Multi-Pollutant Emissions Benefits of Transportation Strategies

Final Report

Publication Number:

FHWA-HEP-07-004

Prepared for

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November 14, 2006

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1. INTRODUCTION

Background and Purpose

The National Ambient Air Quality Standards (NAAQS) are Federal standards that set the allowable concentrations and exposure limits for certain pollutants. Air quality standards have been established for several pollutants associated with transportation, including carbon monoxide (CO), ozone, and particulate matter (PM-10 and PM-2.5). If monitored levels violate the NAAQS, then the Environmental Protection Agency (EPA), in cooperation with the State, will designate the contributing area as "nonattainment." In addition to direct pollutant emissions, motor vehicles emit precursors that contribute to pollutant concentrations, including nitrogen oxides (NOx), volatile organic compounds (VOCs), sulfur oxides (SOx), and ammonia (NH_3).

Transportation is a major source of air pollutant emissions. Nationally, on-road transportation sources are responsible for 27 percent of VOCs emissions, 35 percent of NOx emissions, and 55 percent of CO emissions.[1] Although emissions from most transportation sources have been declining for the last two decades, and are projected to continue to decline due to the beneficial effects of improved emission control technologies and more stringent emission regulations, transportation will continue to contribute to regional air pollution for years to come.

Transportation agencies have a long history of implementing strategies to reduce air pollutant emissions. Since 1991, the Congestion Mitigation and Air Quality Improvement (CMAQ) program has devoted more than $14 billion in highway funds for projects that reduce emissions and relieve congestion, most of which have been implemented by transportation agencies.[2] Some State Implementation Plans (SIPs) include transportation control measures (TCMs), many of which are implemented by state, regional or local transportation agencies. Thus, there is a wealth of experience implementing emission reduction strategies by transportation agencies.

Despite the past efforts, there are few resources, especially comprehensive compilations, of the full range of strategies available to transportation agencies. Moreover, an important deficiency in the existing literature is the lack of documentation of the types of effects of strategies on all transportation-related pollutants. For instance, many studies report only effects on NO_X and VOCs, and many do not include PM-2.5 impacts. Traditionally, transportation agencies have focused their emissions reduction strategies on CO; the ozone precursors, VOCs and NO_X; and PM-10 from road dust. The recent designation of nonattainment areas under the fine particulate matter standard (PM-2.5), however, has also brought new attention to the role of transportation in direct emissions of PM-2.5, and emissions of PM-2.5 precursors, which may include NO_X, SO_X, VOCs and NH_3.

In some cases a control strategy that is successful in reducing one pollutant may actually increase emissions of another pollutant. In some other cases, a control strategy may be beneficial to multiple pollutants. Because many regions are facing multiple air quality objectives (e.g., either designated nonattainment for multiple pollutants or addressing multiple precursor emissions), it is important for transportation agencies to understand the effects of emissions reduction strategies on different pollutants. There is also an increased need for transportation agencies to consider and understand the effects of non-traditional emissions reduction strategies, such as truck idle reduction projects, diesel retrofits, and alternative fuel vehicle programs, which may be effective in addressing some pollutants.

The purpose of this report is to help transportation practitioners consider appropriate transportation strategies for reducing transportation-related emissions of concern. Specifically, this report provides a compendium of traditional and innovative transportation-related control strategies, and for each type of

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[1] National Emissions Inventory Air Pollutant Emissions Trends Data, 2002, http://www.epa.gov/ttn/chief/trends/index.html#tables.

[2] National Highway Institute, 2006, http://www.nhi.fhwa.dot.gov.

strategy, identifies effects on the following seven pollutants: CO, PM-10, PM-2.5, NOx, VOCs, SOx, and NH_3. Strategies included are those that can be implemented by policy makers at a state or local level (Note: strategies that would require a change in federal law or federal action, such as new vehicle emissions standards, are not included). Although many strategies can be funded or implemented directly by transportation agencies (e.g., programs eligible for CMAQ funding), others included in this document are more typically implemented by state air agencies (e.g., inspection and maintenance programs) or require state or local government implementation (e.g., land use policies, fuel tax increases).

For each strategy, the document reports on the direction of emissions impacts (increase, decrease, neutral or uncertain) that typically are expected for each pollutant. It also includes calculations of emissions impacts for sample projects, based on real project examples, and identifies EPA guidance documents that should be referenced and sample methodologies for calculating impacts.

How to Use this Document

Overall Organization

This report is divided into the following chapters.

Summary of Findings (Chapter 2) – This section provides an overview of the impacts of different types of transportation strategies on emissions of the seven pollutants, and provides context regarding targeting of emissions reductions to specific pollutants of concern.

The following five chapters are organized into categories based on the primary objective of each strategy, as follows:

Transportation demand management (TDM) strategies (Chapter 3) – These strategies focus on reducing vehicle travel.

Transportation system management (TSM) strategies (**Chapter 4)** – These strategies focus on improving the operating characteristics of vehicles, such as by affecting traffic flow, vehicle speeds, or idling.

Vehicle technology and fuels strategies (**Chapter 5)** – These strategies focus on reducing vehicle emission rates by changing vehicle characteristics or fuel composition.

Non-road transportation strategies (Chapter 6) – These strategies address railroads, marine vessels, and other non-road engines.

Road dust reduction strategies (Chapter 7) – These strategies focus specifically on reducing fugitive dust emissions from paved and unpaved roads.

Some individual strategies may fall into more than one of these categories (e.g., a high-occupancy vehicle lane can be considered both a TDM and TSM strategy, since it is designed to encourage ridesharing and also improve traffic flow). Strategies that fit into more than one category are included in one chapter only, but the discussion and impacts assessment accounts for all expected effects.

Conclusion (Chapter 8) notes gaps in the findings.

The appendices include a listing of potential (traditional and innovative) transportation emissions reduction strategies (Appendix A), a summary of the contribution of transportation and other mobile sources to national emissions of each pollutant (Appendix B), and an overview of emissions factors and assumptions used in the sample calculations (Appendix C).

Information on Each Strategy

For each of the strategies presented in this report, information is presented using the following structure:

- **Strategy Overview—**This section includes a brief description of the transportation strategy.
- **Emissions Impacts—**This section provides a summary of the direction of expected emissions impacts by pollutant, and displays a table showing the direction of emissions effects for each pollutant (increase, decrease, neutral).
- **General Considerations—**This section notes key factors affecting the level of emissions impact, particularly for strategies in which some pollutants may increase while others decrease. It also addresses implementation considerations that may affect expected emissions impacts, and references EPA guidance documents.
- **Sample Projects—**This section contains a description of a sample project or projects, including for each, assumptions and inputs, the methodology used for the evaluation, and a table showing quantified emissions effects across all the different pollutants. Although the samples are generally drawn from real projects documented in other reports, the emissions figures do not reflect emissions impacts associated with specific projects that have been implemented. Results of past evaluations typically only analyzed some of the pollutants being examined in this report, reflected projects implemented at different times, and often used an older version of MOBILE. Consequently, in order to provide better comparisons, emissions impacts for each sample were calculated for 2006, 2010, and 2020, where applicable, assuming implementation of the sample project so that effects would be achieved in each of these years.

  It is important to note that the three years of emissions results do not represent the expected impact of one project over all of these years; rather, the results are a simplified way of showing the emissions impacts of similar projects implemented at different times. Specifically, vehicle travel and speed changes are assumed to be the same in each case;[3] only the emission factors change over time in these calculations to reflect differences in the vehicle fleet. For instance, for a transit improvement strategy, we assumed that the project would be implemented so that the service begins in 2006, 2010, and 2020, respectively. In all cases, we assume the same VMT reduction, even though a variety of factors might influence the level of travel impact over time. The primary purpose of showing the results in three different years therefore is to demonstrate how changes in emissions factors will affect the level of emissions reductions for a similar project implemented at different times. In some cases, such as retrofits and some non-road strategies, it was not possible to calculate effects for 2010 and 2020. Such instances are noted within the strategy.

  Emissions factors used in these calculations are derived from MOBILE6.2, unless otherwise noted (for more information on the modeling assumptions, see Appendix C). Road dust emissions factors were drawn from EPA's *Compilation of Air Pollutant Emission Factors: AP-42.* In general, the sample calculations utilize simple sketch planning methods, and assumptions about vehicle travel impacts, speed changes, and other strategy impacts are derived from case studies of actual projects. EPA's COMMUTER Model was used when applicable for TDM strategy samples, and EPA's National Mobile Inventory Model (NMIM) was used to estimate emissions reductions from retrofit projects.

Disclaimer

Note that although emissions calculations are provided for sample projects, the methodologies used for the sample calculations are often simplifications of more complex methods.[4] The user should consult EPA guidance to determine appropriate and accepted methodologies for use in quantifying emissions reductions as part of a State Implementation Plan (SIP) or for use in a conformity determination. In some cases, these methods require use of travel forecasting models or other tools, accounting for indirect

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[3] If examining the effects of one project over time, one might expect the travel or speed implications to grow or shrink over time, depending on the strategy.

[4] For instance, for most of the TDM strategies included in this report, the methodologies used for the sample calculations do not incorporate the secondary or indirect effects associated with travel speed changes and do not account for the potential need to increase transit services. These effects are not significant in most cases.

impacts, or additional steps in the calculation that are not accounted for in the sample calculations. Moreover, the approach and data sources that should be used for calculating emissions impacts will depend on whether the analysis is being conducted to forecast impacts prior to implementation or as a post-project evaluation. In a post-project evaluation, additional survey data, field measures, or other data sources on actual transportation system performance should be used.

The assumptions used in the sample calculations are generally drawn from actual projects. However, given the variations across projects and range of factors that influence effects, this document is not intended to provide results that can be expected for all similar projects and the assumptions used in the sample calculations are not meant to be used as standard defaults for calculations of emissions impacts for other projects. Factors such as utilization rates, days of operation, and average trip lengths should be defined based on locally-available data and project-specific information.

2. SUMMARY OF FINDINGS

This section provides an overview of findings regarding the impacts of each type of strategy on each of the seven pollutants examined. It is important to note that the primary purpose of this study is to identify the impacts of each strategy on emissions of each pollutant in terms of direction (e.g., positive, negative, uncertain). This document does not address the relative effectiveness or cost-effectiveness of individual strategies. Within each type of strategy, a wide range of impacts might occur, depending on the scope of implementation (e.g., statewide, regional, local), stringency (e.g., mandatory, incentive-based, or voluntary program; level of financial incentive provided, etc.), and demographic and geographic characteristics (e.g., existing mode shares and levels of travel, availability of travel options, land use patterns, etc.). Moreover, the effectiveness of many of these strategies is enhanced (or conversely, may be inhibited) due to combination with other strategies.

Factors Affecting Emissions Impacts

Type of Strategy Effects

Transportation strategies generally affect emissions by having one or more of the following effects:

- Reducing vehicle miles traveled (VMT) and/or vehicle trips;
- Reducing vehicle idling;
- Shifting travel times (e.g., shifting from peak to off-peak travel times);
- Improving traffic speeds or traffic flow; or
- Altering vehicle fleet characteristics (e.g., vehicle type, size, fuel, or emissions control technology).

Strategy effects are summarized below by major type of effect:

Strategies that reduce vehicle travel – A reduction in vehicle travel can occur in several ways, including shifts from driving to other modes (i.e., transit, bicycling, walking), increasing vehicle occupancy, reducing the number of trips made (e.g., through telecommuting), or reducing vehicle trip lengths (e.g., through better land use mixing).

Strategies that reduce vehicle miles traveled (assuming no other effects) will reduce emissions of all pollutants. Each mile that a vehicle travels, it emits more pollution, so reducing vehicle travel mileage will reduce emissions of all seven gases.[5] However, in conducting emissions analysis, it is important to examine not only the reduction in *vehicle miles traveled (VMT)*, but also the reduction in the number of *vehicle trips*. During the first portion of a vehicle trip, when the vehicle engine starts cold, the vehicle emits some pollutants at a much higher rate than during the remainder of the trip, since emissions control technology does not operate as efficiently as when the vehicle is warm. Some strategies reduce VMT by shortening vehicle trip lengths but do not reduce the number of vehicle trips. For instance, development of a park-and-ride lot may reduce VMT by encouraging carpools, but the park-and-ride lot generally does not reduce vehicle cold starts, only running emissions, since individuals must drive to the lot in the morning. On the other hand, most bicycle/pedestrian projects reduce vehicle trips entirely, and will eliminate both cold start and running emissions. Consequently, VMT-reducing strategies may result in different percentage reductions in different pollutants, depending on whether or not vehicle trip cold starts are reduced.

In MOBILE6.2, incremental emissions associated with a cold start only occur for VOCs, NOx, and CO. In general, among the types of vehicles affected, a reduction in VMT that occurs entirely through vehicle trip

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[5] In some cases, strategies may have other impacts, such as also altering vehicle speeds, which may increase emissions of one or more pollutants.

elimination (such as a bicycle project) will result in a nearly proportional reduction in emissions of all pollutants from light-duty motor vehicles. For instance, reducing light-duty vehicle commute travel by 5 percent due to mode shifts should result in approximately a 5 percent reduction in emissions of all pollutants by light-duty vehicles on work trips, assuming the same emissions factors and not accounting for emissions from the other mode (transit).[6] On the other hand, a strategy, like a park-and-ride facility, which reduces vehicle trip lengths but does not eliminate cold starts, will most likely result in a lower percentage reduction in VOCs, NOx, and CO than other pollutants, since the first few miles of the trip produce a higher share of total trip emissions.

Strategies that reduce vehicle idling – Strategies that reduce vehicle idling (assuming constant emissions factors and no other effects that would further impact emissions) will reduce emissions of all pollutants, since some of each pollutant is producing during engine operation even if a motor vehicle is not moving. Specifically, the combustion process results in exhaust emissions of all seven pollutants. Running loss evaporative emissions also occur during idling, as the hot engine and exhaust system vaporizes gasoline, causing additional release of VOCs. Emissions factors during vehicle idle can be generated using MOBILE6.2 In addition, EPA has developed specific guidance and emissions factors for examining long-duration idling; this guidance, however, currently only addresses NOx and PM.[7]

Strategies that affect vehicle speeds and traffic flow – Strategies that affect vehicle speeds and traffic flow conditions will have different impacts on different pollutants, and may reduce emissions of some pollutants while increasing or having no effect on emissions of others. In MOBILE6.2, emissions rates for VOCs, NOx, and CO vary with vehicle speed. However, in general, MOBILE6.2 emissions rates for PM-10, PM-2.5, SOx, or NH_3, do not vary with vehicle speeds. PM emissions are affected slightly due to tire and break wear. Figure 2-1 shows emissions factors by speed for CO, VOCs, NOx, and the four other pollutants (all have less than 0.1 g/mi). As a can been seen here, strategies that result in higher average speeds might reduce VOCs but could increase CO and NOx emissions. Strategies that involve shifting traffic from peak to off-peak periods, therefore, could also increase CO and NOx emissions. The direction of the impact depends on the speeds of traffic without and with the strategy implemented.

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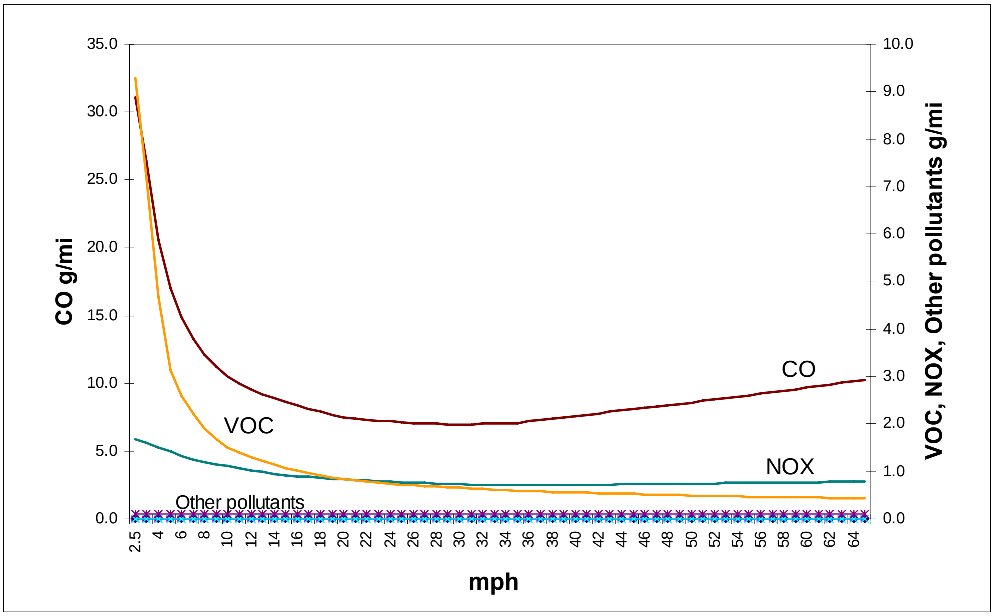
[6] Emissions reductions will depend on all else remaining equal, i.e., reducing VMT on a facility could cause higher speed thus higher emissions.

[7] See EPA's document "Guidance for Quantifying and Using Long Duration Truck Idling Emission Reductions in State Implementation Plans and Transportation Conformity," 2004, http://www.epa.gov/smartway/documents/420b04001.pdf.

Figure 2-1: Emissions Factors by Speed for Light-Duty Vehicles and Trucks, 2006 (arterials)



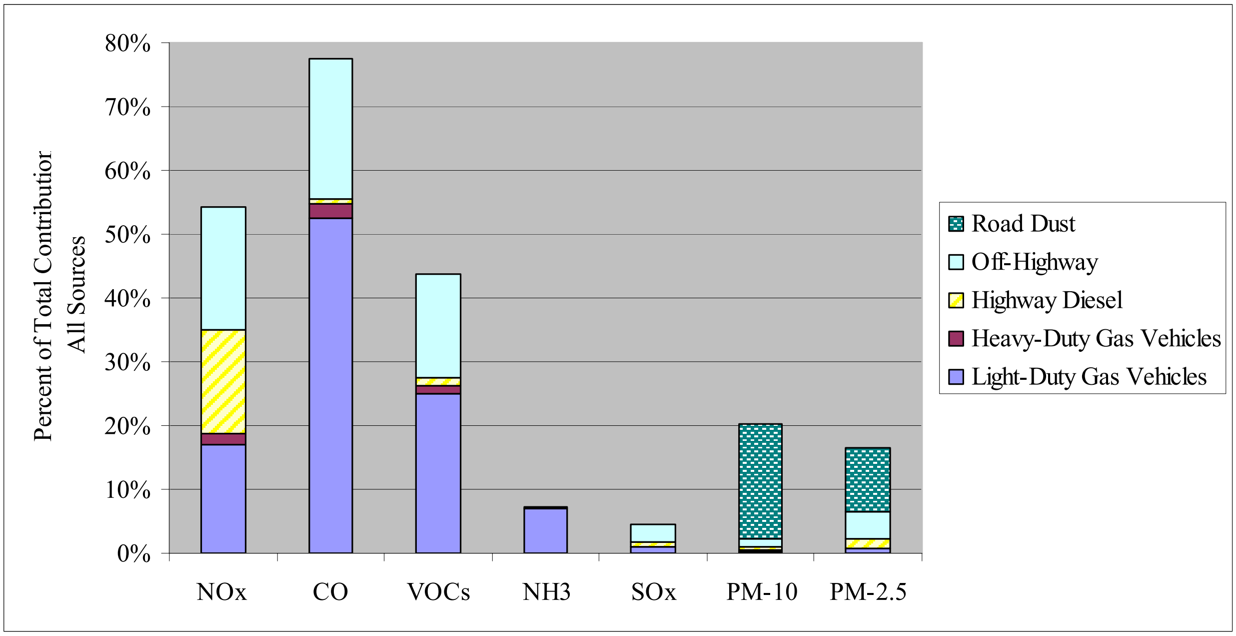
Strategies that alter vehicle fleet characteristics – Strategies that affect vehicle age, fuels, engine technologies, or emission control technologies will have effects that differ by pollutant. Many emission control technologies (catalysts, filters, etc.) and alternative fuels are designed to reduce only selected pollutants. For example, diesel oxidation catalysts (a common retrofit for older trucks and construction equipment) reduce PM emissions but have no effect on NOx emissions. Biodiesel blends have been found to reduce emissions of VOCs, CO, and PM, but to lead to slight increases in NOx; higher percentage biodiesel blends produce larger VOCs, CO, and PM reductions and larger NOx increases. Additionally, it is important to recognize the distinction between national engine and fuel standards that are set by the EPA and strategies that can be carried out at the state or local level to alter fleet characteristics for emissions reductions.

Types of Vehicles Affected and Share of Inventory

In determining which strategies will be most effective at reducing specific pollutants, it is useful to understand what share of the emissions inventory for that pollutant comes from the types of vehicles that are being affected by the strategy. The share of emissions coming from individual sources differs widely among regions, depending on types of industries, amount of freight traffic, and other factors. Using national figures, however, some general patterns are apparent (see Figure 2-2).

Figure 2-2: Contribution of Mobile Sources to U.S. Emissions

From National Emissions Inventory Air Pollutant Emissions Trends Data, 2002



- CO, VOCs, and NH_3 are largely produced by gasoline combustion, with the largest mobile sources being light-duty gas vehicles (including passenger cars, motorcycles, and trucks) and non-road gasoline sources (e.g., lawn and garden equipment and light commercial equipment). Consequently, if a region needs to reduce these pollutants, it should focus its strategies on those that target reductions in emissions from light-duty gasoline vehicles and gasoline equipment. It should be noted that while transportation is a large share of the total inventory of CO and VOC, mobile sources produce a relatively small share of NH_3 nationally.

- The largest source of transportation-related PM-10 and PM-2.5 emissions is fugitive dust from unpaved and paved roads. As a result, specific strategies to reduce the amount of dust that is kicked up from vehicles on roadways are often implemented to reduce particulate matter. Diesel vehicles and equipment are the largest contributors of direct PM-10 and PM-2.5 exhaust emissions from transportation. Therefore, PM reductions strategies may be most effective when focused on diesel vehicles and equipment.

- Transportation-related NO_X and SO_X emissions are not dominantly produced by any one category of vehicles. Light-duty vehicles, heavy-duty vehicles, and off-highway mobile sources each contribute a moderate share toward transportation NO_X and SO_X emissions. Thus, if a region needs to reduce these pollutants, it may implement strategies that focus on any of these sources. Since there are a smaller number of heavy-duty vehicles on the road, some heavy-duty vehicle strategies, in fact, may be very effective in reducing NO_X and SO_X. Although mobile sources make up a substantial portion of the NOx inventory (54 percent nationally), they contribute only a very small share of the SO_2 emitted in the U.S. (less than 5 percent).

Summary Impacts of Strategies

A summary of the types of transportation system effects and the general direction of emissions impacts, by strategy, is presented below. These impacts are based on reviews of reference documents and case studies, understanding of EPA's existing emissions models, and professional judgment. It should be noted that some types of effects have not been quantified by EPA; for instance, in MOBILE6.2, PM, SO_X, and NH_3

emissions are not affected by changes in travel speeds, and EPA guidance does not quantify the impacts of some retrofits on certain pollutants. In these cases, impacts are recorded as no effect or not available.

Impacts are indicated in general terms, and are not intended to represent magnitude. In some instances, reductions or increases of one pollutant may be much larger than for another; the sample strategies provide an indication of the relative magnitude of impacts for each pollutant.

General Emissions Impacts of Transportation Demand Management Strategies

Transportation demand management (TDM) strategies focus on changing travel behavior – trip rates, trip length, travel mode, time-of-day, etc. Most TDM projects and programs reduce emissions by reducing trips and/or vehicle miles traveled (VMT) by personal motor vehicles, or by shifting trips from peak periods to less congested periods. In general, strategies that reduce VMT will reduce emissions of all pollutants. Transportation analysts should be aware that some specific strategies have the potential to increase one or more pollutants, but this would generally not be the case for a program aimed at emissions reductions.[8] In addition, strategies that reduce vehicle travel may also have an indirect impact on travel speeds; however, these effects are generally minor and would not be large enough to offset emissions reductions. The table below provides a summary of the general emissions impacts of selected TDM strategies.

Table 2-1: General Emissions Impacts of TDM Strategies

Strategy	Category of Primary Effect						General Pollutant Effect						
	Reduce VMT	Reduce vehicle trips	Shift travel time	Reduce idling	Change speeds	Change vehicle stock or fuels	PM-2.5	PM-10	CO	NOx	VOCs	SOx	NH_3
1. Park-and-Ride Facilities	√	-					↓	↓	↓	↓	↓	↓	↓
2. HOV Lanes	√	√			√		↓	↓	↓	↓	↓	↓	↓
3. Ridesharing	√	+					↓	↓	↓	↓	↓	↓	↓
4. Vanpools	√	+					↓	↓	↓	↓	↓	↓	↓
5. Bicycle/Pedestrian	√	√					↓	↓	↓	↓	↓	↓	↓
6. Transit Service Enhancement	√	√					↓*	↓*	↓	↓*	↓	↓*	↓
7. Transit Marketing, Information and Amenities	√	√					↓	↓	↓	↓	↓	↓	↓
8. Transit Pricing	√	√					↓	↓	↓	↓	↓	↓	↓
9. Parking Pricing/ Management	√	√					↓	↓	↓	↓	↓	↓	↓
10. Road Pricing	√	√	+				↓	↓	↓*	↓*	↓*	↓	↓

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[8] For instance, an expansion in transit services could potentially increase PM and NO_X emissions if new buses do not take enough cars off the road to offset the emissions associated with increased bus operations. However, in general, a transit service expansion would only be considered as an emissions reduction strategy if there is sufficient ridership expected to yield net emissions benefits.

Strategy	Category of Primary Effect						General Pollutant Effect						
	Reduce VMT	Reduce vehicle trips	Shift travel time	Reduce idling	Change speeds	Change vehicle stock or fuels	PM-2.5	PM-10	CO	NOx	VOCs	SOx	NH_3
11. VMT Pricing	√	√					↓	↓	↓	↓	↓	↓	↓
12. Fuel Pricing	√	√				√	↓	↓	↓	↓	↓	↓	↓
13. Employer-based TDM Programs	√	√	+				↓	↓	↓*	↓*	↓*	↓	↓
14. Non-Employer-based TDM	√	√	+				↓	↓	↓*	↓*	↓*	↓	↓
15. Land-use Strategies	√	√			√		↓	↓	↓*	↓*	↓*	↓	↓

√=primary effect; +=may be a notable effect, but not in all cases; -=may have the opposite effect, in some cases

↓=decrease; ↓*=generally decreases, but possibility of an increase; ↓/↑=varies; ↑=increase; N=no change/not quantified

General Emissions Impacts of Transportation System Management Strategies

Transportation system management (TSM) strategies focus on changing the operation of the transportation system, typically with a primary focus on improving traffic flow and reducing traveler delay. TSM programs can reduce emissions by changing vehicle speeds, reducing rapid vehicle accelerations and decelerations, and reducing vehicle idling. Many of these strategies are under the umbrella of Intelligent Transportation Systems (ITS). In addition, some strategies focus directly on encouraging changes in driving behavior through educational information, incentives, or restrictions on driving speeds, operating patterns, and idling.

The table below provides a summary of the general emissions impacts of selected TSM strategies. Note that strategies that affect vehicle travel speeds will generally show no effect on PM, SO_X, and NH_3, and might result in either an increase or decrease in CO, NO_X, and VOC, depending on the starting vehicle speeds and level of speed change. On the other hand, strategies that reduce vehicle idling will generally reduce all pollutants. Some strategies can affect either travel speeds or vehicle idling time, or affect both.

Table 2-2: General Emissions Impacts of TSM Strategies

Strategy	Category of Primary Effect						General Pollutant Effect						
	Reduce VMT	Reduce vehicle trips	Shift travel time	Reduce idling	Change speeds	Change vehicle stock	PM-2.5	PM-10	CO	NOx	VOCs	SOx	NH_3
16. Signal Synchronization/ Intersection Improvements	-	-		√	√		↓/N	↓/N	↓/↑	↓/↑	↓*	↓/N	↓/N
17. Incident Management/ Traveler Information	+			√	√		↓/N	↓/N	↓/↑	↓/↑	↓*	↓/N	↓/N
18. Speed Control					√		N	N	↓/↑	↓/↑	↓/↑	N	N
19. Shifting/Separating Freight Movements					√		N	N	↓/↑	↓/↑	↓*	N	N

Strategy	Category of Primary Effect						General Pollutant Effect						
	Reduce VMT	Reduce vehicle trips	Shift travel time	Reduce idling	Change speeds	Change vehicle stock	PM-2.5	PM-10	CO	NOx	VOCs	SOx	NH$_3$
20. Vehicle Idling Restrictions/Programs				√			↓	↓	↓	↓	↓	↓	↓

√=primary effect; +=may be a notable effect, but not in all cases; -=may have the opposite effect, in some cases

↓=decrease; ↓*=generally decreases, but possibility of an increase; ↓/↑=varies; ↑=increase; N=no change/not quantified

General Emissions Impacts of Vehicle, Fuel and Technology Strategies

Vehicle, fuel, and technology projects and programs are designed to change the emissions rates of vehicles either by changing the fuel being used, the type of vehicle or emissions control technology, or a combination of both. Some programs also focus on eliminating gross polluters, or vehicles whose emissions controls have failed. The methodologies for these strategies generally involve estimating the number of vehicles affected, and then calculating the change in the emissions factors based on changes in vehicle stock or equipment. The specific emissions reductions depend on the type of technology and/or fuel used. The table below provides a summary of the general emissions impacts of selected vehicle, fuel, and technology strategies. It is important to note that the emissions impacts of these strategies vary considerably based on the specific types of technologies and fuels that are used. For instance, some diesel engine retrofits target reducing PM while others focus on NO$_X$.

