San Diego Association of Governments, Oct.	Presents the methodology and assumptions behind the TCM Tools model built for SANDAG in early 1990s. *Not much in the way of directly usable impact information.*	TCMs.	Not used.

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Literature Sources Reviewed in CMAQ Evaluation Paper (*continued*)

Year	Title/Authorship	Abstract/Assessment	Topic Focus	Use in Paper
1996	Sivasailam, D., and J. Williams. Estimating Impacts of Transportation Control Measures on Work-Related Trips. In *Transportation Research Record 1518,* TRB, National Research Council, Washington, D.C., pp. 32–37.	Specifically deals with the implication of work-related trips being only small portion of total daily travel, and methods to account for in TCM impact assessment. *No impact information directly useful to this assessment.*	TCMs.	Not used.
1994	Systems Applications, Inc. *Methodologies for Estimating Emissions and Travel Activity Effects of TCMs.* U.S. Environmental Protection Agency, Office of Mobile Sources, July.	Mainly suggests analytic approaches, with some factors/rules of thumb, for calculating impacts. *Little/no empirical data.*	TCMs.	Not used.
2000	TCRP B-12. Update of Traveler Response to Transportation System Changes Handbook.	Detailed impact information on wide range of transit, HOV, pricing, land use strategies. *Travel effects only, not emissions or costs.*	TCMs.	For cross-checking validity of assumptions, range of impacts.
1992	Texas Transportation Institute. *HOV Project Case Studies: Historical Trends and Project Experiences.* Research Report 925-4. Aug.	Examines historical trends with HOV projects in six case study sites. *Very informative, but not type of information to support emission or C/E analysis.*	HOV lanes.	Not used.

Year	Title/Authorship	Abstract/Assessment	Topic Focus	Use in Paper
1995	Texas Transportation Institute. *TTI CM/AQ Evaluation Model User's Guide and Workshop Training Materials.* Research Report 1358-1. Aug.	Applies model originally developed for DRCOG by JHK Associates and enhanced by TTI ("CMAQ Model") to evaluate independent projects on the basis of criteria score. Appendix E offers impact estimates for congestion pricing, pedestrian improvements, fleet conversion, telework, park-and-ride, and signal improvement strategies.	All CMAQ strategies.	Used in initial review, assumptions regarding impacts and costs are "assumption based" and judged too generic for final inclusion.
1997	Texas Transportation Institute. *An Evaluation of HOV Lanes in Texas, 1996.* Research Report 1353-5. Nov.	Provides assessment of impact of HOV lanes on five Houston freeways. Uses before-and-after trendline analysis and comparison to control highways.	HOV lanes.	Used example of Katy Freeway.
1990	*Transportation Control Measure: SIP Guidance.* U.S. Environmental Protection Agency, Office of Air and Radiation, Sept.	Developed by SAI and UC Berkeley while 1990 CAA Amendments were being finalized. Summarizes TCM experience of previous 10 to 15 years. *No usable numbers for this assessment.*	TCMs.	Not used.
1995	TTI. *Evaluation and Monitoring of TCMs.* Report 1279-10F.	Reviewed advantages and limitations of TCM evaluation methods currently available, identified critical issues in their accuracy and applicability. Monitoring programs presented for four TCMs: transit plazas, intersection improvements, ridesharing, and park-and-ride lots.	TCMs.	Insufficient data for use in this review.

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Literature Sources Reviewed in CMAQ Evaluation Paper (*continued*)

Year	Title/Authorship	Abstract/Assessment	Topic Focus	Use in Paper
1996	TTI. *Houston Employee Commute Options Program: Analysis of Emissions Benefits.*	Analyzed database of submitted ETR plans for 1,200 worksites/ 396,000 employees in eight-county nonattainment area. Evaluated the potential impact of programs on emissions and energy.	TDM and ECO.	Used example of ECO program in Employer Trip Reduction section.
1995	TTI. *Research Concerning Analysis of CMAQ Transportation Improvement Projects.*	Summarizes literature search and national survey on procedures in use to potentially help Texas MPOs analyze CMAQ projects. Examples focus on traffic flow improvements and park-and-ride. *Emission estimates provided, but no cost information.*	Traffic flow improvements.	Not used.
1994	TTI. *TCM Analyst 1.0 Users Guide.*	Combined SAI and SANDAG tools into one spreadsheet evaluation tool. Covers 11 different TCMs. *Mainly an instruction manual; formulas and sensitivity results too abstract for use in this review.*	TCMs.	Not used.
1993	TTI. *Critical Analysis of Sketch-Planning Tools for Evaluating Emission Benefits of TCMs.*	Reviewed SAI and SANDAG planning tools for effectiveness in assessing TCMs. *Sensitivity analysis performed, results presented, but too generic for use in this assessment.*	TCMs.	Not used.

Year	Title/Authorship	Abstract/Assessment	Topic Focus	Use in Paper
1994	University of Texas at Austin. *Framework for Evaluating TCMs: Energy, Air Quality and Mobility Tradeoffs.*	Focuses on how current four-step models do not adequately account for how individuals make travel decisions, comes up with improved framework, applies to test scenarios to estimate effectiveness of TCMs. *Had concerns about analysis, no cost data provided.*	TCMs.	Not used.
1993	Wachs, M. Regulation XV in Southern California: Success or Failure? *TDM Review,* Vol. 4, No. 1.	Reports on findings from study of Regulation XV in Southern California. Concludes not entirely a failure, that much depends on what types of measures are applied in programs (e.g., pricing).	TDM and ECO.	Used in study.
1993	Wachs, M. *Learning from Los Angeles: Transport, Urban Form, and Air Quality.* University of California Transportation Center.	Takes issue with California experience with increased emphasis on rail transit investment and demand management, contrasts with market-based and emerging technology approaches.	TDM and ECO.	Regulation XV findings used in TDM/ECO assessment.
1997	Wang, M. Mobile Source Emission Control Cost-Effectiveness: Issues, Uncertainties, and Results. *Transportation Research D,* Vol. 2, pp. 43–56.	Source paper dealing with methodological issues in determining cost-effectiveness.	Technology and fuels.	Methodology only.

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Literature Sources Reviewed in CMAQ Evaluation Paper (*continued*)

Year	Title/Authorship	Abstract/Assessment	Topic Focus	Use in Paper
1999	Wellander, C., and K. Leotta. *HOV Lanes—Are They Effective?* Parsons Brinckerhoff.	Overviews sample of freeway HOV lanes across North America. Measures of effectiveness include throughput, utilization, travel time savings. *Not directly useful for emission evaluation.*	HOV lanes.	Not used.
1996	Welzenbach, K. *Analysis of 1995 Bicycle Survey of Suburban Bike Trails.* Working Paper 96-08. Chicago Area Transportation Study, June.	*Provides survey data only, no impacts or strategies.*	Bike/ped.	Not used.
1997	Western Governors' Association. *Air Quality Initiative—Mobile Source Options.*	Provides ranges of travel, emission, and cost impacts for comprehensive list of TCMs in relation to meeting reduction targets in Western states to assess cross-source emission trading program.	TCMs.	Used for preliminary study of fuels, technology, and TCM strategy impacts.
1989	Whinihan. *Use of Economic Incentives to Reduce Mobile Source Emissions.*	Examines economic incentives to meet pending emission requirements, but focuses on accelerated vehicle turnover. *Pretty dated for this application.*	Technology and fuels, pricing.	Not used.
1996	Zarifi, S. *Transportation Demand Management Program—Second Tier Evaluation.* Los Angeles County Metropolitan Transportation Authority, July.	Presents information for 17 additional TDM projects funded and evaluated under MTA's TDM program.	Shuttles, telecommuting, pricing and subsidies, general TDM.	Examples used directly in study.

Year	Title/Authorship	Abstract/Assessment	Topic Focus	Use in Paper
1993	Zupan, J., and J. Dean. *The Effect of VMT and Smog Fees on VMT.* Report to Conservation Law Foundation, March.	Looks at pricing actions but from perspective of assumption testing. Relies a lot on vehicle scrappage/replacement for cost/benefit.	Technology and fuels, pricing.	Not used.
1993	Zupan, J., H. Levinson, and J. Dean. Potential of Transportation Vouchers to Reduce Vehicle Miles of Travel. Presented at 72nd Annual Meeting of the Transportation Research Board, Washington, D.C.	Tests different methodologies for estimating regional VMT, then plays with assumptions about how voucher might work in different locations. Concludes voucher works best in low-density areas where there is no transit conflict. *Unfortunately, too hypothetical for this analysis.*	TDM and pricing.	Not used.

TABLE E-ANNEX-1 CMAQ Project Impacts Evaluation: Project Category, Traffic Flow Improvements; Subcategory, Signalization Systems and Improvements

		Daily Travel Impacts					Emission Reductions (tons per day)		
Source	**Designation**	**VTR**	**VMTR**	**Transit Riders**	**Delay Red. (hr)**	**Speed Imp. (mph)**	**HC**	**NO_x**	**CO**
					Emission Weights:		**1**	**4**	**0**
Hagler Bailly (1999)	Arterial street signal connect (Philadelphia)	NA	NA	NA	NA	NA	0.052	0.0057	
Hagler Bailly (1999)	Maryland Rt. 2 signal systemization	NA	NA	NA	NA	3	0.012	(0.0012)	
Hagler Bailly (1999)	Pulaski Rd. signal interconnect (Chicago)	NA	NA	NA	NA	0.2	0.03		
DVRPC (1994)	Advanced signals on most congested 4-lane arterials	NA	70,554	NA	NA	NA	0.149	0.160	0.601
DVRPC (1994)	Compr. signal improvements in Philadelphia CBD	NA	7,336	NA	NA	NA	0.0353	0.028	0.250
Mean		NA	38,945	NA	NA	1.6	0.056	0.048	
Median		NA	38,945	NA	NA	1.6	0.035	0.017	

Travel term definitions: VTR = vehicle trip reduction; VMTR = vehicle miles of travel reduced; transit riders = increase in daily transit ridership.

Emission term definitions: total emissions = weighted sum of HC, NO_x, CO, and PM_{10}; emission weights = importance weights representing value of individual pollutants; emission year = time period for which source study estimate applies; benefits trend indicates whether emissions are decreasing, increasing, or constant over project life.

Cost-effectiveness definitions: BDF = benefits discount factor (combination of benefits trend and discount rate); annual benefits = weighted emissions ∗ days/year ∗ BDF; annual costs = annualized capital costs plus applicable operating, administrative, and private costs.

			Cost-Effectiveness						
PM_{10}	Total	Emission "Year"	Life (years)	Benefits Trend	Discount Rate (%)	BDF	Annual Benefits (tons/ year)	Annual Costs (2000 $)	Cost/Ton (2000 $)
0									
	0.0748	1994	10	Decrease	7	0.455	8.5	231,156	27,168
	0.0074	1999	12	Decrease	7	0.431	0.8	6,326	7,934
	0.03	Avg. over life of project	20	Decrease	7	0.359	5.4	32,139	5,968
	0.788	1996	10	Decrease	7	0.455	89.6	1,801,653	20,100
	0.146	1996	10	Decrease	7	0.455	16.6	2,121,346	127,997
	0.209						24.2	838,524	37,833
	0.075						8.5	231,156	20,100

TABLE E-ANNEX-2 CMAQ Project Impacts Evaluation: Project Category, Traffic Flow Improvements; Subcategory, Freeway/Incident Management

		Daily Travel Impacts					Emission Reductions (tons per day)		
Source	Designation	VTR	VMTR	Transit Riders	Delay Red. (hr)	Speed Imp. (mph)	HC	NO_x	CO
					Emission Weights:		1	4	0
Hagler Bailly (1999)	ATMS freeway incident management (Atlanta)	NA	NA	NA	NA	NA	0.660	0.632	
DVRPC (1994)	Congestion/incident management on Philadelphia freeways	NA	(12,472)	NA	NA	4.2	0.164	(0.007)	0.703
Univ. of MD (2001)	MDOT CHART Program (ITS)	NA	NA	NA	62,560	NA	0.0213	0.168	0.913
DVRPC (1994)	Ramp metering	NA	43,216	NA			0.412	0.034	3.482
Mean		NA	15,372	NA	62,560	4.2	0.314	0.207	1.699
Median		NA	15,372	NA	62,560	4.2	0.288	0.101	0.913

Travel term definitions: VTR = vehicle trip reduction; VMTR = vehicle miles of travel reduced; transit riders = increase in daily transit ridership.

Emission term definitions: total emissions = weighted sum of HC, NO_x, CO, and PM_{10}; emission weights = importance weights representing value of individual pollutants; emission year = time period for which source study estimate applies; benefits trend indicates whether emissions are decreasing, increasing, or constant over project life.

Cost-effectiveness definitions: BDF = benefits discount factor (combination of benefits trend and discount rate); annual benefits = weighted emissions * days/year * BDF; annual costs = annualized capital costs plus applicable operating, administrative, and private costs.

			Cost-Effectiveness						
PM_{10}	**Total**	**Emission “Year”**	**Life (years)**	**Benefits Trend**	**Discount Rate (%)**	**BDF**	**Ann. Benefits (tons/ year)**	**Annual Costs (2000 $)**	**Cost/Ton (2000 $)**
0									
	3.188	2010	10	Decrease	7	0.455	362.6	853,087	2,352
	0.138	1996	10	Decrease	7	0.455	15.7	8,531,152	543,866
	0.695	1999	5	Decrease	7	0.550	95.5	19,095,000	199,846
	0.549	1996	10	Decrease	7	0.455	62.4	313,856	5,028
	1.142						134.1	7,198,274	187,773
	0.622						79.0	4,692,120	102,437

TABLE E-ANNEX-3 CMAQ Project Impacts Evaluation: Project Category, HOV Facilities

		Daily Travel Impacts					Emission Reductions (tons per day)		
Source	Designation	VTR	VMTR	Transit Riders	Delay Red. (hr)	Speed Imp. (mph)	HC	NO_x	CO
					Emission Weights:		1	4	0
Hagler Bailly (1999)	I-84 HOV lane extension (Hartford)	NA	NA	NA	NA	NA	0.0132	0.0044	
MOCOG (1995)	HOV freeway network	39,400	684,100	(8,000)	NA	NA	0.606	0.847	
TTI (1997)	Katy Freeway HOV (Houston)	5,620	75,600	NA	NA	26%	0.066	(0.035)	
Mean		22,510	379,850	–8,000	NA	0.260	0.228	0.272	
Median		22,510	379,850	–8,000	NA	0.260	0.066	0.004	

Travel term definitions: VTR = vehicle trip reduction; VMTR = vehicle miles of travel reduced; transit riders = increase in daily transit ridership.

Emission term definitions: total emissions = weighted sum of HC, NO_x, CO, and PM_{10}; emission weights = importance weights representing value of individual pollutants; emission year = time period for which source study estimate applies; benefits trend indicates whether emissions are decreasing, increasing, or constant over project life.

Cost-effectiveness definitions: BDF = benefits discount factor (combination of benefits trend and discount rate); annual benefits = weighted emissions * days/year * BDF; annual costs = annualized capital costs plus applicable operating, administrative, and private costs.

			Cost-Effectiveness						
PM_{10}	Total	Emission "Year"	Life (years)	Benefits Trend	Discount Rate (%)	BDF	Annual Benefits (tons/ year)	Annual Costs (2000 $)	Cost/Ton (2000 $)
0									
	0.0308	Avg. over life of project	20	Constant	7	0.567	4.4	1,470,355	336,782
0.339	3.995	1997	20	Constant	6	0.608	607.2	9,527,760	15,690
	(0.074)	1996	20	Constant	7	0.567	(10.5)	8,030,880	NA
	1.317						200.4	6,342,998	176,236
	0.031						4.4	8,030,880	176,236

TABLE E-ANNEX-4 CMAQ Project Impacts Evaluation: Project Category, Ridesharing; Subcategory, Programmatic

		Daily Travel Impacts					Emission Reductions (tons per day)		
Source	Designation	VTR	VMTR	Transit Riders	Delay Red. (hr)	Speed Imp. (mph)	HC	NO_x	CO
					Emission Weights:		1	4	0
Hagler Bailly (1999)	University rideshare program (Atlanta)	864	8,640	NA	NA	NA	0.016	0.016	
Hagler Bailly (1999)	Commuter assistance program (Riverside, CA)	NA	NA	NA	NA	NA	0.011	0.011	0.091
Pansing et al. (1998)	CTS telephone ridematching (Los Angeles)	382	23,868	NA	NA	NA	0.0764	0.0764	
MWCOG (2000)	Integrated ridesharing program	238	6,977	NA	NA	NA	0.0043	0.0093	
DVRPC (1994)	Regional ridesharing program	24,142	184,256	5,539	NA	NA	0.300	0.325	1.542
Mean		6,407	55,935	5,539	NA	NA	0.081	0.087	0.817
Median		623	16,254	5,539	NA	NA	0.016	0.016	0.817

Travel term definitions: VTR = vehicle trip reduction; VMTR = vehicle miles of travel reduced; transit riders = increase in daily transit ridership.

Emission term definitions: total emissions = weighted sum of HC, NO_x, CO, and PM_{10}; emission weights = importance weights representing value of individual pollutants; emission year = time period for which source study estimate applies; benefits trend indicates whether emissions are decreasing, increasing, or constant over project life.

Cost-effectiveness definitions: BDF = benefits discount factor (combination of benefits trend and discount rate); annual benefits = weighted emissions * days/year * BDF; annual costs = annualized capital costs plus applicable operating, administrative, and private costs.

			Cost-Effectiveness						
PM$_{10}$	**Total**	**Emission “Year”**	**Life (years)**	**Benefits Trend**	**Discount Rate (%)**	**BDF**	**Annual Benefits (tons/ year)**	**Annual Costs (2000 $)**	**Cost/Ton (2000 $)**
0									
	0.08	NA	10	Constant	7	0.752	15.0	111,268	7,398
0.007	0.053	1995–96	1	Constant	NA	1.000	26.4	423,287	16,034
0.0382	0.382	1997–2001	1	Constant	NA	1.000	95.5	118,752	1,243
	0.042	1996	1	Constant	NA	1.000	10.4	154,128	14,856
	1.600	1996	1	Constant	NA	1.000	400.1	1,731,785	4,329
0.023	0.431						109.5	507,844	8,772
0.023	0.080						26.4	154,128	7,398

TABLE E-ANNEX-5 CMAQ Project Impacts Evaluation: Project Category, Ridesharing; Subcategory, Vanpool/Buspool Programs

		Daily Travel Impacts					Emission Reductions (tons per day)		
Source	**Designation**	**VTR**	**VMTR**	**Transit Riders**	**Delay Red. (hr)**	**Speed Imp. (mph)**	**HC**	**NO_x**	**CO**
					Emission Weights:		**1**	**4**	**0**
Hagler Bailly (1999)	Regional vanpool program (Houston)	NA	NA	NA	NA	NA	0.12	0.248	
Pansing et al. (1998)	Palmdale community vanpool	66	3,704	NA	NA	NA	0.0026	0.0043	
Pansing et al. (1998)	Torrance vanpool	57	2,950	NA	NA	NA	0.0021	0.0034	
Pansing et al. (1998)	City of Anaheim commuter express buspool	13	2,419	NA	NA	NA	0.0015	0.0027	
Pansing et al. (1998)	UCLA vanpool expansion	127	5,392	NA	NA	NA	0.0040	0.0063	
Pansing et al. (1998)	Coronado TMA vanpool	574	27,520	NA	NA	NA	0.0198	0.0322	
Mean		167	8,397	NA	NA	NA	0.025	0.050	NA
Median		66	3,704	NA	NA	NA	0.003	0.005	NA

Travel term definitions: VTR = vehicle trip reduction; VMTR = vehicle miles of travel reduced; transit riders = increase in daily transit ridership.

Emission term definitions: total emissions = weighted sum of HC, NO_x, CO, and PM_{10}; emission weights = importance weights representing value of individual pollutants; emission year = time period for which source study estimate applies; benefits trend indicates whether emissions are decreasing, increasing, or constant over project life.

Cost-effectiveness definitions: BDF = benefits discount factor (combination of benefits trend and discount rate); annual benefits = weighted emissions * days/year * BDF; annual costs = annualized capital costs plus applicable operating, administrative, and private costs.

			Cost-Effectiveness						
PM_{10}	**Total**	**Emission "Year"**	**Life (years)**	**Benefits Trend**	**Discount Rate (%)**	**BDF**	**Annual Benefits (tons/year)**	**Annual Costs (2000 $)**	**Cost/Ton (2000 $)**
0									
	1.112	1997/98	1	Constant	NA	1.000	278.0	1,708,208	6,145
0.0018	0.020	1997–2001	1	Constant	NA	1.000	5.0	54,516	10,984
0.0015	0.016	1997–2001	1	Constant	NA	1.000	4.0	96,593	24,347
0.0012	0.013	1997–2001	1	Constant	NA	1.000	3.1	31,380	10,017
0.0027	0.029	1997–2001	1	Constant	NA	1.000	7.3	652,379	88,960
0.0136	0.149	1997–2001	1	Constant	NA	1.000	37.2	191,932	5,164
0.004	0.223						55.8	455,835	24,270
0.002	0.025						6.1	144,262	10,501

TABLE E-ANNEX-6 CMAQ Project Impacts Evaluation: Project Category, Ridesharing; Subcategory, Park-and-Ride for Carpool/Vanpool

		Daily Travel Impacts					Emission Reductions (tons per day)		
Source	**Designation**	**VTR**	**VMTR**	**Transit Riders**	**Delay Red. (hr)**	**Speed Imp. (mph)**	**HC**	**NO_x**	**CO**
					Emission Weights:		**1**	**4**	**0**
Hagler Bailly (1999)	Park-and-ride facilities (Baltimore)	0	2,100	42	NA	NA	0.001	0.004	
MWCOG (1995)	Park-and-ride lots at major highway intersections	(730)	63,500	(50)	NA	NA	0.035	0.070	
MOCOG (1995)	Build HOV park-and-ride lots	(2,400)	41,600	NA	NA	NA	0.012	0.041	
DVRPC (1994)	New park-and-ride lots along highways	0	50,616	(1,985)	NA	NA	0.054	0.086	0.330
Mean		(783)	39,454	(664)	NA	NA	0.025	0.050	0.330
Median		(365)	46,108	(50)	NA	NA	0.023	0.056	0.330

Travel term definitions: VTR = vehicle trip reduction; VMTR = vehicle miles of travel reduced; transit riders = increase in daily transit ridership.

Emission term definitions: total emissions = weighted sum of HC, NO_x, CO, and PM_{10}; emission weights = importance weights representing value of individual pollutants; emission year = time period for which source study estimate applies; benefits trend indicates whether emissions are decreasing, increasing, or constant over project life.

Cost-effectiveness definitions: BDF = benefits discount factor (combination of benefits trend and discount rate); annual benefits = weighted emissions * days/year * BDF; annual costs = annualized capital costs plus applicable operating, administrative, and private costs.

			Cost-Effectiveness						
PM$_{10}$	Total	Emission "Year"	Life (years)	Benefits Trend	Discount Rate (%)	BDF	Annual Benefits (tons/year)	Annual Costs (2000 $)	Cost/Ton (2000 $)
0									
	0.017	1999	30	Constant	7	0.443	1.9	16,206	8,607
0.031	0.313	1996	10	Constant	6	0.780	61.1	1,095,692	17,935
0.021	0.177	Avg. over life of project	10	Constant	6	0.780	34.6	2,349,459	67,994
	0.398	1996	10	Constant	7	0.752	74.8	5,291,343	70,717
0.026	0.226						43.1	2,188,175	41,313
0.026	0.245						47.8	1,722,576	42,964

Table E-Annex-7 CMAQ Project Impacts Evaluation: Project Category, Travel Demand Management; Subcategory, Regional Approaches

		Daily Travel Impacts					Emission Reductions (tons per day)		
Source	**Designation**	**VTR**	**VMTR**	**Transit Riders**	**Delay Red. (hr)**	**Speed Imp. (mph)**	**HC**	**NO_x**	**CO**
					Emission Weights:		**1**	**4**	**0**
Hagler Bailly (1999)	Long Island TDM program	300	13,500	NA	NA	NA	0.018	0.028	0.142
Hagler Bailly (1999)	IEPA public education and outreach (Chicago)	NA	NA	NA	NA	NA	0.102	0.102	
Hagler Bailly (1999)	Regional TMAs (Atlanta)	NA	NA	NA	NA	NA	0.105	0.106	
Hagler Bailly (1999)	Glendale, CA, TMA parking management program	NA	NA	NA	NA	NA	0.018	0.020	0.156
Hagler Bailly (1999)	Clean air action program transit subsidy (Houston)	NA	NA	75,627	NA	NA	0.117	0.139	
Pansing et al. (1998)	Santa Monica TMA	253	3802	NA	NA	NA	0.0037	0.0048	
Pansing et al. (1998)	Los Angeles County integrated TDM	215	3867	NA	NA	NA	0.0035	0.0048	
Hagler Bailly (1999)	MARTA employer transit passes	1,504	39,104	1,504	NA	NA	0.066	0.067	
Mean		568	15,068	38,566	NA	NA	0.054	0.059	0.149
Median		277	8,684	38,566	NA	NA	0.042	0.047	0.149

Travel term definitions: VTR = vehicle trip reduction; VMTR = vehicle miles of travel reduced; transit riders = increase in daily transit ridership.

Emission term definitions: total emissions = weighted sum of HC, NO_x, CO, and PM_{10}; emission weights = importance weights representing value of individual pollutants; emission year = time period for which source study estimate applies; benefits trend indicates whether emissions are decreasing, increasing, or constant over project life.

Cost-effectiveness definitions: BDF = benefits discount factor (combination of benefits trend and discount rate); annual benefits = weighted emissions * days/year * BDF; annual costs = annualized capital costs plus applicable operating, administrative, and private costs.

					Cost-Effectiveness				
PM_{10}	Total	Emission “Year”	Life (years)	Benefits Trend	Discount Rate (%)	BDF	Annual Benefits (tons/year)	Annual Costs (2000 $)	Cost/Ton (2000 $)
0									
	0.129	Average	5	Constant	10	0.834	26.9	454,500	16,885
	0.511	1998	2	Constant	NA	1.000	127.8	297,102	2,326
	0.529	2005	12	Increase	7	0.278	36.8	300,183	8,165
0.012	0.098	1995	1	Constant	NA	1.000	24.6	108,889	4,428
	0.673	1996	2	Constant	NA	1.000	168.4	3,549,000	21,081
0.0019	0.023	1997–2001	1	Constant	NA	1.000	5.8	170,214	29,521
0.0019	0.023	1997–2001	1	Constant	NA	1.000	5.7	189,609	33,205
	0.334	1999	1	Constant	NA	1.000	83.5	376,875	4,513
0.005	0.290						59.9	680,797	15,016
0.002	0.232						31.8	298,643	12,525

TABLE E-ANNEX-8 CMAQ Project Impacts Evaluation: Project Category, Travel Demand Management; Subcategory, Employer Trip Reduction Programs and ECO

		Daily Travel Impacts					Emission Reductions (tons per day)		
Source	**Designation**	**VTR**	**VMTR**	**Transit Riders**	**Delay Red. (hr)**	**Speed Imp. (mph)**	**HC**	**NO_x**	**CO**
						Emission Weights:	**1**	**4**	**0**
Wachs (1994)	Regulation XV program	334,480	2,675,840	2.0%	NA	NA	3.455	3.761	
Ernst & Young (1993)	Regulation XV program	334,480	2,675,840	2.0%	NA	NA	3.455	3.761	
TTI (1996)	Houston ECO program (at $50/employee)	NA	NA	NA	NA	NA	2.820	2.830	
TTI (1996)	Houston ECO program (at $200/employee)	NA	NA	NA	NA	NA	2.820	2.830	24.960
MWCOG (1995)	On-site voluntary ETR	95,600	1,411,600	25,800	NA	NA	1.379	1.802	
MWCOG (1995)	Mandatory ECO	415,600	6,135,000	48,400	NA	NA	5.996	7.830	
DVRPC (1994)	Implement ECO/meet APO targets in PA portion of Philadelphia	161,236	1,226,424	55,567	NA	NA	1.791	2.200	11.479
Mean		268,279	2,824,941	25,953	NA	NA	3.102	3.573	18.220
Median		334,480	2,675,840	25,800	NA	NA	2.820	2.830	18.220

Travel term definitions: VTR = vehicle trip reduction; VMTR = vehicle miles of travel reduced; transit riders = increase in daily transit ridership.

Emission term definitions: total emissions = weighted sum of HC, NO_x, CO, and PM_{10}; emission weights = importance weights representing value of individual pollutants; emission year = time period for which source study estimate applies; benefits trend indicates whether emissions are decreasing, increasing, or constant over project life.

