U.S.Department of Transportation
Federal Highway Administration

A Sampling of Emissions Analysis Techniques for Transportation Control Measures

final report

prepared for

Federal Highway Administration

prepared by

Cambridge Systematics, Inc.

under subcontract to

Louis Berger Associates

October 2000

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1.0 Introduction

1.1 Purpose and Motivation

The Congestion Mitigation and Air Quality improvement (CMAQ) program, established under the Intermodal Surface Transportation Efficiency Act of 1991 (ISTEA), is designed to assist regions in attaining ambient air quality standards by funding transportation projects and programs to improve air quality.[1] CMAQ funding is apportioned annually to states, which then allocate funds to eligible areas within the state. The Federal Highway Administration (FHWA) and Federal Transit Administration (FTA) publish guidance on the CMAQ program.[2]

CMAQ funds are intended to support projects that result in measurable reductions in emissions of carbon monoxide (CO), ozone precursors including volatile organic compounds (VOCs) and oxides of nitrogen (NOx), or particulate matter (PM). To show that air quality objectives are being met, state and local governments must demonstrate the benefits of individual CMAQ projects. An annual report is required from each state which specifies how CMAQ funds have been spent and the expected air quality benefits. While quantitative analysis is required whenever possible, a qualitative analysis is also considered acceptable when project benefits cannot be quantified. Groups of projects may be also analyzed in conjunction with each other when appropriate.[3]

This report describes modeling tools and other methods that can be used to assess the emissions benefits of projects applying for CMAQ funds. The methods described in the report may be used by state and local planners to compare alternative projects to assist in selecting the most effective or cost-effective projects. They may also be used to quantify the benefits of implemented projects for the purposes of CMAQ reporting.

The report is intended primarily for state or local air quality/transportation program analysts, as well as for others interested in estimating the emissions benefits of CMAQ projects. Most of the methods in the report do not require an extensive background in travel or emissions modeling. A familiarity with basic transportation data sources, however, can be helpful.

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[1] Specifically, the CMAQ program is designed under ISTEA to assist areas designated "nonattainment" or "maintenance" for ambient ozone and carbon monoxide levels, and is expanded under TEA-21 to include areas with similar designations for particulate matter.

[2] "The Congestion Mitigation and Air Quality Improvement (CMAQ) Program Under the Transportation Efficiency Act for the 21st Century (TEA-21): Program Guidance." Federal Highway Administration and Federal Transit Administration (April 1999). Internet: http://www.fhwa.dot.gov/environment/cmaq.htm.

[3] Federal Register, February 23, 2000, p. 9052.

The report includes a brief overview of 19 methods. The methods include pre-packaged and customizable software tools as well as worksheets or other procedures for calculating benefits. They collectively address a wide range of potential CMAQ projects, including travel demand management, traffic flow improvements, and vehicle and fuel technology strategies. The report also includes references to other sources of information on CMAQ program effectiveness.

Although project sponsors have been able to quantify benefits for a significant number of CMAQ projects, in many cases appropriate data and modeling tools to quantify benefits are not readily available. Nearly all of the public comments received on interim guidance for the CMAQ program under TEA-21 emphasized the need for project evaluation and selection criteria that could quantify air quality benefits more accurately and encourage the selection of the most cost-effective projects.[4] This report is a response to the expressed need for more widespread knowledge of methods to estimate the benefits of CMAQ projects.

A number of disclaimers are in order. First, **inclusion of a particular method in the report does not constitute its endorsement by FHWA or FTA**. Conversely, failure to include a method does not imply that the method is not valid or should not be used. The available methods vary in their technical approaches, assumptions, and underlying data. Limitations in existing data and the uncertainties inherent in both travel and emissions forecasting mean that any analysis method should be applied carefully and judiciously. Care should be taken to utilize a method whose accuracy and required resources are commensurate with the scale of the particular measure or measures being analyzed and the magnitude of impacts expected.

1.2 Structure of Report

Section 2.0 contains a review of forecasting approaches and issues in evaluating CMAQ emissions benefits.

Section 3.0 is designed to assist the user in selecting a method. Methods are identified by the types of CMAQ strategies addressed and by key characteristics such as level of effort.

Section 4.0 contains a brief overview of 19 specific forecasting methods. The overview covers data requirements, outputs, advantages, disadvantages, typical applications, related models, and the availability of each method.

Section 5.0 contains a listing of methods organized by strategy type, along with the primary data inputs required and outputs produced for each strategy type.

Section 6.0 contains references that provide additional information on forecasting techniques or on evidence related to CMAQ project impacts.

Section 7.0 provides a list of acronyms referenced in the document.

[4] *Ibid*.

2.0 Forecasting Approaches

This section provides a basic overview of travel and emissions forecasting approaches. The overview is intended to assist the user in understanding the various analytical approaches that underlie the methods described in the document. The section first reviews the effects of CMAQ strategies that lead to changes in emissions. Next, travel and emissions models commonly used in metropolitan transportation planning are discussed. These models represent the state of practice in travel and emissions forecasting at a regional level, and often serve as a source of data for other forecasting methods. Alternative analytical approaches to forecasting travel and emissions impacts are then described. The methods documented in Section 4.0 typically utilize one or more of these analytical approaches.

2.1 How CMAQ Projects Affect Emissions

The implementation of a CMAQ project (or any other transportation-related project) has a series of effects, as shown in Figure 2.1. The effects depend upon the nature of the CMAQ project. A CMAQ project may be primarily: 1) a travel demand management (TDM) project affecting travel behavior (e.g., ridesharing, transit incentives); 2) a transportation systems management (TSM) project affecting traffic flow (e.g., traffic signal timing, freeway ramp metering); or 3) a strategy affecting vehicle or fuel technology (e.g., alternative-fuel vehicles).

For a TDM project, the effects can be described as follows:

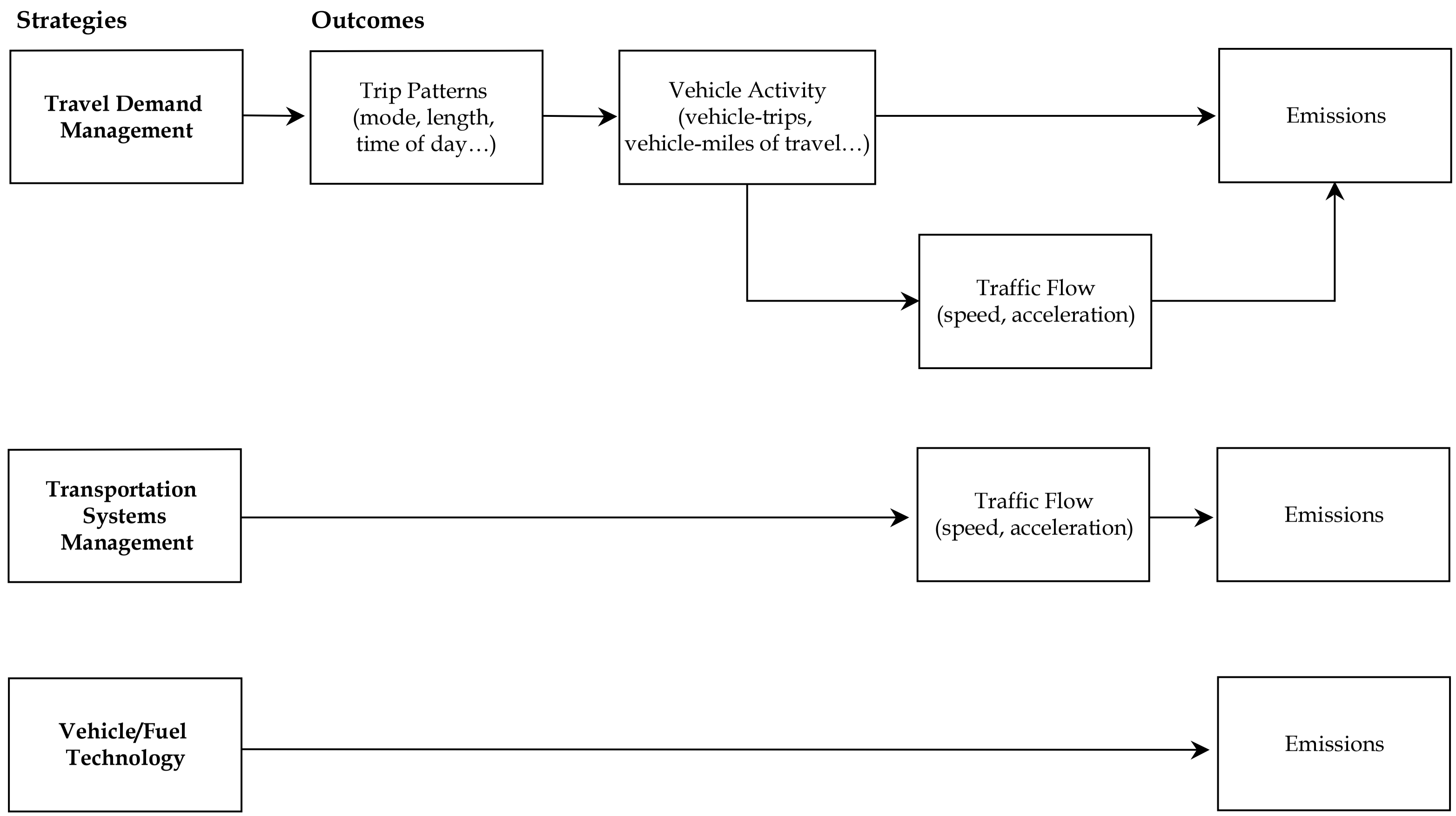
1. The CMAQ project creates changes in trip patterns (e.g., total person-trips, origins and destinations, mode share, time of day of travel);

2. Changes in trip patterns lead to changes in vehicle activity (e.g., total vehicle-trips, vehicle-miles of travel (VMT));

3. Changes in vehicle activity affect traffic flow characteristics, including travel speeds and acceleration characteristics; and

4. Changes in vehicle activity and traffic flow characteristics lead to changes in overall emissions.

Figure 2.1 Analytical Process for Evaluating CMAQ Projects



For a TSM project, the resulting effects are as follows:

1. The CMAQ project affects traffic flow characteristics, such as speed and acceleration; and

2. The resulting changes in vehicle speed and acceleration in turn affect the emission rates of vehicles.

For example, a signal coordination project can smooth vehicular flow, thus reducing acceleration and deceleration, which in turn reduces emissions.

Vehicle and fuel technology-based CMAQ strategies do not affect travel demand or traffic flow, but instead affect overall emission levels by changing the emissions characteristics of vehicles.

Some of the methods documented in this report use various assumptions to simplify the analysis procedure, such as estimating vehicle trip and VMT changes directly from CMAQ project implementation, or ignoring any changes in traffic flow characteristics that may result from demand management strategies. Other methods have a limited focus in that they only estimate travel impacts or only convert travel into emissions impacts. These methods are documented because they provide a valid analytical approach that can readily be applied in conjunction with other approaches. For example, the FHWA TDM Evaluation model provides a sound methodology for estimating VMT changes from TDM projects, but does not estimate emissions changes. To estimate emissions changes, the user would apply trip and/or VMT-based emission factors to the model output.

■ 2.2 Standard Travel and Emissions Forecasting Models

The "benchmark" for travel forecasting in regional transportation planning is an analysis tool known as the "four-step model" or "regional travel model." Most metropolitan planning organizations (MPOs) have a travel model that is specifically developed for their region. The basis for the regional travel model is the division of the urban area into traffic analysis zones (TAZs), and the definition of a network of transportation facilities connecting the zones. The network is described by the time and cost of travel, for each mode, between each pair of zones. Inputs include proposed future transportation networks and forecast population and employment characteristics by zone. Travel survey data and mathematical models are then used to predict the number of trips generated in each zone, the distribution of these trips (origin and destination zones), modal shares, and the routes taken for trips.

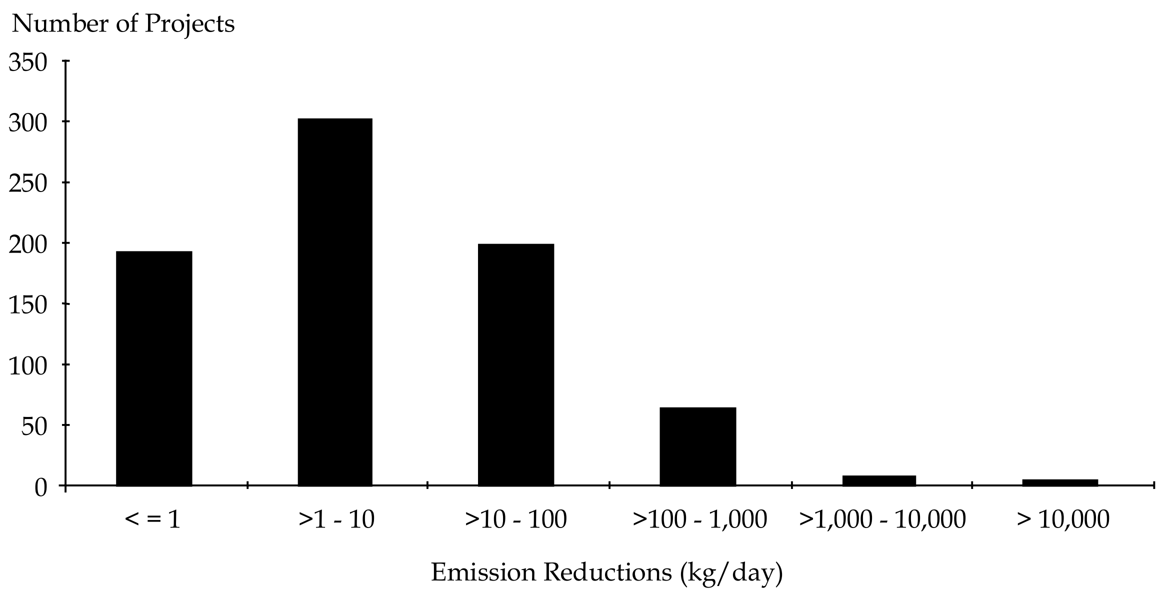
Travel models are typically used in developing an area's long-range transportation plan to predict future traffic volumes, based on changes in development and travel patterns, and to compare forecast volumes to roadway capacities to identify deficiencies and needs. They are good for predicting the results of major projects such as new or expanded facilities, but are not well-suited for analyzing small-scale operational projects such as intersection improvements.