Table 2-3: General Emissions Impacts of Vehicle, Fuel and Technology Strategies

Strategy	Category of Primary Effect						General Pollutant Effect						
	Reduce VMT	Reduce vehicle trips	Shift travel time	Reduce idling	Change speeds	Change vehicle stock	PM-2.5	PM-10	CO	NOx	VOCs	SOx	NH$_3$
21. Idle Reduction Facilities				√			↓	↓	(—)	↓	(—)	(—)	(—)
22. Accelerated Retirement/Replacement of Buses						√	↓	↓	↓	↓	↓	↓	↓
23. Accelerated Retirement/Replacement of Heavy Duty Trucks						√	↓	↓	↓	↓	↓	↓	↓
24. Diesel Engine Retrofits						√	(—)/N	↓/N	↓	↓/N	↓	N	N
25. Clean Diesel Fuel						√	(—)	↓/N	↓/↑	↓/↑	↓/↑	↓/N	N
26. Inspection & Maintenance Programs						√	N	N	↓	↓	↓	N	N

√=primary effect; +=may be a notable effect, but not in all cases; -=may have the opposite effect, in some cases

↓=decrease; ↓/↑=varies; N=no change/not quantified; (—)=decrease expected, but not quantified in EPA guidance

General Emissions Impacts of Non-road Transportation Strategies

Non-road vehicles and equipment include railroads, marine vessels, airport ground support equipment, lawn and garden equipment, construction and agricultural equipment, and other mobile equipment. There are a wide range of technologies and operational strategies available to address these sources. The strategies presented in this report focus on policies and programs that can be implemented at the state and local level. The table below provides a summary of the general emissions impacts of selected non-road transportation strategies. It should be noted that diesel engine retrofits and clean diesel fuels strategies (#24 and 25 above) can also be applied to non-road diesel engines with similar results.

Table 2-4: General Emissions Impacts of Non-Road Transportation Strategies

Strategy	**Category of Primary Effect**						**General Pollutant Effect**						
	Reduce VMT	**Reduce vehicle trips**	**Shift travel time**	**Reduce idling**	**Change speeds**	**Change vehicle stock**	**PM-2.5**	**PM-10**	**CO**	**NOx**	**VOCs**	**SOx**	**NH_3**
27. Locomotive Replacement/Repowers						√	(—)	↓	N	↓	↓	N	N
28. Rail Electrification				+		√	(—)	↓	↓	↓	↓	(—)	(—)
29. Locomotive Idling Reduction				√			↓	↓	(—)	↓	(—)	(—)	(—)
30. Marine Vessel Replacement/Repowers						√	(—)	↓	N	↓	↓	N	N
31. Marine Vessel Operational Strategies				√			(—)	↓	(—)	↓	↓	(—)	(—)
32. Transportation Equipment Replacement/ Repowers						√	(—)	↓	N	↓	↓	N	N

√=primary effect; +=may be a notable effect, but not in all cases; -=may have the opposite effect, in some cases

↓=decrease; ↓/↑=varies; N=no change/not quantified; (—)=decrease expected, but not quantified in EPA guidance

General Emissions Impacts of Road Dust Strategies

Road dust reduction strategies focus on limiting the amount of particulate matter that is kicked up by the movement of vehicles on roadways. These strategies reduce PM-2.5 and PM-10 from road dust, but typically have no effect on other pollutants, as shown in the table below. In the case of street sweepers, there may be a small increase in emissions of other pollutants if the emissions from the street sweeping equipment are considered.

Table 2-5: General Emissions Impacts of Road Dust Strategies

Strategy	Category of Primary Effect						General Pollutant Effect						
	Reduce VMT	Reduce vehicle trips	Shift travel time	Reduce idling	Change speeds	Change vehicle stock	PM-2.5	PM-10	CO	NOx	VOCs	SOx	NH_3
33. Unpaved Road Dust Mitigation							↓	↓	N	N	N	N	N
34. Road Paving	-	-					↓	↓	N	N	N	N	N
35. Street Sweeping							↓	↓	N*	N*	N*	N*	N*

√=primary effect; +=may be a notable effect, but not in all cases; -=may have the opposite effect, in some cases

↓=decrease; ↓/↑=varies; N=no change/not quantified; N* = generally no change, but possibility of an increase

Interactions between Strategies and Effects

While strategies are classified independently, it is important to recognize that many strategies are not typically implemented in isolation, and consequently should not be evaluated as such. Specifically:

- Many strategies are commonly implemented in combination and separating out the impacts of individual program elements is often difficult. Consequently, strategies should often be evaluated together as integrated packages. For example, an expanded bus service strategy may include additional transit service provision, using new CNG vehicles, combined with enhanced marketing and new bus shelters. Analyzing this project as an integrated package of strategies helps both to avoid double-counting and to account for effects that are not additive, due to synergies between strategies or competition.
- Some strategies can have both positive and negative affects on emissions. For example, employer flex-time policies tend to discourage co-worker carpooling, but encourage family carpool arrangements. Park-and-ride lots can encourage transit use, but also increase auto access to transit, thus creating a cold start. Strategies that increase transit ridership may not only reduce personal motor vehicle travel, but may also require additional transit services.

3. TRANSPORTATION DEMAND MANAGEMENT STRATEGIES

Transportation demand management (TDM) strategies focus on changing travel behavior – trip rates, trip length, travel mode, time-of-day, etc. – generally in order to reduce traffic during congested (peak) periods. TDM projects/programs generally reduce emissions of all pollutants by reducing vehicle trips and/or vehicle miles traveled (VMT) by personal motor vehicles, or by shifting trips from peak periods to less congested periods.

TDM strategies generally focus on reducing travel in light-duty vehicles (automobiles and light-duty trucks), which are large contributors to CO, VOC, and NOx emissions; consequently, these strategies may be most effective at targeting one or more of these pollutants.

Methodologies for analyzing the impacts of TDM strategies generally involve the following steps:

1) Estimate number of vehicle trips potentially affected by the strategy, based on the scope of the program.

2) Estimate reductions in vehicle trips, recognizing that some share of trips affected may not result in a reduction in vehicle trips.

3) Calculate reductions in VMT, both due to the elimination of vehicle trips and reductions in trip lengths.

4) Estimate shifts in travel times, as applicable.

5) Calculate emissions, based on emission factors reflective of the vehicle types affected, road types used by those vehicles, speeds, and whether or not vehicle trip cold starts are eliminated.

These strategies, and associated methodologies, are presented below. Some of the strategies covered in this section are addressed by EPA's "Best Workplaces for Commuters" program, and estimates of emissions impacts for these strategies can be derived from the COMMUTER Model, http://www.epa.gov/OMS/stateresources/policy/pag_transp.htm#cp and the accompanying guidance document, http://www.epa.gov/otaq/stateresources/policy/transp/commuter/420b05016.pdf.

Note: For most of the TDM strategies, the methodologies used in the sample calculations do not incorporate secondary or indirect emissions impacts from speed and volume changes or from increases in transit service that may be needed in response to a demand management program. These effects are not significant in most cases, but should be considered on a case-by-case basis.

1. Park-and-Ride Facilities

Strategy Overview

Park-and-ride facilities include the construction or expansion of parking lots where people can park their vehicles and then join a carpool, vanpool or transit service. Typically, park-and-ride facilities are used in suburban areas. This strategy reduces emissions by decreasing the number of single-occupancy vehicles on the road.

Emissions Impacts

By encouraging drivers to reduce VMT by sharing car trips or taking transit, park-and-ride lots reduce emissions of all pollutants associated with driving, as shown in the table below. However, the emissions benefits will not be proportional for all pollutants, since the use of a park-and-ride facility requires individuals to drive to the facility. As a result, this strategy does not reduce the number of vehicle cold starts that are taken, during which time the highest emissions output of CO, NO_X, and VOCs are produced (in fact, it is possible that park-and-ride lots could lead to increased vehicle trip starts if people who used to pick each other up at individual homes now each drive to the park-and-ride lot).

Since park-and-ride facilities reduce VMT but not cold starts, they generally are less effective at reducing CO, NO_X, and VOCs than other demand management strategies that reduce vehicle trip-making entirely. They can be effective, however, in reducing localized CO; for instance, by reducing vehicle trips into a central business district.

Table 3-1. Park-and-Ride Strategy—Overall Impact on Emissions

PM-2.5	PM-10	CO	NOx	VOCs	SOx	NH_3
↓	↓	↓	↓	↓	↓	↓

General Considerations

Factors affecting the level of emissions impacts include:

- The number of spaces available in the park-and-ride facility, and expected utilization
- The form of transportation previously used by commuters (i.e., extent to which people previously drove alone)[9]
- The average length of carpool/vanpool trips using the park-and-ride facility[10]

Park-and-ride facility impacts are typically analyzed using sketch planning methods. The calculation of emissions impacts should ideally account for any changes in trip lengths associated with driving to the park-and-ride lot (e.g., for instance, if someone drives one mile out of the way to access the park-and-ride) and any potential increase in trip starts associated with people who previously were picked up at home but now drive to the park-and-ride. However, these factors are generally very small and are not usually considered in simple sketch planning methods.

For EPA guidance on this strategy, see "Methodologies for Estimating Emissions and Travel Activity Effects of TCMs," http://www.epa.gov/ttnnaaqs/ozone/eac/epa-420-r-94-002_07-94.pdf. For more

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[9] A key factor used in evaluating changes in VMT resulting from park-and-ride programs is the previous mode of park-and-ride users. Analysis conducted by EPA in the early 1990s found that between 11 and 85 percent of park-and-ride patrons had driven alone to their destinations before they began using park-and-ride facilities.

[10] Note that carpool/vanpool trips tend to be longer than overall regional average commute trip lengths. It is not uncommon for vanpool trips of 40 miles or more each way.

information on this strategy, see the EPA TCM Information Document, "Park-and-Ride/Fringe Parking." http://www.epa.gov/otaq/stateresources/policy/transp/tcms/park-fringepark.pdf.

Sample Projects

SAMPLE 1: ADDING SPACES TO AN EXISTING PARK-AND-RIDE FACILITY WITHOUT TRANSIT

This example assumes an addition of parking spaces to an existing park-and-ride facility that is not served by transit, and is based on parameters for an expansion to a park-and-ride lot along Maryland 22 at Bynum Run Park in suburban Baltimore, Maryland.[11] Emissions impacts are calculated using a simple sketch planning technique. The inputs assumed for the sample include:

- 60 parking spaces added
- 70 percent estimated utilization rate
- 80 percent of users previously drove alone
- 50 miles roundtrip average reduced by lot users (distance from lot to destination and return)
- 250 operating days per year

Step 1: Estimate expected lot use.

= (Spaces added to lot) x (estimated utilization rate)
= (60 spaces) x (0.70)
= 42 spaces

Step 2: Calculate expected number of people reducing driving.

= (Spaces used) x (share who previously drove alone)
= (42 spaces) x (0.80)
= 33.6 fewer drivers per day

Step 3: Calculate annual VMT reduction.

= (Number of fewer drivers per day) x (estimated round trip) x (operating days)
= (33.6 fewer drivers) x (50 mi) x (250 days)
= 525,000 annual VMT reduction

Step 2: Calculate reduction in emissions.

= (Running emission factor) x (reduction in VMT)

Table 3-2 shows the annual emissions impacts resulting from the implementation of the example strategy.

Table 3-2. Total Emissions Reduced (ton/year) from Park-and-Ride Example

Year	PM-2.5	PM-10	CO	NOx	VOCs	SOx	NH_3
2006	0.01	0.01	4.09	0.41	0.34	<0 .01	0.06
2010	0.01	0.01	3.15	0.29	0.24	< 0.01	0.06
2020	0.01	0.01	2.17	0.14	0.13	< 0.01	0.06

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[11] Documented in "Summary of Review of Costs and Emissions Information for 24 Congestion Mitigation and Air Quality Improvement Program Projects," developed by Hagler Bailly for U.S. EPA, 1999.

SAMPLE 2: NEW PARK-AND-RIDE LOT SERVED BY TRANSIT

This sample is comprised of a new park-and-ride lot with new transit services. This sample is based on a new lot added along the I-59 corridor in Birmingham, Alabama.[12] Emissions impacts are calculated using a simple sketch planning technique. The inputs assumed for the sample include:

- 100 parking spaces added
- 85 percent expected utilization
- 83 percent of users previously drove alone
- 12 miles expected trip length reduction, round trip
- 4 round-trip (8 one-way) commuter buses serving the lot per day
- 10.5 miles bus trip length
- 250 operating days per year

Step 1: Estimate expected lot use.

= (Historical utilization) x (spaces in lot)
= (0.85) x (100 spaces)
= 85 spaces

Step 2: Calculate the number of people reducing driving.

= (Expected lot use) x (percent of users who previously drove alone)
= (85 spaces) x (0.83)
= 71 auto trips reduced per day

Step 3: Calculate annual VMT reduction.

= (Trips reduced) x (average commute trip length) x (operating days)
= (71 trips) x (12 mi) x (250 days)
= 213,000 annual VMT reduction

Step 4: Calculate the auto emissions reductions from the project.

= (Annual VMT reductions) x (auto running emissions factor)

Step 5: Calculate the emissions from the new bus service.

= (number of bus trips) x (bus trip length) x (bus running emissions factor)
= (8 trips) x (10.5 miles) x (bus running emissions factor)

Step 6: Calculate total emissions reductions.

= (Auto vehicle emissions reduced) - (bus emissions)

Table 3-3 shows the annual emissions impacts resulting from the implementation of the example strategy.

Table 3-3. Total Emissions Reduced (ton/year) from Park-and-Ride Example

Year	PM-2.5	PM-10	CO	NOx	VOCs	SOx	NH_3
2006	< 0.01	<0.01	1.64	0.12	0.14	< 0.01	0.02
2010	< 0.01	0.01	1.26	0.09	0.10	< 0.01	0.02
2020	< 0.01	0.01	0.87	0.05	0.05	< 0.01	0.02

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[12] Documented in “A Guide for Estimating the Emissions Effects and Cost-Effectiveness of Projects Proposed for CMAQ Funding,” by ICF International for the Birmingham Regional Planning Commission, 2002.

2. High-Occupancy Vehicle Lanes

Strategy Overview

High Occupancy Vehicle (HOV) lanes are intended to maximize the person-carrying capacity of a roadway by altering the design and/or operation of the facility to provide priority treatment for HOVs, such as carpools, buses, and vans. By providing two important incentives—reduced travel time and improved trip time reliability—HOV facilities encourage travelers to shift from single occupancy vehicles to HOV use. This shift should reduce vehicle trips, vehicle miles traveled (VMT), and associated emissions from these activities. In addition, HOV lanes are designed to operate at faster speeds, even during peak periods, and so the strategy also results in an increase in travel speeds for vehicles using the HOV lane.

Emissions Impacts

HOV lanes affect air pollution emissions in several ways. First, restricting the additional lanes to certain vehicles encourages ridesharing among commuters, resulting in fewer vehicle trips and emissions of all pollutants. HOV lanes also increase travel speeds for HOV traffic that is able to utilize the lanes, and potentially along the entire roadway. Consequently, the speed changes may have different effects for different pollutants, and could even increase some emissions. Implementation of HOV lanes also could result in some additional emissions that may partially offset the benefits of vehicle trip reduction if some people who previously used transit now switch to carpools, thereby increasing the number of vehicles on the road. However, in general, HOV lanes would be expected to reduce all pollutants, as shown below in Table 3-4.

Table 3-4. High Occupancy Vehicles- Overall Impact on Emissions

PM-2.5	PM-10	CO	NOx	VOCs	SOx	NH_3
↓	↓	↓	↓	↓	↓	↓

General Considerations

Factors affecting level of emissions impacts include:

- Existing number of carpools and vanpools on the roadway
- The extent to which travelers shift from SOVs to HOVs, or from transit to HOVs
- Travel speeds without the HOV lane and with implementation of the new HOV lane
- Duration of HOV operational restrictions and the level of enforcement, which will affect compliance[13]

Emissions impacts of HOV lanes are often estimated using sketch planning methods. More complex tools and models are also available, such as simulation tools and travel demand models, to examine impacts on speeds and traffic patterns in more detail.

For EPA guidance on this strategy, see "Methodologies for Estimating Emissions and Travel Activity Effects of TCMs," http://www.epa.gov/ttnnaaqs/ozone/eac/epa-420-r-94-002_07-94.pdf. For more information, see the EPA TCM Information Document, "High Occupancy Vehicle Lanes," http://www.epa.gov/otaq/stateresources/policy/transp/tcms/high_occvehicles.pdf.

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[13] Compliance will affect traffic and speeds in the HOV lane, and may affect the extent to which people shift to HOVs.

Sample Project

EXTENSION OF AN EXISTING HOV LANE

This sample is based on a project that extended HOV lanes by 2 miles on I-84 from East Hartford to downtown Hartford.[14] HOV lanes can be analyzed using various methods, including travel demand forecasting model approaches and vehicle queuing models. In this case, a sketch planning methodology is used to calculate the changes in emissions on the 2 mile segment of roadway, as well as additional emissions impacts associated with increased ridesharing for commuting (e.g., people who switch from driving alone to a carpool will affect their entire commute trip, not just the last two miles). The calculation relies on the following inputs (for simplicity, this example assumes no increase in bus use, only carpools, and that all carpoolers meet at a park-and-ride facility, so trip start emissions are not reduced, only running emissions):

- 2 mile addition to HOV lanes at HOV-2 requirement (minimum 2 persons per vehicle)
- 8,000 vehicles per hour on road segment during peak periods
- 6 hours with HOV restrictions in place per day (3 hours each direction)
- 9 mph average speed on roadway prior to implementation
- 35 mph average speed in HOV lane after implementation; no change in speed in general use lanes
- 15 percent of vehicles on roadway are HOVs prior to implementation
- 5 percent of SOVs switch to HOVs as a result of implementation
- 2.1 average vehicle occupancy in HOV lane
- 12 mile average commute trip length
- 250 operating days per year

Step 1: Estimate total traffic in corridor that are HOVs and SOVs during HOV enforcement hours, prior to implementation of lane expansion

= (Corridor traffic count per peak hour) x (hours with HOV restrictions) x (percent HOVs)
= (8,000 vehicles per hour) x (6 hours) x (0.15 HOVs) = 7,200 HOVs
(8,000 vehicles per hour) x (6 hours) x (0.85 SOVs) = 40,800 SOVs

Step 2: Estimate shift from SOVs to HOVs with lane expansion.

Reduction in SOV trips
= (SOV travelers) x (share that switch to HOVs)
= (40,800 SOVs) x (0.05)
= 2,040 reduced SOV trips

Increase in HOV trips
= SOV trip reduction / (average HOV occupancy)
= (2,040 reduced SOV trips) / 2.1
= 971 new HOV trips

Step 3: Estimate change in emissions on the expanded roadway segment by comparing no-build to build scenarios.

No build on segment
= (Total vehicle trips) x (trip length) x (auto running emissions factor at 9 mph) x (operating days)

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[14] Documented in "Summary of Review of Costs and Emissions Information for 24 Congestion Mitigation and Air Quality Improvement Program Projects," by Hagler Bailly for U.S. EPA, 1999.

= (48,000 vehicle trips) x (2 miles) x (auto running emissions factor at 9 mph) x (250 days)

Build on segment
= [(SOV trips) x (trip length) x (auto running emissions factor at 10 mph)] + [(HOV trips) x (trip length) x (auto running emissions factor at 35 mph)] x (operating days)
= [(40,800 – 2,040 SOV trips) x (2 miles) x (auto running emissions factor at 10 mph)] + [(7,200 + 971 HOV trips) x (2 miles) x (auto running emissions factor at 35 mph)] x (250 days)

Step 4: Calculate additional emissions reductions off the expanded segment.

Reduced SOV emissions
= (Reduced SOV trips) x (commute trip length – segment length) x (auto running emissions factor at 9 mph) x (operating days)
= (2,040 reduced SOV trips) x (12 miles – 2 miles) x (auto running emissions factor at 9 mph) x (250 days)

Added HOV emissions
= (New HOV trips) x (commute trip length – segment length) x (auto running emissions factor at 35 mph) x operating days
= (971 new HOV trips) x (12 miles – 2 miles) x (auto running emissions factor at 35 mph) x (250 days)

The following table shows the annual emissions impacts resulting from the implementation of the example strategy.

Table 3-5. Total Emissions Reduced (ton/year) from High Occupancy Vehicles Example

Year	PM-2.5	PM-10	CO	NOx	VOCs	SOx	NH_3
2006	0.26	0.56	216	22.9	34.4	0.18	2.20
2010	0.25	0.55	174	16.0	22.8	0.17	2.20
2020	0.25	0.54	130	7.41	13.6	0.17	2.21

3. Ridesharing Programs/Incentives

Strategy Overview

Regional rideshare programs provide ride-matching services, employer outreach, and incentives to commute by carpool or vanpool (such as free gas cards, drawings, award programs, subsidies). Ridematching may be traditional (i.e., people establish regular carpool routines) or dynamic (real-time matching of individuals who want to travel to/from similar locations). The strategy encourages SOV commuters to share trips, thereby reducing vehicle trips and VMT.

Emissions Impacts

Ridesharing programs reduce emissions by decreasing the amount of VMT. Consequently, the programs should generally reduce emissions for all pollutants, as shown below in Table 3-6.

Table 3-6. Ridesharing Programs/Incentives- Overall Impact on Emissions

PM-2.5	PM-10	CO	NOx	VOCs	SOx	NH_3
↓	↓	↓	↓	↓	↓	↓

General Considerations

Factors affecting the level of emissions impact include:

- The number of new carpools/vanpools formed
- The extent to which people previously drove alone (as opposed to using transit)
- The length of carpool trip to pick up riders

Ridesharing impacts are typically analyzed using sketch planning methods or use of EPA's COMMUTER Model. Care should be taken to avoid double-counting benefits of these programs with other related programs, since ridesharing is often incorporated into employer-based transportation demand management programs and is often bundled with additional TDM strategies.

For EPA guidance on this strategy, see "Methodologies for Estimating Emissions and Travel Activity Effects of TCMs," http://www.epa.gov/ttnnaaqs/ozone/eac/epa-420-r-94-002_07-94.pdf. In addition, for more information on this strategy, see the EPA TCM Information Document, "Area-Wide Rideshare Incentives," http://www.epa.gov/otaq/stateresources/policy/transp/tcms/areawide_incentive.pdf, and the COMMUTER Model documentation, http://www.epa.gov/OMS/stateresources/policy/transp/commuter/420b05017.pdf.

Sample Project

REGIONAL RIDESHARE PROGRAM

This sample is based on a scenario where an area-wide ridesharing and incentive program was implemented by 45 percent of employers in the San Francisco-San Mateo-Redwood City Metropolitan Area.[15] Ridesharing support programs include support for carpooling and vanpooling, and financial incentives include parking costs, transit fare/pass subsidies, or other financial incentives. A COMMUTER Model run was conducted using model default parameters and the specific inputs discussed below in the calculations.

Step 1: Estimate the number of commuters that will have access to new commuter options as a result of the ridesharing and incentives program.

For this example, the Bureau of Labor Statistics was used to estimate the number of office and non-office employees in the San Francisco-San Mateo-Redwood City Metropolitan Area. In this metropolitan area, there are approximately 500,000 office employees and 425,000 non-office employees.[16]

Step 2: Determine the typical strategies offered and participation rates.

In the COMMUTER Model, employer-supported commute programs in a geographic area are represented by inputting the employer participation rates at various support levels. The respective rates assumed in the base case and strategy implementation case are listed below.

Base case:

Program	No Participation	Level 1	Level 2	Level 3
Carpool	90 percent	10 percent	0	0
Vanpool	95 percent	5 percent	0	0
Transit	90 percent	10 percent	0	0
Bicycle	100 percent	0	0	0

Action case:

Program	No Participation	Level 1	Level 2	Level 3
Carpool	90 percent	0	10 percent	0
Vanpool	85 percent	0	10 percent	5 percent
Transit	82 percent	5 percent	10 percent	3 percent
Bicycle	95 percent	0	5 percent	0

The COMMUTER Model defines a Level 1 program as the provision of information activities plus a quarter-time transportation coordinator. A Level 2 program is defined as Level 1 plus in-house matching services (carpool and vanpool), work hours flexibility (transit), or bicycle parking and shower facilitates (bicycle). A Level 3 program includes Level 2 plus a half-time transportation coordinator plus preferential parking and flexible work schedules (carpool), vanpool development and operating assistance and preferential parking (vanpool), or on-site transit pass sales (transit).

Step 3: Estimate total change in vehicle trips and VMT.

According to the COMMUTER Model, the employer provided support programs would lead to a reduction of 506 vehicle trips and 0.3 percent reduction in VMT, or 8,097 vehicle miles.

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[15] Documented in "Summary of Review of Costs and Emissions Information for 24 Congestion Mitigation and Air Quality Improvement Program Projects," by Hagler Bailly for U.S. EPA, 1999.

[16] Bureau of Labor Statistics, http://www.bls.gov/oes/current/oes_41884.htm

Step 4: Estimate emissions reductions (average commute speed of 35 mph).

= [(Vehicle trips reduced) x (per trip emissions factor)] + [(VMT reduced x (per mile running emissions factor)]

Table 3-7 shows the annual emissions impacts resulting from the implementation of the example strategy.

Table 3-7. Total Emissions Reduced (ton/year) from Ridesharing Programs/Incentives Example

Year	PM-2.5	PM-10	CO	NOx	VOCs	SOx	NH_3
2006	0.03	0.05	15.6	1.54	1.30	0.02	0.22
2010	0.02	0.05	12.0	1.09	0.91	0.02	0.22
2020	0.02	0.05	8.29	0.53	0.53	0.02	0.22

4. Vanpool Program

Strategy Overview

Particularly well suited for longer commutes, vanpools typically carry from seven to fifteen passengers, and operate weekdays, traveling between one or two common pick-up locations (typically a park-and-ride lot where a rider may leave their car, or a transit station) and the place of work. Vanpool programs typically provide vehicles owned by an organization to commuters who live in a common geographic area and who share an employment destination. The vans or buses may be operated by a driver or by the commuters themselves. Additionally, some programs provide outreach services to attract potential riders.

Emissions Impacts

Vanpools reduce emissions by decreasing vehicle miles that occupants would otherwise travel by auto. Although an individual van may produce more emissions than an individual auto, vanpools typically replace 7 to 15 auto trips each, and therefore should result in reductions of all pollutants, as show in Table 3-8. Since personal vehicles make up a larger share of on-road CO, VOCs, and NH_3 emissions than PM or NO_X, this strategy will be more effective as strategy to reduce CO, VOCs, and NH_3, rather than other pollutants.

Table 3-8. Vanpool Strategy - Overall Impact on Emissions

PM-2.5	PM-10	CO	NOx	VOCs	SOx	NH_3
↓	↓	↓	↓	↓	↓	↓

General Considerations

The level of emissions impact depends on:

- The number of vanpools established through the program
- The extent to which vanpool riders previously were driving alone (vs. already carpooling)
- The extent to which vanpool riders drive to a vanpool pick-up location
- The average length of vanpool trips

Vanpool program impacts are typically analyzed using sketch planning methods. When analyzing vanpool programs, care should be taken to ensure that double-counting of emissions effects does not occur with ridesharing programs, employer-based TDM programs, and other related programs. These strategies may need to be assessed together as a new TDM strategy, instead of individual projects. For EPA guidance, see "Methodologies for Estimating Emissions and Travel Activity Effects of TCMs," http://www.epa.gov/ttnnaaqs/ozone/eac/epa-420-r-94-002_07-94.pdf.

Sample Projects

SAMPLE 1: SUBSIDY OF COMMUTER VANPOOLS

This sample is based on a vanpool subsidy program in California.[17] Emissions impacts are calculated based on the following assumptions:

- 10 long-distance commuter vanpools
- Average of 11 people, 5 days in each vanpool
- Average distance of 48 miles, each way

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[17] Documented in "Methods to Find the Cost-Effectiveness of Funding Air Quality Projects," by the California Air Resources Board, 2005.

- 5 miles is auto trip length to access vanpools
- 83 percent of the riders previously drove to work alone
- 75 percent of vanpool riders drive an average of 5 miles to the access point
- Vans are gas-operating vehicles
- 240 operating days per year

Step 1: Estimate daily vanpool ridership.

= (Number of vanpools) x (average number of riders)
= 10 vanpools x 11 riders
= 110 daily vanpool ridership

Step 2: Calculate auto trip starts reduced per year.

= (Daily vanpool riders) x (percent of riders who previously drove alone) x (1 – percent of riders who drive to access point) x (2 trip per day) x (days of operation)
= (110 vanpool riders) x (.83) x (.25) x (2 trips) x (240 days)
= 11,413 annual auto trip starts reduced

Step 3: Calculate auto VMT reduced per year.

= (Daily vanpool riders) x (percent of riders who previously drove alone) x (2 trips per day) x (days of operation) x { (average one-way trip length) – [(percent of riders driving to access point) x (auto trip length to access point)]}
= (110) x (0.83) x (2) x (240) (48 miles – [(0.75) x (5 miles)])
= 1,939,212 annual VMT reduced

Step 4: Calculate emissions reductions from autos.

= [(Auto trips reduced) x (auto trip start emissions factor)] + [(auto VMT reduced) x (auto running emissions factor)]

Step 5: Calculate emissions resulting from operation of the vanpool

= (Number of vans) x (average van trip length) x (2 trips per day) x (days of operation) x (van running emissions factor)
= (10) x (48 mi) x (2) x (240) x (van emissions factor, including start)

Step 6: Calculate net emissions reduction

= (Auto emissions reduction) – (van emissions)

Table 3-9 shows the annual emissions impacts resulting from the implementation of the example strategy.

Table 3-9. Total Emissions Reduced (ton/year) from Vanpool Subsidy Example

Year	PM-2.5	PM-10	CO	NOx	VOCs	SOx	NH_3
2006	0.02	0.05	14.6	1.30	1.22	0.02	0.21
2010	0.02	0.05	11.3	0.94	0.85	0.02	0.21
2020	0.02	0.05	7.70	0.49	0.45	0.02	0.21

SAMPLE 2: ESTABLISHMENT OF NEW VANPOOLS

This sample focuses on the establishment of new vanpools, which can occur due to financial incentives, provision of vans, or other services. This sample is based on a vanpool project in Dade County, Florida.[18] The emissions calculation uses a sketch planning technique, relying on the following inputs:

- 30 vans are established (capacity of 8 or 15, avg. 11.5 seats per van)
- Vanpool staging area is walking/biking distance or pick-up service is provided
- 80 percent of participants previously drove alone
- 30 mile average distance to work, each way
- 240 operating days per year

Step 1: Estimate annual auto trips reduced.

= (Total number of vanpoolers) x (percent of riders who previously drove alone) x (2 trips per day) x (days of operation)
= (30 vans x 11.5 riders per van) x (0.80) x (2) x (240)
= 132,480 vehicle trips reduced

Step 2: Estimate annual auto VMT reduced.