Cost-effectiveness definitions: BDF = benefits discount factor (combination of benefits trend and discount rate); annual benefits = weighted emissions $*$ days/year $*$ BDF; annual costs = annualized capital costs plus applicable operating, administrative, and private costs.

			Cost-Effectiveness						
PM_{10}	**Total**	**Emission "Year"**	**Life (years)**	**Benefits Trend**	**Discount Rate (%)**	**BDF**	**Annual Benefits (tons/ year)**	**Annual Costs (2000 $)**	**Cost/ Ton (2000 $)**
0									
1.326	18.50	1997–2001	1	Constant	NA	1.000	4,624.9	61,020,000	13,194
1.326	18.50	1997–2001	1	Constant	NA	1.000	4,624.9	263,877,600	57,056
	14.14	1997–2001	1	Constant	NA	1.000	3,535.0	20,101,942	5,687
	14.14	1997–2001	1	Constant	NA	1.000	3,535.0	80,407,766	22,746
	8.59	1997–2001	1	Constant	NA	1.000	2,146.5	376,779,600	175,536
	37.32	1997–2001	1	Constant	NA	1.000	9,328.9	170,786,301	18,307
	10.59	1996	1	Constant	NA	1.000	2,647.8	115,138,686	43,485
1.326	17.40						4,349.0	155,444,556	48,002
1.326	14.14						3,535.0	115,138,686	22,746

TABLE E-ANNEX-9 CMAQ Project Impacts Evaluation: Project Category, Alternative Work Arrangements/Hours; Subcategory, Telecommuting/Telework

		Daily Travel Impacts					Emission Reductions (tons per day)		
Source	**Designation**	**VTR**	**VMTR**	**Transit Riders**	**Delay Red. (hr)**	**Speed Imp. (mph)**	**HC**	**NO_x**	**CO**
					Emission Weights:		**1**	**4**	**0**
Pansing et al. (1998)	Antelope Valley telebusiness center	3	3,732	NA	NA	NA	0.0023	0.0042	
Pansing et al. (1998)	Santa Clarita telebusiness center	0	2,200	NA	NA	NA	0.0013	0.0025	
Pansing et al. (1998)	Pomona telebusiness	3	338	NA	NA	NA	0.0002	0.0004	
Pansing et al. (1998)	Long Beach telebusiness	15	163	NA	NA	NA	0.0002	0.0002	
Pansing et al. (1998)	LA Public Defender interview teleconferencing	9	370	NA	NA	NA	0.0003	0.0004	
Pansing et al. (1998)	San Bernardino Probation Dept. teleconferencing	8	451	NA	NA	NA	0.0003	0.0005	
Pansing et al. (1998)	College of the Desert telecommuting program	7	924	NA	NA	NA	0.0006	0.0011	
MWCOG (1995)	Regional telecommute incentives	62,500	868,700	(12,500)	NA	NA	0.81	0.810	
MWCOG (1995)	Regional telecommute centers	19,000	1,083,400	NA	NA	NA	0.02	0.020	
DVRPC (1994)	Regional telecommute program	48,306	388,368	(20,289)	NA	NA	0.586	0.682	3.309
Mean		12,985	234,865	(16,395)	NA	NA	0.142	0.152	3.309
Median		8	1,562	(16,395)	NA	NA	0.001	0.002	3.309

Travel term definitions: VTR = vehicle trip reduction; VMTR = vehicle miles of travel reduced; transit riders = increase in daily transit ridership.

Emission term definitions: total emissions = weighted sum of HC, NO_x, CO, and PM_{10}; emission weights = importance weights representing value of individual pollutants; emission year = time period for which source study estimate applies; benefits trend indicates whether emissions are decreasing, increasing, or constant over project life.

Cost-effectiveness definitions: BDF = benefits discount factor (combination of benefits trend and discount rate); annual benefits = weighted emissions $*$ days/year $*$ BDF; annual costs = annualized capital costs plus applicable operating, administrative, and private costs.

			Cost-Effectiveness						
PM_{10}	Total	Emission "Year"	Life (years)	Benefits Trend	Discount Rate (%)	BDF	Annual Benefits (tons/ year)	Annual Costs (2000 $)	Cost/ Ton (2000 $)
0									
0.0018	0.019	1997–2001	5	Increasing	10	0.332	1.6	380,045	240,108
0.0011	0.0112	1997–2001	5	Increasing	10	0.332	0.9	245,427	263,588
0.0002	0.0018	1997–2001	5	Increasing	10	0.332	0.1	228,388	1,559,107
0.0001	0.0011	1997–2001	5	Increasing	10	0.332	0.1	720,523	8,227,399
0.0002	0.0020	1997–2001	5	Increasing	10	0.332	0.2	160,296	958,156
0.0002	0.0024	1997–2001	5	Increasing	10	0.332	0.2	173,623	866,193
0.0005	0.0048	1997–2001	5	Increasing	10	0.332	0.4	44,150	110,327
	4.050	1996	1	Constant	NA	1.000	1,012.5	83,494,215	82,463
	0.100	1996	10	Increasing	6	0.314	7.9	1,226,158	156,198
	3.314	1996	1	Increasing	NA	1.000	828.5	11,024,442	13,307
0.001	0.751						185.2	9,769,727	1,247,685
0.000	0.008						0.7	312,736	251,848

TABLE E-ANNEX-10 CMAQ Project Impacts Evaluation: Project Category, Bike/Pedestrian Improvements

		Daily Travel Impacts					Emission Reductions (tons per day)		
Source	**Designation**	**VTR**	**VMTR**	**Transit Riders**	**Delay Red. (hr)**	**Speed Imp. (mph)**	**HC**	**NO_x**	**CO**
				Emission Weights:			**1**	**4**	**0**
Hagler Bailly (1999)	Philadelphia bicycle network plan	NA	NA	NA	NA	NA	0.030	0.026	
Hagler Bailly (1999)	Frankfort, IL, suburban bike rack incentive program	NA	NA	NA	NA	NA	0.001	0.001	
Pansing et al. (1998)	Coronado TMA bike program	85	1,945	NA	NA	NA	0.002	0.002	
MWCOG (1995)	Advanced completion of LRP bike element	23,867	28,100	NA	NA	NA	0.148	0.086	
DVRPC (1994)	Regional bike improvements to capture 5% of work trips < 5 mi	61,985	92,584	(13,469)	NA	NA	0.211	0.180	1.026
DVRPC (1994)	Capture 5% of nonwork trips < 5 mi	112,712	160,336	(7,484)	NA	NA	0.332	0.343	1.750
Pansing et al. (1998)	LA City bike lockers	23	544	NA	NA	NA	0.0005	0.0007	
Pansing et al. (1998)	Santa Clarita bike lockers	18	101	NA	NA	NA	0.0002	0.0002	
Pansing et al. (1998)	OCTA bike and ride	39	629	NA	NA	NA	0.0006	0.0008	
MWCOG (1995)	Improved pedestrian facilities near rail stations	1,900	17,000	2,600	NA	NA	0.021	0.023	
MWCOG (1995)	Transit station bike racks and lockers	20,186	22,800	2,016	NA	NA	0.025	0.030	
MWCOG (1995)	Employer-provided bicycles	4,500	13,500	NA	NA	NA	0.033	0.025	
Pansing et al. (1998)	Fullerton bike loan, Ph. I	135	405	NA	NA	NA	0.0010	0.0008	

			Cost-Effectiveness						
PM$_{10}$	Total	Emission "Year"	Life (years)	Benefits Trend	Discount Rate (%)	BDF	Annual Benefits (tons/ year)	Annual Costs (2000 $)	Cost/ Ton (2000 $)
0									
	0.132	1994	30	Increase	7	0.144	4.8	322,024	67,520
	0.005	Avg. over life of project	30	Increase	7	0.144	0.2	27,232	145,471
0.001	0.011	1997–2001	12	Increase	5	0.318	0.9	9,182	10,364
0.014	0.490	1997–2001	10	Increase	6	0.332	40.7	3,013,876	74,121
	0.929	1996	20	Increase	7	0.144	33.5	3,249,698	97,137
	1.703	1996	20	Increase	7	0.144	61.3	5,627,794	91,795
0.0003	0.0031	1997–2001	12	Increase	5	0.318	0.2	16,149	65,445
0.0000	0.001	1997–2001	12	Increase	5	0.318	0.1	18,091	295,605
0.0003	0.004	1997–2001	12	Increase	5	0.318	0.3	29,660	98,759
0.008	0.114	1997–2001	10	Increase	6	0.332	9.5	3,269,754	344,660
0.011	0.146	1997–2001	10	Increase	6	0.332	12.1	51,368	4,248
0.007	0.134	1997–2001	10	Increase	6	0.332	11.1	2,042,694	183,526
0.0002	0.004	1997–2001	12	Increase	5	0.318	0.3	9,578	29,892

(*continued*)

TABLE E-ANNEX-10 (*continued*) **CMAQ Project Impacts Evaluation: Project Category, Bike/Pedestrian Improvements**

		Daily Travel Impacts					Emission Reductions (tons per day)		
Source	**Designation**	**VTR**	**VMTR**	**Transit Riders**	**Delay Red. (hr)**	**Speed Imp. (mph)**	**HC**	**NO_x**	**CO**
					Emission Weights:		**1**	**4**	**0**
Pansing et al. (1998)	Fullerton bike loan, Ph. II	15	47	NA	NA	NA	0.0001	0.0001	
Mean		18,789	28,166	(4,084)	NA	NA	0.057	0.051	1.388
Median		1,018	7,722	(2,734)	NA	NA	0.011	0.013	1.388

Travel term definitions: VTR = vehicle trip reduction; VMTR = vehicle miles of travel reduced; transit riders = increase in daily transit ridership.

Emission term definitions: total emissions = weighted sum of HC, NO_x, CO, and PM_{10}; emission weights = importance weights representing value of individual pollutants; emission year = time period for which source study estimate applies; benefits trend indicates whether emissions are decreasing, increasing, or constant over project life.

Cost-effectiveness definitions: BDF = benefits discount factor (combination of benefits trend and discount rate); annual benefits = weighted emissions * days/year * BDF; annual costs = annualized capital costs plus applicable operating, administrative, and private costs.

			Cost-Effectiveness						
PM_{10}	Total	Emission "Year"	Life (years)	Benefits Trend	Discount Rate (%)	BDF	Annual Benefits (tons/ year)	Annual Costs (2000 $)	Cost/ Ton (2000 $)
0									
0.0000	0.0005	1997–2001	12	Increase	5	0.318	0.0	2,814	76,475
0.004	0.263						12.5	1,263,565	113,216
0.001	0.063						2.8	40,514	84,135

TABLE E-ANNEX-11 CMAQ Project Impacts Evaluation: Project Category, Transit; Subcategory, New Shuttle and/or Feeder Services

		Daily Travel Impacts					Emission Reductions (tons per day)		
Source	**Description**	**VTR**	**VMTR**	**Transit Riders**	**Delay Red. (hr)**	**Speed Imp. (mph)**	**HC**	**NO_x**	**CO**
				Emission Weights:			**1**	**4**	**0**
Hagler Bailly (1999)	Lake Cook, IL, Shuttle Bug	NA	NA	NA	NA	NA	0.026	0.026	
Hagler Bailly (1999)	University City/30th Street circulator (Philadelphia)	NA	NA	NA	NA	NA	0.004	0.0032	
Pansing et al. (1998)	Children's Court shuttle	67	3,342	NA	NA	NA	0.0024	0.0039	
Pansing et al. (1998)	PVTA Metrolink connection	15	92	NA	NA	NA	0.0001	0.0001	
Pansing et al. (1998)	Santa Clarita shuttles and shelters	8	63	NA	NA	NA	0.0001	0.0001	
Pansing et al. (1998)	West Hollywood Sunset shuttle	25	40	NA	NA	NA	0.0002	0.0001	
Pansing et al. (1998)	Hollywood Connection	66	1,970	NA	NA	NA	0.0016	0.0024	
Pansing et al. (1998)	Burbank Media District TMO shuttle	124	2,471	NA	NA	NA	0.0022	0.0031	
Pansing et al. (1998)	City of Anaheim express feeder	11	167	NA	NA	NA	0.0002	0.0002	
Pansing et al. (1998)	Orange County employer shuttle	22	348	NA	NA	NA	0.0003	0.0004	
Pansing et al. (1998)	Mainplace Santa Ana shuttle	14	70	NA	NA	NA	0.0001	0.0001	
Pansing et al. (1998)	City of Los Angeles EV shuttle	16	183	NA	NA	NA	0.0002	0.0002	
Pansing et al. (1998)	Big Bear transit and dial-a-ride	67	336	NA	NA	NA	0.0006	0.0005	
Michael Baker (1997)	Pace VIP transit van program	2,529	119,956	4,846	NA	NA	0.0666	0.156	0.639
Michael Baker (1997)	NJ Transit WHEELS program	4,070	57,653	11,016	NA	NA	0.057	0.074	
Mean		541	14,361	7,931	NA	NA	0.011	0.018	0.639
Median		25	336	7,931	NA	NA	0.001	0.001	0.639

Travel term definitions: VTR = vehicle trip reduction; VMTR = vehicle miles of travel reduced; transit riders = increase in daily transit ridership.

Emission term definitions: total emissions = weighted sum of HC, NO_x, CO, and PM_{10}; emission weights = importance weights representing value of individual pollutants; emission year = time period for which source study estimate applies; benefits trend indicates whether emissions are decreasing, increasing, or constant over project life.

			Cost-Effectiveness						
PM$_{10}$	**Total**	**Emission "Year"**	**Life (years)**	**Benefits Trend**	**Discount Rate (%)**	**BDF**	**Annual Benefits (tons/ year)**	**Annual Costs (2000 $)**	**Cost/Ton (2000 $)**
0									
	0.129	1998	1	Constant	NA	1.000	32.2	395,460	12,300
	0.0168	1994	1	Constant	NA	1.000	4.2	367,200	87,429
0.0017	0.0180	1997–2001	1	Constant	NA	1.000	4.5	337,975	75,056
0.0000	0.0007	1997–2001	1	Constant	NA	1.000	0.2	49,327	284,761
0.0000	0.0004	1997–2001	1	Constant	NA	1.000	0.1	57,683	525,676
0.0000	0.0006	1997–2001	1	Constant	NA	1.000	0.1	279,191	1,973,671
0.0010	0.011	1997–2001	1	Constant	NA	1.000	2.7	85,704	31,171
0.0012	0.014	1997–2001	1	Constant	NA	1.000	3.6	195,723	54,392
0.0001	0.001	1997–2001	1	Constant	NA	1.000	0.3	11,346	45,155
0.0002	0.002	1997–2001	1	Constant	NA	1.000	0.5	68,064	129,803
0.0000	0.001	1997–2001	1	Constant	NA	1.000	0.1	54,634	385,857
0.0001	0.001	1997–2001	1	Constant	NA	1.000	0.3	227,623	776,958
0.0002	0.003	1997–2001	1	Constant	NA	1.000	0.7	383,201	570,082
0.059	0.691	1997–2001	4	Constant	6	0.918	158.5	3,919,500	24,730
0.029	0.353	1997	1	Constant	NA	1.000	88.3	5,025,000	56,931
0.007	0.083						19.8	763,842	335,598
0.000	0.003						0.7	227,623	87,429

Cost-effectiveness definitions: BDF = benefits discount factor (combination of benefits trend and discount rate); annual benefits = weighted emissions ∗ days/year ∗ BDF; annual costs = annualized capital costs plus applicable operating, administrative, and private costs.

TABLE E-ANNEX-12 CMAQ Project Impacts Evaluation: Project Category, Transit Improvements; Subcategory, New Fixed Guideway Systems or Equipment

		Daily Travel Impacts					Emission Reductions (tons per day)		
Source	**Designation**	**VTR**	**VMTR**	**Transit Riders**	**Delay Red. (hr)**	**Speed Imp. (mph)**	**HC**	**NO$_x$**	**CO**
				Emission Weights:			**1**	**4**	**0**
Hagler Bailly (1999)	New light rail vehicles (Baltimore)	3,044	42,135	3,044	NA	NA	0.025	0.083	
Hagler Bailly (1999)	Commuter rail coaches (MARC/ Maryland)	4,508	271,291	5,410	NA	NA	0.111	0.373	
		97	776	NA	NA	NA	0.001	0.001	0.009
Pansing et al. (1998)	Coronado ferry								
Michael Baker (1997)	St. Louis MetroLink LRT	0	133,560	22,260	NA	NA	0.087	0.1	
Michael Baker (1997)	Ottawa TransitWay	181,818	2,258,609	200,000	NA	NA	2.365	2.948	
Parsons Brinckerhoff (1999)	Metra North Central commuter rail	2,267	67,500	4,306	NA	NA	0.126	0.174	
Mean		31,956	462,312	47,004	NA	NA	0.453	0.613	0.009
Median		2,656	100,530	5,410	NA	NA	0.099	0.137	0.009

Travel term definitions: VTR = vehicle trip reduction; VMTR = vehicle miles of travel reduced; transit riders = increase in daily transit ridership.

Emission term definitions: total emissions = weighted sum of HC, NO$_x$, CO, and PM$_{10}$; emission weights = importance weights representing value of individual pollutants; emission year = time period for which source study estimate applies; benefits trend indicates whether emissions are decreasing, increasing, or constant over project life.

Cost-effectiveness definitions: BDF = benefits discount factor (combination of benefits trend and discount rate); annual benefits = weighted emissions ∗ days/year ∗ BDF; annual costs = annualized capital costs plus applicable operating, administrative, and private costs.

			Cost-Effectiveness						
PM$_{10}$	**Total**	**Emission "Year"**	**Life (years)**	**Benefits Trend**	**Discount Rate (%)**	**BDF**	**Annual Benefits (tons/ year)**	**Annual Costs (2000 $)**	**Cost/ Ton (2000 $)**
0									
	0.358	2005	30	Modif. constant	7	0.567	50.8	5,083,261	100,114
	1.602	1998	30	Modif. constant	7	0.567	227.1	7,410,339	32,627
0.002	0.004	1997–2001	1	Constant	NA	1.000	1.0	138,002	132,617
0.035	0.487	1997	30	Constant + increase	6	0.654	79.6	37,486,500	470,791
1.119	14.156	1997–2001	30	Constant + increase	6	0.654	2,314.5	19,687,950	8,506
0.335	0.822	1996	30	Constant + increase	6	0.654	134.4	2,362,620	17,579
0.373	2.905						467.9	12,028,112	127,039
0.185	0.655						107.0	6,246,800	66,370

TABLE E-ANNEX-13 CMAQ Project Impacts Evaluation: Project Category, Transit Improvements; Subcategory, Conventional Transit Service Improvements

		Daily Travel Impacts					Emission Reductions (tons per day)		
Source	Description	VTR	VMTR	Transit Riders	Delay Red. (hr)	Speed Imp. (mph)	HC	NO_x	CO
				Emission Weights:			1	4	0
Hagler Bailly (1999)	MARTA ITS traveler information system	NA	NA	720	NA	NA	0.008	0.009	
Pansing et al.(1998)	MTDB Route 19	149	892	NA	NA	NA	0.0014	0.0013	
Pansing et al.(1998)	MTDB Route 901	2,100	16,803	NA	NA	NA	0.022	0.024	
Pansing et al.(1998)	MTDB Routes 933/934	2,376	19,011	NA	NA	NA	0.025	0.027	
MWCOG (1995)	Increased frequency of existing transit service	72,100	1,153,300	90,000	NA	NA	1.094	1.458	
MWCOG (1995)	Increased frequency of commuter rail service	8,100	221,400	13,300	NA	NA	0.179	0.267	
MWCOG (1995)	Increased suburban coverage, timed transfer	18,900	274,500	23,300	NA	NA	0.270	0.351	
MWCOG (1995)	Increased bus speeds in bus corridors	4,100	49,500	5,400	NA	NA	0.053	0.065	
DVRPC (1994)	Suburban bus service improvements	5,373	54,000	6,161	NA	NA	0.067	0.101	0.433
DVRPC (1994)	Reduce city transit headways by 10%	4,579	52,512	5,343	NA	NA	0.094	0.089	0.410
Mean		13,086	204,657	20,603	NA	NA	0.181	0.239	0.422
Median		4,579	52,512	6,161	NA	NA	0.060	0.077	0.422

Travel term definitions: VTR = vehicle trip reduction; VMTR = vehicle miles of travel reduced; transit riders = increase in daily transit ridership.

Emission term definitions: total emissions = weighted sum of HC, NO_x, CO, and PM_{10}; emission weights = importance weights representing value of individual pollutants; emission year = time period for which source study estimate applies; benefits trend indicates whether emissions are decreasing, increasing, or constant over project life.

Cost-effectiveness definitions: BDF = benefits discount factor (combination of benefits trend and discount rate); annual benefits = weighted emissions ∗ days/year ∗ BDF; annual costs = annualized capital costs plus applicable operating, administrative, and private costs.

			Cost-Effectiveness						
PM_{10}	Total	Emission "Year"	Life (years)	Benefits Trend	Discount Rate (%)	BDF	Annual Benefits (tons/ year)	Annual Costs (2000 $)	Cost/Ton (2000 $)
0									
	0.044	1999	10	Constant	7	8.3	0.752	31,709	3,833
	0.007	1997–2001	1	Constant	5	1.7	1.000	133,125	79,404
	0.116	1997–2001	1	Constant	5	29.0	1.000	1,107,009	38,118
	0.131	1997–2001	1	Constant	5	32.9	1.000	837,400	25,486
0.572	6.927	1997–2001	10	Constant + increase	6	1,894.6	1.094	41,954,625	22,144
0.110	1.247	1997–2001	30	Constant + increase	6	203.8	0.654	24,472,629	120,080
0.136	1.674	1997–2001	10	Constant + increase	6	457.8	1.094	10,861,887	23,726
0.025	0.312	1997–2001	10	Constant + increase	6	85.4	1.094	2,516,676	29,483
	0.473	1996	10	Constant + increase	7	124.0	1.049	2,065,306	16,657
	0.451	1996	10	Constant + increase	7	118.2	1.049	2,106,468	17,814
0.210	1.138					295.6		8,608,683	37,674
0.123	0.382					101.8		2,085,887	24,606

TABLE E-ANNEX-13A CMAQ Project Impacts Evaluation: Project Category, Transit; Subcategory, Park-and-Ride at Transit Stations

		Daily Travel Impacts					Emission Reductions (tons per day)		
Source	Description	VTR	VMTR	Transit Riders	Delay Red. (hr)	Speed Imp. (mph)	HC	NO_x	CO
				Emission Weights:			1	4	0
DVRPC (1994)	Expand parking at rail stations	0	106,160	7,352	NA	NA	0.111	0.187	0.654

Travel term definitions: VTR = vehicle trip reduction; VMTR = vehicle miles of travel reduced; transit riders = increase in daily transit ridership.

Emission term definitions: total emissions = weighted sum of HC, NO_x, CO, and PM_{10}; emission weights = importance weights representing value of individual pollutants; emission year = time period for which source study estimate applies; benefits trend indicates whether emissions are decreasing, increasing, or constant over project life.

Cost-effectiveness definitions: BDF = benefits discount factor (combination of benefits trend and discount rate); annual benefits = weighted emissions ∗ days/year ∗ BDF; annual costs = annualized capital costs plus applicable operating, administrative, and private costs.

			Cost-Effectiveness						
PM_{10}	Total	Emission “Year”	Life (years)	Benefits Trend	Discount Rate (%)	BDF	Annual Benefits (tons/ year)	Annual Costs (2000 $)	Cost/Ton (2000 $)
0									
	0.861	1996	10	Constant	7	0.752	161.8	9,084,935	56,158
	0.861						161.8	**Mean**	56,158
	0.861						161.8	**Median**	56,158

Table E-Annex-14 CMAQ Project Impacts Evaluation: Project Category, Alternative Fuels; Subcategory, AFV Bus Purchase, Replacement, or Conversion

		Daily Travel Impacts					Emission Reductions (tons per day)		
Source	**Description**	**VTR**	**VMTR**	**Transit Riders**	**Delay Red. (hr)**	**Speed Imp. (mph)**	**HC**	**NO$_x$**	**CO**
					Emission Weights:		**1**	**4**	**0**
Michael Baker (1997)	Boise CNG bus replacement	NA	NA	NA	NA	NA	0.008	0.122	0.375
Pansing et al.(1998)	CUSD clean air van purchase	2	55	NA	NA	NA	0.0000	0.0001	
Pansing et al.(1998)	MTDB Route 904	143	429	NA	NA	NA	0.001	0.001	
Pansing et al.(1998)	MTDB Route 901	2,100	16,803	NA	NA	NA	0.022	0.024	
Pansing et al.(1998)	MTDB Routes 933/934	2,376	19,011	NA	NA	NA	0.025	0.027	
Pansing et al.(1998)	SCE electric vans/shuttles	NA	NA	NA	NA	NA	0.024	0.024	
Pansing et al.(1998)	Laguna Beach electric bus	NA	55	NA	NA	NA	0.012	0.012	
Pansing et al.(1998)	Los Angeles County CNG bus replacement	NA	NA	NA	NA	NA	0.001	0.001	
Pansing et al.(1998)	Pacific Bell CNG bus replacement	NA	NA	NA	NA	NA	0.003	0.003	
Pansing et al.(1998)	Huntington Beach CNG bus replacement	NA	NA	NA	NA	NA	0.000	0.000	
Pansing et al.(1998)	Oldtimers' Foundation CNG bus replacement	NA	NA	NA	NA	NA	0.000	0.000	
Mean		1,155	7,270	NA	NA	NA	0.009	0.019	0.375
Median		1,122	429	NA	NA	NA	0.003	0.003	0.375

Travel term definitions: VTR = vehicle trip reduction; VMTR = vehicle miles of travel reduced; transit riders = increase in daily transit ridership.

Emission term definitions: total emissions = weighted sum of HC, NO$_x$, CO, and PM$_{10}$; emission weights = importance weights representing value of individual pollutants; emission year = time period for which source study estimate applies; benefits trend indicates whether emissions are decreasing, increasing, or constant over project life.

Cost-effectiveness definitions: BDF = benefits discount factor (combination of benefits trend and discount rate); annual benefits = weighted emissions $*$ days/year $*$ BDF; annual costs = annualized capital costs plus applicable operating, administrative, and private costs.

			Cost-Effectiveness						
PM_{10}	Total	Emission "Year"	Life (years)	Benefits Trend	Discount Rate (%)	BDF	Annual Benefits (tons/ year)	Annual Costs (2000 $)	Cost/Ton (2000 $)
0									
0.012	0.495	1997	12	Constant	5	0.776	96.1	652,245	6,788
	0.0003	1997–2001	5	Constant	5	0.909	0.1	8,771	126,396
	0.004	1997–2001	12	Constant	5	0.776	0.8	175,376	212,267
	0.116	1997–2001	12	Constant	5	0.776	22.5	1,107,009	49,121
	0.131	1997–2001	12	Constant	5	0.776	25.5	837,400	32,842
	0.118	1997–2001	12	Constant	5	0.776	23.0	153,888	6,701
	0.059	1997–2001	12	Constant	5	0.776	11.5	82,106	7,150
	0.004	1997–2001	12	Constant	5	0.776	0.8	338,145	443,233
	0.015	1997–2001	12	Constant	5	0.776	2.8	1,603,548	568,676
	0.002	1997–2001	12	Constant	5	0.776	0.4	219,051	508,045
	0.0005	1997–2001	12	Constant	5	0.776	0.1	51,552	518,499
0.012	0.086						16.7	475,372	225,429
0.012	0.015						2.8	219,051	126,396

Table E-Annex-14A CMAQ Project Impacts Evaluation: Project Category, Conventional Fuels; Subcategory, Replacement Buses

		Daily Travel Impacts					Emission Reductions (tons per day)		
Source	**Description**	**VTR**	**VMTR**	**Transit Riders**	**Delay Red. (hr)**	**Speed Imp. (mph)**	**HC**	**NO_x**	**CO**
				Emission Weights:			**1**	**4**	**0**
CARB (1999)	Replace pre-1991 with post-1996 buses; urban use, 15 mph, 4 g/b-hp NO_x std.	NA	NA	NA	NA	NA	0.0001	0.0008	
CARB (1999)	Replace pre-1991 with post-1996 buses; urban use, 15 mph, 2 g/b-hp NO_x std.	NA	NA	NA	NA	NA	0.0001	0.002	
CARB (1999)	Replace pre-1991 with post-1996 buses; commuter use, 45 mph, 4 g/b-hp NO_x std.	NA	NA	NA	NA	NA	0.0001	0.002	
MDOT (2000)	Replace pre-1991 with post-1996 buses; commuter use, 45 mph, 2 g/b-hp NO_x std.	NA	NA	NA	NA	NA	0.0001	0.003	
Schimek (2000)	Replace pre-1991 with post-1996 buses	NA	NA	NA	NA	NA	0.0001	0.003	
	Replace pre-1991 with post-1996 buses	NA	NA	NA	NA	NA	NA	NA	NA
Mean		NA	NA	NA	NA	NA	0.0001	0.0021	NA
Median		NA	NA	NA	NA	NA	0.0001	0.0022	NA

Travel term definitions: VTR = vehicle trip reduction; VMTR = vehicle miles of travel reduced; transit riders = increase in daily transit ridership.