Range of Emission Reductions from CMAQ Projects

The reported benefits from past CMAQ projects can illustrate the range of emission reductions that may be expected. Figure 2.2 shows the frequency distribution of VOC reductions for CMAQ projects funded in 1997. (These are self-reported benefits; also, some projects did not report quantitative benefits and are not reflected in this figure.) The majority of projects resulted in VOC reductions of less than 10 kilograms per day (kg/day), with most of the remainder falling between 10 and 100 kg/day. The median benefit was 5.2 kg/day. Figures 2.3 and 2.4 illustrate the range of benefits for CO and NOx. The median reported benefits were 37 and 4.0 kg/day, respectively. CO benefits are typically higher because CO emission rates from vehicles are higher than for VOC or NOx.

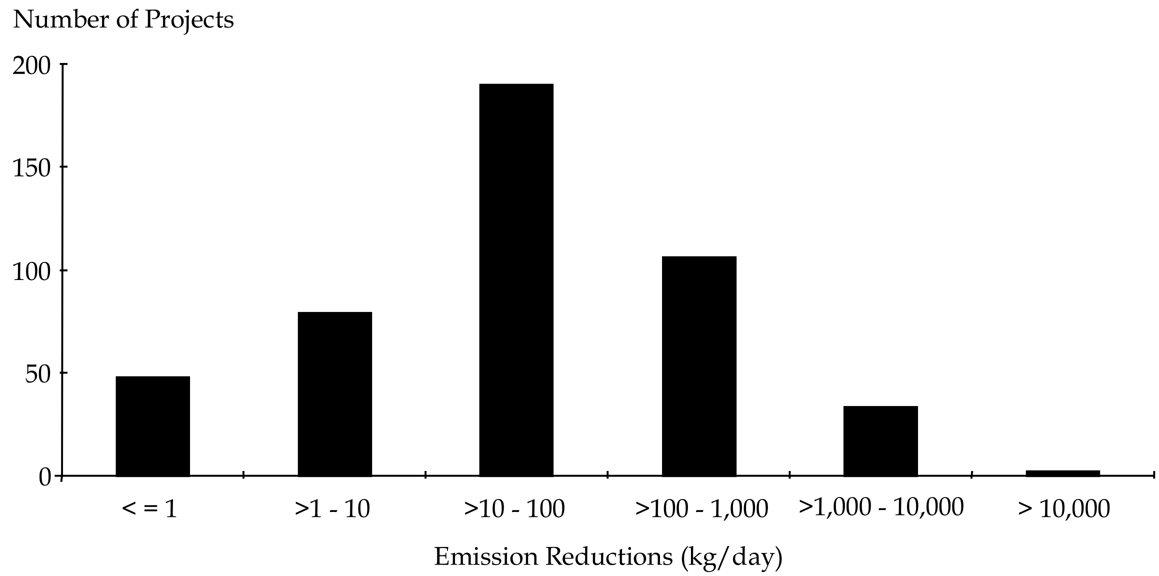
For a metropolitan area with a population of one million, total daily VOC emissions from mobile sources might be on the order of 25,000 to 30,000 kg. The regional impact of an individual "median" CMAQ project would therefore be on the order of 0.02 percent. This is not to diminish the benefit of the CMAQ project, but rather to place it in a regional perspective. Multiple projects, or projects with a broader scope, would of course result in a larger percentage reduction in regional emissions.

Figure 2.2 Distribution of VOC Emission Reductions, 1997 CMAQ Projects*



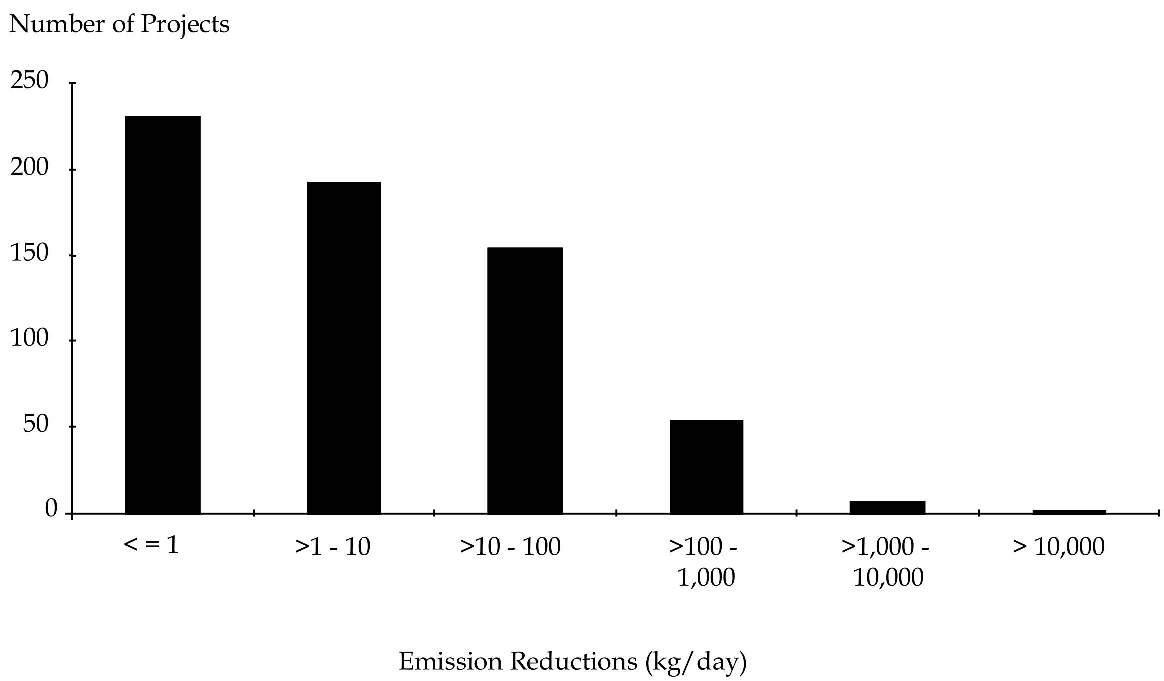
*Note: Emission benefits are self-reported. Only projects reporting quantitative benefits are included.

Figure 2.3 Distribution of CO Emission Reductions, 1997 CMAQ Projects*



*Note: Emission benefits are self-reported. Only projects reporting quantitative benefits are included.

Figure 2.4 Distribution of NOx Emission Reductions, 1997 CMAQ Projects*



*Note: Emission benefits are self-reported. Only projects reporting quantitative benefits are included.

CMAQ strategies that can be translated into changes in the number of vehicle-trips by TAZ (i.e., an area-wide employer trip reduction strategy) or changes in transportation network characteristics (i.e., new transit service between two points) can be analyzed using the MPO's standard regional travel model. This requires working with the MPO travel forecasting staff and also may require a significant level of effort to develop appropriate inputs and run the model. The advantage of this approach is that changes in vehicle miles of travel and speeds are identified across the entire transportation network.

Once outputs of the travel model are obtained, emission factors (expressed in grams per mile or grams per trip) can be applied to VMT and/or vehicle-trips by vehicle type and speed. The standard model used to develop emission factors is EPA's MOBILE model. (A related EPA model, PART5, is used to develop emission factors for particulate matter. In California, the Air Resources Board's EMFAC model is used in place of MOBILE.) Emission factors are typically developed by the State DOT, MPO, and/or air quality agency using locality-specific data describing the mix of vehicles, fuel characteristics, inspection and maintenance (I/M) program, and other factors that influence emissions. MOBILE factors can be applied to travel model output using a spreadsheet; software programs have also been written to automate the processing of travel model outputs and emission factors.[1]

Even if they are not used directly in assessing CMAQ strategy benefits, data and methodologies from regional travel and emission models play an important role in CMAQ evaluation strategies. For example, the Metropolitan Washington Council of Governments has used its mode choice model independently of the four-step model to analyze a range of TCM strategies (FHWA, 1995). Elasticities are sometimes obtained from model coefficients. Trip tables and network data from the regional travel model can be used to obtain average trip lengths for a particular area.

CMAQ evaluation methods that calculate emissions should be able to incorporate locality-specific emission factors as developed using MOBILE or EMFAC. These locality-specific emission factors generally can be obtained from the MPO, state DOT, or state environmental agency.

■ 2.3 Forecasting Travel Impacts

Forecasting travel behavior impacts is typically the most difficult part of CMAQ project analysis. A TDM strategy in particular can have a wide range of effectiveness based on the details of the strategy and its implementation context. The analyst should carefully consider the underlying data and analytical approaches utilized in the chosen method(s).

[1] Examples include the Post Processor for Air Quality (PPAQ) model developed by Garmen Associates for the New Jersey DOT, and the Surface Transportation Efficiency Analysis Model (STEAM) developed by FHWA.

Typical approaches to estimating travel behavior and demand impacts include:

- **Surveys** that assess the likely or actual impacts of a CMAQ project. For example, a survey of employees at a suburban employment site may be performed to determine how many people expect to use or have actually used a rideshare matching service. Surveys that provide adequate data for forecasting purposes are difficult to conduct. On the other hand, pre- and post-implementation surveys of *actual* travel behavior are often both feasible and necessary if the effectiveness of a CMAQ project is to be evaluated retrospectively.

- **Experience from other areas**. For example, a study may have found that five percent of office workers will telecommute one day a week if provided the opportunity. This is the simplest methodology to apply and can be used to assess programs that cannot be described in a quantitative manner (i.e., travel time and cost changes). It involves considerable risks, however, in assuming that results can be transferred from one situation to another.

- **Elasticities**. An elasticity says that an X percent change of an input variable (e.g., the cost of parking) produces a Y percent change of an output variable (e.g., drive-alone mode share). Elasticities may be developed from direct observation or from coefficients of a model such as a mode choice model. While they can account for different levels of the input variable, they are not necessarily valid outside the range for which they were developed. For example, an increase in the cost of parking from $0.00 to $1.00 is an infinite percentage change, producing meaningless results. Also, elasticities developed in one setting cannot necessarily be assumed accurate in another setting.

- **Logit or pivot-point model**. The logit model is a mathematical equation that predicts a particular choice (i.e., auto versus transit mode) as a function of differences in time, cost, or other quantifiable variables affecting travel. Logit mode choice models are typically developed from travel survey data as part of the four-step travel forecasting process. The pivot-point model is a derivative of the logit model with simpler input data requirements. The pivot-point model has the advantage that it requires only a knowledge of *baseline* mode shares and *changes* in travel time and cost. (Baseline travel time and cost information is not required because this information is fully reflected in the baseline mode share.) Logit-based models can account for the interaction of multiple factors, i.e., changing the time and cost of travel simultaneously.

Beyond the direct travel impacts of a CMAQ strategy, induced and offsetting travel may also be of interest to the analyst. Under some circumstances, the total travel and emission reductions resulting from CMAQ strategies may be less than the nominal reductions based on the specific vehicle-trips eliminated. Offsetting travel increases may come from two primary sources. The first is additional vehicle-travel by the same traveler or other members of the household. For example, a telecommuter may make an additional trip from home during the day to run an errand they would normally have run in conjunction with a work trip. The second is a "general" induced demand effect, in which reductions in network travel times (as a result of reduced vehicle-trips or improved traffic flow) are partially offset by additional travel resulting from the improved network performance. Induced travel may therefore occur as a result of TSM as well as TDM measures. A few of the models in this guidebook include factors to account for various types of induced and offsetting travel. Appropriate data on these factors, however, can be difficult to develop.

Another important consideration is interaction among strategies. Some strategies may complement each other (e.g., parking management and ridesharing incentives), leading to cumulative effects greater than the sum of the effects of the strategies if applied individually. Conversely, in some cases the effects of multiple programs may be smaller than the sum of their individual effects. For example, some TDM projects may compete for the same market of travelers, thus leading to diminishing returns as more projects are implemented. Except where noted, the methods described in this report typically do not account for the interactive effects of multiple strategies.

2.4 Forecasting Emissions Impacts

To translate travel changes into emissions changes, emission factors (i.e., grams per mile or grams per trip) are typically applied to changes in VMT and vehicle-trips. In some methods, emission factors may vary according to vehicle speed and/or vehicle type.

A number of important analytical issues arise in translating travel impacts into emissions impacts, or in forecasting the emissions impacts of traffic flow improvements. Some of the most noteworthy include:

- **Trip-end versus VMT (distance)-based emission factors**. Emissions at the beginning of a vehicle-trip are typically much higher than emissions later in the trip when the vehicle has warmed up. Therefore, some emission forecasting approaches apply separate trip-based and VMT (distance)-based emission factors. EPA's MOBILE5 model – the current source of emission factors in most areas – does not calculate trip and VMT-based emission factors separately; instead, cold-start and hot-start emissions are embodied in the VMT-based factor. As a result, the use of standard MOBILE emission factors will overestimate the benefits of strategies that do not reduce trips, but only affect trip lengths (i.e., park-and-ride), and conversely, will underestimate the benefits of strategies that reduce short trips (i.e., bicycle/pedestrian facilities). CARB's EMFAC model produces both trip-based and VMT-based emission factors, as will EPA's upcoming MOBILE6 model. Procedures have also been developed for identifying separate trip and VMT-based factors from MOBILE5. A few methodologies also consider emissions from work and non-work trips separately, under the assumption that hot versus cold start percentages differ between the two types of trips.

- **Traffic speed/flow impacts on emissions**. CMAQ strategies such as signal timing and ramp metering affect the speeds at which vehicles travel on different facilities or affect other characteristics of traffic flow such as idle times and acceleration rates. The way in which a vehicle is operated can have a significant effect on emissions. Vehicles typically emit pollution at higher rates (in grams per mile) at extremely low or high speeds or under hard acceleration.