= (Vehicle trips reduced) x (average distance to work)
= (132,480) x (30 mi)
= 4 million annual vehicle miles reduced

Step 3: Calculate emissions reductions from autos.

= [(Auto trips reduced) x (auto trip start emissions factor)] + [(auto VMT reduced) x (auto running emissions factor)]

Step 4: Calculate emissions resulting from operation of the vanpool.

= (Number of vans) x (average van trip length) x (2 trips per day) x (days of operation) x (van running emissions factor)
= (30) x (30 mi) x (2) x (240) x (van running emissions factor)

Step 5: Calculate net emissions reduction.

= (Auto emissions reduction) – (van emissions)

Table 3-10 shows the total annual amount of emissions reduced as a result of implementing this project.

Table 3-10. Total Emissions Reduced (tons/year) from Vanpool Program Example

Year	PM-2.5	PM-10	CO	NOx	VOCs	SOx	NH_3
2006	0.02	0.07	31.9	1.47	2.04	0,03	0.42
2010	0.03	0.08	24.7	1.21	1.43	0.03	0.42
2020	0.04	0.09	16.6	0.83	0.77	0.03	0.42

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[18] Documented in “Off-Model Air Quality Analysis: A Compendium of Practice,” by Federal Highway Administration, Southern Resource Center, 1999.

5. Bicycle / Pedestrian Projects and Programs

Strategy Overview

Bicycle and pedestrian projects/programs include a wide range of investments and strategies to facilitate and encourage non-motorized travel. Examples of these strategies include: bicycle paths and lanes, sidewalks, bicycle racks or lockers, pedestrian urban design enhancements, bicycle share programs, and bicycle incentives. These projects can serve both commute and non-commute trips.

Emissions Impacts

Bicycle and pedestrian projects/programs should reduce all pollutants by reducing VMT; however, impacts are likely to be small given limited shifts from driving and relatively short trip distances. Improved connections to transit services, however, can result in reductions in longer vehicle trips. General impacts of bicycle and pedestrian projects are shown below in the table below.

Table 3-11. Bicycle/Pedestrian Projects - Overall Impact on Emissions

PM-2.5	PM-10	CO	NOx	VOCs	SOx	NH_3
↓	↓	↓	↓	↓	↓	↓

General Considerations

The level of emissions impact depends on:

- Extent to which the project increases use of bicycling or walking
- Extent to which new bicyclers/walkers previously drove alone (as opposed to using transit or other non-motorized mode)
- Vehicle trip length reduced (which may be longer than the actual bicycle/pedestrian trip if linked with transit)

Bicycle and pedestrian project impacts are typically analyzed using sketch planning methods. For EPA guidance on this strategy, see "Methodologies for Estimating Emissions and Travel Activity Effects of TCMs," http://www.epa.gov/ttnnaaqs/ozone/eac/epa-420-r-94-002_07-94.pdf. For more information, see the EPA TCM Information Document, "Bicycle and Pedestrian Programs," http://www.epa.gov/otaq/stateresources/policy/transp/tcms/bicycle_ped.pdf.

Sample Projects

SAMPLE 1: DEVELOPMENT OF A NEW BIKE LANE

This example includes development of a single 1.13 mile bike lane, and is based on a project in the San Francisco Bay Area, California, which included installation of new pavement, signage, and bike lane striping.[19] The new bike lane provides residents bike access to education, employment, shopping, and transit. Within one-quarter mile of the project, there is a college, a shopping center, a light rail station, and an office building. The parameters of the project consist of:

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[19] Documented in "Methods to Find the Cost-Effectiveness of Funding Air Quality Projects," by the California Air Resources Board, 2005.

- 1.13 miles of bike lanes, both sides
- 1.8 miles average bike trip
- 200 operating days

Step 1: Estimate auto trips reduced.

Auto trips reduced can be estimated in various ways, including use of bicycle/pedestrian factors associated with different types of surrounding land uses, studies of similar bicycle projects, or modeling. In this case, consistent with methods developed by the California Air Resources Board, auto trips reduced are calculated as a function of average daily traffic (ADT) on the roadway.
= (ADT) x (Adjustment on ADT for auto trips replaced by bike trips) x (operating days)
= (20,000) x (0.0109) x 200
= 43,600

Step 2: Estimate VMT reduced.

= (Auto trips reduced) x (length of bike trips)
= (43,600) x (1.8)
= 78,480

Step 3: Calculate annual emissions reduction.

= [(Annual auto trip starts reduced) x (auto trips end factor)] + [(annual auto VMT reduced) x (auto VMT factor)]

Table 3-12 shows the annual emissions impacts resulting from the implementation of the example strategy.

Table 3-12. Total Emissions Reduced (tons/year) from Bike Lane Example

Year	PM-2.5	PM-10	CO	NOx	VOCs	SOx	NH_3
2006	<0.01	<0.01	0.75	0.70	0.07	<0.01	<0.01
2010	<0.01	<0.01	0.59	0.05	0.05	<0.01	<0.01
2020	<0.01	<0.01	0.41	0.03	0.03	<0.01	<0.01

SAMPLE 2: WALKWAY TO TRANSIT

This is an example of a pedestrian connection to transit that results in VMT reductions substantially longer that the actual pedestrian walkway. This project is based on the Cleveland Walkway to Gateway, which provides a link for transit riders arriving at Tower City Center, the main shopping and entertainment area of downtown Cleveland, to the Gateway Sports and Entertainment Complex. The climate-controlled walkway, which is about a quarter mile long, was designed in part to stimulate transit ridership in the metro area and relieve traffic congestion, especially during sporting events.[20] Information on the project is as follows:

- .25 mile climate-controlled walkway
- 940,000 estimated users taking transit over 16-month study period (487 days)
- 70 percent of users would not have taken transit without the walkway
- 8 mile trip length average to the Gateway complex
- 50 percent of transit riders who use the walkway drive to a public transit station on the other trip end

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[20] Adapted from an example documented in "Benefits Estimates for Selected TCM Programs," by ICF International for the U.S.EPA, 1999.

- 1.5 average auto occupancy

Step 1: Estimate the daily increase in transit trips.

> = (Number of transit riders who used the walkway for 16 months) / (number of days studied) x (percent of walkway users who would not have taken transit in absence of walkway)
> = (940,000) / (487 days) x (0.70)
> = 1,351 daily new transit trips

Step 2: Estimate the reduction in vehicle trip starts.

> = [1-Fraction of people who drive to public transit stations) / (avg. vehicle occupancy)] x (increase in transit riders)
> = [(1-0.5)/1.5] x (1,351 trips)
> = 446 vehicle trip starts reduction

Step 3: Estimate VMT reduction.

> = (Increase in transit riders/average vehicle occupancy) x (average trip distance)
> = (1,351)/(1.5) x (8)
> = 7,205 reduction in VMT

Step 4: Estimate emissions reductions.

> = (Auto trip start reduction) x (auto trip start emissions factor)] + [(VMT reduction) x (auto running emissions factor)]

The table below shows the annual emissions impacts resulting from the implementation of the example strategy.

Table 3-13. Total Emissions Reduced (tons/year) from Walkway Example

Year	PM-2.5	PM-10	CO	NOx	VOCs	SOx	NH_3
2006	0.05	0.10	26.1	2.79	2.46	0.03	0.39
2010	0.04	0.10	20.2	1.96	1.70	0.03	0.39
2020	0.04	0.10	14.0	0.96	0.91	0.03	0.39

6. New / Expanded / Increased Transit Service

Strategy Overview

New bus or rail services include any additions to the provision of services through the establishment of new routes, increased frequency, hours of operation or coverage of routes. Emissions reductions occur when the expanded service encourages people to replace driving trips with transit.

Improved transit service involves increasing the frequency or hours of service on existing transit routes. This strategy increases transit ridership and decreases auto trips in several ways. First, increased frequency of service generally results in increased ridership because transit becomes a more convenient transportation option. Waiting time for transit is reduced, leading to a faster trip (start to end). Second, increasing hours of service allows people to use the route at hours that were not previously available.

Emissions Impacts

New transit routes and increased transit service frequency or hours of operation should reduce emissions of all pollutants by reducing VMT. However, emissions benefits will not be proportional for all pollutants, since the buses also emit pollution, and diesel buses produce higher levels of NOx and PM per mile compared to autos. Moreover, if the new services do not substantially increase transit ridership, there may be no net emissions reductions. General impacts of transit service enhancements are shown below in the table below.

Table 3-14. Transit Service Enhancements- Overall Impact on Emissions

PM-2.5	PM-10	CO	NOx	VOCs	SOx	NH_3
↓*	↓*	↓	↓*	↓	↓*	↓

* = Generally reduces emissions, but has the potential to increase emissions

General Considerations

The level of emissions impact depends on:

- The number of additional buses in operation and their type
- The extent to which the new service causes an increase in transit ridership
- The extent to which new transit riders previously drove alone
- The extent to which new transit users drive to the transit station
- Length of vehicle trips reduced

These factors depend on supporting land use patterns, the availability of supporting facilities (e.g., transit station parking, bicycle racks), transit fares and parking prices, supporting services, and other factors. Transit service expansions are typically analyzed using sketch planning methods, based on transit ridership projections. EPA's COMMUTER Model can also be used to analyze the impacts of strategies, such as increased frequency of transit services. Some transit service expansions are combined with other complementary programs, such as transit marketing and incentives, or park-and-ride facilities, so the impacts of these programs should be considered together in order to avoid double-counting.

For EPA guidance on transit service expansion strategies, see "Methodologies for Estimating Emissions and Travel Activity Effects of TCMs," http://www.epa.gov/ttnnaaqs/ozone/eac/epa-420-r-94-002_07-94.pdf. For more information on this strategy, see the EPA TCM Information Document, "Improved Public Transit," http://www.epa.gov/otaq/stateresources/policy/transp/tcms/improved_transit.pdf.

Sample Projects

SAMPLE 1: NEW BUS ROUTE

This strategy is comprised of a new commuter shuttle route running during peak period on weekdays.[21] The program includes the following assumptions:

- New service operates using a new diesel bus
- 18 riders average occupancy per bus
- 8 daily bus trips
- 75 percent of riders previously drove alone
- 25 percent of users use autos to access transit service
- 9.6 mile average auto round trip length
- 12 mile average bus round-trip
- 20 mph average speed
- 250 operating days

Step 1: Calculate increase in average ridership.

= (Estimated occupancy per bus) x (number of daily bus trips)
= (18 passengers) x (8 trips)
= 144 daily passenger-trips

Step 2: Calculate number of auto trip starts eliminated.

= (Average daily bus ridership) x (percent of riders who previously drove alone)
x (1- percent using auto to transit service)
= (144) x (0.75) x (1-.25)
= 81 daily auto trip starts eliminated

Step 3: Calculate auto VMT reduced.

= (Average daily ridership) x (1- portion of riders who did not previously drive) x {(average auto trip length) – [(trip length for auto access to and from transit) x (portion using auto access to transit service)]}
= (144 passengers) x (0.75) x [(9.6 mi) – (0-0)]
= 1,037 daily VMT reduced

Step 4: Calculate transit bus emissions.

= (Daily bus trips) x (bus round trip miles) x (bus running emissions factor)
= (8) x (12 miles) x (bus emission factor)

Step 5: Calculate total annual emissions reduced.

= [[(Auto VMT reduced) x (auto running emissions factors)] + [(auto trip starts reduced)
x (auto trip start emissions factor)] – (bus emissions)] x (operating days)

The following table shows the annual emissions impacts resulting from the implementation of the example strategy.

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[21] Documented in "A Guide for Estimating the Emissions Effects and Cost-Effectiveness of Projects Proposed for CMAQ Funding," by ICF International for the Birmingham Regional Planning Commission, 2002.

Table 3-15. Total Emissions Reduced (tons/year) from Transit Service Enhancement Example

Year	PM-2.5	PM-10	CO	NOx	VOCs	SOx	NH_3
2006	<0.01	<0.01	1.94	Increase 0. 05	0.18	<0.01	0.03
2010	<0.01	<0.01	1.60	0.13	0.12	<0.01	0.03
2020	<0.01	<0.01	1.11	0.05	0.07	<0.01	0.03

SAMPLE 2: EXPANDED BUS SERVICE

This strategy involves additional service on an existing bus route serving a bridge corridor in a major metropolitan area. The project includes the following assumptions:

- New service operates using 6 diesel buses
- 25 new riders average occupancy per new bus
- 8 daily bus trips
- 50 percent of riders previously drove alone
- no users use autos to access transit service
- 16 mile average bus round trip
- 8 mile average auto trip length
- 250 operating days

Step 1: Calculate increase in average ridership.

= (Estimated occupancy per bus) x (number of daily trips per bus) x (number of buses)
= (25 passengers) x (6 trips) x (6 buses)
= 900 daily passenger-trips

Step 2: Calculate number of auto trip starts eliminated.

= (Average daily bus ridership) x (percent of riders who previously drove alone)
x (1- percent using auto to transit service)
= (900) x (0.50) x (1-0)
= 450 daily auto trip starts eliminated

Step 3: Calculate auto VMT reduced.

= (Average daily ridership) x (1- portion of riders who did not previously drive) x {(average auto trip length) – [(trip length for auto access to and from transit) x (portion using auto access to transit service)]}
= (900 passengers) x (0.50) x [(8) – (0-0)]
= 3600 daily VMT reduced

Step 4: Calculate transit bus emissions.

= (Daily bus trips) x (bus round trip miles) x (bus running emissions factor)
= (8) x (16 miles) x (bus emission factor)

Step 5: Calculate total annual emissions reduced.

= [[(Auto VMT reduced) x (auto running emissions factors)] + [(auto trip starts reduced)
x (auto trip start emissions factor)] – (bus emissions)] x (operating days)

The following table shows the annual emissions impacts resulting from the implementation of the example strategy.

Table 3-16. Total Emissions Reduced (tons/year) from Transit Service Enhancement Example

Year	PM-2.5	PM-10	CO	NOx	VOCs	SOx	NH_3
2006	<0.01	<0.01	1.94	Increase 0.05	0.18	<0.01	0.03
2010	<0.01	<0.01	1.60	0.13	0.12	<0.01	0.03
2020	<0.01	<0.01	1.11	0.05	0.07	<0.01	0.03

7. Transit Marketing, Information, and Amenities

Strategy Overview

Increased marketing, provision of more widely accessible transit information, and additional customer service may increase the number of people using public transportation each day. As for passenger amenities, the provision of such things as transit shelters, benches, maps, and visually pleasing aesthetics, or improving the comfort of buses and trains may be a supporting strategy to increase ridership. In addition, service enhancements such as improved transfer facilities and timing of transit services to reduce wait times during transfer may also increase ridership.

Emissions Impacts

Transit information/marketing/amenities will reduce all pollutants by encouraging shifts from driving to using transit, and thereby reducing VMT; these strategies do not involve provision of new bus service, and so there are no new bus emissions. General impacts are shown below in the table below.

Table 3-17. Transit Marketing - Overall Impact on Emissions

PM-2.5	PM-10	CO	NOx	VOCs	SOx	NH_3
↓	↓	↓	↓	↓	↓	↓

General Considerations

The level of emissions impact depends on:

- The extent to which ridership increases as a result of the marketing and other enhancements;
- The extent to which new riders previously drove alone;

These types of programs may result in behavior changes that produce reductions in emissions. However, careful documentation must be provided to demonstrate that the behavior change and resulting emission reductions were a result of the outreach program. This may not be quite so critical if this strategy is bundled with another transportation demand management strategy and the results are not specifically dependent on one strategy or another.

Emissions impacts of transit marketing, information, and amenities are typically analyzed using sketch planning methods. EPA's COMMUTER Model can be used to analyze some types of service improvements, such as increased information about schedules and real-time traveler information, which can be analyzed as a reduction in waiting times. Note that transit service enhancements and marketing are often implemented in combination with service expansions or other complementary programs; if this is the case, the impacts of these programs should be considered together in order to avoid double-counting of emissions benefits and account for the increase emissions from any service expansion.

Sample Project

TRANSIT AMENITIES AND ENHANCEMENTS

This project assumes major improvements in transit system amenities, including additions of bus shelters, real-time bus information, and enhanced signage. It is based loosely on a sample transit route service improvement on Central Coast Area Transit (CCAT) Route 9 in California.[22] The project assumes the following inputs:

- 51,680 increase in annual ridership
- 20.2 mile average home-to-destination trip
- 47 percent of riders shifted from driving alone
- 27 percent of riders shifted from carpooling and vanpooling with an average occupancy of 2.5, combined
- Each reduced driver eliminates 2 vehicle trips per day
- 255 operating days per year

Step 1: Estimate increased transit ridership.

= [(Annual rides) / (service weekdays)] / 2
= (51,680/255)/2
= 101 new riders per day

Step 2: Calculate daily vehicle trips reduced.

= (New daily riders) x (percent prior drive alone) x (roundtrip)
= (101) x (0.47) x (2)
= 95 vehicle trips reduced from SOV switch

= [(New daily riders) x (percent prior carpool/vanpool) / (avg. occupancy of carpool/vanpool)] x (roundtrip)
= [(101) x (0.27) / (2.5)] x (2)
= 18.6 vehicle trips reduced from HOV switch

Total daily vehicle trips reduced = 95 + 18.6 = 114

Step 3: Calculate vehicle miles of travel reduced.

= (Daily vehicle trips reduced) x (Avg. trip distance)
= (114) x (20.2)
= 2,303 miles per day

Step 4: Estimate emissions reductions.

= [(Auto trip end emissions factor) x (trips reduced)] + [(auto running emissions factor) x (miles reduced)] x (operating days)

Table 3-18 shows the annual emissions impacts resulting from the implementation of the example strategy.

Table 3-18. Total Emissions Reduced (tons/year) from Transit Service Enhancement Example

Year	PM-2.5	PM-10	CO	NOx	VOCs	SOx	NH_3
2006	0.01	0.01	4.75	0.42	0.47	<0.01	0.07
2010	0.01	0.02	3.70	0.30	0.32	<0.01	0.07
2020	0.01	0.02	2.60	0.16	0.17	<0.01	0.07

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[22] Documented in "Cuesta Grade Transportation Demand Management Evaluation Draft Report," by Eric Schreffler and Transportation Management Services for the San Luis Obispo Council of Governments, 2003.

8. Transit Pricing

Strategy Overview

Transit pricing strategies are designed to reduce the costs associated with using transit, thereby creating incentives for people to shift from other traveling modes. Fare reductions can be implemented system-wide, in specific fare-free or reduced fare zones, or offered through employer-based benefits programs which are fully or partially paid by the employer.

Emissions Impacts

By encouraging drivers to switch to transit, transit price reductions should reduce emissions of all pollutants, as shown in Table 3-19.

Table 3-19. Transit Pricing Strategy—Overall Impact on Emissions

PM-2.5	PM-10	CO	NOx	VOCs	SOx	NH_3
↓	↓	↓	↓	↓	↓	↓

Since rider response to fare changes is relatively inelastic and transit makes up only a small share of total trips in most urban areas, transit pricing projects by themselves will generally have limited impacts on VMT and emissions on a regional basis. However, when fare changes are implemented in conjunction with other supporting strategies, and particularly when focused on congested areas with good transit service such as downtowns, universities, and major urban employment concentrations, the effect on traffic and emissions can be more notable.

General Considerations

The level of emissions impact depends on:

- The increase in transit ridership associated with the fare reduction, which in turn, depends on auto availability; parking costs; and the frequency, comfort, and perceived safety of transit services
- The extent to which new transit riders were previously driving, versus substituting for walking or bicycling trips or simply taking new trips

Transit pricing projects are often analyzed using sketch planning methods, such as by applying a transit fare pricing elasticity, which estimate the percent increase in transit ridership associated with a given percent reduction in transit fares. EPA's COMMUTER Model can also be used to analyze the effects of transit price changes on commuter routes, or employer-subsidized transit programs. For EPA guidance on transit pricing, see "Opportunities to Improve Air Quality through Transportation Pricing Programs," http://www.epa.gov/otaq/market/pricing.pdf,"Methodologies for Estimating Emissions and Travel Activity Effects of TCMs," http://www.epa.gov/ttnnaaqs/ozone/eac/epa-420-r-94-002_07-94.pdf and the EPA and DOT's document, "Technical Methods for Analyzing Pricing Measures to Reduce Transportation Emissions," http://www.epa.gov/otaq/stateresources/policy/transp/tcms/anpricng.pdf.

Sample Projects

SAMPLE 1: FARE FREE TRANSIT

This example is based on results from several fare-free transit programs, including a system-wide demonstration in Austin, Texas and a fare-free demonstration during off-peak periods in Denver.[23] The inputs for the calculation of emissions benefits on the project are as follows:

- 75 percent ridership increase
- 46 percent of new riders switch from driving
- None of the new riders drive to the transit service
- Average trip length of 6 miles
- 30 mph average speed
- 250 days of effectiveness per year
- No additional transit service (no new buses needed to meet this increase)

Step 1: Estimate the increase in transit ridership from the program.

= (Existing transit ridership) x (percent increase in ridership)
= (10,000) x (0.75)
= 7,500 new transit riders

Step 2: Calculate the daily reduction in vehicle trip starts.

= (Increase in daily transit ridership) x (portion who previously drove) x (1- portion using auto to access transit service)
= (7,500) x (0.46) x (1-0)
= 3,450 auto trips reduced per day

Step 3: Calculate auto VMT reduced.

= (Increase in daily transit ridership) x (portion who previously drove) x (average trip length)
= (7,500) x (0.46) x (6 mi)
= 20,700 vehicle miles reduced per day

Step 4: Calculate annual emissions reduced.

= [(Auto trip starts reduced) x (auto trip start emissions factor)] + [(auto VMT reduced) x (auto running emissions factor)] x (days per year)

The table below shows the annual emissions impacts resulting from the implementation of the example strategy.

Table 3-20. Total Emissions Reduced (tons/year) from Fare Free Transit Example

Year	PM-2.5	PM-10	CO	NOx	VOCs	SOx	NH_3
2006	0.07	0.15	41.9	4.29	3.91	0.05	0.57
2010	0.07	0.14	33.0	2.36	2.74	0.04	0.58
2020	0.06	0.14	23.1	1.48	1.48	0.04	0.58

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[23] Documented in “TCRP Report 95: Traveler Response to Transportation System Changes - Transit Pricing and Fares,” Chapter 12, by McCollom, Brian and Richard Pratt et al. for Transportation Research Board, Transit Cooperative Research Program, 2004.

SAMPLE 2: TRANSIT PASS PROGRAM

This example is based on a universal transit pass program called Eco Pass offered by the Santa Clara Valley Transit Authority, which offers significant fare discounts for participating employers.[24] The emissions benefits of the project are calculate based on the following inputs:

- 26,400 increase in participants (1997-2001)
- 61 percent of Eco Pass recipients are new transit riders
- 96 percent of the new transit riders reported previously driving to work
- 250 days of effectiveness per year
- No additional transit service (no new buses needed to meet this increase)

Step 1: Estimate the increase in transit riders from the program.

= (New pass program participants) x (share new to transit)
= (26,400) x (0.61)
= 16,104 new transit riders

Step 2: Calculate the daily reduction in vehicle trip starts.

= (Increase in daily transit ridership) x (portion who previously drove) x (1- portion using auto to access transit service) x (2 trips per day)
= (16,104) x (0.96) x (1-0.25) x (2)
= 23,190 daily auto trip starts reduced

Step 3: Calculate daily auto VMT reduced.

= (Increase in daily transit ridership) x (portion who previously drove) x (average trip length) x (2 trips per day)
= (16,104) x (0.96) x (6 mi) x (2)
= 185,518 daily vehicle miles reduced per day

Step 4: Calculate annual emissions reduced.

= [(Auto trip starts reduced) x (auto trip start emissions factor)] + [(auto VMT reduced) x (auto running emissions factor)]

The table below shows the annual emissions impacts resulting from the implementation of the example strategy.

Table 3-21. Total Emissions Reduced (tons/year) from Transit Pass Program Example

Year	PM-2.5	PM-10	CO	NOx	VOCs	SOx	NH_3
2006	0.61	1.30	378	40.2	38.1	0.43	5.13
2010	0.59	1.27	163	28.5	26.5	0.39	5.15
2020	0.58	1.27	119	14.0	14.4	0.39	5.16

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[24] Documented in "TCRP Report 107: Analyzing the Effectiveness of Commuter Benefits Programs," by ICF International and Center for Urban Transportation Research for Transportation Research Board, Transit Cooperative Research Program, 2005.

9. Parking Pricing / Management

Strategy Overview

These strategies change the cost and/or convenience associated with driving a private vehicle, through pricing and management of parking on either end of the trip. While some policies increase the cost of parking through taxes or implementation of parking fees, some strategies reduce the supply of spaces through the creation of parking maximums for new development, regional parking caps, peak-hour parking bans, or curb-parking restrictions. Parking supply limits not only can increase the direct price of parking, but can also reduce the likelihood of finding parking at destinations, and may require walking one or more blocks for parking. Some parking management programs are designed to create an incentive for ridesharing, such as preferential spaces for carpools/vanpools or reduced parking prices for carpools/vanpools. All of these strategies reduce emissions by reducing the number of vehicle trips taken.

Emissions Impacts

Parking pricing and management strategies should reduce emissions of all pollutants by reducing vehicle trips and VMT. General impacts of parking pricing/management enhancements are shown below.

Table 3-22. Parking Pricing/Management - Overall Impact on Emissions

PM-2.5	PM-10	CO	NOx	VOCs	SOx	NH_3
↓	↓	↓	↓	↓	↓	↓

General Considerations

The level of emissions impact depends on:

- The extent to which parking pricing or restrictions are applied
- The elasticity of VMT in response to the price of parking
- The availability of free or less-expensive parking on nearby streets, which could diminish the program's effectiveness; parking permit programs, use of short-term parking meters, and other strategies can be implemented to reduce the potential for this spillover

Parking pricing and supply limit strategies may be analyzed using sketch planning methods, or EPA's COMMUTER Model if the parking strategy focuses on work trips (including increased parking charges and preferential parking for carpools/vanpools). For EPA guidance on this strategy, see "Methodologies for Estimating Emissions and Travel Activity Effects of TCMs," http://www.epa.gov/ttnnaaqs/ozone/eac/epa-420-r-94-002_07-94.pdf. For more information, also see TCM Information Document, "Parking Management," http://www.epa.gov/otaq/stateresources/policy/transp/tcms/parkingmgmt.pdf, and "Opportunities to Improve Air Quality through Transportation Pricing Programs," http://www.epa.gov/otaq/market/pricing.pdf.

Sample Projects

SAMPLE 1: REGIONAL PARKING SUPPLY LIMITS

This example reflects a downtown parking policy that limits the supply of parking. It is based on a program that had been operating in Portland, Oregon that set maximum ratios for the number of parking spaces per square foot of office space, based on the type of development and proximity to transit (ratios ranged from 0.7 to 1.0 space per 1000 square feet, compared to typical ratios of 4 spaces per 1000 square feet).[25] Several different approaches can be used to analyze a program such as this, including examination of changes in parking prices, parking per employee, or parking per square foot. A simple sketch planning method is used for this calculation, based on the following factors:

- 92,000 employees working downtown
- 0.44 off-street parking spaces per employee available before the policy
- 0.38 off-street parking spaces per employee after the policy
- 5 mile average home-to-work commute
- 250 operating days

Step 1: Calculate reduction in parking supply due to the program.

> = [(parking spaces per employee without policy) – (parking spaces per employee with policy)] x (number of employees)
> = (0.44-0.38) x (92,000 employees)
> = 5,520 fewer parking spaces

Step 2: Calculate reduction in daily vehicle trips.

> = (fewer parking spaces) x (2 vehicle trips per day)
> = (5,520) x (2)
> = 11,040 vehicle trips reduced

Step 3: Calculate reduction in daily VMT.

> = (vehicle trip reduction) x (average commute trip length)
> = (11,040) x (5 miles)
> = 55,200 vehicle miles reduced

Step 4: Calculate annual emissions reduction.

> = [(vehicle trips reduced) x (trip start emission factor) + (VMT reduced) x (running emissions factor)] x commute days per year
> = [(11,040) x (trip start emission factor) + 55,200 x (running emissions factor)] x 250

The table below shows the annual emissions impacts resulting from the implementation of the example strategy.

Table 3-23. Total Emissions Reduced (tons/year) from Parking Pricing/Management Example

Year	PM-2.5	PM-10	CO	NOx	VOCs	SOx	NH_3
2006	0.18	0.39	117	12.2	11.7	0.13	1.53
2010	0.18	0.38	91.8	8.61	8.09	0.12	1.53
2020	0.17	0.38	64.8	4.29	4.24	0.12	1.53

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[25] Documented in "Reducing Greenhouse Gas Emissions through the Transportation Partners Program: Recent Trends and Case Studies," by Apogee Research, Inc., for U.S. Environmental Protection Agency, 1995.

SAMPLE 2: PARKING CASH OUT

In this example, an employer offers a parking cash out incentive (i.e., provides employees that do not park at work a financial incentive) to encourage ridesharing, transit, and walking and bicycling, instead of driving alone to work.[26] The EPA's COMMUTER Model can be used to analyze the impacts of the program as a reduction in the price of alternatives to parking. A simple sketch planning approach is shown below, based on inputs from the North Central Texas Council of Governments as follows:

- 100 decrease in daily vehicle trips due to implementation
- 14.11 mile average trip length
- 260 work days (days of operation)

Step 1: Calculate decrease in daily VMT.

= (Daily vehicle trips) x (average trip length)
= (100) x (14.11)
= 1411 daily VMT reduction

Step 2: Calculate annual running emissions reduction.

= (Daily VMT reduction) x (days of operation) x (running emissions factor)
= (1411) x (260) x (running emissions factor)

Step 3: Calculate annual trip starts reduction.

= (Daily vehicle trip reduction) x (days of operation) x (auto trip starts emission factor)
= (100) x (260) x (auto trip starts emission factor)

Step 4: Calculate annual total emissions reduction.

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

The table below shows the annual emissions impacts resulting from implementation of the example strategy.