Emission term definitions: total emissions = weighted sum of HC, NO_x, CO, and PM_{10}; emission weights = importance weights representing value of individual pollutants; emission year = time period for which source study estimate applies; benefits trend indicates whether emissions are decreasing, increasing, or constant over project life.

Cost-effectiveness definitions: BDF = benefits discount factor (combination of benefits trend and discount rate); annual benefits = weighted emissions $*$ days/year $*$ BDF; annual costs = annualized capital costs plus applicable operating, administrative, and private costs.

			Cost-Effectiveness						
PM$_{10}$	Total	Emission "Year"	Life (years)	Benefits Trend	Discount Rate (%)	BDF	Annual Benefits (tons/ year)	Annual Costs (2000 $)	Cost/Ton (2000 $)
0									
0.0001	0.0034	2000	12	Constant	5	0.776	0.7	27,500	39,924
0.0001	0.0088	2000	12	Constant	5	0.776	1.7	27,500	16,083
0.0001	0.0064	2000	12	Constant	5	0.776	1.2	27,500	22,239
0.0001	0.0103	2000	12	Constant	5	0.776	2.0	27,500	13,824
	0.0129	2000	12	Constant	5	0.776	2.5	27,500	10,952
NA	NA	2000	12	Constant	5	0.776	NA	NA	388
0.0001	0.0084						1.6	27,500	17,235
0.0001	0.0088						1.7	27,500	14,953

TABLE E-ANNEX-14B CMAQ Project Impacts Evaluation: Project Category, Alternative Fuels; Subcategory, Alternative-Fuel Vehicles (Nontransit) and Refueling Facilities

		Daily Travel Impacts					Emission Reductions (tons per day)		
Source	**Description**	**VTR**	**VMTR**	**Transit Riders**	**Delay Red. (hr)**	**Speed Imp. (mph)**	**HC**	**NO_x**	**CO**
				Emission Weights:			**1**	**4**	**0**
Hagler Bailly (1999)	Fairfax County, VA, alternative fuel vehicles	NA	NA	NA	NA	NA	0.002	0.0045	
Hagler Bailly (1999)	Douglas County, GA, alternative fuels refueling station	NA	NA	NA	NA	NA	0.011	0.0080	
Mean		NA	NA	NA	NA	NA	0.007	0.006	NA
Median		NA	NA	NA	NA	NA	0.007	0.006	NA

Travel term definitions: VTR = vehicle trip reduction; VMTR = vehicle miles of travel reduced; transit riders = increase in daily transit ridership.

Emission term definitions: total emissions = weighted sum of HC, NO_x, CO, and PM_{10}; emission weights = importance weights representing value of individual pollutants; emission year = time period for which source study estimate applies; benefits trend indicates whether emissions are decreasing, increasing, or constant over project life.

Cost-effectiveness definitions: BDF = benefits discount factor (combination of benefits trend and discount rate); annual benefits = weighted emissions ∗ days/year ∗ BDF; annual costs = annualized capital costs plus applicable operating, administrative, and private costs.

			Cost-Effectiveness						
PM$_{10}$	**Total**	**Emission “Year”**	**Life (years)**	**Benefits Trend**	**Discount Rate (%)**	**BDF**	**Annual Benefits (tons/ year)**	**Annual Costs (2000 $)**	**Cost/Ton (2000 $)**
0									
	0.020	2000	5	Constant	7	0.877	4.4	138,391	31,560
	0.043	2005	20	Constant	7	0.567	6.1	24,164	3,964
NA	0.032						5.24		17,762
NA	0.032						5.24		17,762

TABLE E-ANNEX-15 CMAQ Project Impacts Evaluation: Project Category, Inspection and Maintenance

		Daily Travel Impacts					Emission Reductions (tons per day)		
Source	**Description**	**VTR**	**VMTR**	**Transit Riders**	**Delay Red. (hr)**	**Speed Imp. (mph)**	**HC**	**NO_x**	**CO**
				Emission Weights:			**1**	**4**	**0**
Lachance and Mierzejewski (1998)	Standard annual idle test (Florida)	NA	NA	NA	NA	NA	4.72	0.82	
Lachance and Mierzejewski (1998)	Biennial idle test (Florida)	NA	NA	NA	NA	NA	3.78	0.66	
Lachance and Mierzejewski (1998)	Biennial IM240 test	NA	NA	NA	NA	NA	7.56	5.99	
Lachance and Mierzejewski (1998)	Biennial IM240 test with pressure test	NA	NA	NA	NA	NA	11.98	5.99	
Lachance and Mierzejewski (1998)	Biennial accelerated simulation mode with pressure test	NA	NA	NA	NA	NA	9.71	4.20	
Mean		NA	NA	NA	NA	NA	7.55	3.53	NA
Median		NA	NA	NA	NA	NA	7.56	4.20	NA

Travel term definitions: VTR = vehicle trip reduction; VMTR = vehicle miles of travel reduced; transit riders = increase in daily transit ridership.

Emission term definitions: total emissions = weighted sum of HC, NO_x, CO, and PM_{10}; emission weights = importance weights representing value of individual pollutants; emission year = time period for which source study estimate applies; benefits trend indicates whether emissions are decreasing, increasing, or constant over project life.

Cost-effectiveness definitions: BDF = benefits discount factor (combination of benefits trend and discount rate); annual benefits = weighted emissions ∗ days/year ∗ BDF; annual costs = annualized capital costs plus applicable operating, administrative, and private costs.

			Cost-Effectiveness						
PM_{10}	Total	Emission "Year"	Life (years)	Benefits Trend	Discount Rate (%)	BDF	Annual Benefits (tons/ year)	Annual Costs (2000 $)	Cost/Ton (2000 $)
0									
	7.99	1994	1	Constant	NA	1.000	1,996.8	14,119,920	7,071
	6.40	1994	1	Constant	NA	1.000	1,599.5	9,302,040	5,816
	31.53	1994	1	Constant	NA	1.000	7,881.8	15,202,080	1,929
	35.94	1994	1	Constant	NA	1.000	8,985.8	16,237,800	1,807
	26.49	1994	1	Constant	NA	1.000	6,621.8	12,113,280	1,829
NA	21.67						5,417.1	13,395,024	3,690
NA	26.49						6,621.8	14,119,920	1,929

TABLE E-ANNEX-16 CMAQ Project Impacts Evaluation: Project Category, Pricing; Subcategory, Subsidies and Discounts

		Daily Travel Impacts					Emission Reductions (tons per day)		
Source	Description	VTR	VMTR	Transit Riders	Delay Red. (hr)	Speed Imp. (mph)	HC	NO_x	CO
				Emission Weights:			1	4	0
MWCOG (1995)	Compatible regional fare media with discount	45,900	597,500	57,800	NA	NA	0.614	0.775	
MWCOG (1995)	Single price transit service	129,700	2,144,700	175,200	NA	NA	1.992	2.668	
MWCOG (1995)	Half-price feeder bus fares	41,600	453,200	53,900	NA	NA	0.503	0.603	
Pansing et al.(1998)	Route 14 vanpool subsidy	418	22,992	NA	NA	NA	0.016	0.027	
Pansing et al. (1998)	12th District subsidy	163	6,537	NA	NA	NA	0.005	0.008	
Pansing et al. (1998)	Broadway Plaza	254	5,171	NA	NA	NA	0.0045	0.0064	
Pansing et al. (1998)	12th District taxi voucher	77	1,459	NA	NA	NA	0.0013	0.0018	
Pansing et al. (1998)	Burbank flat fare taxi	25	76	NA	NA	NA	0.0002	0.0001	
MWCOG (1995)	Free workplace parking for carpools and vanpools	3,700	108,600	(21,700)	NA	NA	0.086	0.130	
MWCOG (1995)	Regional voucher program	172,800	2,388,800	99,200	NA	NA	2.39	3.07	
MWCOG (1995)	Mandatory employer cashout for transit/HOV	555,300	7,166,500	(138,200)	NA	NA	7.39	9.30	
MWCOG (1995)	Mandatory employer cashout for transit only	312,600	3,963,300	340,600	NA	NA	4.12	5.16	
DVRPC (1994)	20% systemwide fare reductions	8,275	144,016	9,696	NA	NA	0.196	0.262	1.08
DVRPC (1994)	Promotion of $25 Transitcheck	12,348	84,972	7,467	NA	NA	0.119	0.141	0.699
Mean		91,654	1,220,559	64,885	NA	NA	1.245	1.583	0.888
Median		10,312	126,308	53,900	NA	NA	0.158	0.202	0.888

Travel term definitions: VTR = vehicle trip reduction; VMTR = vehicle miles of travel reduced; transit riders = increase in daily transit ridership.

Emission term definitions: total emissions = weighted sum of HC, NO_x, CO, and PM_{10}; emission weights = importance weights representing value of individual pollutants; emission year = time period for which source study estimate applies; benefits trend indicates whether emissions are decreasing, increasing, or constant over project life.

			Cost-Effectiveness						
PM_{10}	**Total**	**Emission “Year”**	**Life (years)**	**Benefits Trend**	**Discount Rate (%)**	**BDF**	**Annual Benefits (tons/ year)**	**Annual Costs (2000 $)**	**Cost/Ton (2000 $)**
0									
0.296	3.71	1997–2001	1	NA	NA	1.000	928.2	5,293,200	5,702
1.048	12.67	1997–2001	1	NA	NA	1.000	3,166.5	19,007,400	6,003
0.225	2.91	1997–2001	1	NA	NA	1.000	728.7	4,863,128	6,674
0.011	0.123	1997–2001	1	NA	NA	1.000	30.8	25,829	838
0.003	0.036	1997–2001	1	NA	NA	1.000	8.9	40,285	4,513
0.0026	0.030	1997–2001	1	NA	NA	1.000	7.5	488,311	65,002
0.0007	0.009	1997–2001	1	NA	NA	1.000	2.1	139,767	65,347
0.0000	0.0008	1997–2001	1	NA	NA	1.000	0.2	89,376	471,012
0.054	0.607	1997–2001	1	NA	NA	1.000	151.8	36,210,300	238,500
1.18	14.69	1997–2001	1	NA	NA	1.000	3,672.3	400,495,061	109,059
3.55	44.60	1997–2001	1	NA	NA	1.000	11,150.8	1,459,960,800	130,929
1.96	24.75	1997–2001	1	NA	NA	1.000	6,186.7	333,229,797	53,862
	1.25	1996	1	NA	NA	1.000	311.4	12,269,807	39,408
	0.683	1996	1	NA	NA	1.000	170.8	4,991,535	29,233
0.695	7.576						1,894.0	162,650,328	87,577
0.139	0.964						241.1	5,142,368	46,635

Cost-effectiveness definitions: BDF = benefits discount factor (combination of benefits trend and discount rate); annual benefits = weighted emissions ∗ days/year ∗ BDF; annual costs = annualized capital costs plus applicable operating, administrative, and private costs.

TABLE E-ANNEX-17 CMAQ Project Impacts Evaluation: Project Category, Pricing; Subcategory, Fees and Charges

		Daily Travel Impacts					Emission Reductions (tons per day)		
Source	**Description**	**VTR**	**VMTR**	**Transit Riders**	**Delay Red. (hr)**	**Speed Imp. (mph)**	**HC**	**NO_x**	**CO**
				Emission Weights:			**1**	**4**	**0**
MWCOG (1995)	$0.10/mile LOV congestion pricing	18,400	108,600	6,300	NA	NA	0.167	0.164	
MWCOG (1995)	$500 annual pollution fee on gas-powered vehicles	56,200	1,027,700	37,200	NA	NA	0.931	1.281	
MWCOG (1995)	Employee parking tax outside metro core	154,500	2,063,100	79,000	NA	NA	2.097	2.666	
MWCOG (1995)	Employee parking tax in metro core	147,100	1,954,500	120,500	NA	NA	1.991	2.528	
MWCOG (1995)	$0.05/mile vehicle mileage tax after first 10,000 miles	13,600	266,500	11,400	NA	NA	0.248	0.353	
Pansing et al. (1998)	Glendale parking management	566	24,228	NA	NA	NA	0.018	0.028	
Mean		65,061	907,438	50,880	NA	NA	0.908	1.170	NA
Median		37,300	647,100	37,200	NA	NA	0.589	0.817	NA

Travel term definitions: VTR = vehicle trip reduction; VMTR = vehicle miles of travel reduced; transit riders = increase in daily transit ridership.

Emission term definitions: total emissions = weighted sum of HC, NO_x, CO, and PM_{10}; emission weights = importance weights representing value of individual pollutants; emission year = time period for which source study estimate applies; benefits trend indicates whether emissions are decreasing, increasing, or constant over project life.

Cost-effectiveness definitions: BDF = benefits discount factor (combination of benefits trend and discount rate); annual benefits = weighted emissions $*$ days/year $*$ BDF; annual costs = annualized capital costs plus applicable operating, administrative, and private costs.

			Cost-Effectiveness						
PM_{10}	Total	Emission "Year"	Life (years)	Benefits Trend	Discount Rate (%)	BDF	Annual Benefits (tons/year)	Annual Costs (2000 $)	Cost/Ton (2000 $)
0									
0.054	0.821	NA	1	Constant	NA	1.000	205.2	5,293,200	25,798
0.482	6.06	NA	1	Constant	NA	1.000	1,514.0	1,203,000	795
1.026	12.76	NA	1	Constant	NA	1.000	3,190.7	157,568,940	49,385
0.969	12.10	NA	1	Constant	NA	1.000	3,025.4	44,847,840	14,824
0.142	1.66	NA	1	Constant	NA	1.000	414.5	2,406,000	5,804
0.012	0.132	NA	1	Constant	NA	1.000	32.9	105,963	3,217
0.447	5.59						1,397.1	35,237,491	16,637
0.312	3.86						964.3	3,849,600	10,314

APPENDIX F

COST-EFFECTIVENESS OF MOBILE SOURCE NON-CMAQ CONTROL MEASURES

METHODOLOGICAL ISSUES AND SUMMARY OF RECENT RESULTS

Michael Q. Wang, *Center for Transportation Research, Argonne National Laboratory*

Government agencies and private organizations often use cost-effectiveness, calculated in dollars per ton of emissions reduced, to determine which control measures should be implemented to meet overall emission reduction requirements for a given region. Different studies may, however, yield significantly different, sometimes contradictory, cost-effectiveness results for the same control measures. The results differ because studies might use different calculation methodologies or make different assumptions about the values of costs and emission reductions. In 1997, the author conducted a study to examine some of the methodological issues involved in calculating the cost-effectiveness of mobile source control measures. In that study, ways were proposed to deal with such methodological issues as using user costs or societal costs, using costs at the manufacturer or the consumer level, determining baseline emissions, using emission reductions in nonattainment or in both nonattainment and attainment areas, using annual or pollution-season emission reductions, considering multiple-pollutant emission reductions, and applying emission discounting.

The Transportation Research Board (TRB) of the National Research Council commissioned the author to conduct a study to reexamine mobile source control cost-effectiveness. Findings of this commissioned study are presented. In particular, mobile source control measures adopted for the near future in the United States were evaluated. Among them are the following:

- The California low-emission vehicle (LEV) II program,
- The federal Tier 2 light-duty vehicle (LDV) emission standards,

- The federal Phase 1 heavy-duty engine (HDE) emission standards,
- The federal Phase 2 HDE emission standards,
- The California Phase 2 reformulated gasoline (RFG),
- The California Phase 3 RFG,
- The federal Phase 2 RFG,
- Alternative-fueled vehicles (AFVs) [including vehicles fueled with compressed natural gas (CNG), liquefied petroleum gas (LPG), ethanol (EtOH), methanol (MeOH), and electricity],
- Hybrid electric vehicles (HEVs),
- Inspection and maintenance (I&M) programs,
- Old vehicle scrappage programs, and
- Remote sensing programs of detecting and reducing vehicular emissions.

The conclusion is that except for AFVs, these control measures generally have emission control costs below $10,000 per ton of emissions reduced.

INTRODUCTION

Motor vehicle emissions contribute significantly to urban air pollution problems in the United States. Consequently, control measures ranging from vehicle emission standards to measures of controlling travel demand have been adopted or proposed to help solve U.S. air pollution problems. Among the many programs of reducing mobile source emissions, the U.S. Congress established the Congestion Mitigation and Air Quality Improvement (CMAQ) Program to reduce traffic congestion and improve air quality.

The CMAQ program was designed to provide federal financial support to local areas to introduce control strategies primarily related to transportation demand-side management. With direction from Congress, TRB established a CMAQ evaluation committee to examine the effectiveness of the CMAQ program. The evaluation committee commissioned the author to evaluate the cost-effectiveness of non-CMAQ mobile source control measures. Findings of the commissioned study are documented in this report.

The scope of the study was limited to summarizing and reconciling the results of past studies on mobile source emission control cost-effectiveness; cost-effectiveness estimates were not conducted by the author. There are two reasons. First, different studies use different methodologies and parametric assumptions concerning control costs and emission reductions for given measures. Though these differences undoubtedly reflect the uncertain nature of the given measures, they also reflect institutional positions on methodological issues. A particular study by this author, however objective, would certainly not cover the wide spectrum of various institutional positions. Second, it was initially thought that the conducting of new control cost estimates by the author could be more time- and resource-consuming than summary and reconciliation of completed studies. However, the path with the original study scope actually showed that the latter approach has been more time- and resource-consuming.

Mainly because of regulatory requirements, various government agencies have been conducting cost-effectiveness analyses for emission control programs. In theory, agencies should use the results of cost-effectiveness analyses to determine which control measures should be adopted for achieving given air quality goals. On the other hand, private organizations have been calculating cost-effectiveness in counterbalancing governmental agencies' results and positions. There is no formal protocol for governments and industries to follow in conducting cost-effectiveness estimates. Different studies may use different methodologies and different assumptions concerning the values of costs and emission reductions, and they may consequently yield significantly different control cost results. Although an attempt is made to reconcile differences in cost-effectiveness methodologies among studies, parametric differences concerning costs and emission reductions between studies are essentially left intact. In this way, results from various studies are converted into the same or a similar methodological basis, but the results of an individual study are maintained by keeping that study's parametric assumptions. If parametric assumptions in completed studies were changed to reflect this author's beliefs, the results from those studies would essentially be those of this author, not those of the original investigators.

This report is organized in six sections. In the first, the mobile source control measures that were evaluated in this study are presented. The key methodological issues involved in calculating mobile source cost-effectiveness are discussed in the second, and ways to deal with these issues are proposed. In the third section, cost-effectiveness results from studies completed in the past several years are summarized, and the adjustments to be applied in this study to the original studies to make results of past studies comparable are presented. Control cost-effectiveness of the mobile source control measures evaluated in this study are then summarized. General conclusions concerning mobile source emission control cost-effectiveness are presented in the fifth section. In the last section, an appendix to the main body of this report, stationary source control cost-effectiveness is summarized as a way to put mobile source cost-effectiveness results into perspective.

NON-CMAQ MOBILE SOURCE CONTROL MEASURES INCLUDED IN THIS STUDY

The 1990 Clean Air Act Amendments (CAAA) specified control measures to reduce mobile source emissions. In particular, the CAAA directed the U.S. Environmental Protection Agency (EPA) to establish new, stringent vehicle emission standards, establish fuel (gasoline and diesel) quality standards, require use of alternative transportation fuels, and implement other control measures such as vehicle I&M programs. Because of the CAAA, various mobile source control measures have been adopted and proposed. Table F-1 summarizes mobile source control measures already in place or to be in place soon.

Control measures in Table F-1 that have already been implemented include the following:

- The federal Tier 1 LDV emission standards,
- The California LEV I program,
- The federal oxygenated fuel requirement,
- The California Phase 1 RFG,
- The California Phase 2 RFG,
- The California low-sulfur (LS) diesel requirement,
- The federal Phase 1 RFG,
- The federal Phase 2 RFG, and
- The federal LS diesel requirement.

TABLE F-1 Mobile Source Emission Control Measures in Place or to Be in Place

Control Measure	Targeted Pollutants for Reductions[a]	Implementation Year	Remark
Vehicle Emission Standards			
Federal Tier 1 LDV standards	HC, CO, NO_x, and PM	1994–1996	49 states
Federal Tier 2 LDV standards	HC, CO, NO_x, and PM	2006–2009	49 states
Federal Phase 1 HDE standards	NO_x and PM	2004	Nationwide
Federal Phase 2 HDE standards	NO_x and PM	2007	Nationwide
CA LEV I program	HC, CO, NO_x, and PM	1996	CA, MA, NY
CA LEV II program	HC, CO, NO_x, and PM	2003	CA, NY
Fuel Quality Standards			
Oxygenated fuels	CO	1992	Some states
CA Phase 1 RFG	HC, CO, NO_x, and air toxics	1991	CA
CA Phase 2 RFG	HC, CO, NO_x, and air toxics	1996	CA
CA Phase 3 RFG	HC, CO, NO_x, and air toxics	2003	CA
CA low-sulfur diesel	HC, CO, NO_x, and SO_x	1993	CA
Federal Phase 1 RFG	HC, CO, NO_x, and air toxics	1996	Some areas
Federal Phase 2 RFG	HC, CO, NO_x, and air toxics	2000	Some areas
Federal low-sulfur gasoline	HC, CO, NO_x, PM, and SO_x	2004–2006	49 states
Federal low-sulfur diesel	HC, CO, NO_x, and SO_x	1993	49 states
Other Control Measures			
Use of alternative fuels	HC, CO, NO_x, PM, SO_x, and air toxics	Varied	Some areas
I&M programs	HC, CO, and NO_x	Varied	Some areas
Remote sensing programs	HC, CO, and NO_x	Proposed	Some areas
Old vehicle scrappage	HC, CO, and NO_x	Varied	Some areas
Gasoline station Stage II control	HC	Varied	Some areas

Note: LDV = light-duty vehicle; HDE = heavy-duty engine; LEV = low-emission vehicle; RFG = reformulated gasoline; I&M = inspection and maintenance; HC = hydrocarbon; CO = carbon monoxide; NO_x = nitrogen oxides; PM = particulate matter; SO_x = sulfur oxides.

[a] These are pollutants targeted by a given program. In some cases, a program reduces emissions of other pollutants besides the targeted pollutants.

Consequently, these measures have become part of the baseline control measures for evaluating new control measures such as CMAQ measures. Thus, these control measures are not, or are less, relevant to the evaluation of CMAQ measures. On the other hand, some measures in Table F-1 are not yet implemented. Furthermore, even though some of the measures are already implemented, their use could be expanded to other regions. Both groups could compete with

CMAQ measures to achieve emission reductions. They are evaluated in this study. Table F-2 presents the control measures selected for evaluation in this study. Each of these measures is discussed below.

California LEV I Program

In 1990, the California Air Resources Board (CARB) adopted the LEV program for the state of California. In 1999, CARB adopted a new LEV program. To differentiate the two programs, the 1990 and 1999 programs are now referred to as the LEV I and LEV II programs, respectively. Because the LEV I program was fully implemented in 1996, it is already part of the baseline control measures. It is presented here to put the LEV II program into perspective.

TABLE F-2 Non-CMAQ Control Measures Selected in This Study and the Nature of Their Impacts

	Travel Response	Congestion Mitigation	Emission Reduction
Vehicle emission standards			
CA LEV II program	No	No	Yes
Federal Tier 2 LDV standards	No	No	Yes
Federal Phase 1 HDE standards	No	No	Yes
Federal Phase 2 HDE standards	No	No	Yes
Clean conventional fuels			
CARFG2	Small[a]	No	Yes
CARFG3	Small[a]	No	Yes
FRFG2	Small[a]	No	Yes
Alternative-fueled or advanced vehicles			
Ethanol vehicles	Small[a]	No	Yes
Methanol vehicles	Small[a]	No	
LPG vehicles	Small[a]	No	Yes
CNG vehicles	Small[a]	No	Yes
Hybrid electric vehicles	Small[a]	No	
Electric vehicles	Small[a]	No	Yes
I&M programs	No	No	Yes
Old vehicle scrappage	Small[a]	No	Yes
Remote sensing programs	No	No	Yes

[a] Differences in fuel prices caused by these measures may result in increased or decreased operating costs of motor vehicles, which may cause changes in travel. However, the changes induced by fuel prices are probably small, and virtually all studies ignored such changes in travel.

Four vehicle types were established under the LEV I program for the purpose of emission regulations: transitional low-emission vehicles (TLEVs), LEVs, ultra-low-emission vehicles (ULEVs), and zero-emission vehicles (ZEVs). Table F-3 presents emission standards for each LEV type. The LEV I program began to take effect in 1994. Together with LEV type-specific standards, the LEV I program established fleet average nonmethane organic gas (NMOG) standards and ZEV sales requirements for individual model years to control the sales mix of these vehicle types. Later, some states in the Northeast adopted part of the LEV I program.

California LEV II Program

In 1999, CARB adopted the LEV II program with more stringent vehicle emission standards and tightened vehicle grouping for emission regulation. Table F-4 presents emission standards under the LEV II program. Relative to the LEV I program, the LEV II program establishes stringent oxides of nitrogen (NO_x) emission standards to achieve large NO_x emission reductions (see Tables F-3 and F-4). The program establishes a new vehicle type—SULEVs (super-ultra-low-emission vehicles)—with emission standards lower than those of ULEVs. The durability for emission certification is increased from

TABLE F-3 Emission Standards of the CA LEV I Program: Passenger Cars and Light-Duty Trucks with Loaded Vehicle Weight of 0 to 3,750 lb: grams/mile (CARB 1990)

Vehicle Type	NMOG	CO	NO_x	PM	Formaldehyde
50,000-Mile Standards					
TLEV	0.125	3.4	0.4	N/A	0.015
LEV	0.075	3.4	0.2	N/A	0.015
ULEV	0.040	1.7	0.2	N/A	0.008
ZEV	0.000	0.0	0.0	N/A	0.000
100,000-Mile Standards					
TLEV	0.156	4.2	0.6	0.08	0.018
LEV	0.090	4.2	0.3	0.08	0.018
ULEV	0.055	2.1	0.3	0.04	0.011
ZEV	0.000	0.0	0.0	0.00	0.000

TABLE F-4 Emission Standards of the CA LEV II Program: Passenger Cars and Light-Duty Trucks with Gross Vehicle Weight of 0 to 8,500 lb: grams/mile (CARB 1998)

Vehicle Type	NMOG	CO	NO_x	PM	Formaldehyde
50,000-Mile Standards					
LEV	0.075	3.4	0.05	N/A	0.015
LEV, Option 1	0.075	3.4	0.07	N/A	0.015
ULEV	0.040	1.7	0.05	N/A	0.008
ZEV	0.000	0.0	0.0	N/A	0.000
120,000-Mile Standards					
LEV	0.090	4.2	0.07	0.01	0.018
LEV, Option 1	0.090	4.2	0.10	0.01	0.018
ULEV	0.055	2.1	0.07	0.01	0.011
SULEV	0.010	1.0	0.02	0.01	0.004
ZEV	0.000	0.0	0.0	0.00	0.000
150,000-Mile Standards (Optional)					
LEV	0.090	4.2	0.07	0.01	0.018
LEV, Option 1	0.090	4.2	0.10	0.01	0.018
ULEV	0.055	2.1	0.07	0.01	0.011
SULEV	0.010	1.0	0.02	0.01	0.004
ZEV	0.000	0.0	0.0	0.00	0.000

100,000 miles to 120,000 miles. The LEV II program includes heavy passenger vehicles to avoid an emission regulation loophole for them. The LEV II program allows SULEVs and HEVs to earn partial ZEV (PZEV) credits to meet ZEV sales requirements. The LEV II program will go into effect in model year (MY) 2004.

Federal Tier 2 LDV Standards

In early 2000, EPA adopted the Tier 2 emission standards for passenger cars and light-duty trucks (LDTs) (EPA 2000a). The CAAA established Tier 2 vehicle emission standards, but the adopted Tier 2 emission standards are much more stringent than the CAAA-specified Tier 2 standards. Table F-5 presents EPA's Tier 2 standards for vehicles at 100,000 miles (another set is established for vehicles at 50,000 miles). A distinguishing feature of the Tier 2 program is that it establishes different vehicle bins to allow automobile makers to certify vehicles with flexibility, as long as a corporate average NO_x emission standard

TABLE F-5 Federal Tier 2 LDV Emission Standards: Fully in Effect in MY 2009 for Vehicles up to 10,000 lb Gross Vehicle Weight Rating: grams/mile at 100,000 miles (EPA 2000a)

	NMOG	CO	NO_x[a]	PM	Formaldehyde
Tier 1 Emission Standards	0.31	4.2	0.60	0.10	N/A
Tier 2 Emission Standards					
Bin 10[b, c]	0.156/0.230	4.2/6.4	0.60	0.08	0.018/0.027
Bin 9[b, c]	0.090/0.180	4.2	0.30	0.06	0.018
Bin 8[b]	0.125/0.156	4.2	0.20	0.02	0.018
Bin 7	0.090	4.2	0.15	0.02	0.018
Bin 6	0.090	4.2	0.10	0.01	0.018
Bin 5	0.090	4.2	0.07	0.01	0.018
Bin 4	0.070	2.1	0.04	0.01	0.011
Bin 3	0.055	2.1	0.03	0.01	0.011
Bin 2	0.010	2.1	0.02	0.01	0.004
Bin 1	0.000	0.0	0.00	0.00	0.000

Note: N/A = not applicable.