Speed changes are typically assessed through equations relating traffic speed to volumes and facility characteristics such as capacity. Such equations are embodied within the regional travel model (see Section 2.2), and may also be applied independently for facility-level analysis. As an alternative, some sketch-planning approaches apply elasticities of average travel speed versus total area-wide VMT. Standard emission factor models such as MOBILE and EMFAC produce emission rates as a function of vehicle speed.[2] By applying speed-based emission factors, the emission impacts of strategies affecting traffic flow can be estimated to some extent.

The speed-based approach, however, does not account for changes in acceleration or idle characteristics, as might be expected from (for example) a signal timing project. To model traffic flow and emission impacts with greater precision, traffic simulation models are typically used. These models, which simulate actual traffic flows, incorporate emission factors that are based on both speed and acceleration rates.

- **Time-of-day shifting**. Some TDM strategies, notably shifted work hours and telecommuting, may affect the time during which trips are taken as well as the total number of vehicle-trips. Shifting trips from the peak to off-peak periods can affect total emissions by changing the speeds at which these trips are taken. Modeling of the emissions impacts of strategies that affect the time of travel requires a knowledge of the speed characteristics of vehicular travel during the peak and off-peak periods (as discussed above).

- **Vehicle type**. In addition to fleet-average factors, MOBILE and EMFAC produce emission factors for different types of vehicles, such as passenger cars, light trucks, and heavy trucks. Emission factors are typically higher for heavier classes of vehicles. While some CMAQ strategies, such as traffic flow improvements, will affect all types of vehicles, others, including most travel demand management strategies, will primarily affect passenger car and light truck travel. Emission factors used in the CMAQ analysis should reflect the general composition of the vehicle fleet affected by the strategy.

[2] These rates are meant to represent emissions from a typical driving cycle performed at a given *average* speed, rather than operation of the vehicle at a constant speed.

Example: California Air Resources Board Project Evaluation

In 1995, the California Air Resources Board (CARB) evaluated a number of emission reduction projects funded by state motor vehicle registration fees. The projects analyzed are similar to the types of projects commonly implemented under the CMAQ program. TDM projects were evaluated using transit or workplace-based survey data, in conjunction with the "California standardized methodology" described in this report. TSM projects were evaluated based on before and after travel speeds. Alternative fuel vehicle projects were evaluated based on various assumptions about emission rates and vehicle utilization.

The estimated VOC emission reductions for various types of strategies are shown in Table 2.1. Average benefits for the 18 projects are roughly 6.0 kg/day for reactive organic gases (ROG)[3] and 9.0 kg/day for NOx. The evaluation report illustrates that a range of emission benefits might be expected, even for similar types of projects, depending upon the specific details of the project. While these results illustrate the order of magnitude of emission reductions that might be expected, it should be noted that overall effectiveness may not correspond directly to cost-effectiveness. For example, a project with low total emission reductions could be cost-effective if total costs were also low.

Table 2.1 Sample Emission Benefits of CMAQ-Type Projects in California

		Average Benefits (kg/day)	
Project Type	**Number of Projects**	**ROG**	**NOx**
Alternative Fuel Buses	3	1	36
Bicycle Facilities	2	1	0
Electric Vehicles	2	0	2
Employer Trip Reduction	3	16	14
Telecommunications	3	1	1
Traffic Signal Timing	2	13	2
Transit (Shuttle)	3	6	2
All Projects	**18**	**6**	**9**

Source: California Air Resources Board. "Evaluation of Selected Projects Funded by Motor Vehicle Registration Fees." Sacramento, CA (1995). Annual benefits from this report were converted to daily benefits using an annualization factor of 260, since most projects are worksite-based.

[3] ROG (reactive organic gases) is similar to VOC (volatile organic compounds).

3.0 Selecting a Method

This section provides summary information on each method that should assist the user in selecting an appropriate method. The methods are loosely placed in four groups, as follows:

1. **Off-the-shelf TDM/TCM analysis software**. These are software packages that can be acquired for free or at a low cost. They have been designed to analyze a variety of strategies aimed at reducing travel impacts (TDM programs) and/or reducing emissions (TCM programs). While the software itself is readily available, the user must generally obtain locality-specific data from the MPO.

2. **Customized TDM/TCM analysis software**. These software packages have similar objectives as those in category 1, but require some customization of the software to apply locally. As a result, a greater initial investment is required to develop the model. The benefits may include greater accuracy and ease of use, since the models can be tailored to local data and needs.

3. **Sketch-plan workbook approaches.** These are not software packages, but instead are worksheets or examples of calculations by other agencies to assess the emission impacts of CMAQ-type projects. They may cover strategies not addressed by existing software packages, but they can become cumbersome to apply for multiple projects.

4. **Specialized software tools and methods.** These are software packages or methods designed to analyze one or more specific strategy types. While the methods address only a limited set of CMAQ strategies, they generally address these strategies with greater depth and accuracy than more general models. The range of customization and level of effort in this group varies significantly.

Table 3.1 summarizes each of the 19 methods. Table 3.2 identifies the types of CMAQ strategies addressed by each method. Table 3.3 provides a summary analysis of some key characteristics of each method, including:

- **Availability,** or the cost and level of effort in obtaining the model in a format that can be applied locally to analyze strategies;

- **Ease of application**, or the level of effort in using the model and in obtaining any data necessary to analyze specific programs;

- **Technical robustness**, or the validity or accuracy of the underlying data and computational techniques embedded in the model;

- **Range of strategies addressed**, or the extent to which a single model is capable of analyzing a broad range of CMAQ strategies; and

- **Self-sufficiency**, or the extent to which the method is capable of addressing the various analytical steps required, including the estimation of both travel benefits and resulting emission changes as a result of project implementation.

To further assist the user of this report, Section 5.0 provides a listing of methods by type of strategy addressed. For each method, the basic inputs required to describe the strategy are identified (e.g., for transit service, percent change in transit fare or frequency of service). This should assist the user in identifying whether the model is capable of evaluating the specific strategies proposed for CMAQ funding.

Table 3.1 Summary of Methods Included*

Method	Description
Off-the-Shelf TDM/TCM Analysis Software	
TDM Evaluation Model	Software to predict trip and VMT impacts of employer-based TDM strategies.
TCM/Commuter Choice Model	Spreadsheet software based on TDM Evaluation Model; also calculates emissions.
TCM Analyst	Spreadsheet software to estimate travel and emission impacts of TCMs.
CM/AQ Evaluation Model	Software for estimating emission benefits and cost-effectiveness of potential CMAQ projects and for ranking projects.
CUTR_AVR	(Center for Urban Transportation Research Average Vehicle Ridership model) Model to predict AVR impacts of workplace-based TDM programs.
Customized TDM/TCM Analysis Software	
TCM Tools	Spreadsheet model for screening and sensitivity testing of a wide range of TCM strategies at an area-wide level.
Off-Net/PAQONE	Models to predict emissions impacts of various transit, non-motorized travel, and traffic flow strategies.
ECO/Regulation XV Software	Software to help employers predict benefits of and track participation in Employee Commute Options (ECO) programs.
Sketch-Plan Workbook Approaches	
California Standardized Methodology	Calculation steps to estimate emissions reductions and cost-effectiveness of TDM programs, based on survey data on mode shares.
RAQC Workbook	Workbook to estimate potential benefits of various TDM strategies applied at a regional level.
MWCOG Sketch-Planning Methods	Sample calculations by the Metropolitan Washington Council of Governments (MWCOG) for various TCM strategies.
NCTCOG Sketch-Planning Methods	Sample calculations and empirical data from North Central Texas Council of Governments (NCTCOG) for TDM and traffic flow strategies.
Specialized Methods	
Quick HOV	Procedures and software to analyze impacts of HOV facilities.
IDAS	(Intelligent Transportation Systems (ITS) Deployment Analysis System) Software to analyze travel and emissions impacts of over 60 ITS strategies, based on regional travel model data.
SMART	(Simplified Model for the Assessment of Regional Travel) Software to estimate air quality impacts of highway and transit network improvements.
Traffic Simulation Models	Commercial software for analyzing traffic flow and emissions impacts of intersection and roadway operational improvements.
AirCred	Model for estimating emissions benefits of alternative fuel light-duty and transit vehicles.
Bus Replacement Spreadsheet	Spreadsheet for analyzing replacements of older buses with new diesel or alternative fuel buses.
Freight Air Quality Analysis Procedures	Report containing methods and procedures for assessing emissions impacts of freight strategies.

* See Section 7.0 for a list of acronyms.

Table 3.2 Methods by Strategy Addressed*

Demand Management

Method	Transit	HOV Lanes	Park 'n' Ride	Car/Van Pool	Emp-based TDM	Bike & Ped.	Traveler Info	Telecom/ Work Hrs.	Pricing/ Subsidy	Land Use	Parking Mgmt.
Off-the-Shelf TDM/TCM Analysis Software											
TDM Evaluation Model	X	X		X	X			X	X		
TCM/Commuter Choice Model	X	X		X	X	X		X	X		
TCM Analyst	X	X		X		X		X	X		
CM/AQ Evaluation Model	X	X	X	X		X	X	X	X		X
CUTR_AVR				X				X	X		
Customized TDM/TCM Analysis Software											
TCM Tools	X	X	X	X	X	X		X	X	X	
OffNet/PAQONE	X		X			X					
ECO/Regulation XV Software	X			X	X	X		X	X		
Sketch-Plan Workbook Approaches											
California Std. Methodology	X			X	X	X		X	X		
RAQC Workbook	X	X		X	X	X		X	X	X	X
MWCOG Sketch-Planning Methods			X	X		X	X	X	X	X	
NCTCOG Sketch-Planning Methods	X	X	X		X	X					
Specialized Methods											
Quick HOV		X									
IDAS							X				
SMART	X	X	X						X		
Traffic Simulation Models											
AirCred											
Bus Replacement Spreadsheet											
Freight Air Quality Analysis Procedures											

* Note: Inclusion of any particular strategy in this table, or elsewhere in this report, does not necessarily imply that the strategy is eligible for CMAQ project funding.

Table 3.2 Methods by Strategy Addressed* (continued)

Traffic Flow and Vehicle/Fuel Technology

Method	Traffic Flow	Incident Mgmt.	Freight/Intermodal	Traffic Calming	Idle Control	Alt. Fuel Vehicles
Off-the-Shelf TDM/TCM Analysis Software						
TDM Evaluation Model						
TCM/Commuter Choice Model						
TCM Analyst	X					
CM/AQ Evaluation Model	X	X	X	X	X	X
CUTR_AVR						
Customized TDM/TCM Analysis Software						
TCM Tools		X				
OffNet/PAQONE	X					
ECO/Regulation XV Software						
Sketch-Plan Workbook Approaches						
California Std. Methodology						
RAQC Workbook						
MWCOG Sketch-Planning Methods					X	
NCTCOG Sketch-Planning Methods		X				X
Specialized Methods						
Quick HOV	X					
IDAS	X	X				
SMART	X					
Traffic Simulation Models	X					
AirCred						X
Bus Replacement Spreadsheet						X
Freight Air Quality Analysis Procedures			X			

* Note: Inclusion of any particular strategy in this table, or elsewhere in this report, does not necessarily imply that the strategy is eligible for CMAQ project funding.

Table 3.3 Methods by Key Characteristic*

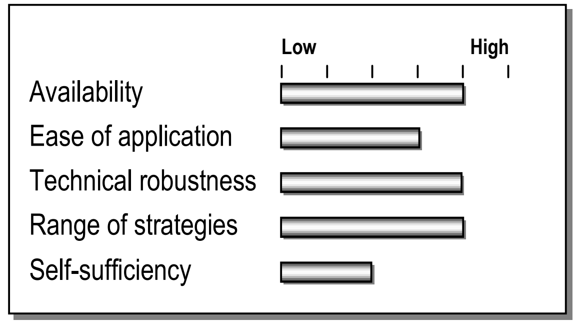
Method	Availability	Ease of Application	Technical Robustness	Range of Strategies	Self-sufficiency
Off-the-Shelf TDM/TCM Analysis Software					
TDM Evaluation Model	4	3	4	4	2
TCM/Commuter Choice Model	5	4	3	4	5
TCM Analyst	4	2	2	4	4
CM/AQ Evaluation Model	4	4	2	5	4
CUTR_AVR	5	5	4	2	2
Customized TDM/TCM Analysis Software					
TCM Tools	3	4	2	5	4
Off-Net/PAQONE	3	4	3	4	5
ECO/Regulation XV Software	1	3	4	4	2
Sketch-Plan Workbook Approaches					
California Standardized Methodology	4	4	3	4	2
RAQC Workbook	4	3	2	5	5
MWCOG Sketch-Planning Methods	4	3	2	5	4
NCTCOG Sketch-Planning Methods	4	3	2	4	4
Specialized Methods					
Quick-HOV	4	2	5	1	5
IDAS	4	1	5	2	5
SMART	1	2	5	2	5
Traffic Simulation Models	3	1	5	2	5
AirCred	5	5	4	1	5
Bus Replacement Spreadsheet	5	4	4	1	5
Freight Air Quality Analysis Procedures	5	1	4	1	3

* Note: 5 = High/Good, 1 = Low/Poor.

4.0 Descriptions of Available Methods

This section provides a one- to two-page description of the following 19 methods. Refer to Table 3.1 for a one-sentence overview of each method.

TDM Evaluation Model



Overview – The TDM Evaluation Model is a software program that analyzes the vehicle-trip reduction effects of a wide range of travel demand management strategies. The TDM model has been widely applied throughout the U.S. for the purpose of analyzing Transportation Control Measures or other TDM programs.

Strategies Addressed – Improved transit; HOV lanes; carpooling and vanpooling promotion; telecommute and work hour strategies; pricing and subsidies.

Methodology – Strategies that affect the time and/or cost of travel are evaluated using a "pivot-point" mode choice model. The pivot point model is a derivative of the logit mode choice model commonly used in four-step travel demand models. It requires information on baseline mode shares and changes in travel time or cost. Other strategies, such as employer-based support programs and work hour shifts, are evaluated using lookup tables based on empirical evidence.