Table 3-24. Total Emissions Reduced (tons/year) from Parking Pricing/Management Example

Year	PM-2.5	PM-10	CO	NOx	VOCs	SOx	NH_3
2006	<0.01	0.01	2.95	0.29	0.25	<0.01	0.04
2010	<0.01	0.01	2.27	0.21	0.17	<0.01	0.04
2020	<0.01	0.01	1.57	0.10	0.09	<0.01	0.04

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[26] Documented in "8-Hour Attainment: Control Strategies: On Road," by ENVIRON Corp. for North Central Texas Council of Governments, 2006.

10. Road Pricing

Strategy Overview

Road pricing strategies reduce emissions by changing the costs to consumers operating private vehicles. Examples include new or increased tolls on roads, high occupancy toll (HOT) lanes, or cordon pricing. As a price-based disincentive to vehicular travel, these policies would cause travelers to shift to other modes or share rides, with resulting emissions reductions. These strategies may also encourage shifts in travel by time of day if developed as a congestion pricing mechanism. Strategies may also impact travel speeds along congested corridors, with associated emissions impacts.

Emissions Impacts

To the extent that pricing encourages reduced vehicle travel by shifting trips to alternate modes, emissions reductions will result across all pollutants. However, if speeds along roadways are also impacted as a result or if a congestion pricing strategy is implemented, effects will not be proportionate for all pollutants. Congestion pricing is designed to increase tolls during peak hours and thereby shift traffic to off-peak periods. In general, congestion pricing will reduce all pollutants, since vehicles traveling under congested travel conditions generally emit more pollution than under non-congested conditions; still, depending on speed changes, there is the possibility of an increase. General impacts of road pricing are shown below.

Table 3-25. Road Pricing - Overall Impact on Emissions

PM-2.5	PM-10	CO	NOx	VOCs	SOx	NH_3
↓	↓	↓*	↓*	↓*	↓	↓

* Generally reduces emissions, but has the potential to increase emissions (in the case of congestion pricing where a new priced lane is added, and the pricing may shift drivers to alternate routes or shift travel to off-peak hours, in which case the increased speeds might be associated with increases in some emissions)

General Considerations

The level of emissions impact depends on:

- The level of the price increase
- The extent to which traffic is diverted to other roads, thereby increasing congestion in other locations
- The response to the increase in the price of driving, which will vary based on the existing traffic levels and the availability of alternatives
- The scope and timing of pricing, which may encourage shifts in travel by time of day, rather than a reduction in driving
- Whether drivers take shorter trips rather than eliminating them completely

Travel demand forecasting models can capture some of the impacts of road pricing strategies on mode shifts and diversion of traffic, and can be used as a basis for analyzing emissions impacts. A much simpler sketch planning analysis is shown in the sample calculation below. For EPA information on road pricing, see “Opportunities to Improve Air Quality through Transportation Pricing Programs,” http://www.epa.gov/otaq/market/pricing.pdf.

Sample Project

FIXED RATE TOLLS

In this example, a \$0.75 toll charge is implemented on regional freeways.[27] Calculations regarding emissions impact of the project include the following assumptions:

- \$0.75 toll
- 29,988,000 average daily VMT
- \$0.115 average out-of-pocket cost per mile
- 8.4 mile average vehicle trip
- Price elasticity of travel is -0.25[28]
- 365 operating days per year

Step 1: Calculate expected percentage vehicle mile reduction.

= (Percent increase in cost per vehicle mile) x (price elasticity of travel)
= {[(\$0.75)/(8.4 mi)] / (\$0.115)]} x (-.25)
= .194

Step 2: Calculate expected reduction in daily VMT.

= (Percent reduction) x (daily VMT)
= (.194) x (29,988,000)
= 5,817,672

Step 3: Calculate trip starts emission reductions.

= (Percent reduction) x [(daily VMT) / (average trip length)] x (365 days/year) x (trip starts emissions factor)
= (.194) x (3,570,000) x (trip starts emissions factor)

Step 4: Calculate annual running emissions reductions.

= (Daily VMT reduction) x (365 days/year) x (auto running emissions factor)
= (5,817,672) x (365) x (auto running emissions factor)

Step 5: Calculate total annual emissions reductions.

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

The table below shows the annual emissions impacts resulting from implementation of the example strategy.

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[27] Documented in "Workbook: Transportation and Land-Use Strategies for Reducing Mobile Source Emissions," by Charlier Associates for the Denver Regional Air Quality Council.

[28] The price elasticity for travel reflects the percent change in VMT associated with a given percent change in the price of travel per mile. For instance, a price elasticity of -0.25 reflects that a 10 percent increase in travel costs will result in a 2.5 percent reduction in VMT. Price elasticities can vary based on many factors, including the starting cost of travel and availability of travel alternatives. The price elasticity used here was provided in the cited sample project.

Table 3-26. Total Emissions Reduced (tons/year) from Road Pricing Example

Year	PM-2.5	PM-10	CO	NOx	VOCs	SOx	NH_3
2006	27.8	59.7	21,297	1,773	1,096	19.7	235
2010	27.8	58.7	16,332	1,254	783	19.7	236
2020	26.4	58.0	11,226	614	415	19.7	236

11. VMT-based Pricing

Strategy Overview

This measure would impose fees based on miles driven. The fees could be collected annually through the vehicle registration process, with mileage calculated through odometer readings. Alternatively, under a Pay-As-You-Drive (variable price) auto insurance program, insurance premiums would be charged with a per-mile component, and could be levied on a monthly or semi-annual basis. VMT based pricing is intended as a price-based disincentive to vehicular travel, causing travelers to shift to other modes, share rides, avoid trips, or shorten trip lengths with resulting reductions in mobile source emissions.

Emissions Impacts

To the extent that VMT pricing encourages reduced vehicle travel, emissions reductions will result across all pollutants. Unlike road pricing strategies, however, the impact on vehicle travel speed will be less, since the pricing is not focused on specific road facilities.

General impacts of VMT-based pricing are shown below.

Table 3-27. VMT-based Pricing - Overall Impact on Emissions

PM-2.5	PM-10	CO	NOx	VOCs	SOx	NH_3
↓	↓	↓	↓	↓	↓	↓

General Considerations

The level of emissions impact depends on:

- The level of the per mile charge
- The response to the increase in the price of driving, which may be affected by the availability of alternatives to driving and the process for collecting fees [29]

VMT-based pricing programs have typically been analyzed using sketch-planning methods, relying on travel price elasticities. For more information, see EPA's document, "Opportunities to Improve Air Quality through Transportation Pricing Programs," http://www.epa.gov/otaq/market/pricing.pdf.

Sample Project

PAY AS YOU DRIVE INSURANCE

The following is a hypothetical example of a Pay as You Drive insurance program in the Dallas-Fort Worth area. In this scenario, the following assumptions have been made:[30]

- 173,003,248 daily vehicle miles are traveled daily by light-duty vehicles in region
- 10 percent of drivers participate in program
- $.06 charge per mile
- 9.7 percent travel reduction results from $.06 charge (calculated based on travel price elasticity)
- 365 operating days per year

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[29] The timing and process of fee collection may affect travel response by making the driver more or less aware of the per mile charge (e.g., annual fees versus fees paid on a daily or monthly basis).

[30] Documented in "8-Hour Attainment: Control Strategies: On Road," by ENVIRON Corp. for North Central Texas Council of Governments, 2006.

Step 1: Calculate daily reduction in vehicle miles traveled.

= (Daily vehicle miles) x (percent participation) x (percent reduction)
= (173,003,248) x (.10) x (.097)
= 1,678,131 daily vehicle miles reduced

Step 2: Calculate annual emissions reduction.

= (Daily VMT reduction) x (auto running emissions factor) x (operating days)

The following table shows the annual emissions impacts resulting from implementation of the example strategy.

Table 3-28. Total Emissions Reduced (tons/year) from VMT-based Pricing Example

Year	PM-2.5	PM-10	CO	NOx	VOCs	SOx	NH_3
2006	8.04	17.2	4,694	493	439	5.70	67.8
2010	7.81	17.0	3.635	347	304	5.20	68.1
2020	7.61	16.7	2,530	170	163	5.19	68.1

12. Fuel Pricing

Strategy Overview

This emissions reduction strategy would increase the tax rates applied to retail sales of motor fuels. Emissions reductions are achieved as drivers shift travel to other modes, share rides, reduce trips, or take shorter trips as a result of the higher costs of vehicle travel. As fuel pricing also creates an incentive for purchasing more fuel efficient vehicles, overall vehicle stock changes may further affect emissions over the long-term.

Emissions Impacts

To the extent that fuel pricing reduce VMT, fuel pricing strategies will reduce all pollutants; however, unless fuel price increases are large, impacts on VMT may be minor. General impacts of fuel pricing are shown below.

Table 3-29. Fuel Pricing—Overall Impact on Emissions

PM-2.5	PM-10	CO	NOx	VOCs	SOx	NH_3
↓	↓	↓	↓	↓	↓	↓

General Considerations

The level of emissions impact depends on:

- The level of the fuel tax increase
- Drivers' response to the increase in fuel prices, which will vary based on project specifics and local conditions, such as land use patterns and the availability of travel alternatives
- The extent to which fuel price increases affect vehicle purchase decisions
- Whether drivers take shorter trips rather than eliminating them completely

It should be noted that gas taxes are often viewed as politically unacceptable, particularly large tax increases that would be necessary to affect travel demand significantly. The emissions impacts of fuel pricing can be analyzed using sketch-planning methods, relying on travel price elasticities. For more information, see EPA's document, "Opportunities to Improve Air Quality through Transportation Pricing Programs," http://www.epa.gov/otaq/market/pricing.pdf.

Sample Project

$0.25 PER GALLON FUEL TAX INCREASE

This regional fuel tax increase strategy includes the following assumptions:[31]

- $0.25 proposed increase in price per gallon
- $210 annual cost to drivers averaging 15,000 miles
- 75 million estimated daily vehicle miles of travel for Denver region
- $0.115 average out-of-pocket vehicle cost per mile
- -0.2 price elasticity for travel[32]

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[31] Documented in "Workbook: Transportation and Land-Use Strategies for reducing Mobile Source Emissions," by Charlier Associates for the Denver Regional Air Quality Council, 1997.

- 8.4 mile average vehicle trip
- 17.8 mpg average fuel efficiency
- 365 operating days per year

Step 1: Calculate expected percent reduction in VMT

= (Percent increase in cost per vehicle mile) x (price elasticity of travel)
= [($.25/17.8)] / ($0.115) x (-.2)
= - 0.024

Step 2: Calculate expected reduction in daily VMT

= (Percent reduction) x (daily VMT)
= (.024) x (75,000,000 miles)
= 1,800,000 miles

Step 3: Calculate annual trip starts emission reductions

= (Percent reduction) x [(daily VMT) / (average vehicle trip)] x (trip starts emissions factors)
= (.024) x [(75,000,000) / (8.4)] x (365 days/year) x (auto trip starts emissions factors)
= 78,214,285 x (auto trip starts emissions factors)

Step 4: Calculate annual running emissions reductions

= (Daily VMT reduction) x (365 days/year) x (auto running emissions factor)
= (1,800,000) x (365) x (auto running emissions factor)
= (657,000,000) x (auto running emissions factor)

Step 5: Calculate total annual emissions reductions

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

The following table shows the annual emissions impacts resulting from the implementation of the example strategy.

Table 3-30. Total Emissions Reduced (tons/year) from Fuel Pricing Example

Year	PM-2.5	PM-10	CO	NOx	VOCs	SOx	NH_3
2006	8.63	18.5	5,308	541	492	6.11	72.7
2010	8.38	18.2	4,113	383	341	5.57	73.0
2020	8.16	18.0	2,873	188	184	5.57	73.1

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[32] The price elasticity for travel reflects the percent change in VMT associated with a given percent change in the price of travel per mile. For instance, a price elasticity of -0.2 reflects that a 10 percent increase in travel costs will result in a 2 percent reduction in VMT. Price elasticities can vary based on many factors, including the starting cost of travel and availability of travel alternatives. The price elasticity used here was provided in the cited sample project.

13. Employer-Based TDM Programs

Strategy Overview

Employer-based TDM programs are designed to encourage employers to offer a range of worksite programs to reduce the number of vehicles using the road system during peak travel hours while providing a wide variety of mobility options. These programs include development of transportation management associations/organizations (TMAs/TMOs), development of employer outreach programs, and regional incentives and marketing programs. Employer-based TDM programs typically focus on encouraging commuters to reduce their level of driving through worksite programs to support carpool/vanpools (e.g., on-site rideshare matching, preferential parking for carpools), programs to support transit use (e.g., transit benefits programs, transit information), compressed/ staggered work weeks, flexible work hours, and telecommuting, among others.

Emissions Impacts

Emissions reductions resulting from implementation of these strategies will vary depending on project specifics. Those focused on reducing VMT will reduce all pollutants, while others will cause shifts in travel time (e.g., flextime) which will also affect emissions since vehicles are traveling at higher speed during less congested travel conditions. General impacts of employer-based TDM programs are shown below.

Table 3-31. Employer-Based TDM Programs - Overall Impact on Emissions

PM-2.5	PM-10	CO	NOx	VOCs	SOx	NH_3
↓	↓	↓*	↓*	↓*	↓	↓

* = Generally will reduce emissions; however, in some cases (i.e., flex-time) may result in some increase in emissions, depending on speeds during peak and off-peak travel hours

General Considerations

The level of emissions impact depends on:

- The extent to which employers participate in offering TDM programs (e.g., voluntary or mandatory; level of marketing outreach)
- The types of programs implemented by employers
- Land use patterns and availability of travel options, which will affect the ease and convenience of using alternatives to driving alone
- The extent to which the program encourages shifts from peak to off-peak periods

The emissions impacts of employer-based TDM programs can be analyzed using EPA's COMMUTER Model. For post-project analyses, sketch planning methods are often used. Note that some types of programs may have indirect effects that should be considered. For instance, telework and compressed work schedules reduce work vehicle trips, but individuals may add other trips on those days. Flexible work-hour schedules can also sometimes make carpooling more difficult..

For EPA guidance, see *Guidance for Quantifying and Using Emission Reductions from Best Workplaces for Commuter Programs in State Implementation Plans and Transportation Conformity Determinations* (EPA-420-B-05-016), October, 2005, http://www.epa.gov/otaq/stateresources/policy/transp/commuter/420b05016.pdf. For more information, see: TCM Information Documents, "Employer-Based Transportation Management Programs," http://www.epa.gov/otaq/stateresources/policy/transp/tcms/

emplyer_transmgt_prog.pdf and COMMUTER Model guidance available at http://www.epa.gov/OMS/stateresources/policy/transp/commuter/420b05017.pdf.

Sample Projects

SAMPLE 1: ENHANCEMENT OF EMPLOYER OUTREACH PROGRAM

This example of a regional employer outreach program is based on an evaluation of the CommuteSmart Program in Birmingham, Alabama, which focuses on encouraging a switch from drive alone commute trips to ridesharing, transit, walking, biking, teleworking, or flexible work hours schedules to move peak trips to off-peak periods. Each of these strategies yields different emission reduction (for example, teleworking eliminates vehicle trips while ridesharing involves combining trips and flexible work hours programs do not reduce vehicle trips).[33] The COMMUTER Model was used to analyze potential impacts, relying on model default parameters and the specific inputs provided below in this sample calculation.

Step 1: Estimate the number of commuters that will have access to new commuter options as a result of the CommuteSmart program.

> In the Birmingham area, there are approximately 200,000 office employees and 100,000 non-office employees.

Step 2: Determine the typical strategies offered and participation rates.

> In the COMMUTER Model, employer-supported commute programs in a geographic area are represented by inputting the employer participation rates at various support levels. Programs specifically included in the model run to determine impacts on commute behavior included Employer Support Programs for carpooling, vanpooling, transit, and/or bicycling, and Alternative Wok Schedules, which accounts for emissions impacts resulting from employee flex time, telecommuting, staggered hours and/or compressed work weeks.
>
> The respective increase in rates of area-wide employer participation in new TDM support programs are as follows:

Program	No Participation	Level 1	Level 2
Carpool	-25 percent	+15 percent	+10 percent
Vanpool	-60 percent	+20 percent	+40 percent
Transit	-45 percent	-5 percent	+50 percent
Bicycle	0 percent	0 percent	0 percent

> The COMMUTER Model defines a Level 1 program as the provision of information activities plus a quarter-time transportation coordinator. A Level 2 program is defined as Level 1 plus in-house matching services (carpool and vanpool), work hours flexibility (transit), or bicycle parking and shower facilitates (bicycle).

Step 3: Estimate the typical effects of the employer-based programs on commute behavior.

> To quantify the effects of employer-based programs on commute behavior, the COMMUTER Model was run using the default inputs available from the model, or inputs based on assumptions as shown above in Step 2.

Step 4: Estimate total change in vehicle trips and VMT.

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[33] Documented in "A Guide for Estimating the Emissions Effects and Cost-Effectiveness of Projects Proposed for CMAQ Funding," by ICF International for the Birmingham Regional Planning Commission, 2002.

According to the COMMUTER Model, the employer-provided support programs would lead to a reduction of 8,944 vehicle trips and 2 percent reduction in VMT, or 124,249 vehicle miles. There is a 2.5 percent mode shift from peak to off-peak periods.

Step 4: Estimate annual emissions reductions (average commute speed of 35 mph).

= [(Vehicle trips reduced) x (per trip emission factor)] + [(VMT reduced) x (per mile running emission factor)]

The table below shows the annual emissions impacts resulting from the implementation of the example strategy.

Table 3-32. Total Emissions Reduced (tons/year) from Employer-Based TDM Program Example

Year	PM-2.5	PM-10	CO	NOx	VOCs	SOx	NH_3
2006	0.39	0.84	240	23.7	20.0	0.28	3.30
2010	0.38	0.82	185	16.7	14.0	0.25	3.31
2020	0.37	0.81	128	7.48	7.48	0.25	3.32

SAMPLE 2: TDM PUBLIC EDUCATION CAMPAIGN

The intent of the Pinellas County, Florida TDM Public Education Campaign was to provide transportation information via several programs within a public education campaign to promote a shift from the use of single occupant vehicles (SOV) to alternatives such as bicycle, public transportation, and ridesharing. By educating the public about these transportation options and their cost-effectiveness, a substantial number of vehicles could be eliminated from the roadway, thereby reducing VMT.[34] The inputs for emissions calculations regarding the program include:

- 377,312 estimated employment
- 1.8 home-based work trip rate
- 0.5 percent reduction in work travel VMT
- 8.68 average trip length
- 250 operating days

Step 1: Estimate daily work trips.

= (Total employment) x (trip rate)
= 377,312 x 1.8
= 679,162 daily work trips

Step 2: Calculate reduction in work VMT.

= (Daily work trips) x (average trip length) x (trip reduction percent)
= (679,162) x (8.68) x (0.005)
= 29,476 reduction of work VMT

Step 3: Calculate annual emissions reductions.

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[34] Documented in “Off-Model Air Quality Analysis: A Compendium of Practice,” by Federal Highway Administration, Southern Resource Center, 1999.

To be conservative, this equation assumes no reduction in vehicle trip starts, only vehicle trip lengths.
(VMT reduction) x (auto running emission factor) x (operating days)
(VMT reduction) x (auto running emission factor) x (250 days)

The following table shows the annual emissions impacts resulting from the implementation of the example strategy.

Table 3-33. Emissions Reduced (tons/year) from TDM Outreach Example

Year	PM-2.5	PM-10	CO	NOx	VOCs	SOx	NH_3
2006	6.00	8.79	519	253	49.2	1.59	15.1
2010	4.24	6.85	393	174	35.1	1.50	15.2
2020	2.45	4.91	275	66.4	19.0	1.53	15.2

14. Non-Employer-Based TDM

Strategy Overview

Programs to reduce non-commute trips are being implemented to address the growth in non-work trips. Examples of non-commute travel that is being addressed with demand management measures include special event travel (to sporting events and entertainment venues), tourism travel, and school-based travel. Non-employer based TDM programs reduce emissions similar to employer-based TDM programs by encouraging alternative mode use, including carpooling, walking, or bicycling and providing incentives to use transit options. In addition, TDM programs can also be developed to target the general population, such as air quality awareness campaigns, and corridor-based programs. Beyond vehicle travel reduction, additional emissions benefits may be achieved if reduced congestion levels (e.g., outside schools and stadiums or along corridors undergoing construction) result in fewer idling vehicles.

Emissions Impacts

Emissions reductions resulting from implementation of a non-employer based TDM strategy will vary depending on project specifics. In general, programs that target reducing VMT will reduce all pollutants. Other programs that shift travel times may have different effects on different pollutants due to changes in travel speeds. General impacts of non-employer-based TDM programs are shown below in the following table.

Table 3-34. Non-Employer-Based TDM Programs - Overall Impact on Emissions

PM-2.5	PM-10	CO	NOx	VOCs	SOx	NH_3
↓	↓	↓*	↓*	↓*	↓	↓

* = Generally will reduce emissions; however, in some cases may result in some increase in emissions if results in increased speeds

General Considerations

The level of emissions impact depends on:

- Types of programs implemented (e.g., school-based, universities) and scope (e.g., local, county-wide, regional)
- Number of vehicle trips and vehicle miles reduced due to program efforts

These TDM program efforts are typically analyzed using sketch planning methods. For more information on one application of this strategy, see the EPA TCM Information Document, “Special Events,” http://www.epa.gov/otaq/stateresources/policy/transp/tcms/events.pdf.

Sample Projects

SAMPLE 1: UNIVERSITY RIDESHARE PROGRAM

This example is based on the University Rideshare program in Atlanta, which includes a lump sum eligible to all colleges and universities within the 10 county region of the Atlanta Regional Commission. The intent is to provide startup funds for a student and staff-based rideshare program to encourage car and vanpooling.[35] The sample includes the following assumptions:

- Program available to 40,000 students/staff (35,000 students and 5,000 staff)

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[35] Documented in “Summary of Review of Costs and Emissions Information for 24 Congestion Mitigation and Air Quality Improvement Program Projects,” developed by Hagler Bailly for U.S. EPA, 1999.

- 40 percent of student trips are drive alone, 90 percent of staff trips are drive-alone
- 2 percent reduction in SOV trips though rideshare program
- Average trip length for students is 7 miles
- Average trip length for employees is 13 miles
- 160 operating days per year (reflecting weekday travel during Fall and Spring semesters)

Step 1: Estimate the number of auto trips eliminated per day.

= (Daily auto trips) x (mode-split diversion)

= (0.4 x 35,000) x (0.02)
= 280 auto trips by students reduced per day

= (0.9 x 5,000) x (0.02)
= 90 auto trips by staff reduced per day

= 280 + 90 = 370 auto trips reduced per day

Step 2: Estimate reduction in daily VMT.

Students = (Trips reduced per day) x (average trip length for students)
= (280) x (7)
= 1,960 daily student VMT reduced

Employees = (Trips reduced per day) x (average trip length for employees)
= (90) x (13)
= 1,170 daily employee VMT reduced

= 1,960 + 1,170 = 3,130 VMT reduced per day

Step 3: Calculate total annual emissions reduction.

= [(Auto trips eliminated) x (trip start emissions factor) + (VMT reduced) x (running emissions factor)] x (operating days)
= [(370 trip starts) x (trip start emissions factor) + (3,130 miles) x (running emissions factor)] x 160 days

The table below shows the annual emissions impacts resulting from the implementation of the example strategy.

Table 3-35. Total Emissions Reduced (tons/year) from University Rideshare Example

Year	PM-2.5	PM-10	CO	NOx	VOCs	SOx	NH_3
2006	0.01	0.01	4.11	0.40	0.34	<0.01	0.06
2010	0.01	0.01	3.17	0.28	0.24	<0.01	0.06
2020	0.01	0.01	2.19	0.14	0.13	<0.01	0.06

SAMPLE 2: SCHOOLPOOL PROGRAM

This example is based on a SchoolPool carpool ridematching program for children in all public and private schools in Contra Costa County, California (kindergarten through college). Staff distributes ridematch brochures in school registration packets at the beginning of each school year. The inputs used for this calculation are as follows:[36]

- 150,000 ridematch lists distributed/1451 ridematch requests processed
- 1204 participants (non-siblings in carpools)
- 5.5 average one-way miles
- 3 trip segments (Unlike regular carpools, parents generally drive back-and-forth to school both in the morning and afternoon, resulting in two round trips. Since some trip linking may have occurred dropping students off on the way to or from work, only 3 one-way trip segments were credited.)
- 180 days of operation per year

Step 1: Calculate daily auto trips reduced.

= (Number of participants) x (number of trip segments)
= (1204) x (3)
= 3,612 auto trips reduced per day

Step 2. Calculate daily VMT reduced.

= (Number of participants) x (number of trip segments) x (one-way trip length)
= (1204) x (3) (5.5)
= 19,866 daily VMT reduced

Step 3: Calculate annual reductions in emissions.

= ([(Daily VMT reduced x auto running emissions factor)] + [(daily auto trips reduced x auto trip start emissions factor)] x (operating days)

The following table shows the annual emissions impacts resulting from the implementation of the example strategy.

Table 3-36. Total Emissions Reduced (tons/year) from School Pool Program Example

Year	PM-2.5	PM-10	CO	NOx	VOCs	SOx	NH_3
2006	0.05	0.10	30.1	2.90	2.51	0.03	0.40
2010	0.05	0.10	23.2	1.75	1.75	0.03	0.40
2020	0.04	0.10	16.1	1.01	0.94	0.03	0.40

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[36] Documented in "SCHOOLPOOL-Carpool to School Program," prepared by Lynn Osborn for Central and Eastern Contra Costa, California, 2000.

15. Land Use Strategies

Strategy Overview

Integrating land use planning with transportation planning can reduce emissions by reducing the demand for vehicle travel and reducing trip distances. Examples of land-use strategies include transit-oriented development (TOD) and clustered activity centers. Integrating land use and transportation planning helps to make common destinations accessible by alternative modes of transportation, including transit, walking, and biking.

Emissions Impacts

Land-use policies that reduce VMT will typically reduce all pollutants; however, the emissions reductions will not be proportionate for all pollutants, since land use strategies may reduce vehicle trip making and reduce vehicle trip lengths (in the case of shorter trips, trip start emissions are still generated) or higher density development may increase localized traffic congestion (since it is often designed for lower travel speeds than more dispersed development), which will affect net emissions benefits. General impacts of land use strategies are shown below.

Table 3-37. Land Use Strategies - Overall Impact on Emissions

PM-2.5	PM-10	CO	NOx	VOCs	SOx	NH_3
↓	↓	↓*	↓*	↓*	↓	↓

* = Generally will reduce emissions; however, in some cases may result in some increase in emissions if results in increased speeds

General Considerations

The level of emissions impact depends on:

- The extent to which land use policies are implemented (e.g., the stringency of the land use controls)
- The extent to which the region is growing (e.g., new population and employment is expected) and there is market demand for new development
- The resulting changes in patterns of development, urban design, and coordination with transit service investment, which will affect changes in vehicle trips, trip lengths, and speeds

Regional land use strategies should typically be examined using a regional travel demand forecasting tool to assess the implications of different growth patterns and transportation investments on vehicle travel, congestion, and speeds. Note that many TDF models are not very sensitive to adequately account for the vehicle trip reductions associated with more mixed-use, high density developments, pedestrian factors, and short trips, and model enhancements or adjustment factors may be needed. For examining specific infill developments, comparisons can be made based on different assumptions about where the growth would otherwise occur, per EPA guidance. It is important to note that the air quality impacts of land use policy changes are long term, generally outside the time frame associated with attainment of NAAQS. Given the complexity of accurately modeling the impacts of land use strategies, the sample calculation below uses a very simplified approach to show potential emissions impacts, but would not be adequate for SIP or conformity purposes.

For EPA guidance on calculation of emissions, see “Improving Air Quality through Land Use Activities,” http://www.epa.gov/otaq/stateresources/policy/transp/landuse/r01001.pdf and related reference materials.

Sample Project

REGIONAL LAND USE ALTERNATIVES ANALYSIS

This sample is based on modeling conducted in Portland, Oregon, as part of the LUTRAQ (Land Use Transportation Air Quality Connection) project. LUTRAQ used the Western Bypass freeway around the Portland, Oregon metropolitan region as a case study to compare and evaluate the impacts of alternative land use patterns on automobile dependency, mobility, and air quality. The study found that alternative land use patterns significantly reduced automobile dependency, and as a result, would reduce auto emissions. Alternative land use patterns were defined by the transit-oriented development concept that focuses future development around transit stations in mixed use, pedestrian designed environments. For the LUTRAQ evaluation, regional transportation modeling procedures were developed to forecast travel behavior associated with alternative land use patterns.

Based on regional analysis using the regional travel demand forecasting model, and enhancements to account for pedestrian factors and other urban design characteristics, the LUTRAQ alternative was estimated to reduce daily VMT by 8 percent compared to a highway-only alternative by the end of the modeling period horizon, based on both the land use and market-based mechanisms in the LUTRAQ package. The land use elements are responsible for a large portion of this VMT reduction. Isolating the effects of the land use elements (by comparing the LUTRAQ alternative with the Highway/Parking Pricing alternative) suggests that changes in urban design are responsible for about three-fourths of the VMT reduction. The LUTRAQ alternative is expected to result in 6 percent less VMT than the Highways/Pricing alternative. The LUTRAQ alternative also is expected to generate significantly higher shares of walk/bike trips and transit trips compared to the alternatives. Motor vehicle emissions impacts all go down in the LUTRAQ scenario, but by different percentages, based on changes in vehicle trip-making, VMT, and speeds, as shown below.[37]

Table 3-38. Portland's LUTRAQ Study: Emissions (Percent Reduction from No Build Alternative)

Travel Indicator	Highways Only	Highways/Pricing	LUTRAQ
Daily VMT	6,995,986	6,856,447	6,442,348
Vehicle Trips per Household	7.50	7.29	7.17
HC/VOCs	-0.2 percent	-3.6 percent	-6.2 percent
NOx	6.7 percent	3.6 percent	-2.6 percent
CO	-0.6 percent	-4.0 percent	-6.7 percent

For a very simplified calculation of emissions impacts for all pollutants, the following procedures were used:

> For VOC, NOx, and CO: Emissions reduction = (Baseline VMT for highway/pricing scenario) x (emissions factor) x (percent reduction for pollutant calculated of this baseline) x 360 days per year
>
> For PM-10, PM-2.5, SO_2, and NH_3: Emissions reduction = (Baseline VMT – LUTRAQ scenario VMT) x (emissions factor) x 360 days per year

The following table shows estimated impacts for this example in 2020, assuming implementation of the land use policy over 20 years; however, the sample calculation reflects the VMT figures reported in the LUTRAQ study. It should be noted that land use strategies generally influence travel and emissions over

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[37] Documented in "Making Connections with LUTRAQ," prepared for 1000 Friends of Oregon, available at: http://www.friends.org/resources/lut_reports.html

relatively long periods of time, as new development occurs in a region and population grows. Consequently, emissions impacts for 2006 and 2010 are not reported here.