[a] A corporate average NO_x standard of 0.07 grams/mile will be fully in place by MY 2009.

[b] The high values apply to heavy light-duty trucks, while the low values apply to light light-duty trucks.

[c] Bins 10 and 9 will be eliminated at the end of MY 2006 for cars and light light-duty trucks and at the end of MY 2008 for heavy light-duty trucks.

of 0.07 g/mile is met. Also, instead of applying separately to passenger cars, light-duty trucks 1, and light-duty trucks 2, the Tier 2 standards apply to all three types together (with a transition period in which heavy light-duty trucks are subject to less stringent standards). The Tier 2 standards will begin to be implemented in MY 2004 and will be fully in place by MY 2009. Besides establishing vehicle tailpipe emission standards, EPA requires gasoline sulfur content to be reduced to 30 ppm beginning in 2004.

Federal HDE Emission Standards for MY 2004–2006 (Phase 1 Standards)

In 2000, EPA adopted the final HDE emission standards for nonmethane hydrocarbon (NMHC) and NO_x for MY 2004–2006 (Table F-6) (EPA 2000b). The so-called Phase 1 HDE standards require

TABLE F-6 Heavy-Duty Engine Emission Standards: g/bhp-hr, Lifetime of 8 Years (EPA 2000b)

	NMHC	NO_x	NMHC + NO_x	CO	PM
MY 1998–2003 standards	1.1/1.3/1.9[a]	4.0	N/A	15.5	0.10
Phase 1 HDE standards: MY 2004 and later					
Diesel-Cycle HDE: Option 1	N/A	N/A	2.4	15.5	0.10
Diesel-Cycle HDE: Option 2	<0.5	N/A	2.5	15.5	0.10
Otto-Cycle HDE: Option 1	N/A	N/A	1.5/1.0[b]	15.5	0.10
Otto-Cycle HDE: Option 2	N/A	N/A	1.5/1.0[c]	15.5	0.10
Otto-Cycle HDE: Option 3	N/A	N/A	1.0[d]	15.5	0.10

Note: g/bhp-hr = grams per brake-horsepower-hour; N/A = not applicable.

[a] These standards are for Otto-cycle light HDEs (8,500 to 14,000 lb gross vehicle weight rating), diesel-cycle HDEs, and Otto-cycle heavy HDEs (greater than 14,000 lb gross vehicle weight rating), respectively.

[b] These standards are for MY 2003–2007 and 2008 and later, respectively.

[c] These standards are for MY 2004–2007 and 2008 and later, respectively. MY 2004–2007 heavy-duty vehicles are required to be certified with vehicle-based standards as well as with the engine-based standards in this table.

[d] This standard applies to MY 2005 and later.

significant reductions in NO_x emissions by HDEs. In addition to these standards, EPA established new testing procedures and required onboard diagnosis systems for HDEs.

Federal HDE Emission Standards for MY 2007 and Later (Phase 2 HDE Standards)

EPA recently adopted the Phase 2 HDE standards for MY 2007 and later (Table F-7) (EPA 2000c). To help HDE manufacturers meet the Phase 2 HDE emission standards, EPA requires diesel fuel with a sulfur content limit of 15 ppm, compared with the current limit of about 340 ppm. The LS diesel fuel requirement could go into effect in June 2006.

California Phase 2 and 3 RFG

In 1992, California began to require use of the so-called Phase 1 reformulated gasoline (CARFG1). CARFG1 had the following composition requirements: a maximum aromatics content of 32 percent by

TABLE F-7 Federal Phase 2 HDE Standards (EPA 2000c)

	Pollutant	Standard (g/bhp-hr)	Phase-In Schedule (%) 2007	2008	2009	2010 and on
Diesel	NO_x	0.20	50	50	50	100
	NMHC	0.14	50	50	50	100
	PM	0.01	100	100	100	100
Gasoline	NO_x	0.20	0	50	100	100
	NMHC	0.14	0	50	100	100
	PM	0.01	0	50	100	100

Note: g/bhp-hr = grams per brake-horsepower-hour.

volume, a maximum sulfur content of 150 ppm by weight, a maximum olefins content of 10 percent by volume, and a maximum temperature of 330°F for 90 percent distillation of gasoline (CARB 1991).

In 1996, California began to require use of the Phase 2 RFG (CARFG2). Table F-8 presents composition requirements of CARFG2. Under the CARFG2 requirement, gasoline producers are allowed to certify gasoline by meeting either the specified composition requirements (Table F-8) or predetermined emission reduction requirements with any alternative gasoline reformulation formula. Emission performance of a given alternative RFG formula would be simulated with CARB's predictive model.

In 1999, because of concern about underground water contamination by methyl tertiary butyl ether (MTBE), California Governor Gray Davis issued an executive order to ban use of MTBE in California's gasoline beginning in 2003. Subsequently, CARB adopted the Phase 3 RFG (CARFG3), to go into effect beginning in 2003 (Table F-8). The differences between CARFG2 and CARFG3 are (*a*) elimination of MTBE and (*b*) reduction of gasoline sulfur content limit from 30 ppm to 15 ppm.

Federal Phase 2 RFG and Tier 2 LS Gasoline

The CAAA required use of RFG in some of the nation's worst ozone nonattainment areas. The so-called federal Phase 1 RFG (FRFG1) took effect in January 1995. Gasoline producers could certify FRFG1

Table F-8 Composition Requirements of CARFG2 and CARFG3 (CARB 1999)

	Flat Limits		Averaging Limits		Cap Limits	
	CARFG2	CARFG3	CARFG2	CARFG3	CARFG2	CARFG3
RVP, summer only (psi)	7.00	7.00	N/A	N/A	7.00	6.40–7.20
Sulfur content (wt. ppm)	40	20	30	15	80	60 (30 after 2004)
Benzene content (vol%)	1.0	0.8	0.8	0.7	1.2	1.1
Aromatics content (vol%)	25.0	25.0	22.0	22.0	30.0	35.0
Olefins content (vol%)	6.0	6.0	4.0	4.0	10.0	10.0
T50 (°F)	210	213	200	203	220	220
T90 (°F)	300	305	290	295	330	330
Oxygen content (wt%)	1.8–2.2	1.8–2.2	N/A	N/A	1.8–3.5 (winter areas); 0–3.5	1.8–3.7 (winter areas); 0–3.7
Ban of MTBE, ETBE, and TAME	No	Yes	No	Yes	No	Yes

Note: N/A = not applicable; RVP = Reid vapor pressure of gasoline; T50 = temperature at which 50 percent of gasoline is distilled; T90 = temperature at which 90 percent of gasoline is distilled; MTBE = methyl tertiary butyl ether; ETBE = ethyl tertiary butyl ether; TAME = tertiary amyl methyl ether.

with specified composition requirements or by meeting emission reduction goals. The FRFG1 composition requirements were a maximum benzene content of 1 percent by volume, a maximum aromatics content of 25 percent by volume, and a minimum oxygen content of 2 percent by weight. The FRFG1 emission reduction requirements were a reduction of volatile organic compound (VOC) emissions by 16 percent (northern regions) to 35 percent (southern regions) and a reduction of air toxic emissions by about 15 percent, all relative to conventional gasoline (CG) (EPA 1994). The reduction for VOC emissions is the combined reductions of exhaust and evaporative emissions by LDVs.

EPA established the Phase 2 RFG (FRFG2) requirements through emission reduction standards: a reduction of 27.5 percent in VOC emissions in southern regions and 25.9 percent in northern regions, a reduction of 20 percent in air toxic emissions, and a reduction of 5.5 percent in NO_x emissions, all relative to CG. EPA allows gasoline producers to use its Complex Model to determine emission reductions of a given gasoline reformulation formula. FRFG2 began to be introduced into the worst ozone nonattainment areas in 2000. Its use has been expanded into other areas.

In early 2000, EPA adopted the final rule of Tier 2 vehicle emission standards (EPA 2000a). Together with vehicle emission standards (see Table F-5), the Tier 2 rule establishes a gasoline sulfur content limit of 30 ppm. In contrast to FRFG1 and FRFG2, which were required only for the worst ozone nonattainment areas, the Tier 2 LS gasoline will be required nationwide beginning in 2004, except for California, where CARFG3 will be in effect. Since the Tier 2 LS gasoline is an integral part of the Tier 2 program, the LS gasoline will be evaluated together with the Tier 2 emission standards in the section on the review of past studies.

Table F-9 presents typical characteristics of CG, FRFG2, and Tier 2 LS gasoline.

Federal LS Diesel Requirement

In October 1993, EPA began to require use of on-road diesel fuels with a sulfur content limit of 500 ppm. Because of that requirement, the average sulfur content of current on-road diesel fuel is about 350 ppm

TABLE F-9 Typical Characteristics of CG, FRFG2, and Tier 2 Low-Sulfur Gasoline (EPA 1994; EPA 2000a)

	CG[a]	FRFG2[b]	Tier 2 LS Gasoline[c]
RVP, summer (psi)	8.9	6.7	NS
Sulfur content (wt. ppm)	339	150	30 (max. 80)
Benzene content (vol%)	1.53	0.68	NS
Aromatics content (vol%)	32.0	25	NS
Olefins content (vol%)	9.2	11	NS
200°F distillation (%)	41	49	NS
300°F distillation (%)	83	87	NS
Oxygen content (wt%)	0.4	2.26	NS

Note: CG = conventional gasoline; RVP = Reid vapor pressure of gasoline; NS = not specified.

[a] From NRC (2000).

[b] Based on representative input parameters to EPA's Complex Model for simulating emission performances of FRFG2.

[c] From EPA (2000a).

nationwide, except for California (EPA 2000b). Before October 1993, the sulfur content of diesel fuel was about 3,000 ppm (EPA 2000b). In 2000, EPA adopted the Phase 2 HDE emission standards. Together with HDE standards (see Table F-7), EPA requires that the diesel sulfur content be limited to a maximum level of 15 ppm effective in June 2006 (EPA 2000c). The LS diesel requirement will be evaluated together with the Phase 2 HDE standards in the section on the review of past studies.

Alternative-Fueled Vehicles

Both the CAAA and the 1992 Energy Policy Act called for use of AFVs to achieve emission and energy benefits. Although there are a significant number of LPG vehicles, ethanol flexible-fuel vehicles (FFVs), and CNG vehicles, use of AFVs has not reached the level that some envisioned in the early 1990s. AFVs account for only 0.2 percent of the 210 million on-road motor vehicles in the United States (Table F-10). The lack of fuel distribution infrastructure for alternative fuels is one of the many difficulties that AFVs must overcome. The so-called chicken-and-egg problem between vehicle availability

TABLE F-10 Number of AFVs in Use in the United States (EIA 2000)

AFV Type	Total Number in 2000
LPG vehicles	270,000
CNG vehicles	101,990
E85 FFVs	30,020[a]
M85 FFVs	18,730
Electric vehicles	7,590
LNG vehicles	1,680
Total	**430,010**

[a] In 1997, some automobile makers began to include E85-fueling capability in certain model lines of their vehicles. These vehicles are capable of using any combination of E85 and gasoline. These vehicles, whose number is large, are not included by the Energy Information Administration.

and adequate fuel infrastructure and the cost of alternative fuels are the major reasons why use of AFVs has not been widespread.

Nonetheless, efforts to overcome the difficulties associated with introduction of AFVs are continuing. As emissions of conventional vehicles become increasingly difficult to control, AFVs could play an important role in solving transportation energy and air pollution problems, especially if the price of crude remains at a high level.

In addition to AFVs, both the public and the private sectors are actively investing in R&D of advanced technologies such as HEVs, direct-injection engines, and fuel-cell vehicles (FCVs). These technologies can improve vehicle fuel economy significantly and can directly or indirectly reduce vehicle emissions.

Vehicle I&M Programs

The CAAA required ozone nonattainment areas to implement I&M programs to control on-road vehicle emissions. With an I&M program, vehicles are brought to inspection stations to undergo emission testing. If a vehicle fails the emission test, it must be fixed, with some exceptions. Emission reductions by I&M programs come from three sources: (*a*) repairs of failed vehicles, (*b*) good maintenance of on-road vehicles by vehicle owners, and (*c*) early retirement of dirty vehicles. I&M programs can be centralized or decentralized (depending on where the emission tests are conducted), basic or enhanced (depending on test procedures and program stringency), and annual or biennial (depending on testing frequency). While most states have adopted a uniform I&M program statewide, California has designed its I&M program (or the smog check program, as it is called in California) with different features for different California air basins (CAIMRC 2000).

Researchers have evaluated the Arizona I&M program (Harrington et al. 1999; Harrington et al. 2000; Ando et al. 2000). They summarized several key issues in evaluating I&M programs. First, the repair durability of an I&M program is a key factor determining its emission reductions. Second, in calculating I&M cost-effectiveness, both monetary and nonmonetary costs (such as drivers' time to and from I&M stations) must be taken into account. Third, emission cut points of an I&M program need to be determined at an optimal level. If the cut points are not stringent enough, the amount of emission reductions is limited. If they are too stringent, the cost of overall emission reductions is high. Fourth, newer vehicles with such devices as onboard diagnosis (OBD) systems may limit the emission benefits associated with I&M programs, since in-use emissions of these vehicles are better controlled by OBD systems.

Old Vehicle Scrappage

Old vehicles, especially vehicles equipped with less advanced emission control technologies, can experience high emission deterioration over their lifetime. Air regulatory agencies have allowed some local air districts and private companies to claim emission reduction credits through the scrappage of old vehicles, which is accomplished by offering financial incentives to owners of old vehicles. Dill (2001) summarizes various vehicle scrappage programs in the United States and in some other countries. While old vehicle scrappage programs can be very cost-effective, by how much they can reduce emissions remains to be seen, especially in the future, when old vehicles may deteriorate less rapidly.

Remote Sensing Programs

In recent years, I&M programs have been criticized for their inability to target potentially dirty vehicles for testing. In order to catch high-emitting vehicles, I&M programs require almost all vehicles to go through emission tests, which can increase the costs of I&M programs considerably. In addition, since vehicle owners can anticipate the timing of emission tests, they can arrange temporary fixes for their cars in order to pass I&M tests, leaving the vehicle emission problems unsolved.

To compensate for the weaknesses of I&M programs, the use of remote sensing programs to replace or supplement I&M programs in identifying superemitting vehicles has been proposed. With a remote sensing program, remote sensing devices can be set along the roadside. When vehicles pass the site, X rays from the devices can measure the emission concentration from vehicle tailpipes, and video cameras can record vehicle license plate numbers. Thus, superemitting vehicles can be identified.

However, emissions measured for a vehicle by remote sensing devices are a snapshot of emission performance of the vehicle during a trip. To be representative, remote sensing sites need to be carefully selected. The potential superemitters identified by remote sensing devices usually need to go through laboratory emission tests for further confirmation. Thus, a remote sensing program could complement an I&M program in identifying superemitters.

METHODOLOGICAL ISSUES IN MOBILE SOURCE COST-EFFECTIVENESS CALCULATIONS

Cost-effectiveness, presented in dollars per ton of emissions reduced, for emission control measures is often used by regulatory agencies, industries, and public interest groups in determining which control measures to adopt to meet given air quality goals. In fact, estimation of cost-effectiveness is usually required by law. In theory, cost-effectiveness is calculated for each control measure, and control measures are adopted, starting with the lowest-cost measures and proceeding to higher-cost measures, until a predetermined air quality goal is achieved. However, it is questionable whether this is actually carried out in such a way. Often, cost-effectiveness results are used for political, not scientific, debates on air pollution control.

Calculating cost-effectiveness appears simple and straightforward—total cost is divided by total emissions reduced. However, in calculating values for costs and emission reductions of control measures, researchers may assume different values for cost items and for emission reductions, consider different cost items, and include emissions of different pollutants in different locations and during different seasons. Thus, biases could be introduced into cost-effectiveness results. Considering different cost items and including different pollutants in different locations and different seasons make studies fundamentally incomparable. In this study, these differences are referred to as methodological differences. Comparison of fundamentally different studies is like comparison of apples and oranges. It is flawed and meaningless. On the other hand, use of different numerical values for cost items and emission reductions could reflect the nature of uncertainties in predicting these values. These differences represent varied views of cost reductions and emission improvements of given technologies over time. They are referred to in this study as technical differences (or parametric assumptions). Comparing studies that have the same fundamental basis but different parametric assumptions helps one understand the uncertainties involved in cost-effectiveness estimations as well as the potential for technological improvements in cost reductions and emission benefit increases of a given control measure.

To summarize different studies and compare them meaningfully, methodological differences among them need to be reconciled. On the other hand, different studies with a similar, if not the same, methodological basis may have different parametric assumptions concerning the costs and emission reductions of the control measures under evaluation. The original parametric assumptions in individual studies can be kept when comparing different studies, so each original study is still maintained as an independent study.

In calculating cost-effectiveness, one must explicitly or implicitly take positions on methodological issues. Readers often fail to pay attention to methodological differences among studies when citing results from different studies, either because they are not fully aware of the methodological issues involved or because the methodologies applied in cited studies are not explicitly presented. Three past studies discussed key methodological issues for mobile source cost-effectiveness calculations (Lareau 1994; Hadder 1995; Wang 1997).

In this section, an update from Wang (1997) of implied meanings of and appropriate solutions to nine methodological issues involved in estimating mobile source cost-effectiveness is presented. Some general guidelines are then proposed to adjust existing studies to make them comparable.

Table F-11 summarizes the nine methodological issues to be discussed in this section and the ways that are proposed here to address these issues. In the section on the review of past studies below, various completed studies are reviewed, and the proposed ways are used to adjust the original results of the completed studies. Since some of the reviewed studies were conducted in certain ways and lacked necessary data for adjustments, this study departs from the theoretically sound or complete ways on (*a*) program versus component cost-effectiveness, (*b*) emissions in nonattainment and attainment areas, (*c*) annual versus seasonal emissions, (*d*) user versus societal costs, and (*e*) estimated versus actual emission reductions.

Determination of Baseline Emissions and Emission Reductions of Control Measures

Calculation of emission reductions by a given control measure requires determination of baseline emissions from which the control

TABLE F-11 Nine Methodological Issues for Mobile Source Cost-Effectiveness

Issue	How the Issue Should Be Addressed	How the Issue Is Addressed in This Study
Baseline emission determination	Considering already adopted control measures	Considering already adopted control measures
Multiple air pollutants reduced to be included?	Yes	Yes
Emission discounting?	Yes	Yes
Program or component cost-effectiveness?	Depending on study scope	Program
Include emissions in attainment areas?	Yes, but with discounting	No
Annual or seasonal emissions?	Seasonal emissions	Annual emissions
User or societal costs?	Societal	User
Manufacturer or consumer costs?	Consumer	Consumer
Estimated or actual emission reductions?	Actual	Estimated

measure reduces emissions, since the amount of emission reductions by the measure is highly dependent on the quantity of baseline emissions. Usually, the higher the baseline emission quantity, the higher the reduction in emission quantity by a control measure. Obviously, the control measures assumed in baseline emission calculations are critical to determining the quantity of baseline emissions. Yet, sometimes it is unclear which measures should be considered as baseline control measures. For example, past studies that evaluated RFG emission reductions assumed Tier 1 vehicles, Tier 2 vehicles, or California LEV types as baseline vehicles. On the other hand, in estimating the cost-effectiveness of vehicle emission standards, past studies assumed CG or RFG to determine emission reductions of vehicle standards. It is proposed here that, in evaluating a given control measure, all the control measures that have already been adopted be considered for baseline emission calculation. In practice, because most cost-effectiveness studies are conducted for future years, it may not be clear which control measures will be adopted. Care must be taken in addressing future baseline control measures.

Considering different control measures in baseline emission calculations can result in very different control costs. For example, Lareau (1994) estimated the cost-effectiveness of vehicle emission standards and RFG with various baseline cases. He showed widely different cost-effectiveness results under different baseline cases.

Some control measures may be integrated to achieve emission reductions. An example is California's LEV program, which includes both vehicle and fuel requirements. The integrated measures should be evaluated as a complete program, not as separate components. EPA's Tier 2 LDV standards and the LS gasoline requirement are summarized together in this study, since the two together form the Tier 2 program. Similarly, EPA's Phase 2 HDE standards and the LS diesel requirement are summarized together. See the section on the review of past studies for these two programs.

If it becomes necessary to separate some measures from others within an integrated program to evaluate the program's components, the measures of interest can be evaluated with or without other measures to be considered as baseline control measures, depending on which will be implemented first. In some past studies, although some control measures were considered in baseline emission calculations, they were not considered in baseline cost calculations. Such inconsistencies must be avoided.

In estimating baseline mobile source emissions, most past studies used either CARB's EMFAC model or EPA's MOBILE model. Until the mid-1990s, there were concerns that both EMFAC and MOBILE might have underestimated actual on-road emissions significantly. However, since then, improvements have been made in both models to better predict vehicle emissions. Nonetheless, these models still have problems in accurately estimating the emissions of certain groups of vehicles and the emission reduction effects of certain control measures.

Emission reductions by vehicle control measures are often estimated with limited vehicle emission testing. Emission testing results are usually generalized to estimate the effects of implementing a given control measure in broad vehicle fleets. Large uncertainties exist in the generalization because (*a*) baseline control technologies in emission testing could be different from those in applicable fleets and (*b*) tested control measures could be different from adopted control measures.

Multiple-Pollutant Emission Reductions

Most mobile source control measures usually reduce emissions for more than one pollutant. However, a single cost-effectiveness value is usually estimated to compare a variety of control measures. Several approaches have been used in past studies to deal with the multiple-pollutant issue. The first approach combines emission reductions of all the affected pollutants with weighting factors. Two methods can be used to determine weighting factors of individual pollutants. The first is based on contributions of individual pollutants to a given air pollution problem (such as the urban ozone problem). For example, some early 1990s studies used weighting factors of 1, 1/7, and 1 for hydrocarbons (HC), carbon monoxide (CO), and NO_x, respectively, on the basis of their contributions to urban ozone formation. In some recent studies, the weighting factors for these three pollutants have been changed to 1, 0, and 1, respectively. The second method determines weighting factors on the basis of damage values of individual pollutants. The damage value of a given pollutant is estimated, in theory, by the modeling of air quality and human exposure, evaluation of health effects, and valuation of health and other effects (McCubbin and Delucchi 1999).

The first method is rough but simple. The second is theoretically correct and complete, and it should be used to the extent possible. Weighting factors based on damage values of individual pollutants were used in this study.

Because emission damage values are determined by many factors such as time and location of emissions, there are great uncertainties in emission values. To address the uncertainties, three sets of weighting factors are used in this study (Table F-12). The base case weighting factors assume that the damage value of NO_x emissions is four times that of VOC emissions. This is primarily based on the ozone formation contributions from the two pollutants in many areas. The equal weighting factors treat NO_x and VOC emissions the same, the treatment used in many past studies. For example, Hahn (1995) used both the base case weighting factors and the equal weighting factors in his calculations of mobile source cost-effectiveness. Under the NO_x-important weighting factors, NO_x emissions are assumed to be eight times as damaging as VOC emissions. This reflects the contribution of NO_x emissions to both ozone formation and secondary particulate matter (PM) formation. For example, McCubbin and Delucchi (1999) showed that NO_x emissions could be eight times as damaging as VOC emissions, considering both ozone and PM health effects.

All three sets assume a zero weighting factor for CO emissions. This means that CO emission reductions are discarded in the adjust-

TABLE F-12 Weighting Factors of Three Pollutants to Combine Their Emissions

	VOC	CO	NO_x
Base case weighting factors	1	0	4
Equal weighting factors	1	0	1
NO_x-important weighting factors	1	0	8

ments made in this study, which reflects the recent trend that CO air pollution has become of far less concern in most U.S. areas.

The weighting factors in Table F-12 indicate that combining different pollutants essentially converts emissions of other pollutants to VOC-equivalent emissions (since the weighting factor for VOC is always 1). Thus, calculated values based on these weighting factors are in terms of dollars per VOC-equivalent ton. This is the case in many past studies. Dollar-per-ton results can be very different if a different pollutant is used as the basis for the tonnage reduction. For example, if emission reductions in VOC-equivalent tonnage are converted into NO_x-equivalent tonnage, the total tonnage becomes smaller and the dollar-per-ton cost becomes larger. Many studies did not explicitly state the underlying pollutant for the tonnage reduction, even though a conversion was conducted.

The second approach to multiple-pollutant emission reductions is to allocate the total cost of a control measure to each pollutant affected. To do so correctly, engineering analysis of the effort spent to control each pollutant could be conducted, and the total cost could be allocated according to the control effort for each pollutant. However, in reality, it is generally impossible to precisely allocate the aggregate effort to individual pollutants. Often, a shortcut for this approach is to divide the total cost evenly among all the pollutants. This is crude and usually is not correct.

The third approach is a hybrid system to combine emissions of some pollutants and to subtract the monetary values of emission reductions of other pollutants from the total cost of a control measure. Usually, one or more primary pollutants are selected for evaluation. The cost for controlling the primary pollutants is the net of the total control cost, subtracting the monetary values of emission reductions for other pollutants. Lareau (1994) used this approach to calculate VOC control costs for different control measures. EPA (2000a) used this approach to evaluate its Tier 2 vehicle emission standards (as described later in the section on review of past studies).

The fourth approach is a hybrid system of the first and second approaches discussed above. First, the total control cost is allocated to individual groups of pollutants. Then, within each group, emissions of pollutants are combined together with their weighting factors. For example, in evaluating CARFG2, CARB (1991) first allocated 20 to 50 percent of RFG costs to air toxic reductions. Then, CARB combined total emissions in HC + CO/7 + NO_x + SO_x (where SO_x represents sulfur oxides) to calculate dollar-per-ton costs for this group.

One way or another, emission reductions of all pollutants affected should be taken into account in calculating cost-effectiveness. Ignoring emission reductions for some pollutants results in upward-biased control costs.

Emission Discounting

Motor vehicles usually last for more than 10 years. While vehicle initial costs occur when vehicles are built or sold, operations and maintenance (O&M) costs occur over the vehicle's lifetime. In calculating cost-effectiveness of motor vehicles, future O&M costs are usually discounted to present costs to reflect the fact that future dollars are worth less than present dollars. Then, vehicle initial costs and the discounted O&M costs are added together to represent total vehicle costs. In fact, discounting future costs is a standard practice in evaluating costs of given projects. If real-term dollars are used in cost estimates, the discount rate adopted should be a real-term discount rate. If current-term dollars are used in cost estimates, the discount rate adopted should be a current-term discount rate to reflect both inflation and the loss of investment opportunity. The current-term discount rate is usually about 10 percent, and the real-term discount rate is 3 to 6 percent.

Although costs are indisputably discounted, vehicle life-cycle emissions are estimated in some studies to be the straight sum of annual emissions, without discounting (some of these studies are reviewed later in this report). Some researchers have argued that because emissions are in physical terms rather than in monetary terms, emissions do not need to be discounted.

However, cost-effectiveness analysis provides useful information only in the broad perspective of cost-benefit analysis. Cost-effectiveness analysis serves as an approximation of cost-benefit analysis. In this context, the cost of a measure is the dollars spent on the measure, and the benefit is the emission reduction achieved by the measure. Both costs and emissions should be discounted (Schimek

2001). This is especially important in comparing measures whose emission reduction profiles over time are different. Emission discounting is the theoretically correct way to conduct cost-effectiveness analysis. In fact, regulatory agencies, such as CARB and EPA, use emission discounting in their cost-effectiveness analyses.

Because there is no inflation effect on physical units such as emissions, a real-term discount rate should always be used for emission discounting, regardless of which rate—real-term or current-term—is used for cost discounting. Some researchers may argue that a negative, rather than a positive, rate should be used for emission discounting. Use of a negative discount rate means that future emissions are worth more than current emissions. The rationale is that the current generation has some control of emissions for future generations, but future generations have no control over the current generation's actions. Assigning a higher value to future emissions helps limit the consequences of the current generation's actions for future generations. In this way, use of a negative discount rate seems to be intended to address the issue of equity among generations. However, discounting of mobile source emissions is usually applicable for the lifetime of a motor vehicle, which is about 15 years. Intergenerational inequity rarely exists over a 15-year period. In addition, cost-effectiveness analysis is usually intended to address issues associated with economic efficiency, not those associated with social equity. Positive discount rates for emissions are appropriate for mobile source cost-effectiveness analysis.