Data Requirements – Baseline travel data requirements include zone-to-zone person and vehicle trip tables for the analysis area (these may be derived from the regional travel model or constructed from employee commute survey data), or total person and vehicle trips for an individual site/area. Other data requirements include impacts of strategies on travel time and cost by mode and descriptions of other (non-time/cost-based) TDM programs. The user has the option to change default parameters affecting strategy effectiveness.

Outputs – Changes in modal share, vehicle-trips, VMT, average vehicle occupancy and ridership.

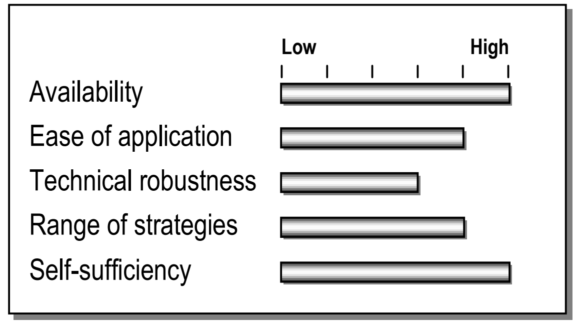
Level of Effort – The TDM model is easy-to-use, off-the-shelf software. Some effort is required to develop inputs in the form of matrices showing the number of trips by mode and the distance between each pair of zones.

Advantages – The logit-based pivot point mode choice approach is theoretically sound, consistent with common practice in travel demand forecasting, and capable of analyzing the joint impacts of time and cost-based strategies. The empirical lookup tables allow for differences in impacts by size and type of employer. Trip-table inputs allow "market segmentation" by origin/destination, and impacts vary for each "market" depending upon trip lengths and starting mode shares.

Limitations – The TDM model does not estimate emissions benefits directly. The user must apply VMT and/or trip-based emission factors. The default coefficients and data on strategy effectiveness in the TDM model date from around 1990 or earlier.

Source/Availability – The TDM Evaluation Model is a DOS-based software program. It is distributed by McTrans (352-392-0378, mctrans@ce.ufl.edu) at a cost of $250.

TCM/Commuter Choice Model



Overview – The TCM/Commuter Choice Model is a spreadsheet-based software program developed for the EPA. It is designed specifically to analyze the travel and emission impacts of employer-based voluntary travel demand management strategies.

Strategies Addressed – Improved transit; HOV lanes; carpooling and vanpooling promotion; bicycle and pedestrian programs; telecommute and work hour strategies; pricing and subsidies.

Methodology – The data and methodologies used to estimate travel impacts are similar to those in the TDM Evaluation Model. Strategies that affect the time and/or cost of travel are evaluated using a "pivot-point" mode choice model. Other strategies, such as employer-based support programs and work hour shifts, are evaluated using lookup tables based on empirical evidence. Emission changes are based on changes in trips, VMT, and speed, using lookup tables derived from MOBILE5a.

Data Requirements – Total persons affected, baseline mode shares, and average trip lengths by mode for an individual site or area; impacts of the strategy on changes in travel time and cost by mode; and description of other (non-time/cost-based) TDM programs. The user has the option to change default parameters.

Outputs – Changes in modal share, vehicle-trips, VMT, and emissions.

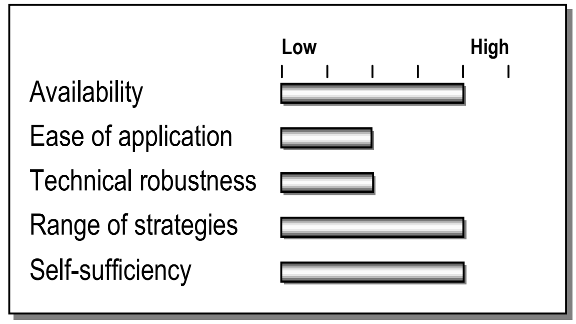
Level of Effort – The TCM/Commuter Choice Model is easy-to-use, off-the-shelf software. Some effort may be required to identify reasonable assumptions on baseline mode shares, trip lengths, and affected employment for the analysis area.

Advantages – The logit-based pivot point mode choice approach is theoretically sound, consistent with common practice in travel demand forecasting, and capable of analyzing the joint impacts of multiple strategies. The empirical lookup tables allow for differences in impacts by size and type of employer.

Limitations – Some of the default data on strategy effectiveness date from around 1990 or earlier. The model is not directly capable of analyzing multiple "market segments." The ability of the software to manage scenarios is limited.

Source/Availability – The EPA TCM/Commuter Choice Model was developed in 1998. It can be downloaded at no charge from the EPA's Office of Transportation and Air Quality web site (http://www.epa.gov/oms/transp.htm).

TCM Analyst/EPA TCM Methodology



Overview – The TCM Analyst is a spreadsheet-based sketch-planning tool developed by the Texas Transportation Institute (TTI) to estimate the emissions benefits of TCMs. It is based on methodologies previously developed for the U.S. Environmental Protection Agency ("EPA TCM Methodology").

Strategies Addressed – Improved transit; HOV lanes; carpooling and vanpooling promotion; telecommute and work hour strategies; traffic flow improvements.

Methodology – All calculations are performed in a Microsoft Excel workbook. Elasticities are used to relate changes in cost or time to travel changes, and to relate VMT changes to speed changes. The calculations account for trip lengths, prior mode of travel, etc. MOBILE emission factors by component (hot start, cold start, running, etc.) are applied to the outputs of the travel calculations. The methods typically use regionwide estimates of existing travel characteristics and calculate regional-scale effects, but they can also be applied at the corridor, facility, or zonal level.

Data Requirements – Data required for the analysis area include travel data (e.g., total person and vehicle-trips, trip distances, speeds for peak and off-peak periods); data on existing TCM implementation (e.g., average carpool size); census data (e.g., number of workers, persons per household, vehicle ownership); potential number of users; and MOBILE emission factors by speed, type, and operating mode. Various assumptions regarding elasticities or participation rates are also required for some strategies.

Outputs – Changes in trips, VMT, average travel speeds, and emissions.

Level of Effort – The baseline regional-level data requirements are fairly extensive and not all inputs will be readily available. Emission factors from over 400 MOBILE scenarios must be copied into the spreadsheet. The user may need to make other assumptions regarding participation levels, elasticities, induced trip-making, etc.

Advantages – By automating calculations, the spreadsheet format greatly simplifies the use of the EPA's methodologies. The methodologies provide a detailed accounting of impacts by emission component, vehicle type, work versus non-work trips, and peak versus off-peak travel. They also include factors to account for prior mode of travel, substitution effects (i.e., increased non-work driving by telecommuters), induced demand, and changes in trip lengths.

Limitations – Baseline regional travel data and emission factors can be somewhat cumbersome to develop. For some strategies, participation rates must be assumed by the user. Some effort may also be required to identify appropriate elasticities or other assumptions.

Source/Availability – The TCM Analyst 1.0 User's Guide and Software are available from the Texas Transportation Institute (979-845-4853, http://tti.tamu.edu/).

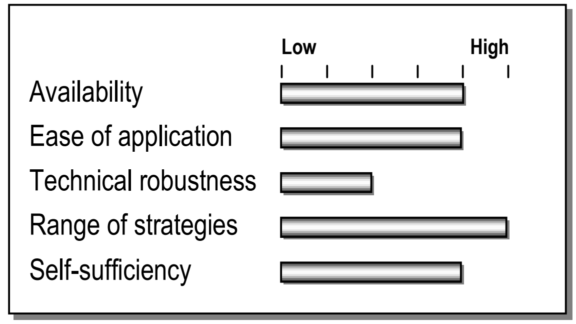
Reference: *TCM Analyst 1.0 User's Guide*. Research Report 1279-7, Texas Transportation Institute, College Station, TX (November 1994).

The following documents describe the underlying methodologies developed for EPA and provide examples of their application:

ICF Incorporated. *Benefits Estimates for Selected TCM Programs*. Prepared for U.S. EPA, publication no. EPA420-R-98-002, March 1999. Provides examples of the methodologies applied to six operating TCM programs. Internet: http://www.epa.gov/oms/transp/publicat/pub_tcms.htm.

Austin, et al. *Methodologies for Estimating Emission and Travel Activity Effects of TCMs*. Prepared by Systems Applications International for U.S. EPA, publication no. EPA420-R-94-002, July 1994. Available from the National Technical Information Service (NTIS) at 800-553-6847. Reference NTIS No. PB92-172566/REB.

CM/AQ Evaluation Model



Overview – The Congestion Mitigation/Air Quality (CM/AQ) Evaluation Model is a software program designed to calculate the emissions benefits of candidate CMAQ projects and to rate projects based on various effectiveness criteria.

Strategies Addressed – Improved transit; HOV lanes; park and ride; carpooling and vanpooling promotion; bicycle and pedestrian facilities; traveler information; telecommuting/work hours; pricing/subsidies; parking management; traffic flow improvements; intermodal freight; traffic calming; idle control; cold start; alternative fuel vehicles (total of 59 individual strategies).

Methodology – The model is a menu-driven custom application designed within the Paradox database software. The methodologies to estimate travel changes are similar to those employed in the TCM Tools model. For some strategies, travel changes are estimated based on elasticities; for others, program participation must be estimated by the user. Emission reductions are estimated based on changes in travel characteristics (VMT, trips, and speed) and user-entered emission factors. The model also estimates cost-effectiveness and provides an overall ranking of projects, based on user-defined weighting factors.

Data Requirements – User inputs include baseline travel characteristics (e.g., number of person-trips, percent of trips in peak period) and behavioral assumptions (elasticities or participation) for the strategy being analyzed. Local emission factors from the MOBILE and PART5 models are also required. Default values are provided for many of the parameters, although local data are preferred.

Outputs – Changes in trips, VMT, speed, and idling time for peak and off-peak periods.

Level of Effort – The model is relatively easy to use, but requires a basic knowledge of Paradox and also requires local data such as MOBILE emission factors and baseline travel characteristics.

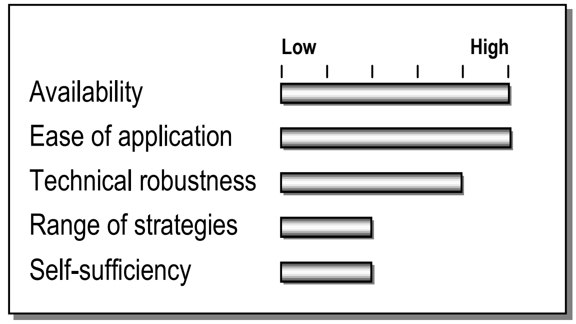
Advantages – The CM/AQ Evaluation Model covers a wide range of potential CMAQ strategies. The cost-effectiveness and criteria weighting modules provide capabilities beyond most CMAQ and TCM evaluation packages, allowing users to rank projects based on various effectiveness criteria. The model accounts for the impacts of reduced idling and cold-start and hot-start trips as well as reduced VMT.

Limitations – The model is limited in its ability to forecast the travel impacts of TDM strategies. Many strategies require the user to estimate participation rates (e.g., telecommuting participants, number of new walkers/bicyclists), as well as to make other assumptions that affect the magnitude of travel impacts.

Source/Availability – The model was originally developed for the Denver Regional Council of Governments by JHK Associates, and was adopted in 1995 by the Texas Transportation Institute for use by metropolitan areas in Texas. The CM/AQ Evaluation Model and User's Guide are available from the Texas Transportation Institute (979-845-4853, http://tti.tamu.edu/).

Reference: *TTI CM/AQ Evaluation Model User's Guide and Workshop Training Materials*. Research Report 1358-1, Texas Transportation Institute, College Station, TX (August 1995).

CUTR_AVR Model



Overview – The CUTR_AVR model predicts changes in average vehicle ridership (AVR) resulting from employer-based TDM programs.

Strategies Addressed – Carpooling and vanpooling promotion; telecommute and work hour strategies; pricing and subsidies.

Methodology – The CUTR_AVR model uses an artificial neural network to predict mode share and average vehicle ridership based on attributes of the employer-based TDM program. TDM program effects can be analyzed either individually or in combination with each other. The model is based on a dataset including 7,000 employer trip reduction plans from three metropolitan areas in Arizona and California. The model is particularly applicable at the site level for single employers with 100 or more employees or multiple employer sites.

Data Requirements – Data are required on the employment sites to be evaluated, including current mode share, number of employees, and area population.

Outputs – Changes in modal share and average vehicle ridership.

Level of Effort – The CUTR_AVR model is easy-to-use, off-the-shelf software. Minimal effort is required to develop the data inputs.

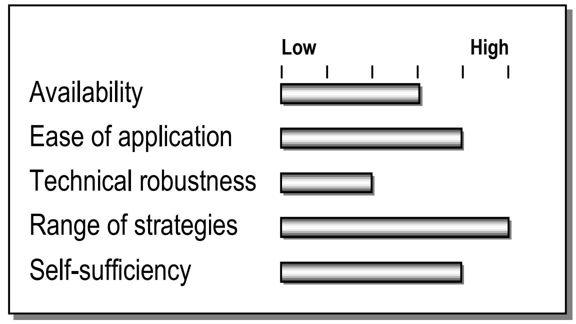
Advantages – Positive attributes include 1) the model is based on a large, real-world data set; 2) it allows non-linear/non-additive effects of programs; 3) effectiveness can vary by the size of the company; and 4) results from multiple employment sites can be combined. The model performed well in a comparison with other TDM evaluation models. The model is best suited for evaluating impacts of TDM programs that cannot be quantified through time and cost changes.

Limitations – The model evaluates only a subset of specific TDM programs. Different levels of program implementation or participation are not considered – each program is either implemented or not implemented. Similarly, the model is not sensitive to varying levels of financial or time-based incentives. The model does not calculate VMT or emissions reductions.

Source/Availability – The CUTR_AVR model, developed in 1999, is available from the Center for Urban Transportation Research (CUTR) at the University of South Florida. It can be downloaded at no charge from CUTR's National TDM and Telework Clearinghouse; (http://www.cutr.eng.usf.edu/). For information contact Phil Winters (winters@cutr.eng.usf.edu).