Table 3-39. Total Emissions Reduced (tons/year) from Land Use Strategies Example

Year	PM-2.5	PM-10	CO	NOx	VOCs	SOx	NH_3
2020	2.45	4.91	275	66.4	19.0	1.53	15.2

4. TRANSPORTATION SYSTEM MANAGEMENT STRATEGIES

Transportation system management (TSM) strategies focus on changing the operation of the transportation system, typically with a primary focus on improving traffic flow and reducing traveler delay. TSM programs can reduce emissions by changing vehicle speeds and reducing vehicle idling. Many of these strategies are under the umbrella of Intelligent Transportation Systems (ITS). In addition, some strategies focus directly on encouraging changes in driving behavior through educational information, incentives, or restrictions on driving speeds, operating patterns, and idling.

Examining the emissions impacts of these strategies typically involves estimating travel speeds without the improvement and with the improvement in order to develop emissions factors in each situation. These emissions factors are then applied to VMT traveling along the facility. In some cases, additional VMT may be induced due to the travel speed change, and the increase in VMT should be accounted for in “with improvement” scenario.

TSM strategies, and associated methodologies and results, are presented below.

16. Signal Synchronization and Roadway Intersection Improvements

Strategy Overview

Corridor-wide or regional traffic flow improvements are designed to increase average travel speeds, reduce vehicle delay and idling, and result in fewer vehicle accelerations and decelerations. Specific projects include traffic signal synchronization, regional congestion management systems, and intersection improvements. Many of these projects involve elements of Intelligent Transportation Systems (ITS).

Emissions Impacts

In general, traffic flow improvements that reduce congestion should reduce emissions of most pollutants by improving the flow of traffic and minimizing stop-and-go conditions and idling. However, traffic flow improvement projects that increase travel speeds may have different effects on different pollutants. Although VOC emissions generally decline with increasing speeds, CO and NOx emissions begin to increase at speeds above about 32-35 miles per hour. As a result, improvements that increase speeds beyond these levels may increase CO and NOx emissions. In MOBILE6.2, particulate matter from exhaust and break and tire wear, SOx, and NH_3 do not vary measurably by speed, given limited information on these emissions-speed relationships. Consequently, if a traffic flow strategy is examined solely as a speed change, no impact will be determined in MOBILE; however, if reduction in idling is accounted for, the strategy will typically show a reduction in all pollutants.

Table 4-1. Signal Timing - Overall Impact on Emissions

PM-2.5	PM-10	CO	NOx	VOCs	SOx	NH_3
↓/N	↓/N	↓/↑	↓/↑	↓*	↓/N	↓/N

↓* = Generally decreases, but possibility of an increase, based on starting speeds and level of speed change; N = No change; not quantified in EPA guidance

Some additional considerations with traffic flow improvement projects include the potential for diverted traffic and induced travel demand. Many corridor-based improvements result in some traffic that previously traveled on other routes switching to the improved roadway in order to reduce trip time. The increase in VMT on the corridor from diverted traffic should not be used in calculating increased emissions, since this is not new VMT in the system, but rather a movement of VMT from one route to another. Induced travel, on the other hand, represents new travel as a result of the roadway improvements. New vehicle trips might occur if people switch modes (from transit or walking or bicycling to driving), reduce average auto occupancy (switch from ridesharing to driving alone), or decide to take new trips. Longer trips may occur if people switch from closer destinations to more remote destinations, such as switching from a neighborhood shopping center to a regional mall. In general, the impact of induced travel is assumed to be relatively small for most signalization and intersection improvement projects. However, large-scale intersection improvements may discourage walking and bicycling if non-motorized travel is not effectively integrated.

It should also be noted that the impacts of most traffic signalization and intersection projects on speeds is limited to several years. Over the long-run, travel speeds may return to previous levels, although the roadway may be serving a larger volume of traffic.

General Considerations

The level of emissions impact depends on:

- Starting average speeds, and the increase in speeds associated with the project
- The extent to which new traffic is induced on the roadway network

For more information, see EPA TCM Information Document, "Traffic Flow Improvements," http://www.epa.gov/otaq/stateresources/policy/transp/tcms/traff_improv.pdf

Sample Projects

SAMPLE 1: SIGNAL COORDINATION PROJECT, CONGESTED ARTERIAL

This example is based on a project in California in which an old traffic signal controller was replaced with a new controller with expanded capacity.[38]

- 5 mile arterial
- 3,000 vehicle traffic volume
- 15 mph travel speeds before project
- 19 mph travel speeds after project
- 240 operating days per year
- No induced traffic is assumed

Step 1: Estimate total VMT affected by speed changes.

= (Days of use per year) x (segment length) x (congested traffic volume)
= (240 days) x (5 mi) x (3,000 vehicles)
= 3.6 million annual vehicle miles

Step 2: Calculated emissions reductions for affected traffic.

= (Project VMT) x [(emissions factor without project) – (emissions factor with project)]

Step 3: Calculate total emissions change as a result of the project.

= (Project VMT) x [(emissions factor without project) – (emissions factor with project)]

Table 4-2. Total Emissions Reduced (tons/year) from Signal Coordination on Congested Arterial Example

Year	PM-2.5	PM-10	CO	NOx	VOCs	SOx	NH_3
2006	0.00	0.00	4.61	0.59	0.87	0.00	0.00
2010	0.00	0.00	3.69	0.41	0.60	0.00	0.00
2020	0.00	0.00	2.98	0.17	0.37	0.00	0.00

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[38] Documented in "Methods to Find the Cost-Effectiveness of Funding Air Quality Projects," by the California Air Resources Board, 2005.

SAMPLE 2: SIGNAL COORDINATION PROJECT, LESS CONGESTED ROADWAY

This project is similar to Sample 1, but is along an arterial with much higher average speeds.[39] Project details include:

- 8.07 mile roadway
- 88,643 trips per day in congested areas
- 32 mph travel speeds before project
- 36 mph travel speeds after project
- No induced traffic is assumed

Step 1: Estimated total VMT affected by speed changes.

= (Days of use per year) x (segment length) x (congested traffic volume)
= (240) x (8.07 mi) x (88,643 vehicles)
= 178,837,253 annual vehicle miles affected

Step 2: Calculate total emissions change as a result of the project.

= (Project VMT) x [(emissions factor without project) – (emissions factor with project)]

In this case, the sample project results in a reduction in VOCs but an increase in CO and NOX due to increased travel speeds, which occur at the point where emissions rates begin to increase. Other pollutants show zero change since MOBILE6.2 emission factors are not sensitive to speeds.

Table 4-3. Total Emissions Reduced (tons/year) from Signal Coordination on Less Congested Roadway Example

Year	PM-2.5	PM-10	CO	NOx	VOCs	SOx	NH_3
2006	0.00	0.00	Increase 18.9	0.76	8.52	0.00	0.00
2010	0.00	0.00	Increase 14.0	0.57	5.86	0.00	0.00
2020	0.00	0.00	Increase 7.00	0.38	3.22	0.00	0.00

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[39] Based on strategy documented in “Methods to Find the Cost-Effectiveness of Funding Air Quality Projects,” by the California Air Resources Board, 2005.

17. Incident Management/Traveler Information

Strategy Overview

Incident management projects include service patrols that assist or remove the disabled vehicles from blocking travel lanes, computer systems that control traffic flow through intersections when incidents occur; and monitoring devices that scan roads and freeways for incidents and, in turn, either send assistance to injured or debilitated vehicles or help reroute traffic around incidents. If incidents are quickly cleared away, then vehicles do not have to idle in traffic as long. Incident management projects also minimize drivers' need to seek alternate routes to avoid congestion due to incidents. Alternate routes can frequently be longer than the original route, and so incident management can also result in some reduction in VMT. Combining incident management with enhanced traveler information can help to reduce the amount of time that vehicles experience delay.

Emissions Impacts

In general, incident management/traveler information programs that reduce congestion should reduce emissions of most pollutants by improving the flow of traffic and minimizing stop-and-go conditions and idling. However, incident management/traveler information projects that increase travel speeds may have different effects on different pollutants. Although VOC emissions generally decline with increasing speeds, CO and NOx emissions begin to increase at speeds above about 32-35 miles per hour. As a result, programs that increase speeds beyond these levels may increase CO and NOx emissions. In MOBILE6.2, particulate matter from exhaust and break and tire wear, SOx, and NH_3 do not vary measurably by speed, given limited information on these emissions-speed relationships. Consequently, if a incident management/traveler information project is examined solely as a speed change, no impact will be determined in MOBILE; however, if reduction in idling is accounted for, the strategy will typically show a reduction in all pollutants.

General impacts of incident management are shown in the table below.

Table 4-4. Incident Management - Overall Impact on Emissions

PM-2.5	PM-10	CO	NOx	VOCs	SOx	NH_3
↓/N	↓/N	↓/↑	↓/↑	↓*	↓/N	↓/N

↓* = Generally decreases, but possibility of an increase, based on starting speeds and level of speed change; N = No change; not quantified in EPA guidance

General Considerations

The level of emissions impact depends on:

- Prevalence of incidents will only reduce delay time for traffic affected by roadway incidents
- Induced travel demand resulting from reduced congestion
- The extent to which traffic is diverted to other roadways reducing the amount of delay, but also increasing VMT

Sample Project

INCIDENT MANAGEMENT

This strategy provides an example of the emissions impacts from an incident management strategy from Arizona's I-20 Mile Marker 130, from July 1, 1999 to June 30, 2000.[40] Calculations use calibrations based on Actual Incident Scenarios simulated with CORSIM. The incident duration prior to project assumes the same percentage reduction in delay achieved by this system and involves the following factors:

- 1,700 vehicles per lane per hour
- 3-lane freeway lanes, average, blocked during incidents
- 9 incidents per year estimated on this corridor
- No induced travel or travel diversion assumed

Step 1: Estimate the average incident duration without and with the project.

= (Based on after-project duration divided by CHART after/before ration for vehicle hours)
= (43 min/67.5 million vehicle hours after/before)
= (67.5-43.6)/67.5 = 0.35
= 43 min / (1-0.35)/(60 min/hr)
= 1.1 hr

Average incident duration with project
= (43 min/(60 min/hr)
= 0.71 hr

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

= Incident delay without project
= $e^{-10.19}$ x (traffic volume)$^{2.8}$ x (avg. number of blocked lanes during incidents/Total number of lanes in project corridor)$^{1.4}$ x Incident duration prior to project)$^{1.78}$
= $e^{-10.19}$ x (1700 vehicles/hr)$^{2.8}$ x (1.11 lanes/3 lanes)$^{1.4}$ x (1.1 hr)$^{1.78}$ = 12,300 veh-hrs

= Incident delay with project
= $e^{-10.19}$ x (traffic volume)$^{2.8}$ x (avg. number of blocked lanes during incidents/total number of lanes in project corridor)$^{1.4}$ x (incident duration with project)$^{1.78}$
= $e^{-10.19}$ x (1700 vehicles/hr)$^{2.8}$ x (1.11 lanes/3 lanes)$^{1.4}$ x (1.1 hr) $^{1.78}$ = 12,300 veh-hrs
= $e^{-10.19}$ x (1700 vehicles/hr)$^{2.8}$ x (1.11 lanes/3 lanes)$^{1.4}$ x (0.71 hr) $^{1.78}$ = 5,630 veh-hrs

Step 3: Calculate the change in delay per incident.

= (Incident delay without project) – (incident delay with project)
= (12,300) – (5,600) = 6,700 veh-hrs

Step 4: Calculate emission reductions per incident.

= (Change in delay) x (idle emissions factor)

Step 5: Calculate annual emission reductions.

= (Emissions reduced per incident) x (number of incidents per year)

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[40] Documented in "A Guide for Estimating the Emissions Effects and Cost-Effectiveness of Projects Proposed for CMAQ Funding," by ICF International for the Birmingham Regional Planning Commission, 2002.

The following table shows the annual emissions impacts resulting from the implementation of the example strategy.

Table 4-5. Total Emissions Reduced (tons/year) from Incident Management Example

Year	PM-2.5	PM-10	CO	NOx	VOCs	SOx	NH_3
2006	<0.01	<0.01	2.07	0.12	0.62	<0.01	<0.01
2010	<0.01	<0.01	1.62	0.08	0.41	<0.01	<0.01
2020	<0.01	<0.01	1.18	0.04	0.21	<0.01	<0.01

18. Speed Control

Strategy Overview

Speed reduction programs are usually implemented by local or state transportation or law enforcement agencies, primarily in order to improve safety. Speed controls can also reduce emissions and fuel consumption since emissions of certain pollutants are highest at travel speeds above 55 miles per hour.

Emissions Impacts

Programs that reduce travel speeds will not have proportionally the same effect on different pollutants since emissions-speed curves differ for each pollutant. In general, emissions tend to be lowest at speeds of 20-40 mph. In MOBILE6, particulate matter from exhaust and break and tire wear does not vary by speed.

General impacts of speed control are shown below.

Table 4-6. Speed Control - Overall Impact on Emissions

PM-2.5	PM-10	CO	NOx	VOCs	SOx	NH_3
N	N	↓/↑	↓/↑	↓/↑	N	N

N = No change; not quantified in EPA guidance

General Considerations

The level of emissions impact depends on:

- The extent to which the controls are enforced
- Application of speed controls in typically congested urban areas as opposed to less congested freeways
- The extent to which incidents are reduced along a corridor, which results in reduced traffic congestion and vehicle idling

Sample Project

INCREASED ADHERENCE TO THE 60 MPH SPEED LIMIT

This Transportation Control Measure would increase adherence to the speed limit on freeways, and lower average freeway speeds by 5 mph. This would be done through education of area motorists and increased enforcement. Data shows that over a 24-hour period, approximately 85 percent of autos using the freeway corridor being analyzed travel at speeds of 68 mph or less and 15 percent are over 68 mph. This is equivalent to an average speed of 62 mph. The measure would lower the 85th percentile to 63 mph, and the average speed to 57 mph. The freeway VMT for the 2.5 mile, 2-lane corridor being analyzed is 105,600 over a 24-hour period. There is no reduction in vehicle trips or vehicle miles of travel due to this measure.[41] The inputs for emissions impact calculations of the program include:

- Base speed factor is based on 62 mph
- Reduced speed factor is based on 57 mph
- Average VMT for 2-lane corridor over 24-hours is 105,600

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[41] Documented in the Metropolitan Planning Technical Report, “Transportation Control Measures Analyzed for the Washington Region’s 15 Percent Rate of Progress Plan,” 1995.

Step 1: Estimate the emission reduction.

= [(Base speed factor) x (freeway VMT)] – [(reduced speed factor) x (freeway VMT)]

The following table shows the annual emissions impacts resulting from the implementation of the example strategy.

Table 4-7. Total Emissions Reduced (tons/year) from Speed Control Example

Year	PM-2.5	PM-10	CO	NOx	VOCs	SOx	NH_3
2006	0.00	0.00	25.6	9.43	Increase 0.76	0.00	0.00
2010	0.00	0.00	19.5	6.33	Increase 0.47	0.00	0.00
2020	0.00	0.00	14.3	1.74	Increase 0.21	0.00	0.00

19. Shifting/Separating Freight Movements

Strategy Overview

Cities can regulate the movement of trucks within some areas of the region at certain times, changing the travel speeds for both trucks and other traffic and improving traffic flow. Historically, these programs have involved restricting trucks on local streets in certain areas of the central business district during peak hours, designating specific loading zones, delivery schedules, and truck routes, as well as multiple business delivery consolidation. Downtown areas or major business activity centers with alternate freeway and arterial routes available are often the best candidates for this type strategy. Some strategies are also voluntary, and are designed to create incentives for trucks to use roadways during off-peak time periods. Development of “truck only” lanes on highways is also a strategy to separate freight movement, and is often implemented primarily for traffic safety reasons.

Emissions Impacts

Measures to shift and/or separate freight movements generally should result in reduction in all pollutants, as shown in the following table. However, it is possible that increases in speeds by trucks could lead to increases in CO and NO_X. There is also a small potential for induced traffic by light-duty vehicles associated with shifting truck traffic off heavily traveled commuter roads.

Table 4-8. Freight Movement Strategy - Overall Impact on Emissions

PM-2.5	PM-10	CO	NOx	VOCs	SOx	NH_3
N	N	↓/↑	↓/↑	↓*	N	N

↓* = Generally decreases, but possibility of an increase, based on starting speeds and level of speed change; N = No change; not quantified in EPA guidance

General Considerations

The level of emissions impact depends on:

- The local cooperation and support of the trucking industry
- The amount of diverted traffic from other roads switching to the roadway where trucks are no longer allowed, and potential for induced travel (new trips) by light-duty vehicles
- Changes in speeds in peak period resulting from removal of trucks

Sample Project

SHIFTING TRUCK TRIPS TO OFF-PEAK PERIODS

This example is based on the PierPASS program in Southern California. To help residents along freeway corridors, PierPASS instituted the OffPeak program to push truck trips into the evening and weekend hours to reduce the impact of big rigs on both truck and automobile congestion and idling. Containers entering or exiting marine terminals in the Ports of Los Angeles and Long Beach by road during peak daytime hours are charged a Traffic Mitigation Fee of $40 per TEU (20-foot equivalent unit), or $80 for all containers larger than 20 feet. The Traffic Mitigation Fee is not charged if the same container enters or exits the terminals outside of peak hours. The inputs for emissions impact calculations of this sample include:

- 70 miles of freeway
- 2,000 freight vehicles shift travel to off-peak times
- 5,000 auto drivers assumed to be affected during rush periods

- 10 mph speed prior to program
- 35 mph speed after program

Step 1: Calculate freight VMT affected by program.

= (Daily freight trips) x (road segment length)
= (2,000) x (70 miles)
= 140,000 freight miles

Step 2: Calculate emissions reduction.

= (Freight VMT) x [(freight emissions factor without project) – (freight emissions factor with project)]
= {(140,000) x [(emissions factor without project) – (emissions factor with project)]}

Note: the calculation demonstrates a very simplified procedure. This analysis could also account for the reduction in truck idle time while waiting to enter the port and changes in travel speeds for automobiles along the affected roadways.

Table 4-9. Total Emissions Reduced (tons/year) from Freight Movement Example

Year	PM-2.5	PM-10	CO	NOx	VOCs	SOx	NH_3
2006	0.00	0.00	1.04	0.75	0.12	0.00	0.00
2010	0.00	0.00	0.63	0.22	0.09	0.00	0.00
2020	0.00	0.00	0.15	0.03	0.06	0.00	0.00

20. Vehicle Idling Restrictions/Programs

Strategy Overview

This emission reduction strategy attempts to reduce the amount of time that vehicles spend in idle mode as part of their overall operation. Examples of idling restrictions include controls on the construction and operation of drive-through facilities, such as banks, fast food restaurants, and pharmacies, and controls on extended idling during layover time, particularly of diesel engines used by transit vehicles and delivery trucks. Anti-idling restrictions on trucks and buses (as well as passenger cars) can be mandatory, voluntary, or incentive-based.

Emissions Impacts

Idling restrictions and programs can reduce emissions of all pollutants.

Table 4-10. Anti-Idling Strategy - Overall Impact on Emissions

PM-2.5	PM-10	CO	NOx	VOCs	SOx	NH_3
↓	↓	↓	↓	↓	↓	↓

General Considerations

Factors affecting level of emissions include:

- The time of the restrictions, which can vary from 30 minutes to 5 minutes
- The level of public support can be affected by public education campaigns
- Increases in starts and hot soak emissions

For information on this strategy, see EPA TCM Information Document, "Extended Vehicle Idling," http://www.epa.gov/otaq/stateresources/policy/transp/tcms/extended_idling.pdf.

Sample Project

CLOSING 3 MINUTE DRIVE-THRUS

Dallas County assessed the emission benefits of a light duty vehicle idling restriction policy. The proposed project would prohibit drive thru services during each day in which ozone levels exceed healthy levels. The policy would apply to fast food, restaurants, banks, pharmacies and dry cleaners.[42] Emissions calculations are based on the following factors:

- 180 seconds average waiting time
- 100,000 vehicles use lanes

Note that the increase in start exhaust emissions resulting from additional vehicles parking is included in the calculation.

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[42] Documented in "8-Hour Attainment: Control Strategies: On Road," by ENVIRON Corp. for North Central Texas Council of Governments, 2006.

Step 1: Calculate daily hours of idling reduced.

= (Number of vehicles using facilities) x (vehicles which park) x (average time spent idling)
= (100,000) x (1) x (.05)
= 5,000

Step 2: Calculate ozone season hours of idling reduced.

= (Daily hours of idling reduced) x (number of ozone days)
= (5,000) x (17)
= 85,000

Step 3: Calculate idling emissions reduction.

= (Ozone season hours of idling reduced) x (idling emission factor)
= (85,000) x (idling emissions factor)

Step 4: Calculate trip starts emissions increase.

= (Vehicles which park) x (trip starts emissions factor)
= (1) x (trip start emissions factor)

Step 5: Total emissions reduced.

= (Idling emissions reduction) - (trip starts emissions increase)

Table 4-11. Total Emissions Reduced (tons/year) from Anti-Idling Example

Year	PM-2.5	PM-10	CO	NOx	VOCs	SOx	NH_3
2006	<0.01	<0.01	0.77	0.03	0.04	<0.01	<0.01
2010	<0.01	<0.01	0.42	0.02	0.02	<0.01	<0.01
2020	<0.01	<0.01	0.36	0.01	0.01	<0.01	<0.01

5. VEHICLE, FUELS, AND TECHNOLOGY STRATEGIES

Vehicle, fuel, and technology projects and programs are designed to change the emission rates of vehicles either by changing the fuel being used, the type of vehicle or emissions control technology, or a combination of both. Some programs also focus on eliminating gross polluters, or vehicles whose emissions controls have failed, or on controlling specific types of emissions (e.g., road dust). The methodologies for these strategies generally involve estimating the number of vehicles affected, and then calculating the change in the emissions factors based on changes in vehicle stock or equipment. These strategies, and associated methodologies, are presented below.

21. Idle Reduction Facilities

Strategy Overview

Long haul truck drivers will often rest for extended periods in their sleeper compartment, during which time they idle the engine to operate air conditioning, heat, or on-board appliances, such as televisions. An idle reduction technology consists of the use of an alternative energy source in lieu of using the main truck engine for the purpose of reducing long duration truck idling. Some of these technologies are mobile and attach onto the truck (mobile auxiliary power units (APUs)), and provide air conditioning, heat, and electrical power to operate auxiliaries such as a microwave. Another technology involves electrifying truck parking spaces (stationary truck stop electrification (TSE)) with or without modifying the truck. In general, this involves power from the electrical grid providing energy to operate stationary equipment or on-board truck equipment to provide cab heating, cooling, and other needs. The EPA defines long duration idling as the operation of the truck's propulsion engine when not engaged in gear for a period greater than 15 consecutive minutes.

Emissions Impacts

Measures to reduce long duration truck idling should result in reductions in all pollutants, as shown below in Table 5-1. However, EPA's guidance documents only provide emissions factors for NO_X and PM. Given that heavy-duty trucks make up a disproportionately large share of the on-road vehicle emissions inventory for NOx and PM, this strategy will be most effective in reducing these pollutants.

Table 5-1. Idle Reduction Facilities - Overall Impact on Emissions

PM-2.5	PM-10	CO	NOx	VOCs	SOx	NH_3
↓	↓	(—)	↓	(—)	(—)	(—)

(—) = Decrease expected, but not quantified in EPA guidance

General Considerations

The level of emissions impact depends on:

- The number of truck parking spaces equipped with anti-idling technology
- The average number of hours of idling each day per truck
- The type of idle reduction technology that is used
- Emissions associated with electrical power generation

Additional considerations include the possibility that demand for the facilities will change. In some situations, the truck stop will experience an increase in the number of vehicles in response to the improved efficiency and comfort of the rest area, or utilization may decrease if too many trucks are not equipped to take advantage of the external power.

For EPA guidance, see "Guidance for Quantifying and Using Long Duration Truck Idling Emission Reductions in State Implementation Plans and Transportation Conformity," http://www.epa.gov/otaq/smartway/documents/420b04001.pdf.

Sample Project

TRUCK STOP ELECTRIFICATION

This project proposes to electrify a single truck stop.[43] The project includes the following inputs:

- 100 parking spaces
- 10 hour use of each space, daily in 2005
- 2 estimated daily idling hours per truck
- 8 hour average reduction in idling per day

The project was analyzed using the following sketch planning methodology, assuming that each electrified parking space is used in a similar manner.

Step 1: Estimate daily hours of truck idling reduced.

> Truck idling hours reduced
> = (Number of TSE truck stops) x (average number of truck parking spaces utilized) x [(average daily idling hours per truck) - (estimated daily idling hours per truck with project)]
> = (1) x (100) x [(10) – (2)]
> = 800 hours per day

Step 2: Calculate annual idling emissions reduced.

> Truck idling emissions reduced
> = (Daily hours of idling reduced) x (idling emission factor)
> = (800 hrs) x (idling emissions factor)

Note: If a mobile idle reduction technology is used, the additional emissions from the mobile idle technology must be considered, and net emissions reductions calculated.

Emissions impacts from this sample are shown below.

Table 5-2. Total Emissions Reduced (tons/year) from Truck Stop Electrification Example

Year	PM-2.5	PM-10	CO	NOx	VOCs	SOx	NH_3
2006	6.48	6.48	NA	238	NA	NA	NA
2010	3.81	3.81	NA	238	NA	NA	NA
2020	0.88	0.88	NA	238	NA	NA	NA

*Emission factors for PM-2.5, PM-10, and NOx were provided by EPA document, “Guidance for Quantifying and Using Long Duration Truck Idling Emission Reductions in State Implementation Plans and Transportation Conformity.”

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[43] Documented in “Guidance for Quantifying and Using Long Duration Truck Idling Emission Reductions in State Implementation Plans and transportation Conformity,” by U.S.EPA, 2004.

22. Accelerated Retirement / Replacement of Buses

Strategy Overview

Bus replacement projects accelerate the replacement of older buses with new vehicles which emit fewer pollutants and often use alternative fuels such CNG, LNG, electric, or hybrid electric. These new, less polluting vehicles run along existing routes, and therefore, do not change vehicle mileage or service levels.

Emissions Impacts

Accelerated retirement of older, more polluting buses will reduce emissions of various pollutants, notably NOx and PM. The specific pollutants that are reduced will depend on the fuel type and technology of the replacement vehicle; some replacements have no known effects on some pollutants. General emissions impacts from the strategy are shown below.

Table 5-3. Accelerated Retirement/New Purchase of Buses - Overall Impact on Emissions

PM-2.5	PM-10	CO	NOx	VOCs	SOx	NH_3
↓	↓	↓	↓	↓	↓	↓

Note: Impacts will vary based on type of replacement vehicle. Some vehicle types have no quantified benefits on some pollutants.

General Considerations

The level of emissions impact is greatly affected by the type of replacement bus. Bus emission factors will vary by the age of bus, the size of the bus, the mileage on the engine and the travel speed. The level of emissions impacts for different types of buses also differs based on when the program is implemented. For instance, a 2006 CNG bus emits less CO and NOx than a 2006 diesel bus; however, due to substantial improvements in diesel emissions factors, a 2010 diesel bus produces less CO and NOx than a CNG bus.

In addition, emissions impacts are affected by the following factors:

- The amount of bus travel, including both revenue and nonrevenue miles, which can contribute to approximately 10 percent of total bus miles and include driver training, road testing, and deadhead miles from the garage to the start of a route and from the end of a route back to the garage
- The extent to which use of new buses might increase transit ridership, and encourage a reduction in automobile travel, if the new buses offer a more comfortable and pleasant ride
- The remaining useful life of the replaced vehicle (i.e., the benefits of the replacement will only occur the years that the old vehicle would have remained in the fleet)

Emissions reductions that come from replacing an older vehicle with a newer, cleaner vehicle will not provide emissions reduction credit longer than the period of time that the older vehicle would have been kept in service without the replacement program.

For more information, see EPA's Diesel Retrofit SIP and Conformity guidance http://www.epa.gov/cleandiesel/publications.htm and EPA's National Clean Diesel Campaign http://www.epa.gov/cleandiesel.

Sample Project

URBAN CNG BUS PURCHASE

A transit agency proposes to purchase a new 2005 CNG bus instead of a new diesel bus.[44] The new CNG bus is not included in the transit agency fleet average used to determine compliance with the Air Resource Board transit bus fleet rule. Project specifics are as follows:

- 2005 CNG urban bus
- 50,000 miles a year in activity
- 1.8g/bhp-hr CNG engine
- 365 operating days per year

Step 1: Calculate baseline bus emissions

= [(Emissions standard) x (conversion factor 4.3 bhp-hr/mi)] x (annual mileage) x (conversion factor ton/907,200g)
= [NOx (2.00g/bhp-hr) x (4.3 bhp-hr/mi)] x (50,000 mi) x (ton/907,200g)
= 0.47 tons/yr NOx
= [PM-10 (0.01g/bhp-hr) x (4.3 bhp-hr/mi)] x (50,000 mi) x (ton/907,200g)
= .002 tons/yr PM-10

Step 2: Calculate new bus emissions.

= [(Emissions standard) x (conversion factor 4.3 bhp-hr/mi)] x (annual mileage)
x (conversion factor ton/907,200g)
= [NOx (0.96g/bhp-hr) x (4.3 bhp-hr/mi)] x (50,000 mi) x (ton/907,200g)
= 0.23 tons/yr NOx
= [PM-10 (0.01g/bhp-hr) x (4.3 bhp-hr/mi)] x (50,000 mi) x (ton/907,200g)
= .002 tons/yr PM-10

Step 3: Calculate the total annual emissions reduction.