Alternatively, one could annualize the vehicle initial cost over the vehicle lifetime. For a given year, the total cost is the sum of that year's O&M cost and the annualized initial cost. By taking into account the estimated annual emission reduction for that year, cost-effectiveness can then be calculated for that year. The lifetime average cost-effectiveness of the vehicle is the average of cost-effectiveness of individual years. In this way, the sometimes controversial emission discounting practice can be avoided.

The emission discounting method and the cost annualization method give similar results in practice. That is, in order to obtain correct cost-effectiveness results, emissions need to be discounted or costs need to be annualized. Table F-13 shows emission control

TABLE F-13 Dollar-per-Ton Cost-Effectiveness Calculations: Straight Sum of Emissions, Sum of Discounted Emissions, and Annualized Costs

		Tier 1 Gasoline Cars with Conventional Gasoline (Estimated with EPA's MOBILE5b)							Tier 2 Vehicle Emission Reductions:					
		Grams/Mile Rates				Emissions (lb/year)			Emission Reductions (lb/year)					
Age	Annual Miles	Exh. HC	Evap. HC	CO	NO_x	HC	CO	NO_x	HC	CO	NO_x	Combined	Discounted Emissions (lb/year)	Annualized Costs ($/ton)
1	10,768	0.254	0.280	4.019	0.305	12.7	95.3	7.2	6.3	47.7	3.6	20.8	20.8	7,096
2	13,808	0.354	0.289	6.184	0.437	19.6	188.1	13.3	9.8	94.0	6.6	36.4	34.3	4,059
3	13,061	0.449	0.300	8.232	0.561	21.5	236.8	16.1	10.8	118.4	8.1	43.1	38.3	3,428
4	12,354	0.539	0.309	10.169	0.679	23.1	276.7	18.5	11.5	138.4	9.2	48.5	40.7	3,044
5	11,688	0.888	0.415	14.509	0.940	33.5	373.5	24.2	16.8	186.8	12.1	65.2	51.6	2,265
6	11,056	1.218	0.517	18.616	1.188	42.3	453.3	28.9	21.1	226.7	14.5	79.0	59.0	1,869
7	10,458	1.530	0.616	22.501	1.422	49.4	518.3	32.8	24.7	259.2	16.4	90.2	63.6	1,636
8	9,892	1.825	0.712	26.176	1.644	55.3	570.3	35.8	27.6	285.2	17.9	99.3	66.0	1,487
9	9,357	2.104	0.805	29.652	1.854	60.0	611.1	38.2	30.0	305.6	19.1	106.4	66.8	1,387
10	8,852	2.368	0.896	32.940	2.052	63.6	642.3	40.0	31.8	321.1	20.0	111.8	66.2	1,320
11	8,373	2.618	0.985	36.050	2.240	66.4	664.9	41.3	33.2	332.4	20.7	115.8	64.7	1,274
12	7,919	2.854	1.072	38.992	2.417	68.5	680.1	42.2	34.2	340.1	21.1	118.6	62.5	1,245
13	7,492	3.078	1.156	41.776	2.585	69.9	689.4	42.7	34.9	344.7	21.3	120.3	59.8	1,227
14	7,087	3.289	1.239	44.409	2.744	70.7	693.2	42.8	35.3	346.6	21.4	121.0	56.7	1,220
15	6,704	3.489	1.321	46.899	2.896	71.0	692.5	42.8	35.5	346.3	21.4	121.0	53.5	1,219
16	6,341	3.678	1.402	49.254	3.036	71.0	687.9	42.4	35.5	344.0	21.2	120.3	50.2	1,227
17	5,998	3.857	1.480	51.483	3.170	70.5	680.2	41.9	35.3	340.1	20.9	119.0	46.8	1,240
18	5,674	4.027	1.556	53.590	3.298	69.8	669.8	41.2	34.9	334.9	20.6	117.3	43.6	1,258

(*continued*)

Table F-13 (*continued*) **Dollar-per-Ton Cost-Effectiveness Calculations: Straight Sum of Emissions, Sum of Discounted Emissions, and Annualized Costs**

		Tier 1 Gasoline Cars with Conventional Gasoline (Estimated with EPA's MOBILE5b)							Tier 2 Vehicle Emission Reductions:					
		Grams/Mile Rates				Emissions (lb/year)			Emission Reductions (lb/year)					
Age	Annual Miles	Exh. HC	Evap. HC	CO	NO_x	HC	CO	NO_x	HC	CO	NO_x	Combined	Discounted Emissions (lb/year)	Annualized Costs ($/ton)
19	5,367	4.187	1.634	55.584	3.418	68.8	657.1	40.4	34.4	328.5	20.2	115.2	40.4	1,281
20	5,077	4.338	1.709	57.470	3.532	67.6	642.7	39.5	33.8	321.3	19.7	112.8	37.3	1,308
21	4,803	4.482	1.785	59.255	3.639	66.3	626.9	38.5	33.2	313.4	19.2	110.1	34.3	1,340
22	4,543	4.617	1.860	60.942	3.741	64.8	609.8	37.4	32.4	304.9	18.7	107.3	31.6	1,376
23	4,298	4.745	1.936	62.539	3.837	63.2	592.1	36.3	31.6	296.0	18.2	104.3	28.9	1,415
24	4,064	4.867	1.994	64.049	3.928	61.4	573.3	35.2	30.7	286.7	17.6	101.0	26.4	1,461
Sum												**2304.7**	**1144.1**	

Note:

Assumed incremental price for Tier 2 car = $1,000.

Interest (or discount) rate (real term) = 6 percent.

HC reductions = 50 percent.

CO reductions = 50 percent.

NO_x reductions = 50 percent.

Weighting factors: 1 for HC; 0 for CO; 4 for NO_x.

Annualized cost: $73.80

Results ($/ton): straight sum, 868; discounted sum, 1,748; annual average, 1,903.

cost-effectiveness results on the basis of a hypothetical case to demonstrate the implications of different methods. As the table shows, while emission discounting and cost annualization give similar results, use of the straight sum of emissions gives much lower dollar-per-ton cost values. That is, the straight sum of emissions underestimates control costs by a large amount. This should be avoided in cost-effectiveness calculations.

The cost-effectiveness of some mobile source control measures is calculated on the basis of annual rather than lifetime emission reductions. Such measures include I&M programs and RFG requirements. The capital costs of these measures are usually annualized. On the other hand, emission reductions from these measures are themselves annual emissions. For the reason stated in the above paragraph, emission discounting is not needed. That is, the cost-effectiveness calculations for these measures are based on annualized costs and annual emission reductions.

Program Cost-Effectiveness Versus Component Cost-Effectiveness

The cost-effectiveness of one component of a control program can be calculated on the basis of the incremental cost of and the incremental emission reductions achieved by the component. Meanwhile, cost-effectiveness can be estimated separately for the entire program. Some researchers maintained that component cost-effectiveness should be estimated to determine the design of a least-cost program. However, components of some control measures may interact with one another in terms of costs and emission reductions. For example, various components and specifications of gasoline may be changed collectively to meet RFG requirements at the least cost. To estimate the actual cost-effectiveness of RFG requirements, collective changes in various components and specifications should be simulated. Otherwise, studies could generate unrealistic results. For example, Sierra Research (1991) estimated the cost-effectiveness of changes in various gasoline components independently and showed very high component cost-effectiveness. Sierra's component cost-effectiveness results showed that many separable refining steps for producing RFG with emissions lowered further are not cost-effective, being even more costly than Sierra's cost estimates for federal and

California Phase 2 RFG. Because refiners would not be likely to take the incremental steps as Sierra Research evaluated, those component cost-effectiveness results have less meaning in comparing the cost-effectiveness of RFG with that of other control measures. Nonetheless, the results did indicate that extreme, inflexible RFG requirements could be very expensive.

Component cost-effectiveness results can be helpful in determining the composition of a control program. For example, component cost-effectiveness results for California's LEV program showed that electric vehicles (EVs) could be very expensive in reducing emissions. While the California LEV program has been relatively successful, California could have used component cost-effectiveness results to decide the fate of the ZEV requirement in the LEV program. On the other hand, program cost-effectiveness is useful in comparing the cost-effectiveness of a designed program with other control programs. This study focuses on program cost-effectiveness.

Emissions in Nonattainment Versus Attainment Areas

In calculating the cost-effectiveness of control measures that reduce emissions in both nonattainment and attainment areas (such as new vehicles to be sold nationwide), some researchers maintain that emission reductions only in nonattainment areas should be considered. This assertion is based on the argument that the purpose of emission reductions is to help meet air quality standards in nonattainment areas. Whether to include emission reductions in attainment areas is especially important in comparing mobile source control measures, because some measures (such as vehicle emission standards) may inevitably be applied to both nonattainment and attainment areas. Other measures (such as RFG requirements and I&M programs), however, can target emissions in nonattainment areas. The latter are more effective than the former in reducing air pollution in nonattainment areas.

Considering emissions only in nonattainment areas implies that emission reductions in attainment areas have no benefits. This may be based on the perception that there are air pollution thresholds below which no air pollution damage occurs and at which air quality standards are set. However, such thresholds may be much lower than air quality standards or may not exist at all. Emissions cause damage, though less severe, even at lower concentrations. Thus, emissions in attainment areas cannot be ignored completely, although they may be assigned lower values. Furthermore, because emissions can be transported for a long distance from attainment to nonattainment areas, emission reductions in attainment areas could benefit attainment goals for nonattainment areas. Emissions in attainment areas may be discounted on the basis of their damage values and then added to the emissions in nonattainment areas. For example, studies have been conducted to estimate emission values in various areas with different air quality problems (Wang et al. 1994). Emission values estimated for different regions could be used to weight emissions in nonattainment and attainment areas.

To the extent possible, in this study results from past studies are adjusted to include emissions in nonattainment areas only.

Annual Versus Seasonal Emissions

Some researchers, on the basis of reasoning similar to that for using emissions only in nonattainment areas, argue that emissions only during the nonattainment season (e.g., ozone precursor emissions in summer) should be used in calculating cost-effectiveness values. For example, Sierra Research (1994) and Lareau (1994) calculated cost-effectiveness values based on one-third of annual emissions. Use of seasonal emissions is especially important in comparing measures to reduce emissions in the nonattainment season with measures to reduce emissions year-round (the former are more effective in reducing air pollution in the peak season than are the latter). For example, while RFG requirements are enforced in summer to reduce VOC and NO_x emissions for ozone attainment, vehicle emission standards reduce VOC and NO_x emissions year-round. As for the case of emissions in nonattainment versus attainment areas, emissions in attainment seasons cannot be ignored completely, although they may be assigned lower values. Emissions in attainment seasons may be discounted on the basis of their damage values and then added to the emissions in nonattainment seasons.

The use of emissions in nonattainment areas and during the nonattainment season undoubtedly results in a low level of emission reductions and consequently high control costs. Comparisons of control cost-effectiveness from studies with different considerations of regions and seasons regarding attainment status may result in incomplete conclusions. In this study, annual emissions are used in order to be consistent with most past studies.

Private Costs Versus Societal Costs

There is no question that costs to users (private costs) should be included in calculating cost-effectiveness. However, societal costs—the costs not paid in markets by individuals, but by society, directly or indirectly—are often ignored. Consumers use private costs to make private decisions, such as buying a new vehicle. On the other hand, cost-effectiveness is intended to help make sound public policies to improve air quality, which is a public good. In designing public policies to address public goods, both private costs and societal costs need to be taken into account. Thus, for a complete cost-effectiveness analysis, societal costs should be included. For example, the use of gasoline incurs costs such as national energy insecurity. In calculating the emission control cost-effectiveness of alternative fuels relative to gasoline, it may be appropriate to include an estimate of the monetary benefit of reducing U.S. dependence on foreign oil by the use of alternative fuels. Such a benefit would be the diminished monopoly power of oil suppliers (Greene and Leiby 1993). Another example involves using transportation control measures to reduce emissions. Transportation control measures can reduce emissions by decreasing vehicle miles traveled, which also reduces the demand for further expansion of transportation infrastructure in the long run. Costs avoided in infrastructure expansion because of reduced vehicle miles traveled may need to be subtracted from the costs of the measures. On the other hand, the welfare loss due to reduced vehicle miles traveled may need to be added to the costs of transportation control measures.

In calculating societal costs, costs transferred in the market from one group to another should not be included, because they are not net costs to society, but the secondary impacts of transfer costs on the economy may be included. Usually, the secondary impacts of transfer costs are minimal. Obvious examples of transfer costs are vehicle registration fees and motor fuel taxes.

Most past studies considered private costs only. Consideration of societal costs involves assessment of the societal costs of control measures, which are subject to great uncertainties. Because of limited data, only private costs are considered in this study.

Costs at the Manufacturer Versus the Consumer Level

It is often not clear in a study whether the costs used are at the manufacturer or the consumer level. Even worse, some studies may use manufacturer costs for some cost items and consumer costs for others. This inconsistency within a study must be avoided.

Manufacturer costs are costs to manufacturers, and consumer costs are costs to consumers. The differences between manufacturer costs and consumer costs are caused by marketing and distribution costs and profit margins. Wang et al. (1993a) concluded that for automotive emission control equipment, the markup factor between manufacturing costs and a manufacturer's charged prices is about 20 percent, and the markup factor between dealer costs and retail prices could be as high as 40 percent. Of course, the markup factors include such transfer costs as manufacturer and dealer profits, as well as real costs, such as division overhead, marketing, and distribution costs. Nonetheless, costs at the consumer level are much higher than costs at the manufacturer level, resulting in control costs calculated on the basis of consumer costs being higher than those calculated on the basis of manufacturing costs. Costs at the consumer level, not the manufacturer level, should be used in calculating cost-effectiveness values.

Estimated Versus Actual On-Road Emissions

Virtually all past studies relied on EPA's MOBILE or CARB's EMFAC model to estimate emission reductions. Despite efforts to upgrade and refine MOBILE and EMFAC, neither yet accurately predicts actual on-road emissions. Early versions of the two models tended to underestimate on-road emissions. Underestimation of on-road emissions was caused primarily by off-cycle emissions; activity factors such as cold starts, hot soaks, and multiple-day diurnals; and underrepresentation of superemitting vehicles. Consequently, emission reductions based on MOBILE or EMFAC may have underrepresented actual reductions, causing higher calculated control costs. To reflect the effect of actual on-road emission reductions on cost-effectiveness, Wang et al. (1993b) established a case of adjusting MOBILE5a-estimated emissions to actual on-road emissions and calculated cost-effectiveness for this case. They showed that adjusting on-road emissions could improve mobile source cost-effectiveness significantly.

Summary

Among the nine methodological issues, some affect completeness and others reflect scope. Consideration of completeness-related issues helps cost-effectiveness studies to be more complete. Such issues include consideration of societal costs, use of costs at the consumer level, consideration of emissions of all pollutants affected, and adjustment for actual on-road emissions. The question for these issues is not whether they should be considered, but rather how they can be considered.

On the other hand, scope-related issues include calculation of baseline emissions, whether to consider attainment-area emissions, whether to consider attainment-season emissions, application of emission discounting, and calculation of program or component cost-effectiveness. Whether these issues should be addressed in one way or the other by a particular study depends on the scope of the study. For example, if the scope of a study is to determine how air quality standards can be met, emissions in attainment areas and seasons may not need to be included; if the scope is to reduce the adverse effects of air pollution, emissions in both nonattainment and attainment areas and in both nonattainment and attainment seasons should be included. If the scope of a study is to evaluate a given control program relative to other control programs, program cost-effectiveness should be calculated; if the scope is to determine the least-cost design of a control program, component cost-effectiveness should be calculated. If cost-effectiveness is calculated as an approximation of the cost-benefit ratio, emissions as well as costs should be discounted; if the scope is to determine the least-cost way of meeting given air quality standards, emissions may not be discounted, because physical units of emissions are the concern. The scope of a study may reflect one's belief in the ultimate goal of emission reductions. Scope-related issues may be addressed differently in different studies without sacrificing the completeness of studies. However, when the results of different studies are compared, scope-related issues need to be adjusted so that the results can be compared on the basis of similar scopes.

REVIEW OF PAST STUDIES: KEY ASSUMPTIONS IN INDIVIDUAL STUDIES AND ADJUSTMENTS APPLIED TO THEM

A review of studies on mobile source control cost-effectiveness completed in the past several years is presented in this section. Some past studies evaluated the control measures that are already in place (such as federal Tier 1 LDV standards). Although those studies were reviewed by Wang (1997), they are not presented in this report, since the control measures evaluated in those studies have already become a part of baseline emission control measures and consequently are irrelevant to the evaluation of CMAQ control measures. Only the studies that evaluate the control measures that are proposed or are to be implemented in the near future are included in this section. They potentially compete against CMAQ measures. The following control measures are included in this study:

- The California LEV II program,
- The federal Tier 2 LDV standards,
- The federal Phase 1 HDE standards,
- The federal Phase 2 HDE standards,
- CARFG2,
- CARFG3,
- FRFG2,
- AFVs,
- I&M programs,
- Remote sensing programs, and
- Old vehicle scrappage programs.

Descriptions of these control measures were presented earlier. Some of the above control measures were evaluated in multiple studies, others in only one study. This is a problem in summarizing the cost-effectiveness of a given control measure from different studies. With multiple studies, institutional biases, in addition to parametric assumption differences, are introduced to a control measure. Usually, the more studies conducted for a given measure, the larger the uncertainty range for the given measure. It could be argued that the measures subject to a large number of studies are usually more controversial and less certain than the measures subject to a small number of studies.

Some studies covering mobile source control cost-effectiveness did not conduct original estimates. Instead, they cited or summarized results of other original studies. Nonoriginal studies are not included in this report for the most part.

In reviewing each of the studies, special attention was paid to (*a*) incremental costs of evaluated control measures, (*b*) emission reductions for each of the affected pollutants, (*c*) the magnitude of emission reductions to be achieved by a given control measure (e.g., tons of emission reductions per year), and (*d*) other details of the control measures. These items, when available from a study, are extracted from the original study and presented here. Some of the items are not used for adjustments applied in this study. However, they could be helpful to the CMAQ evaluation committee, especially when the committee compares a wide spectrum of mobile source and stationary source control measures.

California LEV II Program

CARB (1998) estimated cost-effectiveness of the California LEV II program relative to the California LEV I program. Table F-14 presents CARB's estimated cost-effectiveness for ULEVII and SULEV—two new vehicle categories under the LEV II program. CARB used its EMFAC7G to estimate LEV II emission reductions.

In this study, three adjustments were applied to CARB's original estimates:

1. Dollar amounts were converted from a 1998 base to a 2000 base.
2. Emissions were discounted with a discount rate of 6 percent.
3. Reactive organic gases (ROG) were combined with NO_x with three sets of weighting factors (see Table F-12).

TABLE F-14 Costs, Emission Reductions, and Cost-Effectiveness of the California LEV II Program (1998 dollars) (CARB 1998)

LEV II Vehicle Category	Vehicle Type	Incremental Cost ($)[a]	Per-Vehicle Emission Reduction over 120,000 Miles (lb)			Cost-Effectiveness ($/ton)	
			ROG	CO	NO_x	ROG + NO_x	ROG+NO_x+ CO/7
ULEVII	PC	71.5	0.0	48.4	67.3	2,120	1,920
	LDT1	46.2	0.0	51.5	69.3	1,340	1,200
	LDT2	184.1	2.3	171.2	159.7	2,280	2,200
	MDV2	207.9	10.6	662.4	156.1	2,500	2,280
	MDV3	208.9	13.3	796.8	244.0	1,620	1,120
	MDV4	134.1	11.0	78.4	94.3	2,540	2,300
SULEV	PC	131.1	5.8	205.5	81.6	3,000	2,240
	LDT1	104.9	5.9	216.0	83.9	2,340	1,740
	LDT2	279.4	7.7	335.7	174.4	3,060	2,640
Average[b]	All LDVs	152.0	6.3	285.1	125.6	2,311	1,960

[a] Consumer costs relative to LEV I vehicles.

[b] These are straight averages of the nine vehicle types without considering their sales shares, which are not available.

Federal Tier 2 Emission Standards for Passenger Cars and LDTs and Tier 2 LS Gasoline

EPA (2000a) estimated the cost-effectiveness of its adopted Tier 2 emission standards for passenger cars and LDTs. In estimating cost-effectiveness, the assumed baseline vehicles were national LEVs (NLEVs) for LDV, LDT1, and LDT2 and Tier 1 vehicles for LDT3, LDT4, and medium-duty passenger vehicles (MDPVs). Table F-15 shows incremental retail prices for Tier 2 vehicles. EPA combined NMHC and NO_x emissions and discounted emissions with a discount rate of 7 percent (a real-term discount rate of 7 percent was used to discount costs as well). Table F-16 presents cost-effectiveness results.

EPA included costs for the 30-ppm sulfur gasoline requirement, which was established in the final Tier 2 rule. The baseline gasoline was assumed to be 300-ppm sulfur gasoline. Table F-17 shows EPA-estimated incremental costs for the lower-sulfur gasoline. EPA calculated emission reductions of the Tier 2 program with a modified

TABLE F-15 Incremental Retail Prices of Tier 2 Vehicles (1997 dollars) (EPA 2000a)

	LDV	LDT1	LDT2	LDT3	LDT4/MDPV
Tailpipe control cost					
Near-term (Year 1)	78	70	125	245	258
Long-term (Year 6 and on)	49	45	97	199	208
Evaporative control cost	4	4	4	4	4
Fuel cost					
Near-term	69	120	143	181	196
Long-term	66	113	134	171	185

version of MOBILE5b (Table F-18). Emissions in both attainment and nonattainment areas were taken into account. The cost-effectiveness results are the combined effects of Tier 2 tailpipe standards, vehicle evaporative standards, and LS gasoline requirements. Cost-effectiveness was calculated for a Tier 2 vehicle over its lifetime and for the Tier 2 program over a 30-year time frame. For the latter, emission reductions by non-Tier 2 vehicles due to use of LS gasoline were taken into account.

TABLE F-16 Cost-Effectiveness of Tier 2 Vehicles (1997 dollars) (EPA 2000a)

	Discounted Cost ($)	Discounted NMHC + NO_x (tons)	Cost-Effectiveness Without Considering SO_x and PM Benefits ($/ton)	Cost-Effectiveness Considering SO_x and PM Benefits[a] ($/ton)
Per-vehicle cost-effectiveness				
Near-term	243	0.110	2,211	1,717
Long-term	205	0.110	1,863	1,368
Program cost-effectiveness over 30-year period	48.1×10^9	23.5×10^6	2,047	1,311

[a] Values of $4,800/ton for SO_x and $10,000/ton for PM were used to determine cost savings of SO_x and PM emission reductions by the Tier 2 program. The cost savings translated into a per-vehicle cost savings of $51 and $4 for SO_x and PM, respectively, and $\$13.8 \times 10^9$ for the program over a 30-year time frame.

TABLE F-17 Incremental Costs of 30-ppm Sulfur Gasoline (1997 dollars) (EPA 2000a)

Year	Cost[a] (cents/gallon)
2004	1.9
2005	1.9
2006	1.7
2007	1.7
2008–2018	1.7
2019 and on	1.3

[a] EPA maintained that the costs were those to society. This implies that taxes and some other transfer costs were not included.

In evaluating the Tier 2 program, EPA treated vehicle tailpipe emission standards and the LS gasoline requirement as integral parts of the Tier 2 program. EPA estimated the cost-effectiveness of the complete program, not Tier 2 tailpipe standards and the LS gasoline requirement separately. That is, EPA included the costs of vehicle hardware changes and the costs of producing 30-ppm sulfur gasoline. Emission reductions of Tier 2 vehicles were attributable to both vehicle changes and use of LS gasoline. This is because it becomes increasingly difficult to separate the emission reduction effects of vehicle technologies and fuel qualities—both need to be improved to meet tightened vehicle standards such as the Tier 2 standards.

The Tier 2 program undoubtedly reduces emissions of NMHC, CO, NO_x, PM, and SO_x. While reductions in NMHC, CO, NO_x, and PM

TABLE F-18 Emission Reductions of the Tier 2 Program (tons per year) (EPA 1999)

Year	NO_x	VOC	SO_x	PM_{10}
2004	326,556	127,957	123,850	14,127
2007	956,512	262,174	193,779	23,427
2010	1,554,442	346,126	206,479	25,131
2015	2,527,309	491,336	226,457	27,950
2020	3,205,571	615,239	245,179	30,686
2030	4,049,687	806,343	281,016	36,004

emissions result directly from tightened tailpipe emission standards, reductions in SO_x emissions result primarily from the reduced sulfur content of Tier 2 gasoline. In dealing with emission reductions of multiple pollutants, EPA took a hybrid approach as follows. First, EPA did not consider CO emission reductions in its cost-effectiveness calculations. This is because (*a*) the amount of CO emission reductions is, in general, small (the Tier 2 program focuses mainly on NMHC and NO_x emissions); and (*b*) the monetary value of CO emission reductions is even smaller. Second, EPA combined NMHC and NO_x emissions (with weighting factors of 1 and 1 for NMHC and NO_x, respectively). Third, EPA estimated dollar values of emission reductions of PM and SO_x and subtracted these values from the total cost of the Tier 2 program. Finally, EPA used emission reductions of NMHC and NO_x and the net cost to calculate dollar-per-ton cost-effectiveness for NMHC and NO_x.

EPA used values of \$4,800/ton for SO_x and \$10,000/ton for PM to estimate dollar values of SO_x and PM emission reductions (compared with recent estimates of PM emission damage values, EPA's PM value appears conservative). With these emission values and the amount of SO_x and PM emission reductions by Tier 2 vehicles, EPA estimated per-vehicle values of \$51 and \$4 for SO_x and PM, respectively, and a value of $\$13.8 \times 10^9$ for total SO_x and PM emission reductions by the Tier 2 program over a 30-year time frame.

In this study, three adjustments were applied to EPA's original estimates:

1. Dollar amounts were converted from a 1997 base to a 2000 base.
2. Emission reductions in attainment areas were excluded by using the share of the population living in ozone attainment areas in the United States.
3. VOC and NO_x emissions were combined with three sets of weighting factors (Table F-12).

Federal Phase 1 HDE Standards

EPA (2000b) estimated the cost-effectiveness of its Phase 1 HDE standards. Table F-19 presents EPA's estimates of emission reductions to be achieved by the Phase 1 standards. These emission reductions

TABLE F-19 Emission Reductions of Phase 1 HDE Emission Standards (thousands of tons per year) (EPA 2000b)

	NO_x			NMHC		
Year	Diesel HDE	Gasoline HDE	Total	Diesel HDE	Gasoline HDE	Total
2005	186	16	202	10	1	11
2010	635	151	786	35	13	48
2015	949	242	1,191	52	21	73
2020	1,180	304	1,484	65	28	93
2030	1,520	387	1,907	84	37	121

were estimated with a draft version of MOBILE6. Tables F-20 and F-21 present EPA's estimates of the costs and cost-effectiveness, respectively, of diesel and gasoline HDEs that will meet Phase 1 HDE emission standards.

In this study, four adjustments were applied to EPA's original estimates:

1. Dollar amounts were converted from a 1999 base to a 2000 base.
2. Emissions in attainment areas were excluded by using the share of the population living in ozone attainment areas.

TABLE F-20 Per-Vehicle Costs of HDEs Meeting Phase 1 HDE Emission Standards (1999 dollars) (EPA 2000b)

Vehicle Type	Model Year	Purchase Price Increase	Life-Cycle Operating Cost
Light diesel HDEs	2004	484	8
	2009	241	8
Medium diesel HDEs	2004	657	49
	2009	275	49
Heavy diesel HDEs	2004	803	104
	2009	368	104
Gasoline HDE vehicles	2005	285	–6
	2009	281	–6

TABLE F-21 Cost-Effectiveness of EPA's Phase 1 HDE Emission Standards (1999 dollars) (EPA 2000b)

	NMHC + NO_x ($/ton)	
Vehicle Type	**2004 MY**	**2009 MY**
Light diesel HDEs	1,969	995
Medium diesel HDEs	849	389
Heavy diesel HDEs	271	141
All diesel HDEs	474	238
Gasoline Class 2B	635	633
Gasoline Class 3	596	594
Other gasoline HDEs	565	489
All gasoline HDEs	612	586

3. NMHC and NO_x emissions were combined with three sets of weighting factors (Table F-12).

4. A fuel economy penalty of $271/ton for diesel HDEs was considered (estimated by EPA).

Federal Phase 2 HDE Emission Standards and the LS Diesel Fuel Requirement

EPA (2000c) estimated the cost-effectiveness of its adopted Phase 2 HDE emission standards and the LS diesel fuel requirement. Table F-22 presents EPA's estimates of per-vehicle costs for meeting the

TABLE F-22 Incremental Vehicle and Operating Costs of HDEs Meeting Tier 2 HDE Emission Standards (1999 dollars) (EPA 2000c)

Vehicle Type	Model Year	Vehicle Cost ($)	Lifetime Operating Cost ($)
Light diesel HDE	2007	1,900	509
	2012	1,170	537
Medium diesel HDE	2007	2,560	943
	2012	1,410	996
Heavy diesel HDE	2007	3,230	3,785
	2012	1,870	3,979
Gasoline HDE	2007	198	0
	2012	167	0

Phase 2 HDE standards. EPA estimated a cost of 5 cents/gallon for the 15-ppm sulfur diesel, relative to the current 340-ppm sulfur diesel. Lifetime operating cost increases in Table F-22 are primarily caused by the increased diesel fuel cost. Table F-23 presents emission reductions achieved by Phase 2 HDE standards. Table F-24 presents EPA's estimates of cost-effectiveness for Phase 2 HDE emission standards.