For additional documentation, see Winters, et al. *Predicting Change in Average Vehicle Ridership Based on Employer Trip Reduction Plans*. Paper submitted to the 78th Annual Meeting of the Transportation Research Board (Paper no. 990484), January 1999.

TCM Tools



Overview – TCM Tools is a sketch-planning model designed to calculate the cost-effectiveness of a wide range of TCM measures at achieving emissions reductions. It has been applied in a number of metropolitan areas such as San Diego, Houston, and Tucson.

Strategies Addressed – Improved transit; HOV lanes; park and ride; carpooling and vanpooling promotion; employer-based TDM; bicycle and pedestrian facilities; telecommuting/work hours; pricing/subsidies; land use.

Methodology – TCM Tools is intended for the analysis of strategies employed at a regionwide level. The Transportation Module, a spreadsheet application, calculates changes in peak and off-peak vehicle trips, VMT, and vehicle speeds on an area-wide basis. For some strategies, travel changes are estimated based on elasticities; for others, program participation must be estimated by the user. The Emissions Module, a Fortran program, estimates reductions in emissions based on changes in travel characteristics (VMT, trips, and speed) and MOBILE or EMFAC emission factors.

Data Requirements – User inputs to the Transportation Module include baseline travel characteristics (number of person-trips, percent of trips in peak period, etc.) and behavioral assumptions (elasticities or participation) for the strategy being analyzed. The Emissions Module requires data on VMT and speeds by six facility types, along with other data (such as vehicle registration distributions and ambient temperatures) that are typically developed for analyses using MOBILE.

Outputs – Changes in mode share, vehicle-trips, VMT, average travel speed, and emissions.

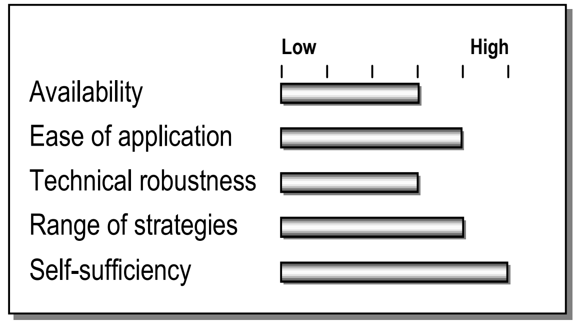
Level of Effort – The Transportation Module is relatively easy to apply. Running the Emissions Module in conjunction with the Transportation Module is a multi-step process, and requires some initial effort to develop inputs.

Advantages – The strength of the model is as a calculation aid, in which the user can input various assumptions regarding program characteristics, behavioral responses, and costs, and can compare the magnitude of impacts for different strategies and assumptions.

Limitations – The model is limited in its ability to forecast the travel impacts of TDM strategies; many strategies require the user to estimate participation rates (e.g., telecommuting participants, number of new walkers/bicyclists), as well as to make other assumptions that affect the magnitude of travel impacts. The ability of the software to manage scenarios is limited.

Source/Availability – TCM Tools was developed in the early 1990s by Sierra Research with assistance from JHK Associates, and has since been customized for applications in various areas. For more information, contact Cecilia Ho, FHWA Office of Natural Environment (202-366-9862); or Bob Dulla, Sierra Research (916-444-6666).

Off-Net/PAQONE



Overview – The Off-Network Tool Set (Off-Net) and PAQONE are similar sketch-planning tools designed to estimate the emissions benefits of TCMs that cannot be readily analyzed using traditional transportation models.

Strategies Addressed – Improved transit; park and ride; employer-based TDM; bicycle and pedestrian facilities; traveler information; traffic flow improvements; incident management.

Methodology – A variety of methodologies are used, including sketch-planning analysis, elasticities, and highway/traffic engineering principles from the Highway Capacity Manual. Vehicle-trips are distributed by time of day and work versus non-work trips. VMT changes are distributed by time of day, facility type, and area type. A stand-alone emissions module runs MOBILE to develop emission factors. Project and scenario data are stored in a Microsoft Access database.

Data Requirements – A variety of different inputs are required, depending on the strategy analyzed. These include factors such as existing transit boardings on affected routes, population of transit or bicycle route service areas, baseline speeds and volumes on affected roadways, and changes in transit, bicycle, or roadway service characteristics. Travel outputs are designed for use in conjunction with VMT and speeds by facility type, as can be obtained from regional travel model output.

Outputs – Vehicle-trips, VMT, emissions.

Level of Effort – The models are Windows-based applications that are easy to use. The software includes a scenario management function. Some effort is required to develop baseline data and assumptions.

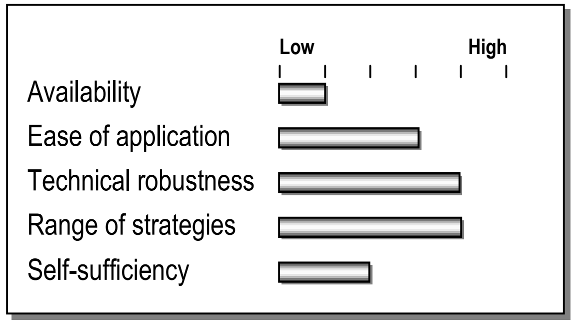
Advantages – The models are designed to analyze a variety of transit, non-motorized travel, and roadway improvements that cannot readily be analyzed through other means, or in a sketch-planning fashion with limited data requirements. The use of VMT and speed data by facility type is designed to make the model output consistent with emissions estimates for conformity analysis based on travel demand models.

Limitations – A number of the assumptions in the model that determine strategy effectiveness are based on judgment or rules of thumb. Appropriate assumptions may vary from place to place, and impacts may vary locally based on factors not included in the model.

Source/Availability – The underlying methodologies were originally developed for the Pennsylvania DOT by COMSIS Corporation in 1993. They have recently been adopted for Illinois DOT by Cambridge Systematics, Inc. with Michael Baker Associates and E.H. Pechan into a Windows-based software package known as Off-Net. PAQONE is a similar package developed by Michael Baker Associates for PennDOT to include additional employer-based and regionwide TDM strategies, to assist MPOs with CMAQ analysis. The original PennDOT procedures have been applied by other states for CMAQ and conformity analysis. The models could be adapted for use by other areas with minor modification.

Contacts – Illinois DOT – Tim Milam (217-524-9067) or Susan Stitt (217-782-2863). Cambridge Systematics, Inc. – Don Vary (202-466-5542) or Dan Beagan (617-354-0167). PennDOT – Mike Baker (Program Center) (717-772-0796). Michael Baker Associates – Robert Kaiser or Jim Frazier (410-571-8706).

ECO/Regulation XV Software



Overview – The ECO (Employee Commute Options) software suite was developed for the Oregon Department of Environmental Quality (DEQ) to help Portland area employers comply with ECO rules. The ECO Software is based closely on the "TDM" model developed for the South Coast Air Quality Management District (SCAQMD) to support the Regulation XV program in California.

Strategies Addressed – Improved transit; HOV lanes; carpooling and vanpooling promotion; employer-based TDM; bicycle and pedestrian facilities; telecommute and work hour strategies; pricing and subsidies.

Methodology – The ECO software is intended for application at the level of single or multiple employer sites. Strategies are evaluated using a "pivot-point" mode choice model, similar to the FHWA TDM Evaluation Model. In addition to time and cost strategies, the mode choice model includes coefficients for a number of other strategies such as provision of bicycle facilities and various ridesharing incentives. The coefficients were developed from the Regulation XV employer dataset in Southern California. The model makes adjustments to effectiveness based on the extent of marketing and awareness programs. The software includes additional features, notably a module for managing employer surveys and data, and a module for tracking program participation.

Data Requirements – Baseline mode shares, other travel characteristics, and characteristics of the employment sites; provision of and eligibility for various programs; amount of costs or subsidies for various modes.

Outputs – Changes in modal share, vehicle-trips, VMT, average vehicle occupancy, and ridership.

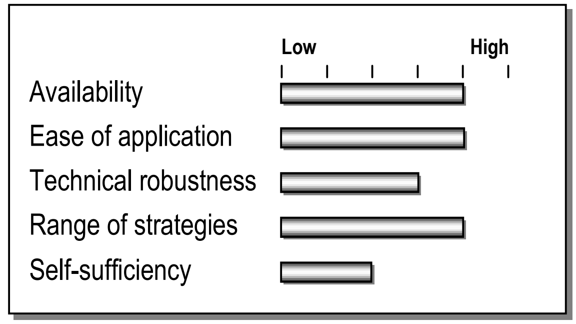
Level of Effort – The ECO software is Windows-based and easy-to-use. However, it would require customization to develop appropriate model coefficients for local application. Also, it requires survey data on baseline employee travel characteristics at affected sites.

Advantages – The logit-based pivot point mode choice approach is theoretically sound, consistent with common practice in travel demand forecasting, and capable of analyzing the joint impacts of multiple strategies. The mode choice model includes a range of employer-based strategies in addition to time and cost-based strategies. The awareness submodel provides a unique adjustment for marketing and promotional efforts.

Limitations – The software does not estimate emissions benefits directly, so the user must apply VMT and/or trip-based emission factors. Many of the default coefficients and data were derived from a dataset in Southern California and their validity in other areas has not been tested. The software would need to be customized for use in other areas.

Source/Availability – The Regulation XV software was developed for SCAQMD by COMSIS corporation. The ECO software was developed for Portland DEQ in 1998 by Cambridge Systematics, Inc. For more information, contact Susan Christensen (503-229-5518) or Sandra Hall (503-229-6154) in the Oregon Department of Environmental Quality (2020 SW Fourth Avenue; Portland OR 97201); or Steve Decker at Cambridge Systematics (510-873-8700).

California Standardized Cost-Effectiveness Methodology



Overview – The "California standardized cost-effectiveness methodology" outlines a series of calculation steps for translating the number of participants in a TDM program into travel changes, emissions benefits, and cost-effectiveness. The California Air Resources Board (CARB) has applied the methodology to assess the impacts of projects funded by motor vehicle registration fees. The Los Angeles Metropolitan Transportation Authority (LAMTA) has applied to the methodology to assess the cost-effectiveness of TDM programs in the Los Angeles region. The methodology is generic and could be applied outside of California.

Strategies Addressed – Improved transit; carpooling and vanpooling promotion; employer-based TDM; telecommuting/work hours; pricing/subsidies.

Methodology – A series of worksheet steps is provided for converting the number of participants in a TDM program into travel changes, emissions benefits, and cost-effectiveness. The methodology is applied at the level at which the strategy is applied (worksite, employment center, etc.). While the methodology was designed for ex-post program evaluations in which user surveys have been conducted, it can also be used in conjunction with pre-implementation surveys or mode shift forecasts to provide forecasts of emissions reductions.

Data Requirements – Number of participants in TDM program by new and prior mode of use; average trip length; emission factors (per trip and per mile) by pollutant.

Outputs – Changes in vehicle-trips, VMT, and emissions.

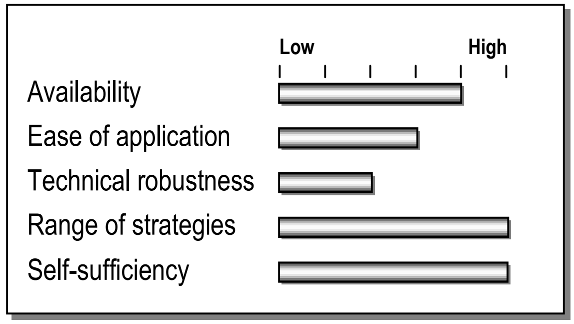
Level of Effort – The method is easy to apply. Some effort may be required in obtaining valid estimates of program participation.

Advantages – The method provides a standard and easy-to-follow set of calculation steps that accounts for prior mode of travel and trip lengths in calculating overall emissions reductions. Worksheets are provided to account for emissions from changes in transit service as well as changes in personal vehicle travel.

Limitations – The method does not estimate travel behavior changes directly, and so it is not a forecasting method *per se*. Instead, it relies on surveys or other estimates of program participation as inputs. The user must also supply appropriate emission factors.

Source/Availability – Schreffler, Eric N.; Theresa Costa, and Carl B. Moyer. "Evaluating Travel and Air-Quality Cost-Effectiveness of Transportation Demand Management Projects." *Transportation Research Record* 1520. For information, contact Eric Schreffler (858-538-9430, enschreff@aol.com).

Regional Air Quality Council (RAQC) Workbook



Overview – The *Workbook of Transportation and Land Use Strategies for Reducing Mobile Source Emissions* was prepared by the Regional Air Quality Council in Denver, CO in order to allow assessment of a wide range of local and regional strategies for improving air quality.

Strategies Addressed – Improved transit; HOV lanes; carpooling and vanpooling promotion; employer-based TDM; bicycle and pedestrian programs; telecommute and work hour strategies; pricing and subsidies; land use.

Methodology – Strategies are analyzed individually through a series of calculation steps. Trip and/or VMT impacts are based on elasticities or empirical evidence from the literature. Changes in emissions are calculated based on changes in VMT. The workbook can be used to analyze strategies applied at particular employment sites or for an entire area.

Data Requirements – Total employees, persons, or vehicles affected; information describing the strategy analyzed; various other parameters (i.e., baseline vehicle trips per employee, total regional VMT) depending upon the strategy. Default parameters are provided for average trip lengths, emission factors, etc., although the user can replace with their own parameters.

Outputs – Changes in VMT and emissions.

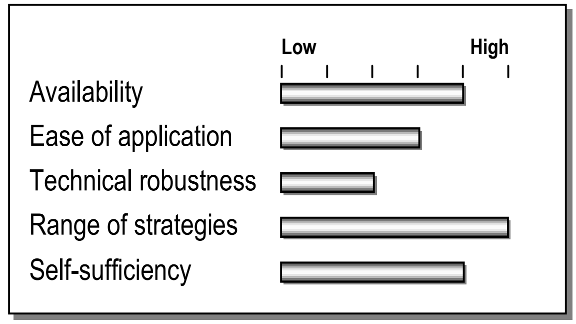
Level of Effort – The workbook is easy to use, but it is in paper format and calculations are not automated. Some effort may be required to gather baseline regional or local data.