= (Baseline emissions) – (new emissions)
= [NOx (.046) – (0.23)] = 0.24 tons/yr NOx
= [PM-10 (0.01) – (0.01)] = 0.0 tons/yr PM-10

Table 5-4. Total Emissions Reduced (tons/year) from Purchase of New Bus Example

Year	PM-2.5	PM-10	CO	NOx	VOCs	SOx	NH_3
2006	NA	<0.01	NA	0.24	NA	NA	NA

Emissions benefits are not calculated for 2010 and 2020, due to lack of availability for emissions factors from EPA guidance, as well as in consideration of the anticipated useful life of vehicle replaced.

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[44] Documented in "The Carl Moyer Memorial Air Quality Standards Attainment Program Guidelines," for the California Air Resources Board, 2003.

23. Accelerated Retirement/Replacement of Heavy-Duty Trucks

Strategy Overview

Replacement projects for heavy-duty vehicles accelerate the retirement of older engines that are less efficient and emit more pollutants. New vehicles which emit fewer emissions may be conventional diesel vehicles, or use alternative fuels for power such CNG, LNG, electric, or hybrid electric. Accelerated retirement programs can be of two types: Fleet wide projects refer to situations where there are general mandates or goals, but the number of individual vehicles or engines which will be replaced is not known in advance. Alternatively, fleet specific replacement projects target a well defined group of vehicles which can encompass multiple model years, vehicle types, or equipment types. This type of program is often implemented by a private company with a diverse vehicle fleet. While fleet wide projects will target a particular engine or heavy duty vehicle type with known emissions levels, a fleet specific strategy will have a precise number of vehicles or engines in each model year of each class that will be replaced or retired, and a more accurate emissions estimate can be developed.

Emissions Impacts

Accelerated retirement of older, more polluting heavy-duty vehicles will reduce emissions of various pollutants, notably NOx and PM. The specific pollutants that are reduced will depend on the fuel type and technology of the replacement vehicle; some replacements have no known effects on some pollutants. General emissions impacts from the strategy are shown below.

Table 5-5. Accelerated Retirement of Heavy-Duty Vehicles - Overall Impact on Emissions

PM-2.5	PM-10	CO	NOx	VOCs	SOx	NH_3
↓	↓	↓	↓	↓	↓	↓

Note: Impacts will vary based on type of replacement vehicle. Some vehicle types have no quantified benefits on some pollutants.

General Considerations

The level of emissions impact depends on:

- The number and type of vehicles that are being replaced
- The age of the existing vehicles being replaced
- The technology and fuel type used in the new vehicles
- The remaining useful life of the replaced vehicle (i.e., if the vehicle is near the end of its useful life, the benefits of the replacement will only occur the years that the old vehicle would have remained in the fleet)
- The annual mileage of the existing and new vehicles (in nonattainment area, only VMT accumulated within the area should be used)

For more information, see EPA's Diesel Retrofit SIP and Conformity guidance see http://www.epa.gov/cleandiesel/publications.htm and EPA's National Clean Diesel Campaign http://www.epa.gov/cleandiesel.

Sample Projects

SAMPLE 1: REPLACEMENT OF 1990 AND EARLIER MODEL LONG HAUL TRUCKS

This example assumes that 1990 and earlier model year long haul Class 8B trucks will be replaced with 2006 model year vehicles. Assumptions include:

- 20 trucks replaced
- Each truck travels an average of 100,000 miles per year

Step 1: Calculate mileage affected.

= (Number of trucks) x (average mileage per year)
= 20 trucks x (50,000 miles)
= 1,000,000 miles per year

Step 2: Calculate reduction in emissions.

= (Mileage affected) x [(1990 emissions factor) – (2006 emissions factor)]

Table 5-6. Total Emissions Reduced (tons/year) from New Heavy Duty Truck Purchase Example

Year	PM-2.5	PM-10	CO	NOx	VOCs	SOx	NH_3
2006	0.34	0.47	3.30	18.74	0.89	<0.01	<0.01

Emissions benefits are not calculated for 2010 and 2020, due to lack of availability for emissions factors from EPA guidance, as well as in consideration of the anticipated useful life of vehicle replaced.

SAMPLE 2: NEW PURCHASE OF A LNG HEAVY DUTY TRUCK IN PLACE OF A TRADITIONAL DIESEL ENGINE VEHICLE

This sample is based on a project in California, whose parameters include:[45]

- Traditional diesel engine baseline
- Assumed 3-year remaining useful life
- LNG engine replacement
- 100,000 miles a year in activity
- 5 vehicles

Step 1: Estimate the number of heavy-duty vehicles expected to participate, accounting for the design of the program, and other local factors.

Step 2: Calculate the daily VMT for the heavy-duty vehicles replaced through the program.

= (Number of vehicles replaced) x (average daily VMT)
= 5 x 100,000 miles

Step 3**:** Calculate the expected emissions reductions as a result of the strategy.

= [(Emission factor from old engines) – (emission factor from new engines)]
x (vehicle VMT affected)

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[45] Documented in "The Carl Moyer Memorial Air Quality Standards Attainment Program Guidelines," for the California Air Resources Board, 2003.

Table 5-7. Total Emissions Reduced (tons/year) from New Heavy Duty Truck Purchase Example

Year	PM-2.5	PM-10	CO	NOx	VOCs	SOx	NH_3
2006	0.02	0.04	0.69	NA	0.16	NA	NA

Emissions benefits are not calculated for 2010 and 2020, due to lack of availability for emissions factors from EPA guidance and in consideration of the anticipated useful life of vehicle replaced.

24. Diesel Engine Retrofits

Strategy Overview

A diesel engine retrofit project includes the addition of any technology, device, fuel or system that achieves emissions reductions beyond that currently required by EPA regulations at the time of its certification. Diesel engine retrofit technologies can be applied to both to on-road vehicles and non-road engines. Policies and programs available to state and local governments include mandatory fleet retrofits, government contracting requirements, and voluntary programs with funding options. There are a range of technologies which can be used to retrofit heavy duty diesel vehicles, including particulate filters, oxidation catalysts, flow through filter, crankcase filters, NOx reducing catalysts, and exhaust gas recirculation (EGR). As each technology will impact emissions levels differently, these differences should be reflected in the emissions reduction calculation and input data.

Emissions Impacts

Emissions reductions by pollutant will depend on the type of retrofit technology. Some are designed primarily to reduce NOx, while others are designed to reduce PM.

Table 5-8. Diesel Engine Retrofits - Overall Impact on Emissions

PM-2.5	PM-10	CO	NOx	VOCs	SOx	NH_3
(—)/N	↓/N	↓	↓/N	↓	N	N

Note: Impacts will vary based on type of retrofit technology applied.
(—) = Decrease expected, but not quantified in EPA guidance; N = No effect; not quantified in EPA guidance

General Considerations

Factors affecting emissions impacts include:

- Type, age, and emissions profile of existing vehicle/equipment
- Retrofit technology used[46]
- Assumed life of project, reflecting expected remaining useful life

EPA recommends using the National Mobile Inventory Model (NMIM) to estimate emissions reductions from retrofit projects for SIPs and conformity analyses. Fleet wide projects refer to situations where there are general mandates or goals, but the actual individual vehicles or engines which will be retrofit are not known in advance. Alternatively, fleet specific retrofit projects target a well defined group of vehicles which can encompass multiple model years, vehicle types, or equipment types. There are important differences between fleet specific and fleet wide projects that affect the kind of information that is needed to run NMIM. It is assumed that for fleet specific projects the precise number of vehicles or engines in each model year of each class that are to be retrofit will be known. In addition, it is assumed that the annual average mileage or hours accumulated by each model year of each class is also known.

For more information, see "Diesel Retrofits: Quantifying and Using Their Benefits in SIPs and Conformity - Guidance for State and Local Air and Transportation Agencies," http://www.epa.gov/otaq/stateresources/transconf/policy/420b06005.pdf.

It is important to only use verified emission reductions approved for the specific retrofit technology being considered. EPA and the California Air Resources Board (CARB) have retrofit technology verification programs that evaluate the performance of advanced emissions control technologies and engine rebuild

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[46] A complete list of all EPA verified technologies and their expected emissions reductions for various pollutants are available at http://www.epa.gov/otaq/retrofit/retroverifiedlist.htm.

kits. A list of EPA verified technologies is available at http://www.epa.gov/otaq/retrofit/retroverifiedlist.htm and CARB's verification program can be found at http://www.arb.ca.gov/diesel/verdev/home/home.htm.

Sample Projects

SAMPLE 1: DIESEL HEAVY DUTY TRUCK RETROFIT

This sample involves a trucking company retrofitting a heavy-duty diesel truck.[47] The following factors are drawn from the sample:

- Retrofit 2003 heavy heavy-duty diesel truck greater than 33,000 GVWR
- Averaging 100,000 miles of activity each year
- The truck currently has an unmodified engine running on regular 2D(<500 ppm sulfur) fuel
- The proposed retrofit is an EPA certified Donaldson diesel oxidation catalyst (DOC) Series 6100 that will operate on ultra low sulfur diesel fuel
- The retrofit is verified for PM and HC reductions

Step 1: Calculate retrofitted vehicle VMT.

= (Number to vehicles to be retrofit) x (average VMT per vehicle)
= (1) (100,000)
= 100,000

Step 2: Emissions reduced.

= [(Emission factor from old engines) x (percent emissions reduced)] x (retrofitted vehicle VMT)

Table 5-9. Total Emissions Reduced (tons/year) from Diesel Retrofit Example

Year	PM-2.5	PM-10	CO	NOx	VOCs	SOx	NH_3
2006	0.009	0.004	0.138	NA	0.033	NA	NA
2010	0.005	0.006	0.080	NA	0.026	NA	NA

Emissions benefits are not calculated for 2020, due to lack of availability for emissions factors from EPA guidance and in consideration of the anticipated useful life of vehicle replaced.

SAMPLE 2: PM-FOCUSED HEAVY DUTY TRUCK RETROFIT

The NMIM user guide scenario posits that a retrofit program is in place for calendar 2006 only and applies to 1990 model year trucks only.[48] The inputs are as follows:

- Vehicle types affected: HDDV8a, HDDV8b
- Fleet penetration of the program is 10 percent, i.e., 10 percent of the 1990 model HDDV8 trucks are retrofitted. The retrofit device is assumed to reduce exhaust PM-10 and PM-2.5 by 20 percent
- Region used for fleet data and VMT totals: Harris County, TX (Houston). Total VMT/yr is 1.417E9

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[47] Documented in "Diesel Retrofits: Quantifying and Using Their Benefits in SIPs and Conformity – Guidance for State and Local Air and Transportation, by U.S.EPA, 2006.

[48] Documented in the National Inventory Model Run User's Guide, http://www.epa.gov/CAIR/pdfs/MobileNMIM_Documentation.pdf .

Table 5-10. Emissions Reductions (tons/year) from Diesel Retrofit Example

Year	PM-2.5	PM-10	CO	NOx	VOCs	SOx	NH_3
2006	0.131	0.142	NA	NA	NA	NA	NA
2010	0.056	0.061	NA	NA	NA	NA	NA
2020	0.000	0.000	NA	NA	NA	NA	NA

Emissions benefits above vary from Sample 1 due to variances in the type of retrofit technology applied; Sample 2 utilizes technology aimed at reducing PM emissions.

25. Clean Diesel Fuels

Strategy Overview

Clean diesel fuels are a potential strategy to reduce emissions from both heavy-duty diesel vehicles and non-road diesel equipment. Clean diesel fuels include emulsified diesel, oxygenated diesel, biodiesel, or fuel borne catalysts. In addition, ultra-low sulfur diesel (ULSD) is increasingly available across the US and will continue to increase under the EPA's National Clean Diesel Campaign. Programs at the local level which increase the use of such fuels reduce emissions without changing driving behavior or the number of vehicles on the road or the use of diesel equipment.

Emissions Impacts

Emissions from diesel engines contribute to smog (ozone), particulate matter, and all air toxics. Cleaner fuels will tend to improve such emissions. However, the level of improvement will vary based on the type of fuel used. Some fuel types can also increase emissions of some pollutants, as shown below.[49]

Table 5-11. Clean Diesel – Overall Impact on Emissions

PM-2.5	PM-10	CO	NOx	VOCs	SOx	NH_3
(—)	↓/N	↓/↑	↓/↑	↓/↑	↓/N	N

Note: Impacts will vary based on type of clean diesel fuel applied.
(—) = Decrease expected, but not quantified in EPA guidance; N = No effect; not quantified in EPA guidance

General Considerations

Factors affecting emissions reduction from cleaner diesel fuels include:

- Type of diesel fuel, especially its sulfur content
- Pricing of new fuel

For a full life-cycle analysis, the emissions from fuel production and refining need to be added to tailpipe emissions from heavy-duty diesel trucks.

For EPA guidance, see "Guidance on Quantifying NOx Benefits for Cetane Improvement Programs for Use in SIPs and Transportation Conformity," http://www.epa.gov/otaq/guidance/420b04005.pdf.

Sample Projects

SAMPLE 1: CETANE ENHANCERS

The addition of cetane enhancers to diesel fuel is one recognized retrofit technology used to reduce diesel engine emissions. Cetane enhancers are compounds added to diesel fuel oil to raise the fuel's measured cetane level. A city implements a demonstration program to raise the cetane level of fuel for calendar year 2006.[50] Calculations are based on the following inputs:

- Increased cetane level from 45 to 50
- Reduce NOx levels 2%, according to EPA

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[49] Biodiesel generally increases NOx emissions by a small amount (up to 10%); PuriNOX water emulsion can increase VOC by 30 to 120% and CO by up to 35%, according to EPA, http://www.epa.gov/otaq/retrofit/retroverifiedlist.htm

[50] http://www.epa.gov/otaq/retrofit/techlist-cetane-enhancers.htm

- Constant representing the fraction of NOx inventory associated with cetane-sensitive trucks (k) = 0.70 (2006), 0.55 (2010), 0.36 (2020)
- Additized cetane (AC) = 50
- Reference cetane (RC) = 45
- 50 heavy heavy-duty diesel trucks will be targeted to use the new fuel
- 15,000 miles averaged annually by each truck

Step 1: Calculate annual miles traveled.

= (Number of trucks in program) x (Average annual VMT)
= (50) x (15,000 miles)
= 750,000 miles

Step 2: Determine the NOx emission benefits using the EPA guidance.[51]

$= k \times 100\% \times [1 - \exp(-0.015151 \times AC + 0.000169 \times AC^2 + 0.000223 \times AC \times RC)]$
= -1.5% (2006)
= -1.2% (2010)
= -0.8% (2020)

Step 3: Calculate emissions reduced.

= [(Emission factor from old engines) x (Percent emissions reduced)] x (VMT)

Table 5-12. Total Emissions Reduced (tons/year) from Clean Diesel Example

Year	PM-2.5	PM-10	CO	NOx	VOCs	SOx	NH_3
2006	NA	NA	NA	0.08	NA	NA	NA
2010	NA	NA	NA	0.04	NA	NA	NA
2020	NA	NA	NA	<0.01	NA	NA	NA

SAMPLE 2: BIODIESEL

The addition of biodiesel to a base diesel fuel is a recognized clean diesel used to reduce diesel engine emissions. In this sample, a city implements a demonstration program to use diesel (non-ULSD) which has been modified to include 10 percent soybean biodiesel.[52] The specifics on the project are as follows:

- 10 medium heavy-duty trucks
- Average activity of 15,000 miles each annually

Step 1: Replaced vehicle VMT.

= (Number of trucks in program) x (average annual VMT)
= (10) x (15,000 miles)
= 150,000

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[51] http://www.epa.gov/otaq/guidance/420b04005.pdf.

[52] http://www.epa.gov/otaq/retrofit/documents/biodiesel_calc.xls

Step 2: Determine the specific emission benefits using EPA calculator.

= PM-10: -4%
= CO: -5%
= NOx: +1%
= VOC: -11%

Step 3: Emissions reduced.

= [(Emission factor from old engines) x (percent emissions reduced)] x (VMT)

Table 5-13. Total Emissions Reduced (tons/year) from Clean Diesel Example

Year	PM-2.5	PM-10	CO	NOx	VOCs	SOx	NH_3
2006	<0.01	<0.01	0.02	Increase 0.01	0.01	NA	NA
2010	<0.01	<0.01	0.01	Increase 0.01	0.01	NA	NA
2020	<0.01	<0.01	<0.01	Increase <0.01	<0.01	NA	NA

Emissions benefits above vary from Sample 1 due to variances in the type of clean diesel technology applied.

26. Inspection & Maintenance Programs

Strategy Overview

A small percentage of vehicles, including older models and newer models with poorly maintained or malfunctioning emissions control equipment, emit a large share of motor vehicle pollution. Consequently, programs designed to detect these "gross polluters" and require them to update their vehicle pollution controls can be very effective in reducing emissions. Examples of these programs include inspection and maintenance programs, on-board diagnostics, remote sensing of roadside pullovers, smoking vehicle programs which provide a toll free number for reporting high polluting vehicles, or frequent vehicle inspections. These programs reduce emissions by identifying and requiring improvements to vehicles with failing emissions control equipment and encouraging vehicle owners to monitor their vehicle's condition.

Emissions Impacts

A small percentage of vehicles, including older models and newer models with poorly maintained or malfunctioning emissions control equipment, emit a large share of motor vehicle pollution. Inspection and maintenance strategies that target these gross emitters can be very effective in reducing pollutants. VOCs and PM are most often reduced as a result of implementation.

Table 5-14. I&M Strategy - Overall Impact on Emissions

PM-2.5	PM-10	CO	NOx	VOCs	SOx	NH_3
N	N	↓	↓	↓	N	N

N = No change; not quantified in EPA guidance

General Considerations

Vehicle inspection and maintenance programs can be made more effective when implemented in conjunction with other strategies designed to accelerate retirement or create advanced technology purchasing incentives. Together, these strategies not only monitor the emissions of individual vehicles, but encourage owners to change their purchase behavior to further reduce emissions.

For EPA guidance, see 40 CFR Part 51, "Amendments to Vehicle Inspection Maintenance Program Requirements to Address the 8-hour National Ambient Air Quality Standard for Ozone; Notice of Proposed Rulemaking," 2005. Additional guidance documents can be found www.epa.gov/otaq/im.htm.

Sample Project

VEHICLE EMISSIONS INSPECTION PROGRAM

A statewide Vehicle Emissions Inspection Program (VEIP) aims to ensure that certain cars and trucks are properly maintained in accordance with manufacturer recommendations. The following I/M parameters were used as inputs in the MOBILE6 Model in order to estimate the emissions benefits accrued from the VEIP:

- 52 million vehicle miles traveled daily
- Applies to light-duty vehicles model year 1977 and later
- Includes a gas cap leak check
- No grace period for new vehicles
- Includes on-board diagnostics test for 1996 and newer model year vehicles, treadmill test (IM240) for 1984 to 1995 model year vehicles; and idle test for model year 1977 to 1983 vehicles
- Applies only to light-duty vehicles (8,500 lbs. or less)

- Constant population (no growth in vehicle population or VMT assumed in each scenario)

Emissions reductions were derived by taking the difference in MOBILE6.2 generated emissions between VEIP light-duty fleet participation and non-participation. Results are as follows:

Table 5-15. Total Emissions Reduced (tons/year) from Gross Polluters Example

Year	PM-2.5	PM-10	CO	NOx	VOCs	SOx	NH_3
2006	0.00	0.00	45,483	1,778	2,908	0.00	0.00
2010	0.00	0.00	41,153	2,071	2,406	0.00	0.00
2020	0.00	0.00	35,378	2,532	1,883	0.00	0.00

6. NON-ROAD STRATEGIES

Non-road vehicles and equipment include railroads, marine vessels, airport ground support equipment, lawn and garden equipment, construction and agricultural equipment, and other mobile equipment. There are a wide range of technologies and operational strategies available to address these sources. The strategies presented below focus on policies and programs which can be implemented at the state and local level.

27. Locomotive Replacement or Repowering

Strategy Overview

Locomotives have long life, with some remaining in active use for more than 30 years. Typically, locomotives are overhauled about every eight years and repowered at least once. EPA has adopted emissions standards for locomotives that substantially reduce emissions compared to uncontrolled levels. The Tier 1 standards apply to original model years between 2002 through 2004; Tier 2 standards apply to original model years of 2005 and later. The standards result in a 45 percent reduction in NOx emissions for Tier I locomotives and a 59 percent reduction in NO_x for Tier II locomotives, compared to baseline values. Thus, replacing or repowering pre-2002 locomotives with newer models tends to reduce emissions. Newer locomotives are also more fuel efficient, and therefore use less fuel and produce fewer emissions for a given level of power output.

Emissions Impacts

The level of emissions reduction will depend on the type of replacement locomotive or engine, the use of the locomotive (line haul, switcher, etc.), and the type of fuel used. In addition, combining locomotive replacement and/or repowers with idling reduction technologies and/or ULSD fuel can achieve additional emissions reductions beyond what is documented here.

Locomotives are a significant source of NOx and PM emissions.[53] Although switcher and passenger locomotives generate less overall emissions than line-haul freight locomotives, their emissions are also of concern because they are often geographically concentrated in urban rail yards. Locomotive replacement/repowering can result in reductions in NO_X, PM, and VOCs, as shown below.

Table 6-1: Locomotive Replacement/Repowers - Expected Emissions Reductions

PM-2.5	PM-10	CO	NOx	VOCs	SOx	NH_3
(—)	↓	N	↓	↓	N	N

(—) = Decrease expected, but not quantified in EPA guidance; N = No effect; not quantified in EPA guidance

General Considerations

Key factors affecting emissions include:

- The age and remaining useful life of the existing locomotive
- The level of use of the existing locomotive
- The age and expected use of the replacement/repowered locomotive

For locomotive replacement, a key factor affecting the level of emission reduction achieved by this strategy is the relative usage of the old and new locomotive. Newer locomotives are significantly more efficient than older locomotives, so railroads use them more intensively. Older line-haul locomotives are sometimes shifted to switch yard operation, where they are used less. If a replacement locomotive is operated more hours than the older locomotive it replaces, or if the older replaced locomotive is not retired but rather shifted to other uses, the calculation of emissions impact must account for this difference.

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[53] According to EPA, most all diesel PM is submicron in size. Therefore, EPA believes it is reasonable to use the same idling emission factor for both PM2.5 and PM10.

For EPA guidance on emission factors, see “Emission Factors for Locomotives,” http://www.epa.gov/otaq/regs/nonroad/locomotv/frm/42097051.pdf

Sample Project

REPOWERING A 1987 LOCOMOTIVE

A Class I railroad operator in California proposes to repower a 1987 line haul locomotive, replacing the original engine with a new 2006 (Tier 2) engine. It is assumed in this example that the locomotive consumes 75,000 gallons of fuel annually within the nonattainment area, with both the old and new engine, in the same type of line-haul service.

Locomotive emissions are calculated based on fuel consumption. Emission factors are often reported in grams per brake horsepower-hour (bhp-hr); they can be converted to grams per gallon by assuming 20.8 bhp-hr/gallon.

Step 1: Calculate annual baseline emissions.

= (Baseline emission factor) x (baseline fuel consumption rate) x (grams to tons conversion)
Baseline NOx = (178 g/gal)(75,000 gal/yr)(1 ton/907,200 g) = 14.7 ton/yr NOx
Baseline VOC = (10 g/gal)(75,000 gal/yr)(1 ton/907,200 g) = 0.83 ton/yr VOC
Baseline PM-10 = (6.7 g/gal)(75,000 gal/yr)(1 ton/907,200 g) = 0.55 ton/yr PM-10

Step 2: Calculate annual repowered locomotive emissions.

= (Repowered emission factor) x (repowered fuel consumption rate) x (grams to tons conversion)
Baseline NOx = (103 g/gal)(75,000 gal/yr)(1 ton/907,200 g) = 8.5 ton/yr NOx
Baseline VOC = (5.4 g/gal)(75,000 gal/yr)(1 ton/907,200 g) = 0.45 ton/yr VOC
Baseline PM-10 = (3.6 g/gal)(75,000 gal/yr)(1 ton/907,200 g) = 0.30 ton/yr PM-10

Step 3: Calculate emissions reductions.

= (Baseline emissions) – (repowered emissions)
NOx = (14.7 tons/yr) – (8.5 tons/yr) = 6.2 tons/yr
VOC = (0.83 tons/yr) – (0.45 tons/yr) = 0.38 tons/yr
PM-10 = (0.55 tons/yr) – (0.30 tons/yr) = 0.26 tons/yr

The impacts of implementing this strategy in 2010 would be similar the 2006. Table 6-2 summarizes the emissions impacts.

Table 6-2: Total Emissions Reduced (tons/year) from Locomotive Replacement Example

Year	PM-2.5	PM-10	CO	NOx	VOCs	SOx	NH_3
2006	0.26	0.26	0	6.2	0.38	NA	NA
2010	0.26	0.26	0	6.2	0.38	NA	NA

It is currently not possible to accurately estimate the impacts of this strategy implemented in 2020. EPA has announced its intent to propose more stringent emission standards for new locomotive diesel engines. The new standards are expected to be modeled after the 2007/2010 highway and Tier 4 non-road diesel engine programs, with an emphasis on achieving large reductions in emissions of PM and air toxics through the use of advanced emission control technology. Thus, a new locomotive in 2020 will likely have much lower emission rates than current new locomotives. But it is not possible to estimate emission factors 2020 locomotives.

28. Rail Electrification

Strategy Overview

Converting railways to electrical power would require installation of an overhead power distribution system along the converted tracks, in addition to restructuring of signaling systems, communication systems, bridges, and other structures to be electrically compatible. Diesel locomotives would also need to be replaced with self-propelled Electric Multiple Unit (EMU) trains, or electric locomotives pulling unpowered railcars similar to the present trains.

Emissions Impacts

Rail electrification should yield reduced emissions of all pollutants emitted by diesel engines. Additional emissions benefits may be achieved if electrification results in increased train reliability, service frequency, and ridership gains. Electrification provides quick acceleration and deceleration, which allows for trains to run more frequently while fewer moving parts and less wear on the wheels decreases delays due to breakdowns and repairs.

Table 6-3. Rail Electrification Strategy - Overall Impact on Emissions

PM-2.5	PM-10	CO	NOx	VOCs	SOx	NH_3
(—)	↓	↓	↓	↓	(—)	(—)

(—) = Decrease expected, but not quantified in EPA guidance

General Considerations

Factors affecting the level of emissions impact include:

- The local power generation source for the new electricity
- The type of service provided by the rail and locomotive being electrified

For EPA guidance on emission factors, see "Emission Factors for Locomotives," http://www.epa.gov/otaq/regs/nonroad/locomotv/frm/42097051.pdf

Sample Project

ELECTRIFICATION OF LOCOMOTIVES

This sample is based on an electrification project of CalTrain for the Metropolitan Transportation Commission in San Francisco, California. The project would replace the existing diesel locomotive fleet on a one-for-one basis with electric locomotives which would continue to haul the existing fleet of gallery cars. Details of the project are as follows:

- Power for the electric vehicles will be drawn from an overhead contact system (OCS) through a roof-mounted pantograph.
- The design locomotive for evaluation of the impacts of electrification is the ADtranz ALP-46.
- CalTrain is a commuter rail system in the San Francisco area covering a 77 mile corridor.
- 96 one-way train trips (weekday) and 30 one-way train trips (weekend)
- 260 operating days per year (weekday service) and 105 operating days per year (weekend service)

Step 1. Calculate miles traveled per year.

= (One-way train trips per day) x (length of one-way trip) x (operating days)

= [(96) x (77 mi) x (260)] + [(30) x (77 mi) x (105)]
= 2,164,470 miles traveled per year

Step 2. Calculate annual baseline emissions and convert to tons per year. Results indicate energy consumption by diesel locomotives that would be offset by electricity.

= (Miles traveled per year) x (fleet average emission factors for all locomotives[54])

Step 3. Calculate emissions from electricity production and transmission, based on the California energy mix.

= (Miles traveled per year) x (electricity emission factors[55])

Step 4. Calculate annual emissions reduced.

= (Baseline emissions) – (electricity emissions)

Table 6-4. Total Emissions Reduced (tons/year) from Rail Electrification Example

Year	PM-2.5	PM-10	CO	NOx	VOCs	SOx	NH_3
2006	93.6	93.6	296	2,603	148	97.3	NA
2010	86.3	86.3	296	2,272	133	97.3	NA
2020	71.7	71.7	296	1,939	116	97.3	NA

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[54] Emission factors can be found in EPA's 'Technical Highlights: Emission Factors in Locomotives," http://www.epa.gov/OTAQ/regs/nonroad/locomotv/frm/42097051.pdf For SOx emission factors: http://www.energyconversions.com/locoemis.htm for SO_2 emissions

[55] Impacts for NOx, and SO_2 obtained from The Emissions & Generation Resource Integrated Database (E-GRID2002), Version 1.0 files, 2000 data sheets, released December 2002, http://www.epa.gov/airmarkets/egrid/, accessed 8/13/03. Impacts for CO and energy consumption obtained from Monterey County 21st Century General Plan Update Fact Sheet, http://www.co.monterey.ca.us/gpu/FactSheets/energy.htm, accessed 2/10/03 and from US DOE (1994) Evaluation of Electricity Consumption in the Manufacturing Division, http://www.eia.doe.gov/emeu/mecs/mecs94/ei/elec.html, accessed 2/10/03.

29. Locomotive Idling Reduction

Strategy Overview

Locomotive operators, similar to heavy-duty truck operators, idle their engines to maintain battery charge, warmth of the engine coolant, fuel, oil, and water, and comfortable temperatures inside the operator cabs. Locomotives also idle to ensure the engine is readily available (avoiding unnecessary starting and shutting-down), and because of timing delays. Encouraging or implementing switching yard operational improvements and vehicle anti-idling technologies reduce emissions by increasing the efficiency of the existing rail system.

An idle reduction technology consists of the use of an alternative energy source in lieu of using the main switch yard line (SYL) engine or a device designed to reduce long duration idling. Some of these technologies are mobile and attach onto the SYL (mobile auxiliary power units (APUs)), and provide heat or electrical power. Another technology involves electrifying SYL parking spaces (stationary locomotive parking electrification) and modifying the SYL. In general, this involves installing electric powered heating systems on SYL which connect to the electrical grid and provide energy to operate on-board equipment.

Emissions Impacts

Rail idling reduction will result in reduced emissions of all pollutants emitted by diesel engines, as shown below.