In calculating the cost-effectiveness of the new standards, EPA assumed a baseline diesel fuel with a 340-ppm sulfur content limit and HDEs that meet the Phase 1 HDE emission standards. Emissions and costs were discounted with a discount rate of 7 percent. Emissions are annual emissions and include those in both nonattainment and attainment areas.

In this study, three adjustments were applied to EPA's original estimates:

1. Dollar amounts were converted from a 1999 base to a 2000 base.
2. Emissions in attainment areas were excluded by using the share of the population living in ozone or PM attainment areas.
3. NMHC and NO_x emissions were combined with three sets of weighting factors (Table F-12).

California Phase 2 RFG

In 1991, CARB estimated the cost-effectiveness of CARFG2 (CARB 1991). CARB estimated emission reductions for VOC, CO, and NO_x on the basis of the equations developed by the Auto/Oil program and

TABLE F-23 Emission Reductions by EPA's Phase 2 HDE Emission Standards (thousands of tons per year) (EPA 2000c)

Year	NO_x	PM	NMHC	CO	SO_x
2007	58	11	2	56	79
2010	419	36	21	317	107
2015	1,260	61	54	691	117
2020	1,820	82	83	982	126
2030	2,570	109	115	1,290	142

TABLE F-24 Cost-Effectiveness of the Phase 2 HDE Emission Standards (1999 dollars) (EPA 2000c)

	Cost-Effectiveness Without Considering SO_x Emission Reductions ($/ton)	Cost-Effectiveness Considering SO_x Emission Reductions[a] ($/ton)
Per-Engine Cost-Effectiveness over Engine Lifetime		
2007 Model Year		
NO_x + NMHC[b]	2,125	2,125
PM[b]	14,237	7,599
2012 Model Year and Later		
NO_x + NMHC[b]	1,621	1,621
PM[b]	11,340	4,701
Program Cost-Effectiveness over 30-Year Time Frame		
NO_x + NMHC[b]	2,149	2,149
PM[b]	13,607	4,195

[a] Cost savings of SO_x emission reductions was estimated at $4,800 per ton of SO_x emissions. The estimated cost savings was subtracted from the control cost for PM emissions.

[b] Total engine control costs were equally divided between NO_x + NMHC and PM emissions. Total fuel costs were allocated between NO_x + NMHC and PM at the 75 and 25 percent split.

testing results for vehicles fueled with CARFG2. VOC evaporative emission reductions were calculated with the CARB-developed evaporative emission formula. SO_x emissions were calculated with the sulfur content of CARFG2. Emission reductions only in California's ozone nonattainment areas were taken into account. Since CARFG2 was required only for summer months, emission reductions only in ozone seasons were taken into account. In estimating total emission reductions achieved by CARFG2, CARB considered emission reductions only by pre–MY 1996 vehicles. Emission reductions for MY 1996 and beyond were credited to California's LEV program, not to CARFG2. In this regard, CARB's cost-effectiveness for CARFG2 is only a partial estimate. Table F-25 gives the estimated emission reductions achieved by CARFG2. In calculating cost-effectiveness, CARB added emission reductions in $VOC + CO/7 + NO_x + SO_x$.

TABLE F-25 Emission Reductions by CARFG2 (tons per day in 2000) (CARB 1991)

	VOC	CO	NO_x	SO_x	Total[a]
Reduction (tons/day)	110	930	150	30	423

[a] Total = VOC + CO/7 + NO_x + SO_x. The total emission reduction value was used for cost-effectiveness calculations.

With data provided by six California refiners, CARB estimated a refining cost of 12 to 16 cents per gallon of CARFG2. Table F-26 shows CARB's estimates of the cost-effectiveness of CARFG2.

The high control costs estimated by CARB are caused primarily by three factors: (*a*) CARB assumed high incremental cost for CARFG2, (*b*) CARB excluded emission reductions by MY 1996 and on vehicles, and (*c*) CARB excluded emission reductions in ozone attainment areas.

In this study, six adjustments were applied to CARB's original estimates:

1. Dollar amounts were converted from a 1991 base to a 2000 base.
2. A fuel economy penalty of CARFG2 was considered (3 cents/gallon, as estimated by CARB).
3. NMHC and NO_x emissions were combined with three sets of weighting factors (Table F-12).
4. SO_x emission reductions were excluded.

TABLE F-26 Cost-Effectiveness of CARFG2 (1991 dollars) (CARB 1991)

	20% RFG Cost Allocated to Air Toxic Reductions		50% RFG Cost Allocated to Air Toxic Reductions	
Period	12 cents/gal	16 cents/gal	12 cents/gal	16 cents/gal
1996	8,000	10,600	5,000	6,600
1996–2005	10,800	14,400	6,800	9,000

5. Air toxic emission reductions were excluded.
6. The CARFG2 incremental price was adjusted to 5 to 10 cents/gallon (CARB 1996).

In 1991, Sierra Research prepared a study for the Western State Petroleum Association to evaluate the cost-effectiveness of CARFG2. Although Sierra's calculation methodology was similar to CARB's methodology, Sierra assumed higher RFG costs and excluded emission reduction benefits for CO, SO_x, and air toxic emissions. Sierra asserted that it used RFG costs to consumers, while CARB used costs to refiners. Sierra considered a fuel economy penalty of CARFG2, while CARB did not. Sierra used a cost of 16 cents/gallon, which was the upper bound of CARB's RFG cost estimates.

Table F-27 gives emission reductions of CARFG2 estimated by Sierra. Sierra calculated cost-effectiveness by considering emission reductions of ROG and NO_x only. Table F-28 presents Sierra's cost-effectiveness values for CARFG2. The high dollar-per-ton costs estimated by Sierra are mainly due to exclusion of emission reductions of CO and SO_x, and no cost allocation to air toxic reductions.

In this study, three adjustments were applied to Sierra's original estimates:

1. Dollar amounts were converted from a 1991 base to a 2000 base.
2. ROG and NO_x emissions were combined with three sets of weighting factors (Table F-12).
3. The CARFG2 incremental price was adjusted to 5 to 10 cents/gallon (CARB 1996).

TABLE F-27 Emission Reductions of CARFG2 (tons per day) (Sierra Research 1991)

Year	ROG	CO	NO_x	SO_x
1996	110	1,066	41	30
2000	88	790	27	30
2005	58	458	20	31
2010	32	175	16	33

TABLE F-28 Cost-Effectiveness of CARFG2 (1991 dollars) (Sierra Research 1991)

	1996	2000	2005	2010	Average
ROG + NO_x ($/ton)	45,000	59,000	87,000	142,000	70,000

California Phase 3 RFG

In 1999, CARB estimated the cost-effectiveness of CARFG3 (CARB 1999). The baseline gasoline was CARFG2. Table F-29 gives CARB's estimates of emission reductions by CARFG3. Table F-29 shows that CARFG3 is intended for NO_x emission reductions. CARB estimated a cost of 4 to 7 cents/gallon for CARFG3 in the first year and 2 to 6 cents/gallon for subsequent years, of which 0.4 cents/gallon was for gasoline sulfur reduction. By attributing the cost of sulfur reduction in gasoline to emission reductions (the remainder of the total costs—1.6 to 5.6 cents/gallon—was attributed to the elimination of MTBE) and considering NO_x emission reductions only, CARB calculated a cost-effectiveness of $8,100/ton.

In this study, two adjustments were applied to CARB's original estimates:

1. Dollar amounts were converted from a 1999 base to a 2000 base.
2. Dollar-per-ton amounts for NO_x emission reductions were converted to dollar-per-ton amounts for VOC-equivalent emission reductions with three sets of weighting factors (Table F-12).

TABLE F-29 Emission Reductions of CARFG3 (tons per day) (CARB 1999)

Year	NO_x	HC
2005	18.7	0.5
2010	15.3	0

TABLE F-30 Emission Reductions of FRFG2 (tons per day) (Sierra Research 1991)

Year	ROG	CO	NO_x	SO_x
1996	75	888	14	0
2000	56	600	9	0
2005	39	346	8	0
2010	25	144	8	0

Federal Phase 2 RFG

In 1991, Sierra Research conducted a study for the Western State Petroleum Association to evaluate the cost-effectiveness of FRFG2 as well as CARFG2 (Sierra Research 1991). Table F-30 gives Sierra's estimates of emission reductions of FRFG2.

Sierra used an incremental cost of 8 cents/gallon for FRFG2. Sierra calculated cost-effectiveness by considering emission reductions of ROG and NO_x only. Table F-31 presents Sierra's cost-effectiveness values for FRFG2. The high dollar-per-ton costs estimated by Sierra are mainly due to exclusion of emission reductions of CO and SO_x, no cost allocation to air toxic reductions, and high RFG costs.

In this study, three adjustments were applied to Sierra's original estimates:

1. Dollar amounts were converted from a 1991 base to a 2000 base.
2. ROG and NO_x emissions were combined with three sets of weighting factors (Table F-12).
3. The FRFG2 incremental price was adjusted to 5 to 15 cents/gallon (CARB 1996).

TABLE F-31 Cost-Effectiveness of FRFG2 (1991 dollars) (Sierra Research 1991)

	1996	2000	2005	2010	Average
ROG + NO_x (\$/ton)	38,000	52,000	72,000	102,000	56,000

In 1993, the National Petroleum Council (NPC) estimated the cost-effectiveness of various RFG formulas, including FRFG2 (NPC 1993). NPC estimated an incremental cost of 18 to 29 cents/gallon (including a fuel economy penalty). Emission reductions were estimated with MY 1990 vehicles and for six summer months only. Table F-32 gives NPC's estimates of cost-effectiveness for FRFG2. NPC did not consider emission reductions of CO, SO_x, or air toxics in its cost-effectiveness calculations.

In this study, three adjustments were applied to NPC's original estimates:

1. Dollar amounts were converted from a 1991 base to a 2000 base.
2. ROG and NO_x emissions were combined with three sets of weighting factors (Table F-12).
3. The FRFG2 incremental price was adjusted to 5 to 15 cents/gallon (CARB 1996).

Lareau of the American Petroleum Institute estimated the cost-effectiveness of CARFG2 and FRFG in 1994 (Lareau 1994). He used costs of 9 to 12 and 15 to 26 cents/gallon for FRFG2 and CARFG2, respectively. Since his cost of 9 to 12 cents/gallon is close to CARB's updated cost estimate (CARB 1996), his low-cost-based estimates are cited in this study. He used MOBILE5 to estimate emission reductions of RFG with Tier 1 vehicle technologies. Table F-33 gives Lareau's estimates of cost-effectiveness values for FRFG2.

TABLE F-32 Cost-Effectiveness of FRFG2 (1991 dollars) (NPC 1993)

	PADD I	PADD II	PADD IV
Cost (cents/gal)	24	18	29
ROG only ($/ton)	20,500	18,000	29,500
ROG + NO_x ($/ton)	14,000	15,000	21,000

Note: NPC estimated RFG emission reductions with two sets of formulas. The cost-effectiveness values here are the average of the two sets. PADD = petroleum administration defense district.

TABLE F-33 Cost-Effectiveness of FRFG2 ($/ton of VOC-equivalent emissions, 1993 dollars) (Lareau 1994)

	2000	2005	2010
VOC Reductions Only			
Stage II	20,800–227,800	26,300–253,400	27,800–253,400
Stage II & basic I&M	24,400–264,500	25,400–253,500	29,600–263,100
Stage II & enhanced I&M	39,200–335,800	45,000–432,000	47,500–472,200
VOC Reductions, a Cost Savings of $200/ton for CO Reductions Considered			
Stage II	20,600–227,100	26,300–252,900	27,700–252,900
Stage II & basic I&M	24,200–264,200	25,300–252,200	29,500–262,700
Stage II & enhanced I&M	39,200–335,600	44,900–432,100	47,400–471,600
VOC + NO$_x$/2			
Stage II	15,200–132,000	19,400–146,600	20,200–141,300
Stage II & basic I&M	17,300–143,400	18,900–138,700	21,200–147,900
Stage II & enhanced I&M	27,200–188,400	31,900–237,300	32,700–258,600
VOC + NO$_x$/2, a Cost Savings of $200/ton for CO Reductions Considered			
Stage II	15,100–131,700	19,300–146,000	20,000–140,600
Stage II & basic I&M	17,300–143,100	18,800–137,300	21,100–147,700
Stage II & enhanced I&M	27,100–188,200	31,800–236,000	32,600–258,000

In this study, two adjustments were applied to Lareau's original estimates:

1. Dollar amounts were converted from a 1993 base to a 2000 base.
2. VOC and NO$_x$ emissions were combined with three sets of weighting factors (Table F-12).

Vehicle I&M Programs

Harrington et al. (2000) evaluated the Arizona I&M program. The Arizona program is a centralized, biennial program with vehicle emissions being measured on vehicle chassis dynamometers with the 240-second test procedure. The program measures emissions of HC, CO, and NO$_x$. Table F-34 presents Harrington et al.'s estimates of emission reductions achieved by the Arizona program.

Harrington et al. estimated the cost of the Arizona I&M program by including costs for inspection, repairs (in the case that a vehicle fails the I&M test), and time spent by motorists, and the dollar sav-

TABLE F-34 Emission Reductions of the Arizona I&M Program (Harrington et al. 2000)

	HC	CO	NO_x
Emission reductions (tons/1,000 vehicles)	0.965	14.300	1.120

ings attributable to fuel economy gains. They estimated a total cost of $17.60 (in 1992 dollars) per tested vehicle. The cost-effectiveness of the I&M program was estimated to be $18,240/ton if only HC emission reductions were considered. When emissions are combined together in $HC + NO_x \pm 3.33$ (meaning that NO_x emissions are 3.33 times as damaging as HC emissions), the cost-effectiveness was estimated to be $3,750/ton.

In this study, two adjustments were applied to Harrington et al.'s original estimates:

1. Dollar amounts were converted from a 1992 base to a 2000 base.
2. VOC and NO_x emissions were combined with three sets of weighting factors (Table F-12).

The California Inspection and Maintenance Review Committee conducted its biennial review of California's I&M program (CAIMRC 2000). California's I&M program consists of enhanced and basic programs. It is a biennial, decentralized program. On the basis of emissions from I&M tests, the study estimated emission reductions achieved by the I&M program (Table F-35).

TABLE F-35 Emission Reductions of the California I&M Program (tons per day) (CAIMRC 2000)

	HC	CO	NO_x
Lower bound	40	864	59
Best estimate	86	1,686	83
Upper bound	116	2,235	93

The study estimated a statewide annual I&M cost of $854 million (in 1999 dollars). Of the total cost, initial vehicle tests account for 55 percent, repairs (including retests) 28 percent, administration 8 percent, and motorist time 9 percent. The study combined emission reductions together in HC + CO/60 + NO_x. The estimated cost-effectiveness values for the California I&M program are presented in Table F-36.

In this study, two adjustments were applied to California's original estimates:

1. Dollar amounts were converted from a 1999 base to a 2000 base.
2. VOC and NO_x emissions were combined with three sets of weighting factors (Table F-12).

Old Vehicle Scrappage Programs

Dill (2000; 2001) summarized cost-effectiveness estimates of 10 vehicle scrappage programs around the world. She concluded that dollar-per-ton costs for old vehicle scrappage were below $10,000 in most cases.

Sierra Research (1998) conducted a study for the Western State Petroleum Association to evaluate the cost-effectiveness of scrapping old passenger cars and heavy-duty trucks (HDTs) (among other control measures) in California's two Central Valley counties—Fresno and Kern Counties. Sierra assumed scrappage of vehicles 3 years before the end of the vehicle's natural lifetime. Using CARB's EMFAC model, it estimated emission reductions of scrapping 5 percent of the available vehicle population (Table F-37).

TABLE F-36 Cost-Effectiveness of the California I&M Program ($/ton, 1999 dollars) (CAIMRC 2000)

	Including Fuel Economy Savings	Excluding Fuel Economy Savings
Upper bound	4,400	5,000
Best estimate	5,400	6,000
Lower bound	9,000	9,500

TABLE F-37 Emission Reductions of Scrapping Old Passenger Vehicles (tons per day in 1999) (Sierra Research 1998)

	NO_X	VOC
Fresno County	0.17	0.32
Kern County	0.15	0.26

On the basis of assumptions of $1,000 for purchase price and $150 for administrative cost per car, Sierra calculated dollar-per-ton costs. The calculation was based on annual emissions. Table F-38 presents the cost-effectiveness values.

In the same study, Sierra estimated the cost-effectiveness of scrapping old HDTs. Table F-39 gives the emission reductions and cost-effectiveness estimates. Cost-effectiveness values were based on assumptions of $5,000 and $150 per HDT for purchase price and administrative cost, respectively.

In this study, two adjustments were applied to Sierra's original estimates:

1. Dollar amounts were converted from a 1998 base to a 2000 base.
2. VOC and NO_x emissions were combined with three sets of weighting factors (Table F-12).

Alberini et al. (1994) evaluated an old car scrappage program in Delaware. They used emission-testing results from scrapped cars to

TABLE F-38 Cost-Effectiveness of Scrapping Old Passenger Vehicles ($/ton, 1998 dollars, Based on NO_x Emission Reductions Only) (Sierra Research 1998)

	1999	2002
Fresno County	17,000	17,110
Kern County	13,740	13,900

TABLE F-39 Emission Reductions and Cost-Effectiveness of Scrapping Old HDTs (Sierra Research 1998)

	Emission Reductions in 1999 (tons/day)		Cost-Effectiveness (Based on NO_x Emission Reductions Only) ($/ton, 1998 dollars)	
	NO_x	VOC	1999	2002
Fresno County	0.19	0.05	16,660	21,550
Kern County	0.13	0.04	18,340	23,310

estimate emission reductions of the program, assuming that 2 years of the vehicle's natural life were left at the time of scrappage. Table F-40 presents the emission reductions estimated for the Delaware program.

On the basis of three assumed offering prices and HC emission reductions only, the researchers calculated cost-effectiveness of the scrappage program. Table F-41 presents cost-effectiveness values estimated in the study.

In this study, two adjustments were applied to Alberini et al.'s original estimates:

1. Dollar amounts were converted from a 1993 base to a 2000 base.
2. VOC and NO_x emissions were combined with three sets of weighting factors (Table F-12).

Remote Sensing Programs

Harrington and McConnell (1993) evaluated cost-effectiveness of a remote sensing program in conjunction with a follow-up enhanced I&M test for failed vehicles. The cost for the integrated program included remote-sensing costs, I&M tests (for vehicles failing remote

TABLE F-40 Emission Reductions of Old Car Scrappage (Alberini et al. 1994)

	HC	CO	NO_x
Reduction (tons)	14.82	68.84	1.10

TABLE F-41 Cost-Effectiveness of Old Car Scrappage (1993 dollars, Based on HC Emission Reductions Only) (Alberini et al. 1994)

Offering Price ($/car)	Cost-Effectiveness ($/ton)
500	5,950
700	6,590
1,000	7,510

sensing tests), repairs (for vehicles failing I&M tests), driver time costs, and fuel economy savings. By considering HC emission reductions only, they estimated a cost-effectiveness of $3,690/ton (in 1993 dollars) for the program.

In this study, one adjustment was applied to their original estimates: dollar amounts were converted from a 1993 base to a 2000 base.

AFVs and Advanced Vehicle Technologies

AFVs have been promoted to help solve urban air pollution problems, reduce U.S. dependence on foreign oil, and reduce greenhouse gas (GHG) emissions. AFV types and advanced vehicle technologies of interest include CNG vehicles, EtOH vehicles, LPG vehicles, EVs, HEVs, and FCVs. HEVs can achieve large gains in fuel economy, thus helping reduce fuel use and consequently GHG emissions. Although HEVs could be designed to achieve low emissions (such as California's ULEV or SULEV standards), they do not have inherently low emissions. FCVs have zero vehicular emissions, if hydrogen is the fuel-cell fuel. However, FCVs are still in the R&D stage, and they may not become commercial for a long time. The cost-effectiveness of CNG vehicles, EtOH vehicles, LPG vehicles, EVs, and HEVs is summarized here. These vehicles can be applied to passenger cars and buses. When the data allow, cost-effectiveness values are separated for the two applications.

Wang et al. (1993b) estimated AFV cost-effectiveness. Table F-42 shows their cost assumptions. Table F-43 presents their estimates of emission reductions. They discounted emissions with a discount rate of 6 percent.

TABLE F-42 Cost Assumptions for AFVs (1993 dollars) (Wang et al. 1993b)

	Low-Cost Scenario	High-Cost Scenario
Vehicle costs ($/vehicle)		
Ethanol vehicles	400	800
Methanol vehicles	400	800
LPG vehicles	800	1,700
CNG vehicles	1,000	2,000
EVs	8,750	18,000
Fuel costs (gasoline-equivalent gallon, except as noted)		
Gasoline ($/gal)	1.22	1.64
Ethanol ($/gal)	1.20	1.87
Methanol ($/gal)	0.82	1.02
CNG ($/million Btu)	8.00	11.00
LPG ($/gal)	0.75	1.21
Electricity (cents/kW-h)	6.5	11.0

TABLE F-43 AFV Emission Reductions (Pounds per Lifetime) (Wang et al. 1993b)

	NMOG	CO	NO_x	1,3-Butadiene	Benzene	Formaldehyde	Acetaldehyde
Low Emission Reduction Scenario							
EtOH vehicles	79.9	0.0	0.0	0.25	4.50	–0.70	–7.26
MeOH vehicles	79.9	0.0	0.0	0.25	4.00	–3.90	0.56
LPG vehicles	118.3	132.1	0.0	0.29	6.10	–0.60	0.27
CNG vehicles	146.1	209.4	0.0	0.33	6.70	–1.10	0.51
EVs	166.0	728.2	85.6	0.37	7.40	1.30	0.93
High Emission Reduction Scenario							
EtOH vehicles	236.4	264.2	12.1	1.25	26.50	–1.40	–23.66
MeOH vehicles	236.4	264.2	12.1	1.25	24.60	–14.00	2.51
LPG vehicles	326.3	1056.9	0.0	1.46	28.00	1.90	1.99
CNG vehicles	395.9	1395.9	12.9	1.59	30.00	1.50	2.72
EVs	452.7	3035.6	114.5	1.78	33.30	6.90	3.73

Note: A positive value indicates a reduction; a negative value indicates an increase.

Wang et al. calculated cost-effectiveness values with the following weighting factors to combine pollutants: 1, 0.49, 1.40, 10, 9.37, 1.31, and 0.31 for NMOG, CO, NO_x, benzene, 1,3-butadiene, formaldehyde, and acetaldehyde, respectively. The weighting factors for the three criteria pollutants were based on damage values, and those for the four air toxics were based on their cancer risk factors. Table F-44 presents their estimated cost-effectiveness values.

In this study, three adjustments were applied to Wang et al.'s original estimates:

1. Dollar amounts were converted from a 1993 base to a 2000 base.
2. NMOG and NO_x emissions were combined with three sets of weighting factors (Table F-12).
3. Air toxic emission reductions of AFVs were excluded.

CARB (1993) estimated cost-effectiveness of CNG buses versus diesel buses. In its estimates, CARB assumed that NO_x emissions of CNG buses were one-half those of diesel buses. CARB assumed that no emission benefits for ROG, CO, or PM were achieved by CNG buses. It assumed a lifetime of 12 years, during which CNG buses would travel 500,000 miles with one engine rebuild. CARB calculated

TABLE F-44 AFV Cost-Effectiveness ($/ton, 1993 dollars) (Wang et al. 1993b)

	Low-Cost Case	High-Cost Case
Air Toxic Emissions Included		
EtOH vehicles	4,860	66,750
MeOH vehicles	4,260	26,600
LPG vehicles	3,500	34,510
CNG vehicles	–180	3,990
EVs	2,260	37,800
Air Toxic Emissions Excluded		
EtOH vehicles	8,410	136,920
MeOH vehicles	6,420	39,210
LPG vehicles	4,530	46,500
CNG vehicles	–230	5,090
EVs	2,590	42,490

a lifetime NO_x emission reduction of 6.2 tons for a CNG bus relative to a diesel bus. It took into account incremental vehicle costs, fuel costs, and CNG refueling station costs. Table F-45 shows CARB-estimated cost-effectiveness for CNG buses. CARB did not discount emissions over the bus lifetime of 12 years and did not consider potential emission reductions for ROG, CO, or PM.

In this study, three adjustments were applied to CARB's original estimates:

1. Dollar amounts were converted from a 1993 base to a 2000 base.
2. NO_x-emission-based dollar-per-ton amounts were converted to VOC-emission-based dollar-per-ton amounts with three sets of weighting factors (Table F-12).
3. Emissions were discounted over the bus lifetime of 12 years.

Sierra Research (1994) estimated cost-effectiveness of CNG cars and electric cars, together with many other mobile source control measures, for the American Automobile Manufacturers Association. In estimating EV emission reduction benefits, Sierra assumed that EVs would displace 78 percent of gasoline vehicle miles, since EVs have much shorter driving ranges. Sierra estimated EV costs of \$21,030 per car for California and \$12,590 nationwide and a CNG vehicle cost of \$2,730 per car. Table F-46 presents lifetime emission reductions of CNG LEVs, CNG ULEVs, and EVs. Sierra discounted lifetime emissions with a discount rate of 7 percent. It combined emissions together in VOC + NO_x + CO/7 to calculate cost-effectiveness. Table F-47 presents Sierra's estimates of cost-effectiveness.

TABLE F-45 Cost-Effectiveness of CNG Buses (\$/ton, 1993 dollars, NO_x Emission Reductions Only) (CARB 1993)

	Low-Cost Case	High-Cost Case
10-bus fleet	5,700	16,000
200-bus fleet	1,300	7,000

TABLE F-46 Per-Vehicle Discounted Lifetime Emission Reductions (lb) (Sierra Research 1994)

	VOC	NO_x	CO
CNG LEV	161.03	21.82	373.07
CNG ULEV	167.28	21.82	373.07
EV	270.16	171.40	2,761.45

In this study, two adjustments were applied to Sierra's original estimates:

1. Dollar amounts were converted from a 1993 base to a 2000 base.
2. VOC and NO_x emissions were combined with three sets of weighting factors (Table F-12).

In 1994, CARB estimated EV cost-effectiveness (CARB 1994). CARB established two scenarios—a low-cost and a high-cost scenario. Under the low-cost scenario, EV incremental costs were reduced from $5,000 to $0 in 3 years. Under the high-cost scenario, EV incremental costs were reduced from $10,000 to $0 in 5 years. With total emission reductions of ROG + NO_x + CO/7, CARB estimated EV cost-effectiveness of $5,200/ton to $19,000/ton (in 1993 dollars). In 1998 and 2000, CARB conducted biennial reviews of its ZEV requirements. In the 2000 review (CARB 2000), CARB increased full-function EV costs to

TABLE F-47 Cost-Effectiveness of CNGVs and EVs ($/ton, 1993 dollars) (Sierra Research 1994)

	California	Nationwide
CNG LEV	34,060	28,660
CNG ULEV	32,980	27,880
EV	74,400	34,810

Note: Sierra calculated two sets of cost-effectiveness values. One was based on annual emissions in both attainment and nonattainment areas. The other was based on seasonal emissions in nonattainment areas. To be consistent with results from other studies, the first set of Sierra's cost-effectiveness values is cited here.

\$13,000 to \$24,000 per car. Interestingly, CARB did not estimate cost-effectiveness of EVs in that review. CARB stated that its decision on maintaining ZEV requirements was not based on EV cost-effectiveness. EV cost-effectiveness could have become extremely high, considering the progress that was made in the past several years in reducing emissions of baseline gasoline vehicles.