Advantages – The workbook is a simple means of developing a rough estimate of the emissions impacts of a wide range of strategies. The elasticities and empirical data contained in the workbook represent the state of knowledge as of 1996. The workbook also contains a discussion of supporting strategies and policy design issues, as well as an assessment of the relative magnitude of impacts at a regional level.

Limitations – Elasticities and empirical factors derived from one situation may not necessarily be applicable to a specific local situation. Impacts calculated using elasticities are heavily influenced by the choice of baseline parameters (e.g., vehicle operating cost per mile).

Source/Availability – The *Workbook of Transportation and Land Use Strategies for Reducing Mobile Source Emissions* (April 1997) is available from the Regional Air Quality Council (303-629-5450, staff@raqc.org.)

MWCOG Sketch-Planning Methods



Overview – The Metropolitan Washington Council of Governments (MWCOG) developed a set of sketch-planning calculations to estimate emissions benefits for TCM strategies that could not be assessed through quantitative modeling. MWCOG used these sketch-planning approaches in conjunction with the TDM Evaluation Model and their regional mode choice model to estimate the impacts of over 50 individual strategies.

Strategies Addressed – Park and ride; carpooling and vanpooling promotion; bicycle and pedestrian facilities; traveler information; telecommuting/work hours; pricing/subsidies; land use; idle control; other strategies.

Methodology – The sketch-planning calculations are applied to strategies proposed for regional-level implementation. Various assumptions about program effectiveness are employed, based on either experience from other areas or judgment. Additional assumptions account for other factors such as prior mode of travel and trip lengths. Impacts are estimated separately for work and non-work trips. Cold start, hot start, and running (VMT-based) emission factors are used.

Data Requirements – Inputs vary by project type, but include factors such as total number of park-and-ride spaces, average trip lengths, utilization of various strategies, employment affected by the strategy, and existing mode shares.

Outputs – Changes in vehicle-trips, VMT, emissions.

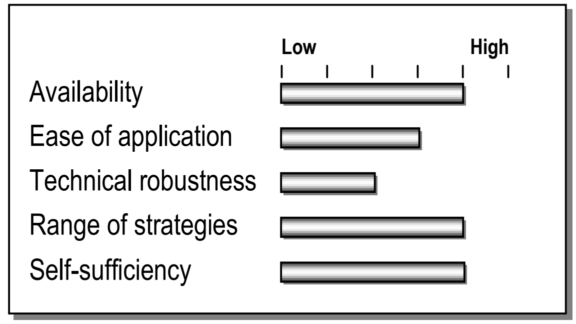
Level of Effort – The calculation steps are clearly documented. Some effort may be required to develop assumptions appropriate for local use, and to set up calculations either on paper or in a spreadsheet.

Advantages – Potentially helpful examples of calculations and assumptions are included for a number of strategy types. The calculations account for prior mode of travel as well as both trip and VMT-based emissions.

Limitations – Estimation of travel impacts is frequently based on judgment. (This is due to the lack of reliable data and analytical procedures for estimating the travel impacts of these strategies.) The particular assumptions and calculation approaches may not be appropriate in all situations.

Source/Availability – U.S. DOT. *Transportation Control Measure Analysis: Transportation Control Measures Analyzed for the Washington Region's 15 Percent Rate of Progress Plan*. Metropolitan Planning Technical Report No. 5, FHWA Publication No. FHWA-PD-95-008, February 1995. Contact Michael Culp, FHWA Office of Metropolitan Planning and Programs (202-366-9229, michael.culp@fhwa.dot.gov).

NCTCOG Sketch-Planning Methods



Overview – The North Central Texas Council of Governments (NCTCOG) applied a set of sketch-planning procedures to assess the emissions benefits of TCMs implemented in an air quality attainment plan for the Dallas-Fort Worth metropolitan area.

Strategies Addressed – Improved transit; HOV lanes; park and ride; carpooling and vanpooling promotion; employer-based TDM; bicycle and pedestrian facilities; traffic flow improvements; incident management; alternative fuel vehicles.

Methodology – The procedures are at a sketch-planning level with data sources, assumptions, and basic equations described in a report. The procedures are applied to analyze specific projects or sets of projects.

Data Requirements – Inputs vary by project type but typically include extent of project (i.e., miles of HOV or bike lane), average before and after travel speeds, traffic volumes, ridership levels or participation rates, trip lengths, and emission factors by speed. Empirical data on impacts for similar projects (or simulations for traffic flow projects) are used to develop or verify assumptions for most strategies.

Outputs – Changes in emissions.

Level of Effort – The calculation methodologies are generally straightforward and easy to apply. Some effort may be required to conduct data collection or to identify existing studies from which to draw assumptions.

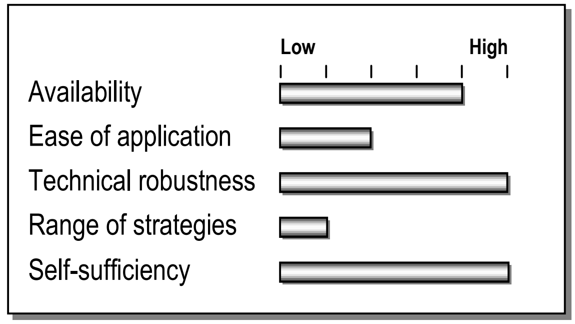
Advantages – The document illustrates some simplified techniques for developing project-level emissions estimates. Assumptions on travel behavior and traffic flow impacts were developed or validated based on real-world observations of similar implemented strategies. The document describes the types of studies undertaken to develop the inputs to the sketch-planning procedures.

Limitations – The methods generally do not forecast travel demand or traffic flow impacts directly, but instead require the user to identify reasonable assumptions about these impacts. Trip-based emissions impacts are not considered.

Source/Availability – *Transportation Control Measure: Effectiveness Study*. Technical Report Series No. 44, North Central Texas Council of Governments, Arlington, TX (August 1996). Contact the Regional Information Center (817-640-3300, http://www.dfwinfo.com/publications.html).

Quick-HOV

Overview – Quick-HOV is a set of procedures and a software model for predicting and evaluating the impacts of HOV lanes on person travel, vehicle travel, auto occupancy, congestion, delay, air quality, and fuel consumption.



Strategies Addressed – HOV lanes; traffic flow improvements (ramp meter bypass).

Methodology – The methodology addresses HOV facilities proposed for specific links in the transportation network. Travel time differences are computed based on facility and demand characteristics, and are used to predict demand shifts. An equilibration process balances supply and demand. Emissions are calculated using MOBILE5 or EMFAC emission factors, based on the speeds and mixes of traffic.

Data Requirements – Project description inputs include various characteristics of the proposed HOV facility and parallel roadway, such as length and capacity. Demand and travel inputs include peak-period and free-flow travel times, vehicle volumes, and person volumes. Parameters are assigned default values that can be changed by the user.

Outputs – Changes in person travel, vehicle travel, auto occupancy, congestion, delay, air quality, and fuel consumption.

Level of Effort – Quick-HOV is a Windows-based application that is easy to use. The calculation methodologies are generally straightforward and easy to apply. The calculation steps are clearly documented. Some effort may be required to develop assumptions appropriate for local use.

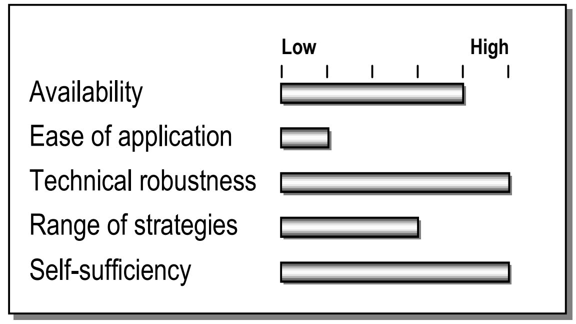
Advantages – The Quick-HOV model can provide a reasonable estimate of HOV facility diversion and use, along with corresponding emissions benefits, without the data and time requirements for a network-level analysis. At the same time, the methodology includes enough facility-specific detail that it should be more accurate than the sketch-planning approaches embodied in more general TCM analysis tools.

Limitations – Some effort is involved in developing the inputs for the model and running the model. It does not account for network-level changes in travel patterns or traffic flow characteristics.

Source/Availability – The Quick-HOV model, developed for FHWA in 1996, is a DOS-based software program. It is distributed by McTrans (352-392-0378, mctrans@ce.ufl.edu) at a cost of $250. The documentation only is available for $20.

ITS Deployment Analysis System (IDAS)

Overview – The Intelligent Transportation System (ITS) Deployment Analysis System (IDAS) is a modeling tool that enables the user to conduct systematic assessments and quantitative evaluations of the relative benefits and costs of more than 60 types of ITS investments, in combination or in isolation. IDAS has been tested in three metropolitan areas and is currently being applied in seven additional areas.



Strategies Addressed – Improved transit; HOV lanes; traveler information; traffic flow improvements; incident management.

Methodology – The model utilizes network and trip data from the regional transportation model. Strategies are applied either for links in the transportation network or at the traffic analysis zone level. Strategies that affect the time or cost of travel affect mode choice, temporal choice, and induced/foregone demand through a "pivot-point" model, which is based on coefficients from the regional travel model. Other strategy impacts are based on findings from various empirical studies. Changes in trips by mode, time of day, and origin/destination subsequently affect vehicle speeds and volumes. Emissions are calculated based either on default or user-input MOBILE5 or EMFAC emission factors by speed range.

Data Requirements – Transportation network and trip tables by mode and/or purpose, which can be obtained from the regional travel model; deployment of ITS strategies by type and location on the transportation network.

Outputs – Changes in vehicle-trips, VMT, emissions; travel time savings and improvements in travel time reliability; energy consumption, noise impacts, safety impacts, and monetary values of these changes; and lists of ITS equipment and costs.

Level of Effort – Familiarity with travel demand model structure and output is required in doing initial set-up for the model. Some effort is also needed to identify the various ITS improvements to be analyzed. Data entry and alternatives analysis are conducted in a user-friendly Windows environment.

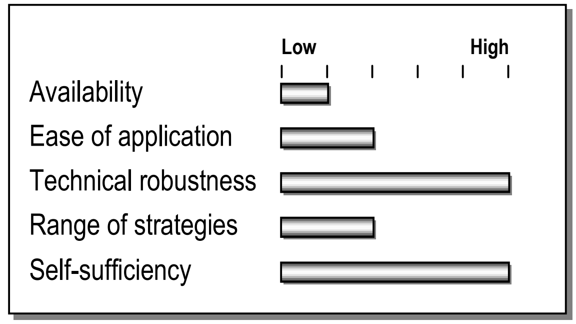
Advantages – IDAS can analyze the benefits of a wide range of ITS strategies. It can also analyze "generic" strategies affecting travel time or cost that are input for transportation links or analysis zones. Changes in emissions are based on network-wide VMT and speed impacts, consistent with network data used in regional travel modeling. The model can account for time-of-day shifts, induced demand, and changes in travel time reliability.

Limitations – IDAS requires some time investment to learn and some user skills; in particular, it is helpful to have familiarity with travel model data in setting up the model. Run time is non-trivial (anywhere from a few minutes to a few hours, depending on the number of zones and other factors.)

Source/Availability – IDAS was developed for FHWA and is distributed through McTrans at the University of Florida (352-392-0378, http://mctrans.ce.ufl.edu/) and PCTrans at the University of Kansas (785-864-5655, http://kuhub.cc.ukans.edu/~pctrans/), at a cost of $600. Information is available at http://www.tfhrc.gov/its/its.htm or http://www.camsys.com/.

Simplified Method for Analysis of Regional Travel (SMART)

Overview – The SMART (Simplified Method for Analysis of Regional Travel) Model was developed in the Chicago area to support air quality conformity modeling and is compatible with regional modeling datasets. It could be modified for similar application in other metropolitan areas.



Strategies Addressed – Improved transit; HOV lanes; roadway pricing; land use.

Methodology – SMART is applied for an area covered by the regional travel demand model upon which it is based. Strategies are applied to specific links in the roadway and transit networks. SMART's distinguishing features include the use of a "combined model" for trip distribution, mode choice and assignment of auto trips; and the use of a sketch planning zone system in conjunction with a detailed regional highway network and zone system. SMART includes a stand-alone emissions module, which utilizes a speed post-processor.

Data Requirements – Travel model data, including land use/socioeconomic and highway/ transit network data, are required. Strategies are entered as changes to highway and transit network characteristics (e.g., capacity, speed, cost).

Outputs – VMT and speeds by link; overall VMT and emissions changes.

Level of Effort – SMART requires significant customization.

Advantages – The use of the sketch zone system for trip distribution and mode choice provides efficiencies for quick turnaround with very little loss of accuracy, compared to a regional travel model. SMART is sensitive to regional shifts that result from redistribution or reassignment of trips in response to the alternative being tested.

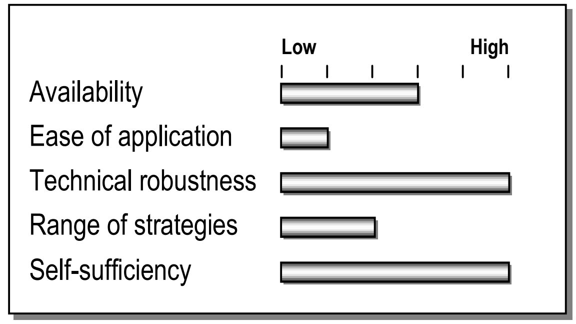
Limitations – SMART would require significant customization for local use, and is designed to address only network-level transportation investments and policies.

Source/Availability – SMART was initially developed for IDOT by COMSIS Corporation in conjunction with the Chicago Area Transportation Study (CATS), and was enhanced in 1998 by Cambridge Systematics, with Michael Baker Corporation and E.H. Pechan.

Contacts – Illinois DOT – Tim Milam (217-524-9067) or Susan Stitt (217-782-2863). Cambridge Systematics, Inc. – Don Vary (202-466-5542) or Dan Beagan (617-354-0167).