Table 6-5: Locomotive Idling Reduction - Overall Impact on Emissions

PM-2.5	PM-10	CO	NOx	VOCs	SOx	NH_3
↓	↓	(—)	↓	(—)	(—)	(—)

(—) = Decrease expected, but not quantified in EPA guidance

General Considerations

Factors affecting emissions reductions include:

- The number of locomotives equipped with anti-idling technologies
- The average number of hours idling each day
- Implementation in conjunction with locomotive replacement or repower projects may offset some benefits.
- Installation of APU does not guarantee idle reduction. Operators may require training and monitoring in order to ensure that use of the main engine is minimized

For EPA guidance, see “Guidance for Quantifying and Using Long Durations Switch Yard Locomotive Idling Emissions reductions in State Implementation Plans,” http://www.epa.gov/otaq/smartway/documents/420b04002.pdf. For more information, also see,

Sample Project

SWITCH YARD LOCOMOTIVE APUS

This project would install auxiliary power units (APUs) on all switch yard locomotives. An APU consists of a small diesel engine that allows the locomotive engine to be shut down while maintaining the vital systems of the locomotive, such as heating and circulating the coolant and oil, charging the batteries, and powering the cab heaters. The sample project includes the following inputs, based on those provided in EPA guidance[56] and a demonstration project.[57]

- 5 EMD switch yard locomotives
- Average 10 hours of long duration idling, daily
- APU engine is a 3-Cylinder, 27 hp EPA Tier 1 Certified Diesel Engine (Lister Petter LPWS 3)
- The APU operates at 10.2 brake horsepower
- 8 out of 10 hours of locomotive idling time to be eliminated

Step 1: Calculate the average annual emissions reduced.

= (Emissions factor for switch-yard locomotive) x (number of hours per day idle reduction technology is to be used) x (days in use per year) x (grams to tons conversion)
NOx = (777 g/hr) x (8 hrs/day) x (300 days/yr) x (1 ton/907,200 g) = 2.06 tons/yr
PM-10 = (20 g/hr) x (8 hrs/day) x (300 days/yr) x (1 ton/907,200 g) = 0.053 tons/yr

Step 2: Calculate the annual emissions from the APU.

= (Emissions factor for APU) x (average daily hp load for engine) x (daily operation hours) x (days in use per year) x (grams to tons conversion)
NOx = (12.6 g/bhp-hr) x (10.2 bhp) x (8 hr/day) x (300 days/yr) x (1 ton/907,200 g) = 0.340 tpy
PM-10 = (0.66 g/bhp-hr) x (10.2 bhp) x (8 hr/day) x (300 days/yr) x (1 ton/907,200 g) = 0.018 tpy

Step 3: Determine net NOx emissions reduction per locomotive.

= (Average annual locomotive emissions reduced) - (average annual emissions of APU)
NOx = (2.06 tons/yr) – (0.34 tons/yr) = 1.72 tons/yr
PM-10 = (0.053 tons/yr) – (0.018 tons/yr) = 0.035 tons/yr

Step 4: Determine sum of all emissions reductions for project.

= (Number of participating locomotives) x (net emission reduction)
NOx = (5) x (1.72 tons/yr) = 8.58 tons/yr
PM-10 = (5) x (0.035 tons/yr) = 0.18 tons/yr

The impacts of implementing this strategy in 2010 would be similar the 2006. The table below summarizes the emissions impacts.

Table 6-6: Total Emissions Reduced (tons/year) from Locomotive Idle Reduction Example

Year	PM-2.5	PM-10	CO	NOx	VOCs	SOx	NH_3
2006	0.18	0.18	NA	8.58	NA	NA	NA
2010	0.18	0.18	NA	8.58	NA	NA	NA

According to EPA, most all diesel PM is submicron in size. Therefore, EPA believes it is reasonable to use the same idling emission factor for both PM2.5 and PM10.[58] It is currently not possible to accurately estimate the impacts of

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[56] Guidance for Quantifying and Using Long Durations Switch Yard Locomotive Idling Emissions reductions in State Implementation Plans, available at: http://www.epa.gov/smartway/idle-guid.htm

[57] Vancouver, WA Switchyard Locomotive Idle Reduction Project: Final Report to EPA, Southwest Clean Air Agency, October 18, 2005, available at http://www.westcoastdiesel.org/files/other/EPA%20Locomotive%20Case%20Study.pdf

[58] See: EPA, Guidance for Quantifying and Using Long Durations Switch Yard Locomotive Idling Emissions reductions in State Implementation Plans.

this strategy implemented in 2020. EPA is expected to adopt more stringent emission standards for new locomotive diesel engines by that time, but details of those standards are not yet available.

30. Marine Vessel Replacement or Repowering

Strategy Overview

Marine vessel emissions can be reduced through accelerated retirement of existing vessels (replacement) or repowering, which involves replacing an older mechanical engine with a newer, electronic one. EPA recently established new emission standards for Category 1, 2, and 3 commercial marine engines, which take effect between 2004 and 2007. Use of these engines to replace older engines will reduce emissions of most pollutants. In addition, natural gas engines have recently entered the marine engine market with growing support, and can offer significant emissions benefits over diesel engines.

Emissions Impacts

Engine optimization modifications are evolving through land-based engines in response to the tightening of on-road and off-road regulatory requirements. Marine engines are expected to incorporate many of these improvements over time, including basic redesign of the combustion chambers, retarding the timing, improving high-pressure fuel injection systems, upgrading or adding aftercooling and turbocharging, injecting water into the air intake using humid air motors (HAM), and exhaust gas recirculation (EGR). The benefits of these technology improvements will be reflected through the certification of new engines with lower emission rates and adoption of the National Blue Skies Series Program standards. The level of emissions reduction will depend on the type of engine used in the replacement.

Table 6-7: Marine Replacement or Repower - Overall Impact on Emissions

PM-2.5	PM-10	CO	NOx	VOCs	SOx	NH_3
(—)	↓	N	↓	↓	N	N

N = No change; not quantified in EPA guidance; (—) = Decrease expected, but not quantified

General Considerations

The following factors may affect emissions impacts:

- Age and emissions characteristics of engine
- Annual hours of usage
- Any change in usage (type or hours) after the project
- Any change in engine horsepower
- Disposition of replaced vessel/engine (must be scrapped for full benefits)

Sample Project

FISHING VESSEL AUXILIARY ENGINE REPOWER

A charter fishing vessel owner wishes to repower a 125 horsepower 1985 auxiliary engine with a new 2005 model year 200 horsepower engine.[59] The auxiliary engine is operated 900 hours per year. The old engine operates at a load factor of 0.43; the new engine operates at a load factor of 0.27. The following steps illustrate the calculation of the emissions benefits of this project.

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[59] This example taken from *The Carl Moyer Program Guidelines*, Part IV, California Air Resources Board, 2005.

Step 1: Calculate annual baseline emissions.

= (Baseline emissions factor) x (baseline horsepower) x (baseline engine load factor) x (baseline annual hours of operation) x (grams to tons conversion factor)
Baseline NOx = (10.2 g/bhp-hr) x (125 hp) x (0.43) x (900 hr/yr) x (1 ton / 907,200 g) = 0.54 ton/yr
Baseline VOC = (1.06 g/bhp-hr) x (125 hp) x (0.43) x (900 hr/yr) x (1 ton / 907,200 g) = 0.057 ton/yr
Baseline PM10 = (0.396 g/bhp-hr) x (125 hp) x (0.43) x (900 hr/yr) x (1 ton / 907,200 g) = 0.021 ton/yr

Step 2: Calculate annual repowered vessel emissions.

= (Repower emissions factor) x (repower horsepower) x (repower engine load factor) x (repower annual hours of operation) x (grams to tons conversion factor)
Repower NOx = (4.17 g/bhp-hr) x (200 hp) x (0.27) x (900 hr/yr) x (1 ton / 907,200 g) = 0.22 ton/yr
Repower VOC = (0.39 g/bhp-hr) x (200 hp) x (0.27) x (900 hr/yr) x (1 ton / 907,200 g) = 0.021 ton/yr
Repower PM10 = (0.14 g/bhp-hr) x (200 hp) x (0.27) x (900 hr/yr) x (1 ton / 907,200 g) = 0.008 ton/yr

Step 3: Calculate emissions reductions

= (Baseline emissions) – (repowered emissions)
NOx = (0.54 tons/yr) – (0.22 tons/yr) = 0.32 tons/yr
VOC = (0.057 tons/yr) – (0.021 tons/yr) = 0.036 tons/yr
PM10 = (0.021 tons/yr) – (0.008 tons/yr) = 0.013 tons/yr

The impacts of implementing this strategy in 2010 would be similar the 2006. The following table summarizes the emissions impacts.

Table 6-8: Total Emissions Reduced (tons/year) from Fishing Vessel Repower Example

Year	PM-2.5	PM-10	CO	NOx	VOCs	SOx	NH_3
2006	NA	0.01	NA	0.32	0.04	NA	NA
2010	NA	0.01	NA	0.32	0.04	NA	NA

It is currently not possible to accurately estimate the impacts of this strategy implemented in 2020. EPA announced its intent to propose more stringent emission standards for all new Category 1 and 2 marine diesel engines. The new emission standards are expected to be modeled after the 2007/2010 highway and Tier 4 non-road diesel engine programs, with an emphasis on achieving large reductions in emissions of PM and air toxics through the use of advanced emission control technology. Thus, a new marine engine in 2020 will likely have much lower emission rates than current new engines, but it is not possible to estimate emission factors for 2020 marine engines.

31. Marine Vessel Operational Strategies

Strategy Overview

Several operational strategies are effective for reducing emissions from marine vessels. In general, four operating modes characterize ship calls on a port: hotelling at a berth, maneuvering around the berth area, maneuvering within the designated reduced speed zone (RSZ) between the berthing area and the breakwater, and cruising in open water. Vessel emissions from hotelling are due solely to the auxiliary engines used to provide power to the ship for climate control, pump operation, etc. while docked. Hotelling emissions can be reduced through "cold ironing", which uses shore power to replace operation of the vessel auxiliary engine. Reducing vessel speed is another strategy for reducing emissions. Ports can implement this strategy by expanding the reduced speed zone around a port.

Emissions Impacts

Marine vessel operational strategies have the potential to reduce emissions of all pollutants.

Table 6-9: Marine Operational Strategy - Overall Impact on Emissions

PM-2.5	PM-10	CO	NOx	VOCs	SOx	NH_3
(—)	↓	(—)	↓	↓	(—)	(—)

(—) = Decrease expected, but not quantified

General Considerations

Factors affecting emissions impact include:

- Type of vessels serving a port and number of vessels calls
- Type of fuel (and sulfur level) available for auxiliary engines
- Vessel power demands during hotelling time

Sample Project

COLD IRONING (VESSEL SHORE POWER)

Cold ironing involves retrofitting ocean going vessels to allow them to receive shore power from the local grid to meet their energy needs while docked at the port, thus allowing them to shut off their auxiliary engines. These projects typically also require major improvements to the electrical infrastructure at a port. The effectiveness of the strategy is related to the hotelling time of the participating vessels, the annual number of calls on the port by each vessel, vessel generator load, and the pollutant emission factors of the auxiliary power supply.

Annual hotelling emissions for a given vessel are the product of the average time in hotelling mode, power used, emissions factors, and number of annual calls. To estimate the effect of cold ironing on emissions, it is important to first determine the number of vessels that are likely to participate. Very few vessels are currently equipped to use shore power for all hotelling needs, and retrofitting vessels is cost-effective only for those that have long hotelling times, multiple annual vessel calls, and high auxiliary power needs. For participating vessels, it can be assumed that all hotelling power is derived from shore power rather than auxiliary engine, so the only factor changed in calculating the effect of cold ironing is the emission factor.

Emissions factors for marine vessels are poorly understood. The development of the latest emission inventory for the Port of Los Angeles included collection of in-use emissions data and development of new vessel emission factors, and this study offers the most accurate values currently available.[60] For Category 2 auxiliary engines, these factors are 19.71 g/hp-hr for NOx and 0.40 g/hp-hr for PM.

Accurately calculating emissions required obtaining, for each vessel, the number of annual calls, the time in hotelling mode, the power, and load factor. Emissions for each participating vessel can then be summed to determine total baseline emissions. Emission factors associated with electrical power generation for a specific region can be obtained from EPA's Emissions & Generation Resource Integrated Database (eGRID).[61]

Step 1: Calculate baseline vessel emissions [to be repeated for each vessel type].

> = (Annual calls on port) x (average time in hotelling mode) x (operating power in hotelling mode) x (load factor) x (emissions factor)
> Containership NOx = (72 calls/yr) x (13.7 hotelling hrs/call) x (7,700 horsepower in auxiliary mode) x (0.17 load factor) x (19.71 g/hp-hr) = 28.1 tons/yr
> Containership PM-10 = (72 calls/yr) x (13.7 hotelling hrs/call) x (7,700 horsepower in auxiliary mode) x (0.17 load factor) x (0.40 g/hp-hr) = 0.57 tons/yr
> [Repeat for each ship type]

Step 2: Calculate vessel emissions using cold ironing.

> = (Annual calls on port) x (average time in hotelling mode) x (operating power in hotelling mode) x (load factor) x (emissions factor for power generation)
> Containership NOx with cold ironing = (72 calls/yr) x (13.7 hotelling hrs/call) x (7,700 hp) x (0.17 load factor) x (0.846 g/hp-hr) = 1.2 tons/yr
> Containership PM=10 with cold ironing = (72 calls/yr) x (13.7 hotelling hrs/call) x (7,700 hp) x (0.17 load factor) x (0.017 g/hp-hr) = 0.024 tons/yr

Step 3: Calculate emission reduction.

> = (Emissions without cold ironing) – (emissions with cold ironing)
> NOx = 28.1 – 1.2 = 26.8 tons/yr
> PM-10 = 0.57 – 0.024 = 0.54 tons/yr

The impacts of implementing this strategy in 2010 would be similar the 2006. The following table summarizes the emissions impacts.

Table 6-10: Total Emissions Reduced (tons/year) from Marine Operations Example

Year	PM-2.5	PM-10	CO	NOx	VOCs	SOx	NH_3
2006	NA	0.54	NA	26.8	NA	NA	NA
2010	NA	0.54	NA	26.8	NA	NA	NA

It is not possible to accurately quantify the impact of this strategy in 2020 because of the lack of emission factors for marine vessels in that year.

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[60] Starcrest Consulting Group, *Port-Wide Baseline Air Emissions Inventory,* Prepared for the Port of Los Angeles, 2004.

[61] Available at http://www.epa.gov/cleanenergy/egrid/index.htm

32. Transportation Equipment Replacement / Repowers

Strategy Overview

While transportation construction and related equipment produces only short term impacts, they are also one of the only mobile emissions sources under the direct control of transportation agencies. Thus, these projects have little uncertainty and potentially fewer unknown implementation costs. Projects to replace or repower uncontrolled diesel engines in off-road equipment with lower-emitting, controlled diesel engines or alternative fueled engines can reduce emissions associated with transportation project construction.

Emissions Impacts

Emissions reductions are typically associated with NOx reductions, although this is dependant on the type of engine found in the heavy-duty transportation machinery.

Table 6-11. Transportation Related Equipment Strategy - Overall Impact on Emissions

PM-2.5	PM-10	CO	NOx	VOCs	SOx	NH_3
(—)	↓	N	↓	↓	N	N

(—) = Decrease expected, but not quantified in EPA guidance; N = No effect; not quantified in EPA guidance

General Considerations

Factor affecting emissions impacts include:

- The number of engines estimated to be equipped with new technologies
- The age and emissions characteristics of the engine
- The activity life of the equipment on the construction project
- The remaining useful life of the equipment

For EPA guidance, see "Diesel Retrofits: Quantifying and Using Their Benefits in SIPs and Conformity," http://www.epa.gov/oms/stateresources/transconf/policy/420b06005.pdf.

Sample Project

A SCRAPER REPOWER

A city transportation construction department will purchase a new off-road diesel engine rated at 300 hp (Tier 2 engine) to replace a 1997 diesel engine rates at 300 hp (Tier 1) used in a construction scraper.[62] Project specifics are as follows:

- Baseline engine is a 300 hp 1997 engine (Tier 1)
- 1,000 hours annual operation
- New engine is 300 hp 2003 engine (Tier 2)

Step 1: Estimate baseline emissions based on hours of operation

= (Emissions factor) x (load factor) x (horsepower) x (annual hours of operation) x (1 ton/907,200 g)
= (6.0 g/bhp-hr) x (.72) x (300) x (1,000) x (1/907,200)

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[62] Documented in "The Carl Moyer Memorial Air Quality Standards Attainment Program Guidelines," for the California Air Resources Board, 2003.

= 1.43 tons/year

Step 2: Estimate new emissions based on hours of operation

= (Emissions factor) x (load factor) x (horsepower) x (annual hours of operation) x (1 ton/907,200 g)
= (3.97 g/bhp-hr) x (.72) x (300) x (1,000) x (1/907,200)
= 0.94 ton/yr

Step 3: Calculate annual emissions reductions

= (Baseline emissions) – (new emissions)
= (1.43) – (0.94)
= 0.49 ton/year NOx

Table 6-12. Total Emissions Reduced (tons/year) from Transportation Equipment Example

Year	PM-2.5	PM-10	CO	NOx	VOCs	SOx	NH_3
2006	NA	NA	NA	0.49	NA	NA	NA

Emissions benefits are not calculated for 2010 and 2020, due to lack of availability for emissions factors from EPA guidance and in consideration of the anticipated useful life of vehicle replaced.

7. ROAD DUST REDUCTION STRATEGIES

Road dust reduction strategies are designed to reduce the amount of fugitive dust (PM-10 and PM-2.5) that is suspended into the air by tires on roadways. Several different methods are available, including strategies geared toward paved roads and unpaved roads. These strategies generally have no impact, or minimal impacts, on other pollutants.

Road dust emissions factors were drawn from EPA's Compilation of Air Pollutant Emission Factors: AP-42, and do not account for new research which suggests that a larger portion of road dust is in the form of PM-2.5. Note that the EPA guidance recommends regions develop their own emission rates based on local silt loading data.

The following examples do not take into account any changes in exhaust emissions that may occur, such as in response to speed restrictions.

33. Unpaved Road Dust Mitigation

Strategy Overview

Surface treatments for road dust mitigation are control options requiring periodic reapplication and can be divided between two main categories. Wet suppression strategies add moisture to the road surface which conglomerates particles and reduces their likelihood to become suspended in the air when vehicles pass over the surface. The second major type of control is chemical stabilization treatment which attempts to change the physical characteristics of the surface.

Emissions Impacts

This strategy focuses on PM reduction. Sometimes paving is not feasible for industrial roads subject to very heavy vehicles and/or spillage of material in transport. Watering and chemical suppressants, on the other hand, are potentially applicable to most industrial roads at moderate to low costs, though they require frequent reapplication to maintain an acceptable level of control. Chemical suppressants are generally more cost-effective than water but not in cases of temporary roads (which are common at mines, landfills, and construction sites).

Table 7-1. Unpaved Road Dust Mitigation Strategy - Overall Impact on Emissions

PM-2.5	PM-10	CO	NOx	VOCs	SOx	NH_3
↓	↓	N	N	N	N	N

N = No change; not quantified in EPA guidance

General Considerations

PM emissions from resuspended road surface material vary linearly with traffic volume. They also vary linearly with the fraction of silt (particles with diameters smaller than 75 micrometers [µm]). The silt fraction is the proportion of loose dry surface dust that passes a 200-mesh screen, based on the ASTM-C-136 method. Vehicle weight is also highly correlated with emissions on industrial sites, where heavy equipment is common. On public roads where passenger vehicles are more common, vehicle weight tends to be more uniform, thus not affecting emissions considerably. Moisture content is also highly correlated with PM emissions. Strategies to mitigate PM emissions from unpaved road dust are divided in three categories:

- Vehicle restrictions to limit the speed, weight, or number of vehicles
- Surface improvement, such as paving or adding gravel to the surface
- Surface treatment, such as watering or chemical treatment

For EPA guidance, see AP 42, Fifth Edition, Volume I, Chapter 13, Section 13.2.2, http://www.epa.gov/ttn/chief/ap42/ch13/draft/d13s0202.pdf.

Sample Project

CONSTRUCTION SITE WATERING CONTROL

This calculates PM emissions from suspended road surface material on an unpaved road adjacent to a construction site in Southern California. The strategy proposed is watering control. Necessary inputs include:

- Average vehicle weight: 30 tons
- Road length: 2 miles
- 260 days of operation

Step 1: Calculate VMT Affected.

= (Average daily traffic) x (project length)
= 10 trucks x 2 miles x 2 (return trip) x 5 days/week x 52 weeks/year = 10,400 VMT

Step 2: Determine road silt content.

8.5 percent

Step 3: Determine average vehicle weight.

30 tons

Step 4: Determine number of days with significant precipitation (more than 0.01”).

40

Step 5: Calculate emission factor (lb/VMT).

$E = [k.(S/12)^a.(W/3)^b]*[(365-P)/365]$, where:

E = Emission factor (lb/VMT)

S = Road silt content (%)

W = Average vehicle weight (tons)

P = Number of days in a year with at least 0.01” of precipitation

k, a, b = Constants (See table below)

Variable	PM2.5	PM10
K	0.23	1.5
A	0.9	0.9
B	0.45	0.45

Based on these calculations: $E_{PM2.5}$ = 0.4232 lb/VMT ; E_{PM10} = 2.7599 lb/VMT

Step 6: Calculate total baseline emissions (TBE).

= (Total VMT) x (emission factor)

$TBE_{PM2.5}$ = 4,401 lb = 2 tons

TBE_{PM10} = 28,703 lb = 13 tons

Step 7: Calculate updated emissions with watering controls (WE).

The application of 0.056 gallons of water per square yard of road is equivalent to 0.01 inch of precipitation, which is considered a “rainy day” for calculation purposes. To compensate for the dry months (June through September), water will be applied during these days. By repeating the calculations from the previous steps (with P increased to 160), the following results are obtained:

$WE_{PM2.5}$ = 2,776 lb = 1.3 tons

WE_{PM10} = 18,105 lb = 8.2 tons

This represents a reduction of 37 percent in PM emissions.

Table 7-2. Total Emissions Reduced (tons/year) from Dust Mitigation Example

Year	PM-2.5	PM-10	CO	NOx	VOCs	SOx	NH_3
2006	0.7	4.8	NA	NA	NA	NA	NA
2010	0.7	4.8	NA	NA	NA	NA	NA
2020	0.7	4.8	NA	NA	NA	NA	NA

34. Road Paving

Strategy Overview

Road paving reduces air pollution caused by dust particulates released into the air. According to EPA estimates, the difference between paved and unpaved emission rates is close to 572.32 g/VMT, which represents a significant reduction in PM-10 emissions due with implementation of this strategy. Typical projects include paving shoulders, curbs and gutters, roads, and access points.

Emissions Impacts

This strategy focuses on PM reduction.

Table 7-3: Road Paving Strategy - Overall Impact on Emissions

PM-2.5	PM-10	CO	NOx	VOCs	SOx	NH_3
↓	↓	N	N	N	N	N

N = No change; not quantified in EPA guidance

General Considerations

PM emissions from suspended road surface material are affected by the following factors:

- Vehicle average speed
- Average daily traffic (ADT)
- Number of lanes, and ADT/lane
- Fraction of heavy-duty vehicles and buses
- Presence of curbs, storm sewers, and parking lanes

For EPA Guidance, see AP 42, Fifth Edition, Volume I, Chapter 13, Section 13.2.1, http://www.epa.gov/ttn/chief/ap42/ch13/draft/d13s0201.pdf and Section 13.2.2, http://www.epa.gov/ttn/chief/ap42/ch13/draft/d13s0202.pdf.

Sample Project

PAVING 1.5 MILES OF LOW-VOLUME ROAD

The city of Maricopa in central Arizona proposes to pave a 1.5 mile section of unpaved road. The project will pave highway lanes only (i.e., shoulders, curb, and gutter will remain unpaved). Necessary inputs include:

- Length of section: 1.5 miles
- ADT: 150 vehicles/day
- PM-10 emission factor for unpaved roads: 573.91 grams/vehicle-mile
- PM-10 emission factor for paved roads (low volume): 1.59 grams/vehicle-mile
- Fraction of PM2.5 (PM-2.5/PM-10): 25%

Step 1: Calculate VMT Affected.

= (Average daily traffic) x (project length) = 150 x 1.5 = 225 vehicle miles/day

Step 2: Calculate emissions reduced.

= (VMT Affected) x [(emissions factor for unpaved roads) – (emissions factor for paved roads)]

PM10: 225 x (573.91 – 1.59) = 128,772 grams/day = 47 tons/year
PM2.5: 225 x (143 – 0.4) = 32,193 grams/day = 12 tons/year

Table 7-4. Total Emissions Reduced (tons/year) from Road Paving Example

Year	**PM-2.5**	**PM-10**	**CO**	**NOx**	**VOCs**	**SOx**	**NH_3**
2006	12	47	NA	NA	NA	NA	NA
2010	12	47	NA	NA	NA	NA	NA
2020	12	47	NA	NA	NA	NA	NA

35. Street Sweeping

Strategy Overview

Regular street sweeping on paved roads removes sand and/or other de-icing materials, and other deposition of dust or dirt on roads, reducing the amount of particulate matter released into the air. Projects may add street sweepers, replace non-certified sweepers with newer vehicles, use new vehicles to increase the frequency of sweeping in existing areas, or use new vehicles to expand the area that is regularly swept. Specific approaches to street sweeping include vacuum sweeping, water flushing, and broom sweeping and flushing.

Emissions Impacts

Street sweeping projects affect only particulate matter associated with road dust, not direct vehicle emissions. While street sweeping removes material that can potentially be suspended in the form of particulate matter, the street sweeping equipment also produces exhaust emissions, which are generally minor, but may need to be considered in regard to other pollutants.

Table 7-5: Street Sweeping Strategy - Overall Impact on Emissions

PM-2.5	PM-10	CO	NOx	VOCs	SOx	NH_3
↓	↓	N*	N*	N*	N*	N*

N* = Generally considered to have no impact, but may increase emissions (associated with use of sweepers)

General Considerations

The reduction of PM emission due to street sweeping comes from the reduction of reentrained dust from vehicles traveling on roadways. It is important to note that sweeping of curb and gutter areas may increase emissions, given that it redistributes loose material onto the travel lanes. Factors affecting emission include:

- Use of alternative fuel street sweeping vehicles, which will also reduce other pollutants compared to using a diesel street sweeper
- Frequency of sweeping
- Type of sweeping process used

For EPA Guidance, see AP 42, Fifth Edition, Volume I, Chapter 13, Section 13.2.1, http://www.epa.gov/ttn/chief/ap42/ch13/draft/d13s0201.pdf

Sample Project

PM-10 EFFICIENT STREET SWEEPERS

The city of Maricopa in central Arizona proposes the use of “PM10 Efficient Street Sweepers” for non-freeway streets. This strategy focuses on PM-10 only. Necessary inputs include:

- Average daily traffic per through lane: 5,000 vehicle/day
- Number of lane miles: 200
- Sweep cycle: 7 days

Step 1: Calculate current emissions from reentrained dust from vehicles traveling on the road, assuming that there is no street sweeping performed.

VMT = (Average daily traffic) x (number of lane miles) = 5,000 x 200 = 1,000,000 veh. mile/day
PM10 = (Emission factor) x (VMT) x 52 weeks x 7 days = 400 tons/year

Step 2: Calculate proposed emissions from reentrained dust from vehicles traveling on the road.

Based on a 7-day cycle, the PM10 emission factor with an efficient sweeper is 0.6871 g/VMT.
PM10 = (Emission factor) x (VMT) x 52 weeks x 7 days = 250 tons/year

Step 3: Determine total emission reduction.

= (Baseline emissions) - (emissions with sweeper)
= (400 – 250) = 150 tons/year

The emissions from the sweeping process itself are negligible.

Table 7-6. Total Emissions Reduced (tons/year) from More Frequent Street Sweeping Example

Year	PM-2.5	PM-10	CO	NOx	VOCs	SOx	NH_3
2006	NA	150	NA	NA	NA	NA	NA
2010	NA	150	NA	NA	NA	NA	NA
2020	NA	150	NA	NA	NA	NA	NA

8. CONCLUSION

This report has provided an overview of traditional and innovative transportation-related control strategies intended to assist transportation practitioners in considering a broad range of strategies to reduce transportation-related emissions of concern. Specifically, this report has focused on identifying the effect of strategies on seven major pollutants – CO, PM-10, PM-2.5, NOx, VOCs, SOx, and NH_3 – through the calculations of emissions impacts for sample projects. It is increasingly relevant for transportation agencies to understand the effects of emissions reduction strategies on a range of these seven pollutants since many regions are facing multiple air quality objectives. Additionally, in some cases, control strategies successful in reducing one pollutant may actually increase emissions of another pollutant. In other cases, control strategies may effectively reduce multiple pollutants.

In summary, the strategies examined within the document demonstrate the following general emissions effects, based on type of transportation system effect:

- Vehicle travel reduction and idling reduction strategies generally reduce all pollutants.
- Strategies that alter vehicle travel speeds and traffic flow may either increase or decrease VOCs, CO, and NOx, depending on starting speeds and the levels of speed change. They will have minimal or no impact on PM, SOx, and NH_3.
- Strategies that focus on vehicle technologies and fuels will have different impacts on different pollutants, and some types of technologies can be targeted to reduce specific pollutants.
- Specific strategies can be targeted to reduce PM-2.5 and PM-10 from road dust that is resuspended in the air due to the movement of vehicles over paved and unpaved roads. These strategies are effective in reducing PM emissions and have essentially no effect on other pollutants.

The findings are limited somewhat by the current state of research and limitations in the established motor vehicle emissions model, MOBILE6.2, in regard to speed effects of PM, SOx, and NH_3. EPA's new MOVES model, as a modal emissions model, will more accurately be able to capture the effects of changes in traffic flow, and speed implications for the various pollutants. EPA guidance should be consulted for information on calculating emissions impacts for use in SIP development, and methods and assumptions for use in a conformity determination should be determined through the interagency consultation process.

Cost-effectiveness of these strategies is not evaluated as part of this report. Resources are available that provide a rough indication as to how strategies compare with respect to cost effectiveness. Provided below is a list of recommended resources for further discussion on this topic. By no means is this list intended to be comprehensive, but rather serve to highlight useful and relevant sources of further guidance.