In this study, three adjustments were applied to CARB's original estimates:

1. Dollar amounts were converted from a 1993 base to a 2000 base.
2. VOC and NO_x emissions were combined with three sets of weighting factors (Table F-12).
3. Emissions were discounted with a discount rate of 6 percent.

Schimek (2001) evaluated several measures for reducing emissions from transit buses. In his analysis, Schimek estimated emissions of transit buses with statistical relationships that were developed from testing data primarily from West Virginia University. While emission reductions for NO_x and PM were considered, emissions of other pollutants were not. In estimating cost-effectiveness, Schimek applied a discount rate of 7 percent for both emissions and costs. Table F-48 summarizes the diesel bus control measures that Schimek evaluated.

In this study, one adjustment was applied to Schimek's original estimates: dollar amounts were converted from a 1995 base to a 2000 base.

Lave and Maclean (2001) evaluated the economics of HEVs. HEVs have been promoted for their fuel economy benefits and resultant GHG emission reductions. Lave and Maclean concluded that with current HEV production costs and gasoline prices, HEVs may not be economic, even after taking into account their social benefits such as reduced emissions. On the basis of the results presented in their paper, an estimate has been made here of an emission control cost of \$14,870/ton (in 2000 dollars). This is based on their weighting factors of 1, 0.75, and 0.75 for VOC, CO, and NO_x, respectively.

In this study, one adjustment was applied to Lave and Maclean's original estimates: VOC and NO_x emissions were combined with three sets of weighting factors (Table F-12).

TABLE F-48 Emission Control Measures, Their Costs, and Emission Reductions Calculated by Schimek (2001) (Results Are for Each Bus)

Control Measure	Cost (1995$ per bus)[a]	Emission Reduction (kg/bus)[b]		Cost-Effectiveness ($/ton)	
		NO_x	PM	NO_x	PM
1998 NO_x standard	188	495	None	345	None
1996 PM standard	705	None	242	None	2,641
PM retrofit for old bus	2,172–8,625	None	119–290	None	7,256–26,999
MeOH bus	123,353	5,494	None	20,383	None
CNG bus	85,000–138,000	5,975	210	6,457–10,483[c]	184,144–298,963[c]
Hybrid bus	34,000–166,000	3,812	220	4,049–19,766[c]	70,006–431,794[c]

[a] Costs include both incremental initial costs and operating costs during bus lifetime.

[b] Emission reductions were discounted emissions over bus lifetime.

[c] Cost-effectiveness was calculated for CNG and hybrid buses by allocating total costs between NO_x and PM emission reductions evenly.

SUMMARY OF ORIGINAL AND ADJUSTED ESTIMATES OF MOBILE SOURCE COST-EFFECTIVENESS VALUES

The methodological adjustments applied to each of the reviewed studies were presented in the preceding section. The purpose of those adjustments is to put the studies on the same or a similar basis so that they can be compared with each other. Because of data limitations in the reviewed studies, the adjustments applied in this study are limited relative to methodological differences among the studies. The adjusted cost-effectiveness results from the reviewed studies are still not fully comparable. To compare the cost-effectiveness of different control measures on a fully consistent basis, one's own estimates must be constructed, in which case the results are no longer the synthesized results of other studies, and others may disagree with the parametric assumptions used to construct the estimates. In practice, results from different studies, without any adjustments, are often compared to support an agenda. One purpose of this study is to show the degree of the incomparability problem among different studies and to show the effect on results of even limited adjustments.

Besides methodological differences, parametric differences in values used for cost items and emission reductions of control measures are often substantial among the reviewed studies. No adjustments were made for parametric assumptions.[1] Hadder (1995) applied parametric adjustments to some previous studies and showed, not surprisingly, significant changes in cost-effectiveness.

Table F-49 presents original and adjusted cost-effectiveness estimates for various mobile source control measures from the reviewed studies. For a given control measure, low, high, and median values are derived from dollar-per-ton estimates in the reviewed studies. There were not enough data for many of the control measures evaluated in this study to conduct any meaningful statistical analysis. The median value, instead of the mean value, is selected for each measure in this study, since for a given control measure an extremely high value from a study (which was the case for some measures) could distort the mean value significantly.

The adjustments that were applied to individual studies were presented in the preceding section. A systematic adjustment is the use of weighting factors for emissions of VOC, CO, and NO_x. Because weighting factors of pollutants are a key factor in determining control cost estimates, three sets of weighting factors were applied in this study to demonstrate the effects of such factors (Table F-12). In the three sets, a weighting factor of zero is adopted for CO emissions. This implies that CO emission reduction benefits are excluded in this study, which results in increased dollar-per-ton results. However, since many of the reviewed studies gave little or no value to CO emission reductions in their original estimates, increases in dollar-per-ton results attributable to the use of the zero CO weighting factor are small.

Among the three sets of weighting factors, the base case set (i.e., 1:0:4) treats NO_x emissions as 4 times as important as VOC emissions.

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[1] Besides methodological adjustments, one adjustment to parametric assumptions was made in this study. That is the adjustment of RFG incremental cost to three studies (CARB 1991; Sierra Research 1991; NPC 1993) based on more up-to-date cost data from CARB (1996). See those studies presented in the preceding section.

TABLE F-49 Mobile Source Dollar-per-Ton Cost-Effectiveness: VOC-Equivalent Tons, 2000 dollars (Except for Original Estimates)

				Adjusted Estimates in This Study											
	Original Estimates			1:0:4 for VOC:CO:NO_x				1:0:1 for VOC:CO:NO_x				1:0:8 for VOC:CO:NO_x			
Control Program	Low ($)	High ($)	Median ($)	Low ($)	High ($)	Median ($)	Change (%)	Low ($)	High ($)	Median ($)	Change (%)	Low ($)	High ($)	Median ($)	Change (%)
CA LEV II Program															
ULEVII, CARB (1998)	1,340	2,540	1,940	700	1,400	1,100	–43	2,800	5,300	4,100	111	300	700	500	–74
SULEV, CARB (1998)	2,340	3,060	2,700	1,300	1,600	1,500	–44	4,900	6,400	5,700	111	600	800	700	–74
EPA Tier 2, EPA (2000a)	1,311	2,211	1,761	800	1,400	1,100	–38	2,800	4,700	3,800	116	400	700	600	–66
EPA Phase 1 HDE															
Diesel HDE, EPA (2000b)	141	1,969	1,055	200	1,200	700	–34	900	4,800	2,900	175	100	600	400	–62
Gasoline HDE, EPA (2000b)	489	635	562	300	400	400	–29	1,000	1,300	1,200	114	100	200	200	–64
Bus NO_x, Schimek (2001)	345	345	345	100	100	100	–71	400	400	400	16	0	0	0	–100
EPA Phase 2 HDE, EPA (2000c)	1,621	2,149	1,885	900	1,200	1,100	–42	3,400	4,600	4,000	112	400	600	500	–73
CARFG2															
CARB (1991)	8,000	14,400	11,200	2,600	9,300	6,000	–46	7,100	25,400	16,300	46	1,400	5,000	3,200	–71
Sierra Research (1991)	45,000	142,000	93,500	15,700	45,000	30,400	–67	28,500	90,000	59,300	–37	9,800	27,000	18,400	–80
FRFG2															
Sierra Research (1991)	38,000	102,000	70,000	13,300	32,300	22,800	–67	24,100	64,600	44,400	–37	8,300	19,400	13,900	–80
NPC (1993)	14,000	21,000	17,500	3,600	5,600	4,600	–74	7,000	10,500	8,800	–50	2,200	3,500	2,900	–83
Lareau (1994)	6,950	37,400	22,175	4,400	17,200	10,800	–51	7,700	41,600	24,700	11	2,800	9,600	6,200	–72
CARFG3, CARB (1999)	8,100	8,100	8,100	2,000	2,000	2,000	–75	8,100	8,100	8,100	0	1,000	1,000	1,000	–88
I&M programs															
Harrington et al. (2000)	3,750	3,750	3,750	3,700	3,700	3,700	–1	9,700	9,700	9,700	159	2,000	2,000	2,000	–47
CAIMRC (2000)	4,400	9,000	6,700	1,800	4,600	3,200	–52	5,100	10,700	7,900	18	1,000	2,600	1,800	–73

(*continued*)

Table F-49 (*continued*) **Mobile Source Dollar-per-Ton Cost-Effectiveness: VOC-Equivalent Tons, 2000 dollars (Except for Original Estimates)**

				Adjusted Estimates in This Study											
	Original Estimates			1:0:4 for VOC:CO:NO_x				1:0:1 for VOC:CO:NO_x				1:0:8 for VOC:CO:NO_x			
Control Program	**Low ($)**	**High ($)**	**Median ($)**	**Low ($)**	**High ($)**	**Median ($)**	**Change (%)**	**Low ($)**	**High ($)**	**Median ($)**	**Change (%)**	**Low ($)**	**High ($)**	**Median ($)**	**Change (%)**
Old vehicle scrappage															
Sierra Research (1998): LDV	13,740	17,111	15,426	2,500	3,000	2,800	–82	5,100	6,100	5,600	–64	1,400	1,800	1,600	–90
Sierra Research (1998): HDV	16,660	23,310	19,985	4,000	5,500	4,800	–76	13,500	18,300	15,900	–20	2,100	2,900	2,500	–87
Alberini et al. (1994)	5,950	7,510	6,730	5,100	6,400	5,800	–14	6,200	7,800	7,000	4	4,200	5,200	4,700	–30
Remote sensing, Harrington and McConnell (1993)	3,690	3,690	3,690	4,100	4,100	4,100	11	4,100	4,100	4,100	11	4,100	4,100	4,100	11
MeOH vehicles															
Schimek (2001): bus	20,383	20,383	20,383	5,300	5,300	5,300	–74	21,200	21,200	21,200	4	2,700	2,700	2,700	–87
Wang et al. (1993b)	6,415	39,211	22,813	9,600	43,600	26,600	17	11,000	43,600	27,300	20	8,200	43,600	25,900	14
EtOH vehicles, Wang et al. (1993b)	8,406	136,918	72,662	12,600	152,200	82,400	13	14,400	152,200	83,300	15	10,700	152,200	81,500	12
LPG vehicles, Wang et al. (1993b)	4,532	46,503	25,518	13,000	80,000	46,500	82	13,000	80,000	46,500	82	13,000	80,000	46,500	82
CNG vehicles															
Wang et al. (1993b)	–226	5,085	2,430	–600	9,600	4,500	85	–700	9,600	4,500	85	–600	9,600	4,500	85
CARB (1993): bus	1,300	16,000	8,650	500	6,400	3,500	–60	2,100	25,500	13,800	60	300	3,200	1,800	–79
Sierra Research (1994)	27,880	34,060	30,970	29,500	36,000	32,800	6	39,700	48,900	44,300	43	22,000	26,700	24,400	–21
Schimek (2001): bus	6,457	10,483	8,470	1,700	2,700	2,200	–74	6,700	10,900	8,800	4	800	1,400	1,100	–87
Electric vehicles															
Wang et al. (1993b)	2,591	42,487	22,539	6,600	59,700	33,200	47	10,700	120,700	65,700	191	4,400	35,700	20,100	–11
Sierra Research (1994)	34,810	74,400	54,605	33,900	72,400	53,200	–3	73,300	156,600	115,000	111	19,700	42,100	30,900	–43
CARB (1994)	5,200	19,000	12,100	10,200	37,200	23,700	96	22,200	81,200	51,700	327	5,900	21,600	13,800	14
Hybrid electric vehicles															
Schimek (2001): Bus	4,049	19,766	11,908	1,100	5,200	3,100	–74	4,200	20,600	12,400	4	500	2,600	1,600	–87
Lave and Maclean (2001): Car	14,868	14,868	14,868	18,900	18,900	18,900	27	65,700	65,700	65,700	342	9,700	9,700	9,700	–35

Therefore, any control measures with NO_x emission reductions now have lower dollar-per-ton costs. The equal weighting factors set treats VOC and NO_x emissions as equally important. The NO_x-important set treats NO_x emissions as 8 times as important as VOC emissions. Because of the differing treatment of NO_x emissions among the three sets, dollar-per-ton cost results are the smallest with the NO_x-important set, moderate with the base case set, and the largest with the equal weighting factors set. It is important to keep in mind that all three sets convert NO_x emissions into VOC-equivalent emissions. This conversion results in control costs in dollars per *VOC-equivalent* ton. To convert dollar-per-ton results into an *NO_x-equivalent* emission basis, the adjusted dollar-per-ton results in Table F-49 need to be multiplied by a factor of 4 under the base case weighting factor set, by a factor of 1 under the equal weighting factors set, and by a factor of 8 under the NO_x-important set.

Table F-49 presents original and adjusted estimates for each control measure. The purpose of the table is to show the differences between original and adjusted estimates.

The cost-effectiveness of various mobile source control measures can now be compared according to the adjusted cost-effectiveness estimates. Figure F-1 presents a comparison of cost-effectiveness values among various control measures. The figure is based on adjusted control cost estimates with the base case weighting factors for the three pollutants (see Table F-12). The number next to each control measure represents the number of studies reviewed in this report. Table F-50 presents adjusted dollar-per-ton costs under all three weighting factor sets. Figure F-1 presents the low, high, and median values of cost-effectiveness for each measure. Control measures are presented from left to right in Figure F-1 from the lowest to the highest median control cost values.

Among control measures with a range of cost-effectiveness estimated, it can be seen from Figure F-1 that the measures with wide ranges are usually controversial. Such measures include CNG vehicles, MeOH vehicles, federal Phase 2 RFG, HEVs, California Phase 2 RFG, EVs, LPG vehicles, and EtOH vehicles. These control measures have control costs above $10,000/ton. The variation in cost-effectiveness for each of these control measures is caused by methods

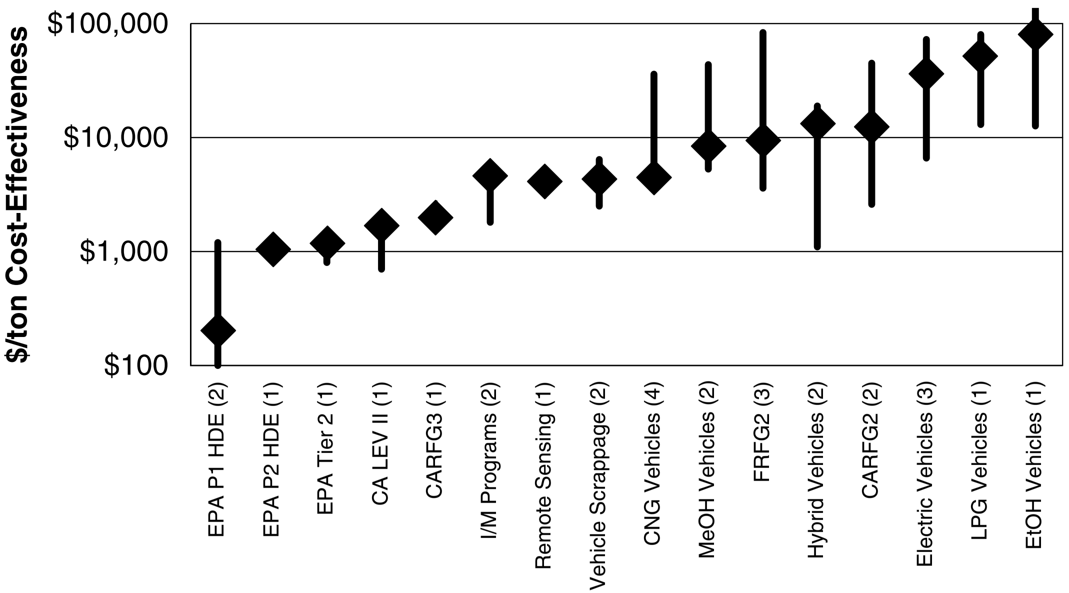

FIGURE F-1 Adjusted dollar-per-ton cost-effectiveness of mobile source control measures (2000 dollars, VOC-equivalent emission reductions).

TABLE F-50 Adjusted Dollar-per-Ton Mobile Source Emission Control Costs: VOC-Equivalent Tons, 2000 dollars

	1:0:4 for VOC:CO:NO_x			1:0:1 for VOC:CO:NO_x			1:0:8 for VOC:CO:NO_x		
Control Program	**Low**	**High**	**Median**	**Low**	**High**	**Median**	**Low**	**High**	**Median**
Vehicle emission standards									
EPA Phase 1 HDE standards (2)	100	1,200	250	400	4,800	950	0	600	100
EPA Phase 2 HDE standards (1)	900	1,200	1,050	3,400	4,600	4,000	400	600	500
EPA Tier 2 LDV standards (1)	800	1,400	1,100	2,800	4,700	3,750	400	700	550
California LEV II Program (1)	700	1,600	1,350	2,800	6,400	5,100	300	800	650
Reformulated gasoline									
California Phase 3 RFG (1)	2,000	2,000	2,000	8,100	8,100	8,100	1,000	1,000	1,000
Federal Phase 2 RFG (3)	3,600	32,300	9,450	7,000	64,600	17,300	2,200	19,400	5,900
California Phase 2 RFG (2)	2,600	45,000	12,500	7,100	90,000	26,950	1,400	27,000	7,400
In-use vehicle emission reductions									
I&M programs (2)	1,800	4,600	3,700	5,100	10,700	9,700	1,000	2,600	2,000
Remote sensing programs (1)	4,100	4,100	4,100	4,100	4,100	4,100	4,100	4,100	4,100
Old vehicle scrappage (2)	2,500	6,400	4,550	5,100	18,300	7,000	1,400	5,200	2,500
Alternative-fueled vehicles									
CNG vehicles (4)	0	36,000	4,550	0	48,900	10,250	0	26,700	2,300
Methanol vehicles (2)	5,300	43,600	7,450	11,000	43,600	21,200	2,700	43,600	5,450
Hybrid electric vehicles (2)	1,100	18,900	12,050	4,200	65,700	43,150	500	9,700	6,150
Electric vehicles (3)	6,600	72,400	35,550	10,700	156,600	77,250	4,400	42,100	20,650
LPG vehicles (1)	13,000	80,000	46,500	13,000	80,000	46,500	13,000	80,000	46,500
Ethanol vehicles (1)	12,600	152,200	82,400	14,400	152,200	83,300	10,700	152,200	81,450

Note: The number in parentheses next to each control measure represents the number of studies that evaluated the control measure.

used, variance of the expected values of costs and emission reductions, and other unreported bias. On the other hand, cost-effectiveness for some of the measures was estimated in only one study. Consequently, a range may not be available for published per-ton cost estimates. The lack of a range for some measures here does not necessarily indicate that less uncertainty is associated with the cost-effectiveness values of these measures.

Although precise quantitative conclusions cannot be drawn from Figure F-1, some general conclusions about the relative cost-effectiveness of various control measures can be drawn. On the basis of median cost-effectiveness values, in general, the most cost-effective measures are EPA's Phase 1 and 2 HDE emission standards, EPA's Tier 2 LDV emission standards, California's LEV II program, California's Phase 3 RFG, I&M programs, remote sensing programs, and old vehicle scrappage. These control measures have cost-effectiveness values of less than $10,000/ton. Separately, Beaton et al. (1995) showed that repairs or scrappage of old cars could be very cost-effective.

Figure F-1 shows that AFVs generally have high control costs and large variances in control costs. This implies technological uncertainties surrounding AFVs. Similar conclusions for AFVs were drawn by Krupnick and Walls (1992) and Hahn (1995). Besides having high control costs, AFVs may be subject to great market uncertainties because of potentially inferior attributes of some AFV types, fuel infrastructure inadequacy, and high initial costs to consumers.

Control of mobile source emissions focused on emissions of VOC, CO, and NO_x until the early 1990s. The focus was then shifted to control emissions of VOC and NO_x. In the late 1990s, the focus was shifted further to NO_x emissions. In recent years, it has been found that PM emissions may cause more damage than do VOC and NO_x emissions. Subsequently, attention began to be paid to the control of PM emissions. Because PM emission control is a relatively new phenomenon, most past cost-effectiveness studies did not analyze it. Consequently, data for PM control cost-effectiveness are scarce. Among the reviewed studies, only two estimated dollar-per-ton costs for PM emissions. The PM control costs from two studies are summarized in Table F-51. The table shows significant increases between PM control costs from an EPA study and the adjusted

TABLE F-51 PM Emission Control Costs ($/ton, 2000 dollars)

	Original Estimate			Adjusted Estimate			
Control Program	Low	High	Median	Low	High	Median	Change (%)
96 Diesel stand., Schimek (2001)	2,641	2,641	2,641	2,800	2,800	2,800	6
Bus Retrofit, Schimek (2001)	7,256	26,999	17,127	7,600	28,100	17,900	5
EPA Phase 2 HDE, EPA (2000c)	4,195	14,237	9,216	40,000	135,800	87,900	854
Hybrid bus, Schimek (2001)	70,006	341,794	205,900	73,000	356,300	214,600	4
CNG bus, Schimek (2001)	184,144	298,963	241,553	192,000	311,600	251,800	4

results in this study. This is caused by excluding PM emission reductions in PM air quality attainment areas in this study.

Table F-51 shows that the 1996 diesel PM emission standard and the bus retrofitting program could be cost-effective in reducing PM emissions. In general, cost estimates of PM emission control were not dealt with adequately in past studies. One problem is that modeling of PM emissions is much less accurate. If PM emissions had been treated adequately in past studies, some of the evaluated control measures, which help reduce PM emissions, might have had favorable cost-effectiveness results. Such measures include EPA's light-duty Tier 2 program, CARB's LEV II program, I&M programs, remote sensing programs, and AFVs.

PM damage values are much higher than those for VOC and NO_x. For example, McCubbin and Delucchi (1999) estimated that PM damage value could be 7 to 8 times as great as NO_x damage value. This implies that even with PM emission control costs as high as 7 to 8 times those of NO_x, PM control measures could still be as effective as NO_x control measures in reducing air pollution damage.

CONCLUSIONS

Calculating the cost-effectiveness of mobile source control measures involves dealing with both methodological and technical issues. Technical issues are related to values assumed for costs and emission reductions, whereas methodological issues are related to which costs are accounted for, how emission reductions are calculated, and which pollutants are included. To adequately (and correctly) estimate comparable cost-effectiveness, the following methodologies should be consistently applied to mobile source cost-effectiveness calculations. For cost estimation, societal (as well as user) costs need to be considered, and costs should be estimated at the consumer rather than the manufacturer level. For emission reduction estimation, baseline emissions should be calculated by taking into account the control programs already implemented. Although emissions in nonattainment seasons and nonattainment areas are directly related to attainment of air quality standards, emissions in attainment seasons and attainment areas should not be treated as having zero value. For control measures that reduce emissions of multiple pollutants, emission reductions of all affected pollutants should be taken into account. To be consistent with cost estimates where discounting is applied, discounting should be applied to emissions as well.

The studies reviewed in this report show wide ranges in cost-effectiveness for control measures, attributable to both methodological and technical differences. Because of the different methodologies used in the studies, their cost-effectiveness estimates are not comparable. Limited methodological adjustments were made to the original estimates in this study to allow a consistent comparison of the study results.

Although precise quantitative conclusions cannot be drawn from the adjusted cost-effectiveness results, the results show general trends in the relative cost-effectiveness of various mobile source control measures. In general, among the mobile source control measures evaluated, the most cost-effective measures are EPA's Phase 1 and 2 HDE emission standards, EPA's Tier 2 vehicle emission standards, the California LEV II program, California Phase 3 RFG, I&M programs, remote sensing programs, and old vehicle scrappage. These control measures have cost-effectiveness values of less than $10,000/ton.

APPENDIX: SUMMARY OF STATIONARY SOURCE EMISSION CONTROL COST-EFFECTIVENESS

Regulatory agencies, such as EPA, CARB, and local air districts, estimate control cost-effectiveness for stationary source emission control measures as well as for mobile source control measures. One of the extensive studies covering stationary and mobile source control measures was completed by E. H. Pechan and Associates for EPA (EPA 1997a; EPA 1997b; E. H. Pechan and Associates 1997). Pechan estimated about 150 control measures, including seven mobile source control measures, to reduce emissions of VOC, NO_x, particulate matter with size less than 10 microns (PM_{10}), and SO_x. The results were used by EPA to determine ways of meeting EPA-proposed ozone and PM ambient concentration standards in different U.S. regions.

In estimating control costs, Pechan used a 7 percent real-term discount rate to discount both costs and emissions over time. All costs were estimated in 1990 dollars. In this study, the 1990 dollar-based costs were converted into 2000 dollar-based costs.

In simulating the air quality effects of adopting various control measures, EPA decided to take all control measures with control costs below $10,000/ton (1990 dollars). The threshold of $10,000/ton was used for all pollutants (VOC, NO_x, PM_{10}, and SO_x). However, recent assessments show that PM_{10} emissions could cause much more significant health damage than emissions of VOC and NO_x (via ozone). Thus, the control cost threshold for PM_{10} emission control should have been set at a much higher level.

Tables F-52 through F-55 present dollar-per-ton control costs for stationary VOC, NO_x, PM_{10}, and SO_x emissions, respectively. Pechan's study indicated that each stationary source control measure reduced emissions of one pollutant only. Single-pollutant reduction measures are applicable to stationary source emission control, since stationary control measures can be designed to reduce emissions of one pollutant. Thus, estimation of stationary source control cost-effectiveness did not face the issue of multiple-pollutant emission reductions, as mobile source control measures usually do.

Table F-52 presents dollar-per-ton costs for VOC control in terms of tons of VOC emissions reduced; Table F-53 presents dollar-per-ton costs for NO_x control in terms of tons of NO_x emissions reduced; Table F-54 presents dollar-per-ton costs for PM_{10} control in terms of tons of PM_{10} emission reduced; and Table F-55 presents dollar-per-ton costs for SO_x emissions in terms of tons of SO_x emissions reduced. That is, each individual table presents the costs to reduce a ton of the pollutant being evaluated. On the other hand, the results presented in the section summarizing the original and adjusted estimates of mobile source cost-effectiveness values are for a ton of VOC-equivalent emissions. Readers cannot directly compare results in

TABLE F-52 Stationary Source VOC Control Costs: VOC Tons ($/ton, 2000 dollars)

Control Measure	Low	High	Average
New CGT for lithographic printing	–700	–600	–400
New CGT for web offset lithography	–100	–100	–100
Carbon adsorption for whiskey fermentation	0	0	0
Switch to emulsified asphalts for road surfacing	0	0	0
Advisory programs for open burning	0	0	0
Low VOC solvents for open top/convey. degreasing	100	100	100
Stage I control in gasoline stations	0	100	200
CARB Tier 2 standard for reformulated aerosols	400	400	400
RACT for oil and NG production fields	400	400	400
New CGT control for SOCMI reactor processes	500	500	500
Low VOC coatings for rubber and plastic manufacture	1,200	1,200	1,300
Incineration at bakeries	1,800	1,800	1,800
RACT for leather products	1,900	1,900	1,900
RACT for organic acid manufacture	1,900	1,900	1,900
Incineration for charcoal manufacture	2,100	2,100	2,100
CARB limit on consumer solvents	2,200	2,500	3,000
Limits on traffic marking paints	4,600	4,700	4,900
Carbon adsorption for letterpress printing	300	1,200	5,400
Limits for mach/electr/railroad coatings	3,400	4,700	6,500
Low VOC for misc. electronic surface coating	7,200	8,300	8,800
Stripper and equipment for vegetable oil manufacture	–200	1,000	9,000
Flare for carbon black manufacture	1,100	2,000	9,200
New CGT control for SOCMI distillation	1,000	3,300	9,700
Incineration for fabric coating	9,900	9,900	9,900
Incineration for plastic parts coating	10,700	10,800	10,800
Incineration for wood furniture coating	10,700	10,800	10,800
Incineration for aircraft surface coating	10,600	10,800	10,900
Incineration for marine surface coating	10,000	10,800	11,000
Incineration for metal coil and can coating	10,500	10,800	11,100
Incineration for motor vehicle surface coating	10,500	10,800	11,100
Incineration for beverage can coating	9,500	10,800	11,500
Limits for metal furn/appli/parts coatings	3,100	5,600	11,800
Content limit for industrial adhesives	2,400	5,600	11,900
Incineration for terephthalic acid manufacture	1,100	7,000	12,900
RACT for urea resins	1,100	7,000	12,900
CA reformulation of pesticides	9,700	11,200	13,400
Limits for ind. maintenance coatings	4,600	4,900	17,700
Limits for autobody finishing	4,700	11,600	18,900
Carbon adsorption for cellulose acetate manufacture	700	11,400	25,100
Phase 1 limit for architectural coatings	4,600	5,000	26,800

Note: CGT = combustion gas turbine; RACT = reasonable available control technology; SOCMI = synthetic organic chemical manufacturing industry.