Traffic Simulation Models

Overview – Traffic simulation models are used to evaluate the impacts of changes in traffic volumes and transportation network characteristics (capacity, signal timing, etc.) on traffic flow patterns (vehicle speeds, acceleration, and delay). A number of the models are capable of calculating changes in emissions resulting from changes in traffic characteristics.



Strategies Addressed – HOV lanes; traffic flow improvements.

Methodology – Traffic simulation models can be divided into two general classes: macroscopic and microscopic. Macroscopic models (TRANSYT-7F, TRAF, FREQ) are based on deterministic relationships between roadway and intersection characteristics and traffic flow. Microscopic models (TSIS, INTEGRATION, Paramics, SIDRA, Synchro/SimTraffic) simulate the movement of individual vehicles through the network being modeled. In either type of model, emissions are estimated based on vehicle speed and acceleration characteristics.

Some simulation models are designed for analysis of individual intersections or specific types of facilities, while others are designed for network-level analysis. Models capable of network-level analysis include TRANSYT-7F, Synchro/SimTraffic, INTEGRATION, and Paramics. The TRAF and TSIS sets of models include NETFLO and NETSIM (respectively) for network analysis, FREFLO and FRESIM for freeway analysis, and CORFLO and CORSIM, which are integrated packages of the network and freeway models. SIDRA is designed for intersection analysis. FREQ simulates corridor traffic operations including one freeway and one parallel arterial.

Data Requirements – Requirements for traffic data include volumes by link and intersection turning movement, link travel times, and percent heavy vehicles and buses. Requirements for network data include characteristics of each link (e.g., lanes, turning lanes, speed limits, lane widths) and intersection (e.g., signal phasing).

Outputs – Changes in average speeds, travel time, delay, and emissions.

Level of Effort – The individual models vary in their ease of use. A significant amount of effort generally is required to learn to use traffic simulation models, including setting up the appropriate inputs and parameters. (Most regional and local transportation agencies will have staff that are familiar with the use of one or more of these software packages.) A significant amount of effort may also be required to obtain traffic and network data to conduct the analysis and to calibrate the model to local conditions. Data requirements are proportional to the extent of the network being modeled.

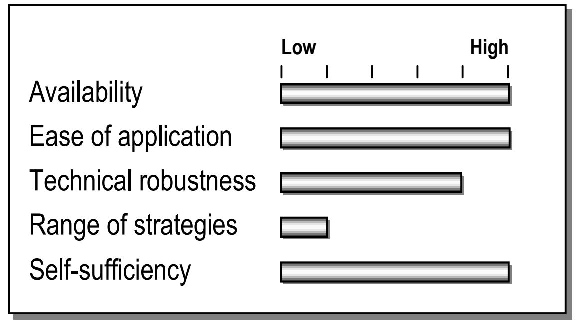
Advantages – Traffic simulation models are the best means of estimating changes in emissions resulting from strategies that affect traffic flow, and can provide a relatively accurate assessment of impacts. Microsimulation models can account for the effects of the variance of driver behavior on emissions.

Limitations – The models generally require a non-trivial analysis effort as described above. Also, the quality of the emissions data and the vehicle trajectories (speed/acceleration profiles) produced by the models varies; for example, emissions factors may not be available or are often based on old data and may not closely represent the current vehicle fleet.

Source/Availability – TRANSYT-7F, the TRAF suite, the TSIS suite, and INTEGRATION are available through McTrans (352-392-0378, http://www-mctrans.ce.ufl.edu) or PC-TRANS (785-864-5655, http://kuhub.cc.ukans.edu/~pctrans/). Information on TSIS can be found at http://www.fhwa-tsis.com/. Paramics is available from SIAS Ltd., Edinburgh, Scotland (+0131-225-7900, http://www.sias.com/). SIDRA is available from Akcelik & Associates, Greythorn, Australia (+61-3-9857-9351, http://www.akcelik.com.au/sidra/sidra.htm). Synchro/SimTraffic is available from Trafficware, Albany CA (510-526-5891, http://www.trafficware.com/).

AirCred

Overview – The AirCred model estimates emissions benefits from the fleet use of alternative-fuel vehicles. The model is designed to assist states in estimating emissions credits for non-attainment areas and to help fleet operators meet the Department of Energy's Energy Policy Act fleet-conversion and alternative-fuel market penetration goals.



Strategies Addressed – Alternative-fuel vehicles.

Methodology – The model compares current year alternative fuel vehicle certification values with conventional fuel vehicle emission factors from the MOBILE model. The same incremental benefit is assumed for future years. The model is based on current, area-specific MOBILE inputs for a variety of metropolitan regions throughout the country. Versions using both MOBILE5a and MOBILE5b outputs are available.

Data Requirements – AirCred requires data on the number of new alternative fuel vehicles delivered for last year and the current year by vehicle and fuel type, the average daily distance driven, and the average number of days per week the vehicle is in use. Additional information on vehicle usage patterns is required to compute cold start credits. Vehicle types include light-duty vehicles, light-duty trucks, transit buses, and school buses. Fuel types include compressed natural gas (CNG), liquid propane gas (LPG), and electric. Dual-fuel vehicles can also be included.

Outputs – Emission "credits" (reduction in total and/or cold start emissions) per day for NMHC, CO, and NOx.

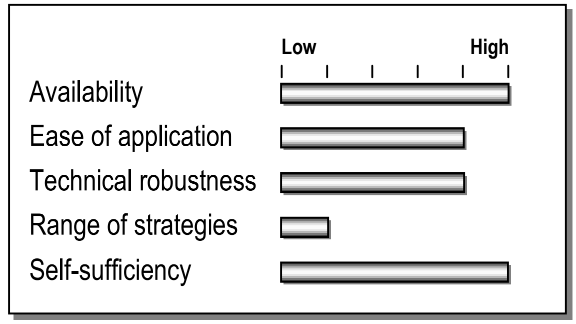
Level of Effort – AirCred is easy to use.

Advantages – The model provides a quick way of estimating the emission benefits of alternative-fuel passenger vehicles and buses. The emission rates in the model are based on the best available current information.

Limitations – AirCred is not designed to calculate future year benefits, only current year benefits. Therefore, emission benefits for planned future year purchases may be different if emission standards or deterioration rates for these vehicles are different.

Source/Availability – The AirCred model is available through the Department of Energy's web site (http://www.fleets.doe.gov/). It was initially developed in 2000, and emission factors will be updated regularly.

Bus Replacement Spreadsheet



Overview – The bus replacement spreadsheet estimates the emission impacts of one-for-one replacements within an existing bus fleet, or purchases of vehicles not dedicated to specific service improvements. The methodology can assess the replacement of older diesel buses with new diesel or alternative fuel buses.

Strategies Addressed – Alternative fuel vehicles.

Methodology – The approach for estimating the emissions reductions of vehicle replacements is based on the average daily revenue miles per vehicle of in-service vehicles, the procurement/replacement schedule and the difference in emissions between retired vehicles and the replacement vehicles. Emissions are estimated based on the year of manufacture of old vehicles and the technology of new vehicles. The spreadsheet converts factors in terms of g/bhp-hr to g/mile.

Data Requirements – Data are required on the number of new buses procured by year and the number of buses retired by model year. Data on annual vehicle revenue miles and the number of vehicle operating during maximum service are obtained from the National Transit Database. The average speed of bus operation locally is also required, to adjust emission factors.

Outputs – Annual and cumulative emission reductions.

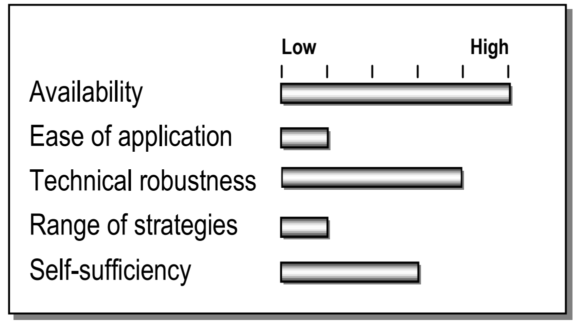
Level of Effort – This method is easy to apply.

Advantages – Data requirements for the spreadsheet are modest. The spreadsheet provides a quick way of estimating the emission benefits of new bus purchases.

Limitations – Emission factors and conversion factors may need to be updated by the user to reflect current data on bus emission characteristics. The method does not account for differences in activity patterns (distance driven, driving cycles, etc.) among individual buses in the fleet.

Source/Availability – The Bus Replacement Spreadsheet was developed by COMSIS for the Pennsylvania DOT and updated in 1998 by Cambridge Systematics, with E.H. Pechan for the Atlanta Regional Commission. The spreadsheet can be downloaded from the Travel Model Improvement Program web site, http://www.bts.gov/tmip/. Contact: Cambridge Systematics, Inc. – Chris Porter (617-354-0167).

Freight Air Quality Analysis Procedures



Overview – A methodology was developed for the U.S. DOT and EPA to analyze the air quality impacts of actions to address freight transportation problems. The methodology provides for a range of analysis procedures, from sketch planning to detailed analysis, depending upon available resource and accuracy needs. The methodology is aimed at strategies within a metropolitan area that affect movements of intercity freight (e.g., intermodal terminals).

Strategies Addressed – Freight/intermodal.

Methodology – A series of analysis steps are outlined, including 1) assess overall freight contributions to regional air quality; 2) develop a profile of the freight system; 3) identify freight strategy options; 4) identify and characterize potential impacts of strategies; and 5) assess impacts. Options for impact assessment include 1) judgment; 2) sketch planning using secondary data; 3) adaptation of existing models; and 4) local case studies, data collection, and model development. The steps are outlined in worksheet form with examples provided. Information to help characterize strategy impacts is also provided.

Data Requirements – Data requirements vary but may include, at a minimum, descriptive data on the local freight system (e.g., ton-miles by mode or terminal) and the strategies to be analyzed, as well as anticipated effects on freight movement. Some data, such as projected truck and rail emission factors, are provided in the report.

Outputs – Changes in modal activity, VMT by mode, emissions.

Level of Effort – A significant level of effort would be required to develop baseline data and strategy assumptions.

Advantages – The freight air quality analysis methodology provides a good framework for analyzing freight projects. The framework is geared toward helping to understand the range of potential impacts of a transportation improvement affecting freight movement. The report also includes some useful data and sample calculations.

Limitations – The options for assessing impacts of specific strategies are not described in detail. The assessment of the impacts of strategies will generally require additional analysis and assumptions by the user.

Source/Availability – Cambridge Systematics, Inc., with Jack Faucett Associates, Inc. and Sierra Research. *Air Quality Issues in Intercity Freight: Final Report*. Prepared for Federal Railroad Administration, FHWA, and EPA (March 1997). The report is available through the TMIP web site, http://www.bts.gov/tmip/.

5.0 Key Inputs and Outputs for Each Method

Strategy and Method	Key Inputs	Outputs
Improved Transit		
TDM Evaluation Model	Change in travel time and/or cost by transit	Trips, VMT
TCM/Commuter Choice Model	Change in travel time and/or cost by transit	Trips, VMT, Emissions
TCM Analyst/EPA TCM Methodology	Percent change in fares or service frequency, or survey data on ridership (shuttle)	Trips, VMT, Emissions
CM/AQ Evaluation Model	Percent change in transit fare, wait time, travel time, and/or total revenue-miles; number of riders (shuttle)	Trips, VMT, Emissions
TCM Tools	Percent change in fare/cost of using transit	Trips, VMT, Emissions
Off-Net/PAQONE	Strategies: bus shelters, bike access, service changes, new service, transit center. Data: variously include daily boardings, adjacent pop., current local mode share, change in revenue miles, headways, route travel times, wait/access times	Trips, VMT, Emissions
ECO/Regulation XV Software	Change in travel time and/or cost by transit	Trips, VMT
California Standardized Methodology	New transit riders by prior mode of travel	Trips, VMT, Emissions
RAQC Workbook	Percent increase in service (peak-period departures)	VMT, Emissions
NCTCOG Sketch-Plan Methods	Rail: Average daily ridership, previous mode of rail travelers	Emissions
Quick-HOV	Traffic volumes and physical characteristics (length, lanes, etc.) of HOV/bus lane and parallel facility	Trips, Emissions
SMART	Change in travel time, cost by link in transit network	Trips, VMT, Emissions

Strategy and Method	Key Inputs	Outputs
HOV Lanes		
TDM Evaluation Model	Changes in travel time by HOV lane	Trips, VMT
TCM Analyst/EPA TCM Methodology	Number of HOV lane-miles	Trips, VMT, Emissions
CM/AQ Evaluation Model	Increase in number of HOVs	Trips, VMT, Emissions
TCM Tools	Miles of HOV lanes added	Trips, VMT, Emissions
NCTCOG Sketch-Plan Methods	Before/after traffic volumes and speeds (freeway and parallel arterial); length of facilities	Emissions
Quick-HOV	Traffic volumes and physical characteristics (length, lanes, etc.) of HOV lane and parallel facility	Trips, Emissions
SMART	Addition of HOV link(s) to network, and time/cost characteristics	Trips, VMT, Emissions
Park and Ride		
CM/AQ Evaluation Model	Number of spaces, utilization rate	Trips, VMT, Emissions
TCM Tools	Number of spaces, utilization rate	Trips, VMT, Emissions
Off-Net/PAQONE	Number of new spaces, utilization rate	Trips, VMT, Emissions
MWCOG Sketch-Plan Methods	Total number of spaces; work trip length	Trips, VMT, Emissions
NCTCOG Sketch-Plan Methods	Number of spaces, utilization rate, speeds on adjacent freeway	Emissions
Carpooling and Vanpooling Promotion		
TDM Evaluation Model	"Level" of employer-based program in impact area	Trips, VMT
TCM/Commuter Choice Model	"Level" of employer-based program in impact area	Trips, VMT, Emissions
TCM Analyst/EPA TCM Methodology	Vanpooling: number of vanpools, average vehicle occupancy	Trips, VMT, Emissions
CM/AQ Evaluation Model	Number of new ridesharers	Trips, VMT, Emissions