TABLE F-53 Stationary Source NO_x Control Costs: NO_x Tons ($/ton, 2000 dollars)

Control Measure	Low	High	Average
Low-emission combustion for NG-fired IC engines	0	15,500	200
Low-NO_x burners for NG-fired ICI boilers	0	1,700	400
Low-NO_x burners for iron and steel mills	400	400	400
Low-NO_x burners for NG gas turbines	300	6,700	600
Mid-kiln firing for wet cement manufacture	600	600	600
Ignition timing retard for oil-fired IC engines	200	700	600
Low-NO_x burners for oil process heater	600	600	600
Ignition timing retard for NG, diesel, LPG-fired IC engines	600	1,000	700
Mid-kiln firing for dry cement manufacture	700	700	700
Mid-kiln firing for lime kilns	700	700	700
O_2 trim and water injection for NG reformers in ammonia plants	900	900	900
Low-NO_x burners for LPG process heater	900	900	900
O_2 trim + water injection for NG space heater	900	1,000	900
Low-NO_x burners for industrial NG combustion	800	1,100	900
Low-NO_x burners for oil reformers in ammonia plants	1,200	1,200	1,200
Low-NO_x burners for industrial oil combustion	100	2,500	1,200
SNCR for coke-fired ICI boilers	400	3,300	1,400
O_2 trim + water injection for NG-fired ICI boilers	0	14,900	1,400
Urea-based SNCR for dry cement manufacture	1,500	1,500	1,500
Water injection for oil-fired gas turbines	1,500	1,500	1,500
SNCR for lime kilns	1,500	1,500	1,500
SCR for coal-fired utility boilers	1,100	3,200	1,500
Low-NO_x burners for oil-fired ICI boilers	100	44,000	1,600
Low-NO_x burner + flue gas recirculation for iron and steel mills	1,600	1,700	1,600
Low-NO_x burners for industrial coal combustion	800	2,600	1,600
Low-NO_x burners for diesel process heater	400	3,700	1,700
Low-NO_x burners for NG process heater	0	17,000	1,900
Low-NO_x burners for LPG-fired ICI boilers	0	8,900	2,400
SCR for NG, diesel, LPG-fired IC engines	1,400	2,900	2,500
SCR for oil-fired IC engines	1,400	6,000	2,600
SNCR for coal-fired ICI boilers	400	14,500	3,100
SCR for container glass manufacture	2,100	6,400	3,200
SNCR for commercial/institutional incinerators	3,400	3,400	3,400
SNCR for industrial and medical incinerators	2,900	15,200	3,400
SNCR for municipal waste combustion	3,400	3,400	3,400
NG reburn for coal-fired ICI boilers	3,600	3,600	3,600
Low-NO_x burners for coke-fired ICI boilers	2,900	4,800	3,800
Low-NO_x burners + flue gas recirculation for oil-fired ICI boilers	1,300	6,100	3,900
Low-NO_x burners for coal-fired ICI boilers	400	57,600	4,000
Low-NO_x burners for diesel-fired ICI boilers	300	61,100	5,200
SCR for wet cement manufacture	5,900	5,900	5,900
SCR for oil reformers in ammonia plants	6,200	6,200	6,200
SCR for NG reformers in ammonia plants	0	27,500	9,500
Low-NO_x burners + flue gas recirculation for LPG-fired ICI boilers	8,700	11,300	10,000

(*continued*)

TABLE F-53 (*continued*) **Stationary Source NO_x Control Costs: NO_x Tons ($/ton, 2000 dollars)**

Control Measure	Low	High	Average
Extended absorption for nitric acid manufacture	10,400	10,400	10,400
Low-NO_x burners + SCR for iron and steel mills	11,000	12,300	11,600
SCR for dry cement manufacture	11,700	11,900	11,900
SCR for lime kilns	11,800	11,900	11,900
Low-NO_x burners + flue gas recirculation for NG-fired ICI boilers	4,000	13,600	12,200
NSCR for nitric acid manufacture	10,300	24,900	12,400
SCR for coke-fired ICI boilers	5,000	44,900	13,200
SCR for oil-fired ICI boilers	100	397,900	14,700
SCR for NG-fired ICI boilers	0	2,089,500	17,400
Low-NO_x burners + SNCR for oil process heater	17,600	23,900	19,700
SCR for flat glass manufacture	1,700	76,800	20,500
Low-NO_x burners + SCR for oil process heater	21,100	27,300	22,300
SCR + water injection for oil-fired gas turbines	21,100	29,200	23,700
SCR for LPG-fired ICI boilers	200	140,100	26,900
SCR for NG space heater	100	392,900	28,600
NSCR for NG-fired IC engines	100	765,800	29,600
SCR + low-NO_x burners for NG gas turbines	8,200	86,500	34,000
Low-NO_x burners + SNCR for NG process heater	4,900	4,982,000	36,700
Low-NO_x burners + SCR for LPG process heater	36,600	37,200	36,900
O_2 firing for container glass manufacture	18,900	115,900	38,900
SCR for diesel fuel space heater	3,400	302,600	41,000
O_2 firing for pressed/blown glass manufacture	21,700	122,700	41,500
Low-NO_x burners + SCR for diesel process heater	6,700	390,800	47,400
SCR + water injections for NG gas turbines	39,400	58,300	48,900
SCR for oil- and gas-fired utility boiler	1,300	233,100	52,700
O_2 firing for flat glass manufacture	12,200	642,600	53,600
Low-NO_x burners + SNCR for diesel process heater	6,400	281,700	55,800
SCR for coal-fired ICE boilers	100	1,567,700	59,100
SCR for diesel-fired ICI boilers	100	12,439,800	59,900
Low-NO_x burners + SCR for NG process heater	5,400	19,133,700	91,400
Low-NO_x burners + flue gas recirculation for diesel-fired ICI boilers	5,900	4,976,400	176,100
SCR + steam injection for NG gas turbines	800	3,282,900	287,400

Note: IC = internal combustion; ICI = industrial, commercial, and institutional; NG = natural gas; NSCR = nonselective catalyst reduction; SCR = selective catalyst reduction; SNCR = selective noncatalyst reduction.

Tables F-53 through F-55 with the results in that section, since the tonnage in each of the tables here is not the same as in that section, except for VOC emission controls in Table F-52.

Of the 40 stationary VOC control measures in Table F-52, 24 have control costs below $10,000 (average values in the table) per ton of

TABLE F-54 Stationary Source PM_{10} Control Costs: PM_{10} Tons ($/ton, 2000 dollars)

Control Measure	Low	High	Average
Scrubber for phosphate rock calcining	100	300	200
Soil conservation for agricultural tilling	200	200	200
Watering of beef cattle feedlots	400	400	400
Paved road vacuum sweeping	100	1,700	500
Unpaved road controls	0	8,700	1,900
Grain elevators	2,900	2,900	2,900
Agricultural burning control	2,200	9,800	4,000
Dust control for construction activities	4,300	4,300	4,300
Fabric filters for coal-fired utility boiler	400	13,700	5,200
Coal cleaning	0	113,300	5,500
Surface mining	200	21,700	5,700
Primary metal—material handling	100	54,600	5,900
Mineral production—material handling	0	131,500	10,500
Mineral production—fuel combustion	300	915,300	16,400
Fabric filters for ore processing	0	79,700	17,700
Baghouse for coke manufacture	5,100	54,800	18,700
Baghouses for iron and steel manufacture	9,000	34,100	20,800
Fabric filter for coal-fired ICI boiler	0	571,300	30,700
Fabric filter for oil-fired ICI boiler	500	8,733,200	51,100
Fabric filter for gas-fired ICI boiler	0	8,418,800	82,900
Kraft process	0	1,992,500	212,600
Fabric filters for NG-fired utility boiler	2,000	3,017,900	688,700

Note: ICI = industrial, commercial, and institutional; NG = natural gas.

TABLE F-55 Stationary Source SO_x Control Costs: SO_x Tons ($/ton, 2000 dollars)

Control Measure	Low	High	Average
FGD scrubbers for pulp and paper industry	1,000	526,000	5,500
FGD scrubbers for chemical manufacture	300	86,200	8,800
FGD scrubbers for ICI boilers	1,300	231,700	27,300
FGD scrubbers for primary metal production	200	437,000	38,500
FGD scrubbers for mineral production—fuel combustion	1,100	480,400	41,700
FGD scrubbers for petroleum industry	100	552,600	43,100

Note: FGD = flue gas desulfurization.

VOC emissions reduced; 14 have control costs between \$10,000 and \$20,000; and 2 have control costs between \$25,000 and \$27,000. Note that a negative control cost number in the table means that the monetary benefit of a given control measure exceeds the cost of the control measure. On the other hand, Table F-50 shows that except for AFVs, mobile source control measures have control costs below \$10,000/ton. Mobile source control measures appear to be competitive with stationary VOC control measures.

Table F-53 presents 76 stationary NO_x control measures. Among them, 44 have control costs below \$10,000 (average values in the table) per ton of NO_x emissions reduced; 10 have control costs between \$10,000 and \$20,000 per NO_x ton; and the remaining 22 have control costs above \$20,000 per NO_x ton. In comparing these results with those in Table F-50, the results under the 1:0:1 weighting factor set in Table F-50 should be used, since this set treats 1 NO_x ton the same as 1 VOC ton. Table F-50 shows that 8 of the 16 mobile source control measures have emission control costs below \$10,000; 2 have control costs between \$10,000 and \$20,000; and the remaining 6 have control costs above \$20,000. Mobile and stationary control measures are competitive with each other in terms of NO_x control costs. However, both mobile and stationary control measures have higher NO_x control costs than VOC control costs.

Table F-54 shows costs for 22 stationary PM_{10} control measures. Among them, 12 have PM_{10} control costs below \$10,000 per PM_{10} ton; 4 have control costs between \$10,000 and \$20,000; and the remaining 6 have control costs above \$20,000 (with 2 having control costs above \$200,000 per PM_{10} ton). On the other hand, among the five mobile PM_{10} control measures included in Table F-51, only two have control costs below \$20,000. The other three have control costs between \$88,000 and \$250,000 per PM_{10} ton. Though it appears that control of mobile source PM_{10} emissions is more costly than control of stationary PM_{10} emissions, one needs to be cautious with such an interpretation. Of the PM_{10} emissions reduced, stationary control measures may reduce emissions of large-size PM (e.g., $PM_{2.5}$ to PM_{10}), while mobile source control measures may reduce fine PM (e.g., $PM_{2.5}$ and smaller). Assessments have shown that fine PM is more damaging to health than is large-size PM. Mobile source fine PM emission control could be as cost-effective as or more cost-effective than stationary fine PM emission control. In addition, Table F-54 (and Tables F-52 and F-53) shows that many of the stationary control measures are for large stationary facilities, which are usually located outside of populated areas. On the other hand, motor vehicles are concentrated in populated areas, and large populations are exposed to their emissions. The geographic locations of mobile and stationary source emissions imply that mobile source emissions may cause more damage to health than do stationary source emissions. This could justify implementation of some mobile source control measures, which could have higher control costs than stationary source control measures.

Table F-55 presents control costs for stationary SO_x control measures. The table shows that scrubbers can be expensive in reducing SO_x emissions, considering the value of $4,800/ton of SO_x emissions that was used by EPA in evaluating its Tier 2 vehicle standards (see the section on review of past studies).

Table F-56 presents Pechan's results for seven mobile source control measures. For mobile source control measures reducing emissions of multiple pollutants, Pechan combined emissions of VOC, NO_x, and PM_{10} according to their contributions to ambient PM_{10} concentrations. This requires detailed air quality modeling, and it is conceivable that each control measure could have different weighting factors.

TABLE F-56 Mobile Source Emission Control Costs ($/ton, 2000 dollars)

Control Measure	Low	High	Average
Enhanced I&M programs	500	1,000	800
FRFG2 for off-road vehicles	200	32,600	5,300
FRFG2 for on-road vehicles	4,500	30,500	7,700
Off-road HDDV retrofit program	10,000	16,800	11,400
On-road HDDV retrofit program	30,700	30,900	30,700
Fleet ILEV	7,900	91,300	27,000
Tier 2 standards for LDGT	6,800	64,400	42,900

Notes: These control measures reduce emissions of VOC, NO_x, and PM_{10}. They were combined by Pechan according to their contributions to ambient PM concentrations. Note also earlier discussion in the text regarding comparability of results in this table with those in Table F-50.

Considering the mechanism of PM formation in the atmosphere, it is likely that Pechan's implicit weighting factors could be between the base case and the NO_x-important weighting factor sets established in this study (Table F-12). Thus, the results in Table F-56 are compared with the results under those two weighting factor sets in Table F-50.

Tables F-50 and F-56 show that I&M programs and RFG could be cost-effective. Table F-50 does not include heavy-duty diesel vehicle (HDDV) retrofits, so those results in Table F-56 cannot be compared. The fleet ILEV (inherently low-emission vehicle) program in Table F-56 was meant to be CNG vehicles. Table F-50 shows much lower control costs for CNG vehicles ($4,550/ton under the base case weighting factors and $2,300/ton under the NO_x-important weighting factors) than does Table F-56 ($27,000/ton). The Tier 2 standards in Table F-56 were the standards specified in the CAAA, which were less stringent than EPA's final Tier 2 standards. However, even with less stringent Tier 2 standards, Pechan's cost estimates were much higher than EPA's cost estimates.

The above sections show the cost-effectiveness of mobile and stationary source control measures. The cost-effectiveness result of a given control measure does not indicate by how much the particular measure can reduce emissions, which is beyond the scope of this study. To provide some hints about the potential magnitude of emission reductions achievable by the control measures evaluated in this study, Table F-57 presents emission inventory data for 1999 in the United States. The table indicates major emission sources for a given pollutant. One can examine the control measures evaluated in this study together with the emission inventory data in the table to determine whether a given control measure targets major emission sources. If so, the control measure should be able to provide a large quantity of emission reductions.

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TABLE F-57 U.S. Annual Emissions from Different Sources (thousands of tons in 1999) (EPA 2001)

	VOC	CO	NO_x	PM_{10}	SO_x
Electric utility fuel combustion (total)	56	445	5,715	221	12,698
Coal	29	239	4,935	194	11,856
Oil	5	18	202	5	657
Natural gas	9	94	385	1	12
Others	1	33	26	7	115
Industrial fuel combustion (total)	178	1,178	3,136	236	2,805
Coal	7	109	542	74	1,317
Oil	8	52	214	43	757
Natural gas	60	342	1,202	43	576
Others	35	341	118	60	135
Other fuel combustion	670	3,699	1,175	568	588
Chemical & allied product manufacturing	395	1,081	131	66	262
Metal processing	77	1,678	88	147	401
Petroleum & related industries	424	366	143	29	341
Other industrial processes	449	599	470	343	418
Solvent utilization	4,825	2	3	6	1
Storage and transportation	1,240	72	16	85	5
Waste disposal & recycling	586	3,792	91	587	37
Transportation (total)	8,529	75,151	14,105	753	1,299
Light-duty vehicles	4,633	43,497	4,497	95	228
Heavy-duty vehicles	664	6,492	4,094	201	135
Off-road vehicles	3,232	25,162	5,515	458	936
Miscellaneous sources	716	9,387	320	NA	12
Grand total	**18,145**	**97,441**	**25,393**	**3,045**	**18,867**

Note: Subtotals for a group may not add to the total of the group because not all subcategories for the group are presented in this table.

two committee members, for their helpful comments and suggestions. The author is solely responsible for the contents of this report.

REFERENCES

Abbreviations

CAIMRC	California Inspection and Maintenance Review Committee
CARB	California Air Resources Board
EIA	Energy Information Administration
EPA	U.S. Environmental Protection Agency
NPC	National Petroleum Council
NRC	National Research Council

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STUDY COMMITTEE
BIOGRAPHICAL INFORMATION

Martin Wachs, *Chair,* is Professor of Civil and Environmental Engineering and City and Regional Planning, and Director of the Institute of Transportation Studies at the University of California at Berkeley. He was formerly Professor of Urban Planning and Director of the Institute of Transportation Studies at the University of California at Los Angeles, where he served three terms as Head of the Urban Planning Program. His research interests include methods for evaluating alternative transportation projects; relationships among land use, transportation, and air quality; and fare and subsidy policies in urban transportation. Most recently, Dr. Wachs chaired the Transportation Research Board's (TRB's) Committee for a Study on Urban Transportation Congestion Pricing. He is past Chairman of the TRB Executive Committee. Dr. Wachs holds a Ph.D. in transportation planning from Northwestern University.

Carla J. Berroyer is a Senior Transportation Policy Specialist for Wilbur Smith Associates (WSA). Before joining WSA, Ms. Berroyer enjoyed a 24-year career with the Illinois Department of Transportation, where she held the position of Bureau Chief of Urban Program Planning for 9 years. During her tenure she oversaw the development of urban transportation programs in Illinois, including highway, aviation, and public transit programs; administered the metropolitan planning program and air quality functions; and managed development of the department's technical database. Ms. Berroyer was a member of the CMAQ Project Selection committee for the Chicago region and Chairman of the Subcommittee on Air Quality of the American Association of State Highway and Transportation Officials for 7 years. She is a past member of the Board of Directors for the American Road and Transportation Builders Association and past member of the Federal Advisory Committee on Ozone, PM, and Regional Haze. Ms. Berroyer was formerly a member of Governor George Ryan's Balanced Growth Subcabinet and of the Regional Growth Strategies' Task Force for the Northeastern Illinois Planning Commission. She currently serves on two panels of the National Cooperative Highway Research Program of TRB on the Economic Implications of Congestion and the Transportation Impacts of the National Ambient Air Quality Standards.

David S. Cordray is Professor of Public Policy and Professor of Psychology at Vanderbilt University. He is also Co-Director of the Center for Evaluation Research and Methodology at the Vanderbilt Institute for Public Policy Studies. Before joining the Vanderbilt faculty, he served as Assistant Director of the Division of Program Evaluation and Methodology at the U.S. General Accounting Office and as Associate Professor of Psychology at Northwestern University. Dr. Cordray has written extensively on evaluation methodology, primarily in the human services area. He is past president and past member of the Board of Directors of the American Evaluation Association and has served on several National Research Council (NRC) policy study committees.

Henry E. Dittmar is President of the Great American Station Foundation, a not-for-profit organization that promotes community economic development through the revitalization of railroad stations into centers of economic activity and intermodal transportation hubs. Mr. Dittmar remains a member of the Board of Directors of the Surface Transportation Policy Project (STPP), where he had served as Director, and most recently, as Director for Transportation and Quality of Life Campaign. The mission of STPP, a foundation-funded organization, is to ensure that transportation policy and investments help conserve energy, protect environmental and aesthetic quality, strengthen the economy, promote social equity, and make communities more livable. Before joining STPP, Mr. Dittmar was Manager of Legislation and Finance for the Metropolitan Transportation Commission in Oakland, California, and before that, Director of the

Santa Monica Airport. He is a member of two TRB policy study committees—the Research and Technology Coordinating Committee (FHWA) and the Committee for a Study for a Future Strategic Highway Research Program—and one standing committee, the Committee on Intergovernmental Relations and Policy Processes.

Eric M. Fujita is Research Professor in the Division of Atmospheric Sciences of the Desert Research Institute in Reno, Nevada. Dr. Fujita has 20 years of experience in planning and conducting air quality studies. He is the principal author of the field study plans for the 2000 Central California Ozone Study, the 1997 Southern California Ozone Study (SCOS97-NARSTO), and the 1996–1997 Northern Front Range Air Quality Study. His primary research interests include source apportionment of ozone precursors and fine particles and the application of ambient air quality and on-road measurements to evaluate the accuracy of emission inventories and the effectiveness of vehicle emission control programs. Dr. Fujita is a member of the Air and Waste Management Association and the American Geophysical Union.

Genevieve Giuliano is Professor in the School of Policy, Planning, and Development at the University of Southern California (USC) at Los Angeles. Before coming to USC in 1988, she taught at the University of California at Irvine. Dr. Giuliano's research interests include the relationship between land use and transportation, the cost and effectiveness of transportation demand management measures, and transportation policy evaluation. She is a Faculty Fellow of the Lincoln Institute of Land Policy, member of the Executive Committee of the Association of Collegiate Schools of Planning, and member of the editorial boards of several professional journals. Dr. Giuliano has served on several NRC and TRB policy study committees, including the Committee for Study of Impacts of Highway Capacity Improvements on Air Quality and Energy Consumption, the Committee on Metropolitan Area Governance, and the Committee on International Comparison of National Policies and Expectations Affecting Public Transit. Currently, she is Vice Chair of the TRB Executive Committee.

Joel L. Horowitz is Charles E. and Emma H. Morrison Professor of Economics at Northwestern University. Before his move to Northwestern in 2001, he was Henry B. Tippie Research Professor of Economics at the University of Iowa. He has also been a Senior Operations Research Analyst at the U.S. Environmental Protection Agency and has taught at George Washington University and the Massachusetts Institute of Technology. He has conducted research in air quality analysis for urban transportation planning, econometric analysis of choice behavior for travel demand modeling, and reduction of adverse environmental impacts of urban transport systems. Dr. Horowitz is a Fellow of the Econometric Society and is a member of the American Economic Association, the American Statistical Association, and the American Association for the Advancement of Science. He is co-editor or associate editor of several professional journals. Professor Horowitz served on TRB's Committee for a Study on Urban Transportation Congestion Pricing and on NRC's Committee on Data and Research for Policy on Illegal Drugs. He is currently serving on an NRC standing committee, the Committee on National Statistics, and an NRC policy study committee, the Committee to Improve Research Information and Data on Firearms.

Alan J. Krupnick is Senior Fellow at Resources for the Future and Director of its Quality of the Environment Division. His research focuses on the analysis of environmental issues, with a particular focus on air pollution, cost-benefit analysis, and the design of environmental policies, including their intersection with transportation policies. He recently co-chaired a federal advisory committee that provided counsel to the U.S. Environmental Protection Agency on implementing its new ozone and particulate standards. In 1994 Dr. Krupnick served as a senior staff economist for environment and natural resources on the President's Council of Economic Advisers. He served on TRB's Committee for a Review of the Highway Cost Allocation Study and is currently a member of the NRC Surface Transportation Environmental Cooperative Research Program Advisory Board.

T. Keith Lawton is Director of Technical Services in the Planning Department at Metro, the metropolitan planning organization for the Portland, Oregon, area. Mr. Lawton leads the model development work at Metro, where he has concentrated on bringing pedestrian environment variables into the modeling process. Currently he is involved in the development of activity-based models that consider daily activity schedules and use tours, rather than trips, as the unit of travel. Mr. Lawton is also involved in the federally supported activity-based model development known as TRANSIMS at the Los Alamos National Laboratories. He is on the Editorial Board of the journal *Transportation* and is past chair and currently a member of TRB's Committee on Passenger Travel Demand Forecasting.

Michael D. Meyer is Professor of Civil and Environmental Engineering at the Georgia Institute of Technology. He served previously as Chair of the School of Civil and Environmental Engineering for 6 years. Before coming to Georgia Tech in 1988, Dr. Meyer served for 5 years as the Director of the Bureau of Transportation Planning and Development at the Massachusetts Department of Public Works. Before that, he was a professor in the civil engineering department of the Massachusetts Institute of Technology. Dr. Meyer's research interests include transportation planning and policy analysis, environmental impact assessment, analysis of transportation control measures, and intermodal and transit planning. He is a Professional Engineer in the state of Georgia and member of the American Society of Civil Engineers and the Institute of Transportation Engineers. Dr. Meyer has chaired several TRB activities, including the Task Force on Transportation Demand Management, the Public Policy Committee, the Committee on Education and Training, and the Statewide Multimodal Transportation Planning Committee. He was also a member of the NRC Panel on Statistical Programs and Practices of the Bureau of Transportation Statistics. Currently, he is a member of the TRB Executive Committee and the TRB Committee on Statewide Multimodal Transportation Planning.

Michael R. Morris is Director of Transportation at the North Central Texas Council of Governments, which he joined as a Transportation

Analyst in 1979. As Transportation Director for the metropolitan planning organization for the Dallas–Fort Worth area, he is responsible for analysis and implementation of CMAQ projects and the conformity process, among other areas of responsibility. Mr. Morris is a registered engineer in the state of Texas. He is a member of the Association of Metropolitan Planning Organizations, the Institute of Transportation Engineers, the American Society of Civil Engineers, the National Society of Professional Engineers, and the Travel Model Improvement Program of the Federal Highway Administration. Mr. Morris has served on the NRC Committee to Review EPA's Mobile Source Emissions Factor (MOBILE) Model and is currently a member of the NRC Committee on Air Quality Management in the United States.

Robert F. Sawyer is Professor in the Graduate School at the University of California at Berkeley, where he is associated with the Department of Mechanical Engineering, the Energy and Resources Group, and the Lawrence Berkeley National Laboratory. He is a Visiting Professor of Energy and Environment at University College London. Dr. Sawyer conducts research on engine emissions, pollutant formation and control, thermal destruction of toxic wastes, and regulatory policy. He is co-chair of the Environmental Protection Agency's Mobile Source Technical Advisory Subcommittee of the Clean Air Act Advisory Committee, chair of the Special Committee on Emerging Technology of the Health Effects Institute, former member of the California Air Resources Board, and past president of the Combustion Institute. He has served on numerous NRC policy study committees, including the Committee to Review EPA's Mobile Source Emissions Factor (MOBILE) Model and the Committee to Study Diesel Impacts (chair of the Technology Panel of that committee). He was Consultant Panel Chairman for Technology to an earlier NRC Committee on Motor Vehicle Emissions. Dr. Sawyer is a Fellow of the Society of Automotive Engineers and a member of the American Society of Mechanical Engineering, the American Institute of Aeronautics and Astronautics, and the Air and Waste Management Association. He is a registered Professional Engineer in the state of California.

Kenneth A. Small is Professor of Economics at the University of California at Irvine, where he served 3 years as chair of the Department of Economics and 6 years as Associate Dean of Social Sciences. He previously taught at Princeton University and was a Research Associate at The Brookings Institution. Dr. Small has written numerous books and articles on urban economics, transportation, public finance, and environmental economics. He serves on the editorial boards of several professional journals in the fields of urban and transportation studies and has served as co-editor or guest editor for four of them. In 1999 he received the Distinguished Member award of the Transport and Public Utilities Group of the American Economic Association. During 1999–2000 he held a Gilbert White Fellowship at Resources for the Future. He has served on two TRB policy study committees—the Committee for a Review of the Highway Cost Allocation Study and the Committee for a Study on Urban Transportation Congestion Pricing.

Katherine F. Turnbull is an Associate Director at the Texas Transportation Institute, part of the Texas A&M University System. She is also a Visiting Professor in the Department of Landscape Architecture and Urban Planning at Texas A&M University. She is responsible for the overall management of programs in College Station, Arlington, and Austin. Dr. Turnbull's research interests include high-occupancy vehicle (HOV) facilities, public transportation services, and transportation demand management. She served as Chair of TRB's Committee on HOV Systems and is the incoming chair of the Group 5 Council. Dr. Turnbull also chaired the Steering Committee for the Conference on Travel Demand Management Innovation and Research. She is a member of several TRB standing committees, including the Task Force on Transportation Needs of National Parks and Public Lands and the Committees on Transportation Demand Management, Public Transportation Planning and Development, Light Rail Transit, Conduct of Research, and New Transportation Systems and Technology. She is a member of the ITS America Coordination Council and is the Chair of the Transit Council of the Institute of Transportation Engineers.

Kathleen C. Weathers is Forest Ecologist and Head of Laboratory Services at the Institute of Ecosystem Studies. She is also a member of the graduate faculty of the Cornell-IES Program in Biogeochemistry and of the Bard College Graduate Program in Environmental Studies. Her research focuses on the interaction of air pollutants and ecosystems. A particular research interest is the effect of edge areas, such as a transportation corridor, on atmospheric pollutants. Dr. Weathers is a member of the Ecological Society of America, the American Chemical Society, and the American Association for the Advancement of Science.

Arthur M. Winer is Professor of Environmental Health Sciences in the School of Public Health at the University of California, Los Angeles (UCLA), and from 1989 until 1998 he served as Director and Chair of the UCLA Environmental Science and Engineering Program. Since 1995 he has also served as Associate Director for the five southern campuses of the University of California's Toxic Substances Research and Teaching Program. Before joining the UCLA faculty, Dr. Winer was a member of the research faculty of the Statewide Air Pollution Research Center at the University of California, Riverside, where he served as Assistant Director for 8 years. Among his current research interests are field-based exposure assessments for toxic air pollutants and development and application of human exposure models for criteria air pollutants and air toxics. Dr. Winer has been a member of several NRC policy study committees, including the Environmental Impacts Panel of the Diesel Impacts Study Committee. He has also served on the Health Effects Institute's Exposure Analysis Subcommittee, Diesel Working Group, and Review Panel on Epidemiologic Investigations of Effects of Automotive Emissions. Dr. Winer is a member of the International Society of Exposure Analysis, the American Chemical Society, and the Air and Waste Management Association.

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