Strategy and Method	Key Inputs	Outputs
CUTR_AVR	Whether guaranteed ride home or ridematching program are in place	Trips
TCM Tools	Percent increase in non-drive alone modes	Trips, VMT, Emissions
ECO/Regulation XV Software	Provision of guaranteed ride home, company vehicle, transportation coordinator, rideshare matching, vanpools, preferential parking	Trips, VMT
California Standardized Methodology	Number of commuters by new and prior mode of travel	Trips, VMT, Emissions
MWCOG Sketch-Plan Methods	Survey data on rideshare service utilization/placement	Trips, VMT, Emissions
NCTCOG Sketch-Plan Methods	Number of vanpools, minimum riders/vanpool	Emissions
Employer-Based TDM		
TDM Evaluation Model	Assume other strategies to achieve trip reduction or AVR increase of X percent	Trips, VMT
TCM/Commuter Choice Model	Assume other strategies to achieve trip reduction or AVR increase of X percent	Trips, VMT, Emissions
CM/AQ Evaluation Model	Transit pass subsidy amount; number of people switching to each mode	Trips, VMT, Emissions
ECO/Regulation XV Software	Eligibility for various incentives; marketing and administrative expenditures	Trips, VMT
California Standardized Methodology	Number of commuters by new and prior mode of travel	Trips, VMT, Emissions
NCTCOG Sketch-Plan Methods	Number of companies with TDM programs, reported number of active participants	Emissions
Bicycle and Pedestrian Facilities		
TCM/Commuter Choice Model	"Level" of bicycle/pedestrian support program	Trips, VMT, Emissions
TCM Analyst/EPA TCM Methodology	Vehicle volumes on roads adjacent to proposed trails; percent switching mode	Trips, VMT, Emissions
CM/AQ Evaluation Model	Number of new walkers/bicyclists or percent of trips that would bicycle	Trips, VMT, Emissions

Strategy and Method	Key Inputs	Outputs
TCM Tools	Percent of trips that would bicycle	Trips, VMT, Emissions
Off-Net/PAQONE	Size of service area, population density, existing mode share, length of existing and new bike network; budget for promo. programs; bike coordinator	Trips, VMT, Emissions
ECO/Regulation XV Software	Provision of bicycle racks or storage, provision of showers and lockers	Trips, VMT
California Standardized Methodology	Number of commuters by new and prior mode of travel	Trips, VMT, Emissions
RAQC Workbook	Population served by bike facilities	VMT, Emissions
MWCOG Sketch-Plan Methods	Utilization and trip lengths for various strategies	Trips, VMT, Emissions
NCTCOG Sketch-Plan Methods	Size of service area, population density, bicycle mode share, length of project	Emissions
Traveler Information		
CM/AQ Evaluation Model	ATIS: percent increase in transit ridership; motorist info: trip reduction during incidents	Trips, VMT, Emissions
Off-Net/PAQONE	Freeway section length, baseline speed and volume	Trips, VMT, Emissions
IDAS	Types and locations of deployed ITS strategies	Trips, VMT, Emissions
Telecommuting/Work Hours		
TDM Evaluation Model	Eligibility and participation in flex-time, staggered hours, telecommute, 4/40 or 9/80 work week	Trips, VMT
TCM/Commuter Choice Model	Eligibility and participation in flex-time, staggered hours, telecommute, 4/40 or 9/80 work week	Trips, VMT, Emissions
TCM Analyst/EPA TCM Methodology	Percent of eligible people telecommuting (home or satellite); avg. days/week	Trips, VMT, Emissions
CM/AQ Evaluation Model	Telecommuting, compressed hours: participation rate and days/week, shift from peak to off-peak	Trips, VMT, Emissions
CUTR_AVR	Whether a compressed work week is in place	Trips

Strategy and Method	Key Inputs	Outputs
TCM Tools	Telecommuting, compressed hours: participation rate and days/week, shift from peak to off-peak	Trips, VMT, Emissions
ECO/Regulation XV Software	Eligibility and participation in flex-time, staggered hours, telecommute, 4/40 or 9/80 work week	Trips, VMT
California Standardized Methodology	Number of commuters by new and prior mode of travel	Trips, VMT, Emissions
RAQC Workbook	Telecommuting, compressed hours: participation rate and days/week	VMT, Emissions
MWCOG Sketch-Plan Methods	HBW trip lengths and utilization of telecommute centers in outlying areas	Trips, VMT, Emissions
Pricing/Subsidies		
TDM Evaluation Model	Changes in travel cost by mode to impact area	Trips, VMT
TCM/Commuter Choice Model	Changes in travel cost by mode to impact area	Trips, VMT, Emissions
TCM Analyst/EPA TCM Methodology	Percent change in travel cost by mode	Trips, VMT, Emissions
CM/AQ Evaluation Model	Increase in cost per gallon or cost per mile; percent change in transit cost; parking charge	Trips, VMT, Emissions
CUTR_AVR	Whether higher costs for driving alone or alternative mode use subsidies are in place	Trips, AVR
TCM Tools	Increase in cost per gallon or cost per mile; percent change in transit cost; parking charge	Trips, VMT, Emissions
ECO/Regulation XV Software	Changes in travel cost by mode to impact area; change in parking cost	Trips, VMT
California Standardized Methodology	Number of commuters by new and prior mode of travel	Trips, VMT, Emissions
RAQC Workbook	Increase in cost per gallon, VMT, or trip; peak-period tolls; parking charge; parking cash-out; pay-at-the-pump insurance	VMT, Emissions
MWCOG Sketch-Plan Methods	Free midday fares: percent increased ridership by mode shift, time shift, other	Trips, VMT, Emissions
SMART	Change in cost of travel by link, zone	Trips, VMT, Emissions

Strategy and Method	Key Inputs	Outputs
Land Use		
CM/AQ Evaluation Model	Percent increase in density, mixed use, pedestrian amenities in employment centers	Trips, VMT, Emissions
TCM Tools	Percent increase in density, mixed use, pedestrian amenities in employment centers	Trips, VMT, Emissions
RAQC Workbook	Site design: grid streets, density standards, etc.; regional growth management; infill development	VMT, Emissions
MWCOG Sketch-Plan Methods	Allow convenience uses in residential areas (trip generation, mode share, trip lengths)	Trips, VMT, Emissions
SMART	Change in location of development by zone	Trips, VMT, Emissions
Parking Management		
TCM Analyst/EPA TCM Methodology	Percent change in parking cost	Trips, VMT, Emissions
CM/AQ Evaluation Model	Change in vehicle-trips to site and elsewhere, number of short-term and long-term spaces	Trips, VMT, Emissions
RAQC Workbook	Current parking space utilization, cap on parking spaces, maximum parking ratios	VMT, Emissions
MWCOG Sketch-Plan Methods	Maximum parking ratios, employment, trips, mode share by area	Trips, VMT, Emissions
Traffic Flow Improvements		
TCM Analyst/EPA TCM Methodology	Percent change in traffic speed; affected VMT	Emissions
CM/AQ Evaluation Model	Percent change in traffic speed; affected VMT	Emissions
TCM Tools	Percent change in traffic speed; reduction in trips	Emissions
Off-Net/PAQONE	Arterial improvements: baseline speeds, volumes, LOS; improvements made and added capacity	Emissions
MWCOG Sketch-Plan Methods	Flashing yellow: number of signals, traffic counts, savings/signal; ATMS: speed increase, emission rates by speed	Emissions
NCTCOG Sketch-Plan Methods	Project-specific average speed improvements, traffic volumes, distance affected	Emissions

Strategy and Method	Key Inputs	Outputs
IDAS	Types and locations of deployed ITS strategies	Trips, VMT, Emissions
SMART	Change in capacity, travel speeds of links in transportation network	Trips, VMT, Emissions
Traffic Simulation Models	Roadway and intersection characteristics, traffic and turning volumes	Emissions
Incident Management		
Off-Net/PAQONE	Freeway section length, baseline speed and volume	Emissions
NCTCOG Sketch-Plan Methods	Traffic volumes affected; change in speeds and incident duration as a result of strategies	Emissions
IDAS	Types and locations of deployed ITS strategies	Emissions
Freight/Intermodal		
CM/AQ Evaluation Model	Number of trucks shifted from peak to off-peak	Emissions
TCM Tools	Number of trucks shifted from peak to off-peak	Emissions
Freight Air Quality Analysis Procedures	Various methodologies and inputs for determining freight activity levels and emission factors	Emissions
Idle Control		
CM/AQ Evaluation Model	Number of sites impacted, number of affected trips/vehicles, idling time/vehicle	Emissions
MWCOG Sketch-Plan Methods	Vehicles affected, idle time, idle emission factors (from MOBILE)	Emissions
Alternative Fuel Vehicles		
CM/AQ Evaluation Model	Number of affected trips, emission rates	Emissions
NCTCOG Sketch-Plan Methods	Number of vehicles by agency and fuel type; relative emission rates	Emissions
AirCred	Number of alternative fuel vehicles purchased by vehicle type and fuel type, miles driven per year	Emissions
Bus Replacement Spreadsheet	Number of buses procured and retired by model year and fuel type	Emissions

6.0 References

6.1 General Resources

FHWA information and guidance related to air quality and the CMAQ program is available through the Office of Natural Environment. Internet: http://www.fhwa.dot.gov/environment/aq.htm.

EPA's Transportation Air Quality (TRAQ) Center contains data, models, and reports to assist in quantifying the emissions benefits of transportation control measures. TRAQ is maintained by the EPA Office of Transportation and Air Quality. Internet: http://www.epa.gov/oms/transp.htm.

The Center for Urban Transportation Research at the University of South Florida maintains a web site of "Products and Services Available to Assist the TDM and Telework Professional." Internet: http://www.cutr.eng.usf.edu/.

6.2 Other Emissions Estimation Methodologies

California Air Resources Board. "Evaluation of Selected Projects Funded by Motor Vehicle Registration Fees." Sacramento, CA (1995).

> Estimates the emissions benefits of specific projects including alternative fuel vehicles, electric vehicles, vehicle scrappage, traffic signal timing, shuttle services, employer trip reduction, telecommunications, bicycle use and infrastructure, public education, and smoking vehicle abatement. Assumptions and calculation methods are clearly documented.

Federal Highway Administration. "Off-Model Air Quality Analysis: A Compendium of Practice." FHWA Southern Resource Center (August 1999). Contact Andrew Edwards, (404) 562-3673.

> Includes examples of emission reduction calculations from programs throughout the southeastern U.S. Examples cover a variety of strategies such as traffic flow improvements, HOV, transit, vanpool, pedestrian/bicycle, incident management, and public education.

North Jersey Transportation Planning Authority. "TCM Quick Response Handbook: Tools for Local Planners." Prepared by Sarah Siwek and Associates and Apogee Research, Inc.

Contains examples of calculation approaches and worksheets for estimating the emissions impacts of TCM measures including activity center-based trip reduction, bicycling improvements, incident management and information advisory systems, land use measures, parking controls, parking pricing measures, traffic flow improvements, transit pricing programs, and transit improvement programs.

U.S. Environmental Protection Agency, Office of Policy, Planning, and Evaluation. *Guidance on the Use of Market Mechanisms to Reduce Transportation Emissions* (March 1998). Prepared by Apogee Research, Inc., et al. Internet: http://www.epa.gov/oms/transp/traqmkti.htm.

Discusses modeling approaches to address parking fees, VMT fees, and other cost-based TCMs. Methods include the STEP model (a microsimulation approach to travel modeling), the logit mode choice model, and the Post Processor for Air Quality (PPAQ) developed by Garmen Associates for applying MOBILE emission factors to travel model output.

Federal Highway Administration, Turner-Fairbanks Highway Research Center. *Guidebook on Methods to Estimate Non-Motorized Travel*. Prepared by Cambridge Systematics, Inc., and Bicycle Federation of America. Publication No. FHWA-RD-98-165 (July 1999). Internet: http://www.tfhrc.gov/.

Reviews available methods to forecast changes in bicycle and pedestrian travel as a result of facility improvements or policies.

6.3 Information on CMAQ/TCM Strategy Effectiveness

National Association of Regional Councils. *Costs and Effectiveness of Transportation Control Measures (TCM): A Review and Analysis of the Literature*. Prepared by Apogee Research, Inc. (1994).

Federal Highway Administration. *Transportation and Global Climate Change: A Review and Analysis of the Literature*. Prepared by Hagler-Bailly, Inc. Publication No. DOT-T-97-03 (1998).

Institute of Transportation Engineers. *A Toolbox for Alleviating Traffic Congestion and Enhancing Mobility*. Prepared by Michael D. Meyer for Federal Highway Administration (1997). Internet: http://www.ite.org.

Transit Cooperative Research Program. *Traveler Response to Transportation System Changes Handbook, 3rd Edition*. Prepared by Richard Pratt. TCRP Project B-12, TCRP Web Document 12 (2000). Internet: http://www4.nationalacademies.org/trb/crp.nsf.

7.0 List of Acronyms

AVO	Average Vehicle Occupancy
AVR	Average Vehicle Ridership
CMAQ	Congestion Mitigation and Air Quality Improvement Program
CO	Carbon Monoxide
CUTR	Center for Urban Transportation Research
DOT	Department of Transportation
ECO	Employee Commute Options
EPA	Environmental Protection Agency
FHWA	Federal Highway Administration
FTA	Federal Transit Administration
HOV	High Occupancy Vehicle
I/M	Inspection and Maintenance
IDAS	ITS Deployment and Analysis System
ITS	Intelligent Transportation Systems
MPO	Metropolitan Planning Organization
MWCOG	Metropolitan Washington Council of Governments
NCTCOG	North Central Texas Council of Governments
NMHC	Non-Methane Hydrocarbons
NOx	Oxides of Nitrogen
PM	Particulate Matter
RAQC	(Denver) Regional Air Quality Council
SMART	Simplified Model for the Analysis of Regional Travel
TAZ	Traffic Analysis Zone
TCM	Transportation Control Measure
TDM	Travel Demand Management
TEA-21	Transportation Equity Act for the 21st Century
TSM	Transportation Systems Management
TTI	Texas Transportation Institute
VMT	Vehicle-Miles of Travel
VOC	Volatile Organic Compounds