"8-Hour Attainment: Control Strategies: On Road," prepared for North Central Texas Council of Governments by ENVIRON Corp., 2006, http://www.nctcog.org/trans/air/sip/future/lists/Environ.pdf.

"The Carl Moyer Memorial Air Quality Standards Attainment Program Guidelines," California Air Resources Board, 2005, http://www.arb.ca.gov/msprog/moyer/guidelines/current.htm

"Clearinghouse for Inventories and Emissions Factors," U.S. Environmental Protection Agency, 2006, http://www.epa.gov/ttn/chief/.

"Congestion Mitigation and Air Quality (CMAQ) Improvement Program," Federal Highway Administration, 2006, http://www.fhwa.dot.gov/environment/cmaqpgs/.

"Costs and Emissions Impacts of CMAQ Project Types," prepared for U.S. Environmental Protection Agency Office of Policy by Hagler Bailly, Inc., September 1999, http://www.fhwa.dot.gov/environment/cmaq_pt1.htm.

"Mobile Sources," U.S. Environmental Protection Agency, 2006, http://www.epa.gov/air/topics/comotaq.html

"A Sampling of Emissions Analysis Techniques for Transportation Control Measures," prepared for Federal Highway Administration by Cambridge Systematics, Inc., October 2000, http://www.fhwa.dot.gov/environment/cmaqeat/index.htm.

APPENDIX A: LIST OF TRANSPORTATION STRATEGIES

This appendix includes a list of transportation emission reduction strategies that is intended to be comprehensive of the full range of strategies that would be examined by transportation agencies as part of transportation conformity analyses or other emissions analyses. Although this list is intended to be comprehensive, it is not exhaustive of all potential strategies. Two primary criteria were applied for inclusion of strategies:

1) The strategy can be implemented by policy makers at a state or local level (i.e., it does not require a change in federal law or federal action) – Many strategies in the list below can be funded or implemented directly by transportation agencies (e.g., transit programs, traffic flow improvements). However, we did not limit the list only to those that would be implemented directly by transportation agencies. Some strategies are typically funded by state air agencies (e.g., inspection and maintenance programs, vehicle buy-back programs) or require implementation by local governments (e.g., land use policies, parking policies).
2) The strategy is generally considered at least marginally useful as an emission reduction strategy – Some strategies have limited documentation of effectiveness, and may not generate significant emission reductions on their own; however, all strategies included are generally considered to be supportive of other strategies and contributing to emissions reductions.

The strategies are grouped into four broad categories:

1) **Transportation demand management (TDM) strategies** – these strategies generally focus on reducing the amount of vehicle travel;
2) **Transportation system management (TSM) / driver behavior-oriented strategies** – these strategies generally focus on improving the operating characteristics of vehicles, affecting speeds, traffic flow, idling, etc.;
3) **Vehicle, fuels, and technology strategies** – these strategies generally focus on reducing vehicle emission rates; and
4) **Non-road transportation strategies** – these strategies address railroads, marine vessels, airport ground support equipment, and other non-road engines.

Some individual strategies fall into more than one of these categories (e.g., high-occupancy vehicle lanes can be considered both a TDM and TSM strategy since they encourage ridesharing, and also may help to improve traffic flow) but are only listed once in order to avoid duplication.

Within these four broad categories, the strategies have been sub-categorized so that those with similar goals or targets are grouped together (e.g., transit strategies are grouped together, as are bicycle and pedestrian strategies). Often, strategies within a sub-category are implemented together and are analyzed as a package. In total, this memo identifies 137 different strategies in 29 sub-categories. For many of the strategies, examples of specific implementation approaches are provided. Although each of these examples is sometimes listed as a separate strategy in other resource documents, the examples for a given strategy generally serve the same purpose and would typically use the same general methodology for emissions analysis.

Each of the strategies focuses on policy or programmatic approaches that could be implemented by the public sector. Following the strategies, a table identifies specific technologies that can be applied as emission reduction measures.

Transportation Demand Management Strategies

Transportation demand management (TDM) strategies focus on changing travel behavior – trip rates, trip length, travel mode, time-of-day, etc. Most TDM projects/programs reduce emissions by reducing trips and/or vehicle miles traveled (VMT) by personal motor vehicles, or by shifting trips from peak periods to less congested periods. These strategies are listed below.

1. Shared Ride Programs/Projects

Strategy	Examples
Park-and-Ride facilities	• New park-and-ride facility • Add parking to existing facilities
High-Occupancy Vehicle (HOV) lanes	• Separate roadway for exclusive HOV use • Barrier separated lanes within freeway right-of-way • Concurrent flow lane • Contra-flow lane • HOV on arterial streets • Bypass lanes for HOVs at metered freeway entrance ramps
Regional rideshare outreach/matching	• Implement regional rideshare matching programs • Upgrade ridematching software (for full regional address recognition, corridor searching, etc.
Regional rideshare incentives	• Carpool incentives (e.g., free gas card, drawings) • Vanpool incentives (e.g., subsidized vanpools)
Dynamic rideshare programs	• Real-time rideshare matching
Encourage shared ride taxis	
Regional vanpool network	
Short-distance vanpools	• Vanshare program providing access from transit to workplaces

2. Bicycle and Pedestrian Programs/Projects

Strategy	Examples
New bicycle paths, lanes, routes, or safety enhancements	• Bicycle paths/lanes • On-street bicycle routes • Multi-use trails • Rails-to-trails conversions • Bicycle safety enhancements (lighting, grades, markings, etc.)
Bicycle parking	• Bicycle racks • Bicycle lockers • Attended bicycle parking • Ordinances requiring bicycle parking
Bikes on transit programs	• Bicycles on buses • Bicycles on rail

Strategy	Examples
Bicycle information	• Informational signage (e.g., Share the Road signs, designated bicycle routes) • Bicycle maps/plans • Bicycle educational information, including bicycle safety information • Bicycle coordinators • Bicycle awareness/safety events
Bicycle share programs	• Public use bicycles • Bike stations providing maintenance facilities
Financial incentives to own bicycles	• Free bikes program • Cash rebates for bicycle purchases
Pedestrian connections/sidewalks	• New sidewalks • Sidewalk improvements (curb ramps, sidewalk gap closure, etc.) • Pedestrian bridges/tunnels • Mid-block pedestrian connections
Enhancing the pedestrian environment	• Wider sidewalks • Tree plantings • Crosswalk light fixtures • Street lights • Sidewalk furniture (benches, etc.) • Pedestrian safety modifications (count down pedestrian signals)

3. Transit

Strategy	Examples
New transit routes/services	• New bus routes • New rail lines • Demand response shuttle • Circulator buses • Express bus service
More frequent service	• Additional buses in service on existing routes (to reduce headways)
Longer service hours	• Expansion beyond peak periods • Late night hours
More capacity on services	• Larger buses • Additional railcars on trains • Redesign of seating/standing
Faster travel times/improved system performance	• Busways/bus rapid transit (BRT) • Improved bus/rail integration • Transit signal prioritization • Improved connections/reduced transfer times • Transit centers • Change routing

Strategy	Examples
Passenger amenities	• Bus shelters • Benches/seating at bus stops • Improved maintenance of buses/trains and stops/stations
Improved transit access	• Increased parking at transit stations • Shuttle and feeder bus services • Improved pedestrian/bicycle access and bicycle parking
Transit information	• Signage/maps/schedules at bus/train stops • Signage/maps/schedules at major activity centers (e.g., malls, sports venues, etc.) • Terminal displays/kiosks with real-time passenger information • Transit information kiosks (e.g., in suburban employment sites, downtown, tourist sites) • Web page with transit planning capabilities • Inclusion of transit information in 511 and other travel planning services • Real-time text messaging/on-line information on bus schedules
Transit marketing and promotions	• Transit promotional campaign • Branding of services / routes
Reduced fares/free services	• Lower transit fares • Fare free zones • Free transit services
Fare structure/convenience improvements	• Fare structure simplifications • Elimination of fares for transfers • SmartCards • Automated fareboxes
Transit pass programs	• Monthly passes • Annual passes • Ecopasses/universal passes • Multimodal/Smart passes (for transit, parking, carshare) • Off-peak pass (low cost pass for unlimited use in off-peak hours)
“Try it” transit pass give-aways	• Promotional transit pass give aways • First month free program for new services

4. Parking Management

Strategy	Examples
Parking pricing / fees	• Increase public parking fees • Increase taxes on parking providers • Impose or increase fees/surcharges on SOVs • Free or reduced priced parking for carpools/vanpools
Parking supply limits	• Parking maximums for new development • Regional parking caps • Create parking/traffic-free zones • Peak-hour parking bans • Curb-parking restrictions
Preferential parking for carpools/vanpools	• Premium parking spots for carpools/vanpools • Guaranteed parking for carpools/vanpools
Parking cash out program	

5. Pricing

Strategy	Examples
Road pricing	• New tolls • Increase tolls on roads • Increase bridge tolls • High Occupancy Toll (HOT) lanes
Cordon pricing	• Charge vehicles for entering high-use area, such as CBD
Variable priced tolls	• Peak period surcharge • Prices vary based on traffic levels
Variable parking fees	
Pay-As-You-Drive Vehicle Insurance	• Incentives for per-mile vehicle insurance • Pilot programs for per-mile vehicle insurance
VMT-based registration fees	
Increase in gas tax	
Employee tax credits	• Tax credit for using transit, HOV, or bicycling

6. Employer-based TDM Programs

Note: A wide range of different employer-based demand management options are available, including: transit passes, vanpool subsidies, rideshare matching, bicycle lockers/showers, telecommuting programs, flexible work hours, compressed work schedules, etc. These programs typically are not promoted individually but as packages of strategies, and would be analyzed as a comprehensive program. As a result, the list below focuses on government policies or programs, not individual TDM program elements. The analysis of these strategies requires an assessment of levels of participation in different types of TDM activities.

Strategy	Examples
Employer marketing and support	• Outreach to employers/information programs to encourage commute options • Recognition/awards programs
Telecommuting support/incentives	• Support in establishing telecommuting programs • Telecommuting financial incentives
Telework centers	• Remote/satellite offices close to residential areas • Telework centers in communities
On-going incentives for employer-based transit/vanpool/carpool programs	• Subsidized transit passes • Subsidized vanpools • Tax credit for employers that offer TDM programs, employer transportation coordinators, etc.
Start up incentives for employer-based transit/vanpool/carpool programs	• Short-term (start-up) financial incentives for implementing transit pass program • Short-term (start-up) financial incentives for implementing vanpool/carpooling program
Implement programs at government worksites	• Flexible work hours programs • Compressed work scheduled programs • Telecommuting • Promote ridesharing, transit, bicycling, walking
Mandatory commute trip reduction programs	• Mandatory programs for employers of certain size • Mandatory program for employers in certain locations/business districts
Regional guaranteed ride home program	• Guaranteed ride home program • Emergency ride home program
Support proximate commuting	• Reassigning employees so they can work at a location closest to home

7. Non-employer-based TDM Programs

Strategy	Examples
School-based programs	• School pools • Safe Routes to Schools programs • "Walking bus" programs
Campus programs	• University parking pricing / TDM programs
Community-based programs	• Community association/residential building based TDM programs
Development-based programs	• Require new developments to meet trip reduction targets, implement TDM programs
Airport-based programs	• Airport parking / TDM programs
Tourism promotions	• Hotel partnerships to promote transit use, walking/bicycling • Tourism site partnerships to promote transit use, ridesharing, walking, bicycling
Special events-based programs	• Stadium events management • Festivals and other events management • Combined event ticket/transit pass

8. Outreach/Marketing/Education

Strategy	Examples
Regional TDM program outreach	• Media campaigns/Public service announcements • Voluntary "No Drive," "Share a Ride" Days
Episodic (Spare the Air / Ozone Action Days) programs	• Media campaigns • Ozone Action Coordinators • Free/reduced price transit on Ozone Action Days • Special incentives on Spare the Air Days • Voluntary business closures / business practices
Educational curriculum	• Incorporate air quality awareness into public school curriculum • Incorporate information about transit, ridesharing into public school curriculum
Transportation management organizations	• Regional Commute Management Organizations • Local Transportation Management Associations

9. Integrated Land Use-Transportation Planning

Note: A wide range of different land use policy mechanisms are available, including: zoning requirements, impact fees, developer incentives, regional growth boundaries, etc. These policies typically would not be analyzed individually but as a package of strategies that affects land use patterns, and hence, travel and emissions. As a result, these strategies are not listed individually. Sometimes, strategies are identified based on the focus of the efforts: transit-oriented development, mixed-use activity centers, pedestrian-oriented design, etc. Five strategies are listed below that are organized around different types of programmatic approaches.

Strategy	Examples
Transit-oriented development (TOD) programs	• Joint-development programs
Programs/requirements/ incentives to encourage better regional land use/transportation coordination	• Developer incentives (e.g., density bonuses for development near transit/urban core, reduced impact fees in TOD) • Impact fees • Zoning requirements • Regional growth boundaries • Concurrency requirements (adequate public facilities ordinances) • Accessibility contracts (e.g., preferred access to road system for land use projects that reduce trips)
Programs/requirements/ incentives to improve community design	• Design standards (requirements for amenities, layout to street, etc.) • Incentives for developers to incorporate public spaces and other amenities into new developments
Neighborhood schools	• Locate schools in communities, with access via walking and bicycling
Incentives to live near work/transit/downtown	• Location Efficient Mortgage • Energy Efficient Mortgage • Tax credits for redeveloping in blighted neighborhoods • Tax credits for living downtown

10. Vehicle Use Restrictions

Strategy	Examples
Auto-free zones	• Pedestrian malls • Transit malls • Car bans in CBD
Limit access to HOVs only	• Require 2+ vehicle occupancy to enter designated congested activity centers/parking facilities during peak periods
No Drive Days	

11. Other Options to Reduce Auto Ownership / Avoid Vehicle Trips

Strategy	Examples
Carsharing programs	• Car-sharing programs • Station cars • Incentives for use of carsharing programs
Using technology to avoid vehicle trips	• E-government initiatives • Use teleconferences/web conferences

Transportation System Management / Vehicle Driver Behavior-Oriented Strategies

Transportation system management (TSM) strategies focus on changing the operation of the transportation system, typically with a primary focus on improving traffic flow and reducing traveler delay. TSM programs can reduce emissions by changing vehicle speeds, reducing rapid vehicle accelerations and decelerations, and reducing vehicle idling. Many of these strategies are under the umbrella of Intelligent Transportation Systems (ITS). In addition, some strategies focus directly on encouraging changes in driving behavior through educational information, incentives, or restrictions on driving speeds, operating patterns, and idling. These strategies are listed below.

12. Traffic Signal Synchronization

Strategy	Examples
Signal retiming	
Advanced traffic signal controls	• Adjust traffic control/signals based on traffic levels

13. Roadway / Intersection Improvements

Strategy	Examples
One-way streets	• Convert two-way streets to one-way to improve operations
Turn restrictions	• Restrict left turns on two-way streets
Turning lanes	• Separate turning vehicles from through traffic to avoid unnecessary backups
Roundabouts	• Implement traffic circles to improve traffic movement
Limit on-street parking	• Remove or limit on-street parking during peak hours • Enforce on-street parking limits
Intersection improvements	• Construct interchanges instead of signalized intersections • Develop tunnels/overpasses • Grade separations at railroad/transit crossings
Bus pullouts	• Bus pullouts in curbs • Queue jumper lanes for passenger loading/unloading

14. Incident Management / Operations

Strategy	Examples
Incident management programs	• Intersection/corridor monitoring and response • Call number to report incidents • Roadside assistance vehicles • Motorist aid call boxes • Rerouting traffic at incidents • Active/dynamic traffic management systems (e.g., manage speeds; routes)
Ramp metering	
Encourage use of underutilized capacity	• Route marking directing traffic to underutilized capacity • Reversible traffic lanes
Allow use of road shoulders during peak periods/to get around incidents	

15. Traveler Information Systems

Strategy	Examples
Real-time traveler information systems	• Variable message signs (directing traffic from incidents) • Variable message signs and information including comparative travel times • Real-time information services (including integrated, multi-modal information) • Web site with real-time traffic information, speed information • Toll-free phone number (511)
Real-time parking information	• Availability updates (to reduce unnecessary searching for parking) • Automated reservations and payment

16. Speed Control

Strategy	Examples
Lower speed limits	• 55 mph highways
Increased speed enforcement	• Photo speed enforcement • Increased police enforcement • Enforcement against aggressive driving (to reduce crashes/incidents, which cause delay)
Driver training/education	• Information about saving fuel with less vehicle stops/starts

17. Access Management

Strategy	Examples
Access management	• Limit development of access points to arterials/highways • Parallel access roads

18. Shifting/Separating Freight Movements

Strategy	Examples
Shifting freight movement to off-peak periods	• PierPASS program
Truck-only lanes/routes	• Truck-only lanes • Truck-only roads/routes
Truck restrictions	• Road restrictions on trucks • Restrictions during peak hours
Consolidated freight/package delivery	• Consolidation at peripheral CBD locations or neighborhood locations
Rail shuttles	• Containers brought to inland distribution center
Container matching services	• Transport of empty containers minimized

19. Anti-Idling

Strategy	Examples
Anti-idling restrictions	• School bus anti-idling restrictions • Truck anti-idling restrictions • Personal vehicle anti-idling restrictions (in specific zones, near schools, etc.)
Anti-idling information campaigns	• Idling reminder hang-tags for trucks and commercial fleets • Remote idling reminders (On-Star-type service) • Inclusion of information in drivers education and at auto dealerships
Restrictions on drive-through services	
Freight facility improvements	• Expansion/improvement of port terminals, intermodal facilities, etc. to reduce queuing and idling

Vehicle, Fuels, and Technology Strategies

Vehicle, fuel, and technology projects and programs are designed to change the emission rates of vehicles either by changing the fuel being used, the type of vehicle or emissions control technology, or a combination of both. Some programs also focus on eliminating gross polluters, or vehicles whose emissions controls have failed, or on controlling specific types of emissions (e.g., road dust). These strategies are listed below.

20. Accelerated Vehicle Retirement/Fleet Renewal/Replacement

Strategy	Examples
Vehicle buy-back programs	• Vehicle scrapping program
Fleet renewal / clean vehicle programs	• School bus replacements • Transit bus purchases/replacements • New purchases/replacements of heavy-duty trucks for solid waste trucks, etc. • New purchases/replacements of light-duty vehicles (e.g., government fleets) • Repowering / replacing existing older diesel engine with a newer, cleaner engine.

21. Heavy-Duty Diesel Vehicle Repowering/Retrofits*

Note: There are a range of technologies that can be used to retrofit heavy duty diesel vehicles, including particulate filters, oxidation catalysts, flow through filters, crankcase filters, NO_X reducing catalysts, exhaust gas recirculation (EGR), and selective catalytic reduction. Each of these technologies has a different effect on pollutants of concern, and can be examined as an emissions reduction measure independently. Strategies listed below are those that are policy/program options available to state/local governments.

Strategy	Examples
Mandatory fleet retrofits	
Government contracting requirements	
Voluntary programs with funding	• Carl Moyer, TERP-type programs

* See section “Samples of Technology Samples/Options” for a more detailed list of technology options

22. Idle Reduction Technologies

Strategy	Examples
Truck stop electrification	
Purchase of auxiliary power units	• APUs • Electronically-driven auxiliary systems

23. Purchases of Advanced Technology and Alternative Fuel Vehicles

Strategy	Examples
Cleaner diesel fuels	• Emulsified diesel • Oxygenated diesel • Biodiesel • Fuel borne catalyst
Purchases of alternative fuel vehicles (buses, other heavy-duty vehicles, light-duty vehicles)	• LNG vehicles • CNG vehicles • Ethanol / methanol • LPG vehicles • Electric vehicles
	•

24. Programs to Encourage Purchases of Advanced Technology/Alternative Fuel Vehicles

Strategy	Examples
General tax / financial incentives	• Tax credits for purchase of low emissions vehicles • Tax credits for purchase of alternative fuel vehicle • Feebates • Vehicle emissions fees
Specific target market programs with funding	• CNG taxicab program
HOV lane use allowed for advanced technology/ alternative fuel vehicles	
Preferential/free parking for advanced technology/ alternative fuel vehicles	
Government contracting requirements	• Contracts requiring alternative fuel/low emissions vehicles

25. Inspection and Maintenance

Strategy	Examples
Basic I&M	
Enhanced I&M and on-board diagnostics	
Remote Sensing	• Roadside pullovers
Smoking vehicle programs	• Toll-free number for reporting high polluting vehicles
Heavy-duty vehicle inspections	

26. Road Dust Reduction Strategies

Strategy	Examples
Mitigation for unpaved roads	• Apply water • Apply wet gravel • Apply chemical/organic dust suppressant • Use vegetative matter to reduce blowing dust
Road paving	• Pave previously unpaved roads • Pave road shoulders
Street sweeping	• Regular street sweeping on paved roads • Sweeping to remove sand and other de-icing/de-skid materials on paved roads
Transportation construction site mitigation efforts	• Require water or chemical stabilizers to be applied • Require wind barriers

Non-Road Strategies

Non-road vehicles and equipment include railroads, marine vessels, airport ground support equipment, lawn and garden equipment, construction and agricultural equipment, and other mobile equipment. There are a wide range of technologies and operational strategies available to address these sources. The list of strategies below focuses on policies and programs. Following this strategy list is an appendix that includes more detail on the specific types of modifications that can be made to equipment.

27. Encourage Replacement/Repowering/Retrofits*

Strategy	Examples
Mandatory fleet retrofits	• Only CA requirements can be adopted
Scrappage programs	• Equipment buy-back programs • Replacement of gasoline lawnmowers with electric • Replace older yard tractors with newer, lower emission ones
Government contracting requirements regarding vehicle/equipment technologies	
Voluntary repower / retrofit programs, with funding*	• Carl Moyer, TERP-type programs

* See section "Samples of Technology Samples/Options" for a more detailed list of technology options

28. Encourage / Implement Use of Alternative Fuels

Strategy	Examples
Encourage use of on-road fuels by non-road diesel vehicles	• Use of ultra low-sulfur on-road diesel
Purchase alternative fuel vehicles / equipment	• Purchase CNG street sweepers
Incentives for purchase of alternative fuel vehicles / equipment	
Rail electrification	• Commuter rail electrification

29. Encourage / Implement Operational Improvements and Anti-Idling Technologies

Strategy	Examples
Rail infrastructure improvements	• Track geometry improvements • Use of concrete ties/heavier rails
Rail operational strategies/practices	• Switcher yard locomotives (anti-idling) • Idle reductions using APUs • Idle reductions using automatic shut-down
Marine vessel equipment modifications	• Hull design/larger vessels • Increased atomization • Reduction of dead volume/Reduced sack volume

Strategy	Examples
Marine vessel fleet operational strategies/practices	• Speed reductions • Vessel route modifications • Programmable logic controllers • Hull cleaning • Cold ironing (anti-idling technologies while in port) • Shoreside power
Airport operational strategies	• Idling reduction policy • Full electrification of gates / ground electrification / HVAC systems at gates • Improved airport configuration and expanded capacity (to reduce idling)
Government contracting requirements limiting idling	• Contracting requirements limiting idling during construction/maintenance activities

Samples of Technology Approaches / Options

Approach	Options
Heavy-duty diesel engine retrofits (trucks, locomotives, marine vessels, other)	• Particulate filters • Flow through filters • Diesel oxidation catalysts • Crank case filters • NO_X reducing catalysts • Exhaust gas recirculation (EGR) • Selective catalytic reduction
Locomotive engine modifications	• Low heat rejection • Bottoming cycles • Improved engine lubricants • Use of hybrid switcher locomotives • Scrappage/fleet renewal
Railroad equipment modifications	• Tare weight reduction, higher capacity cars • Use of low-friction bearings • Use of improved suspensions • Use of hopper car covers • Use of steerable rail car trucks • Energy-minimizing train control • Improved drive-train lubricants
Railroad alternative fuels	• Use of natural gas • Use of cellulosic ethanol
Marine vessel engine modifications	• Cooled exhaust gas recirculation • Charge air cooling • Turbocharging • Electric propulsion • Podded propulsion • Pre-injection

Approach	Options
	• Modified valve timing • Lower compression ratio • Detail design of combustion space • Water injection in cyclinder • Variable exhaust back pressure • More uniform injection • Insulating combustion space • Shutting off cyclinder at low load • Delay injector timing; injector upgrade • Exhaust gas recirculation system or engine cycle modification • Install an inlet air humidification system • Modify cylinder heads for direct water injection
Marine vessel alternative fuels	• Fuel homogenization • Fuel/water emulsion • Humid air motor technology • Use of off-road diesel instead of residual fuel • Use of ULSD • Uses of LNG • Use of Fischer-Tropsch diesel • Use of Biodiesel • Use of ethanol-blended diesel • Use of low sulfur marine diesel fuel (SECA) • Control fuel oil quality
Airport ground support equipment engine modifications/ alternative fuels	• Replace GSE with LPG/CNG equipment • Replace 2-stroke engines with 4-stroke gasoline equipment • Use of hybrid or electric ground support vehicles • Replace mobile GSE with fixed, electrically hardwired “at gate” equipment • Use of alternative fuels in ground support vehicles (e.g., ultra low sulfur diesel)

APPENDIX B: SUMMARY OF THE CONTRIBUTION OF TRANSPORTATION AND MOTOR VEHICLES TO NATIONAL EMISSIONS OF EACH POLLUTANT

Contribution of Emissions by Vehicle Classification Compared to Total Stationary and Mobile Sources (Thousand Short Tons, 2002)

Source Category	NOX		CO		VOC		NH3		SO2		PM10		PM2.5	
TOTAL ALL SOURCES	**21,102**		**112,049**		**16,544**		**3,712**		**15,353**		**22,154**		**6,803**	
MOBILE SOURCES TOTAL	**11,451**	54.26%	**86,611**	77.30%	**7,231**	43.71%	**290**	7.81%	**696**	4.53%	**515**	2.32%	**434**	6.38%
HIGHWAY VEHICLES	**7,365**	**34.90%**	**62,161**	**55.48%**	**4,543**	**27.46%**	**287**	**7.73%**	**275**	**1.79%**	**204**	**0.92%**	**149**	**2.19%**
Light-Duty Gas Vehicles & Motorcycles	2,166	10.26%	34,400	30.70%	2,496	15.09%	184	4.96%	93	0.61%	52	0.23%	27	0.40%
Light-Duty Gas Trucks	1,401	6.64%	24,191	21.59%	1,638	9.90%	92	2.48%	65	0.42%	30	0.14%	16	0.24%
Heavy-Duty Gas Vehicles	404	1.91%	2,554	2.28%	201	1.21%	4	0.11%	12	0.08%	9	0.04%	7	0.10%
Diesels	3,395	16.09%	1,016	0.91%	208	1.26%	6	0.16%	105	0.68%	113	0.51%	99	1.46%
OFF-HIGHWAY	**4,086**	**19.36%**	**24,450**	**21.82%**	**2,688**	**16.25%**	**3**	**0.08%**	**420**	**2.74%**	**311**	**1.40%**	**285**	**4.19%**
Non-Road Gasoline	211	1.00%	21,940	19.58%	2,342	14.16%	1	0.03%	8	0.05%	72	0.32%	67	0.98%
Non-Road Diesel	1,600	7.58%	872	0.78%	188	1.14%	2	0.05%	198	1.29%	169	0.76%	155	2.28%
Aircraft	81	0.38%	257	0.23%	21	0.13%	NA		8	0.05%	3	0.01%	2	0.03%
Marine Vessels	1,011	4.79%	133	0.12%	32	0.19%	NA		160	1.04%	44	0.20%	40	0.59%
Railroads	889	4.21%	88	0.08%	35	0.21%	NA		47	0.31%	22	0.10%	20	0.29%
Other	295	1.40%	1,160	1.04%	71	0.43%	0		0	0.00%	1	0.00%	1	0.01%
ROAD DUST	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	3,951	17.83%	684	10.05%

Source:National Emissions Inventory Air Pollutant Emissions Trends Data, http://ww.epa.gov/ttn/chief/trends/index.html#tables

APPENDIX C: OVERVIEW OF EMISSIONS FACTORS AND ASSUMPTIONS USED IN SAMPLE CALCULATIONS

Methodological Procedures

Most strategies can be analyzed in multiple ways, and variations of these approaches are available. The methods described in this report are generally simple sketch planning approaches that involve two main processes: 1) estimating the travel, speed, or vehicle changes associated with the strategy; and 2) estimating emissions impacts. For those strategies where sketch planning was not appropriate, we used the COMMUTER Model and the National Inventory Model (NMIM) Model.

The most challenging part of each methodology is developing the values for changes in travel activity, speeds, or vehicle stock. Various approaches can be used for these inputs, such as using models (e.g., travel demand forecasting models, COMMUTER Model), original data collection (e.g., surveys), past experience/studies of similar projects, standardized factors drawn from the literature, or professional judgment.

Application of Emissions Factors

Unless otherwise noted in each of the strategy review sections, all of the on-road strategies analyzed and presented in this report use emissions factors generated from MOBILE6.2 to determine emissions impacts. Factors generated for PM-2.5, PM-10, CO, NOx, VOCs, SOx, and NH_3 were used to estimate the emissions impacts of documented strategies. Standard defaults have been applied, covering years 2006, 2010, and 2020. Emissions were generated for start (trip-based factors assuming 100 percent cold start) and running emissions (per mile factors). The recognition of a difference between trip starts emissions and running emissions is significant, since emissions control equipment does not function as effectively from a "cold start'" causing the release of more pollutants during the first few miles of a trip.

MOBILE6.2 allows the calculation of several different types of vehicle emissions. This is important for some strategies because they affect running and trip emissions differently, as noted in this report. In areas that are concerned with VOC emissions, MOBILE6.2 modeling can be tailored to account for only the emissions that are affected by a particular strategy. For example, a trip reduction strategy not only reduces running emissions, but also start and "hot soak" emissions. Strategies that shorten trip length but do not eliminate trips affect running exhaust and running loss emissions, but not start, hot soak or diurnal soak emissions. Finally, most modeling should employ the "NO REFUELING" command in MOBILE6.2, since refueling emissions are associated with gas stations and are not normally affected by the types of stategies outlined in this document. Guidance is available from EPA and FHWA for those wishing to refine their analyses.

This section discusses the emissions factors used to perform the sample calculations.

MOBILE6.2 Emissions Factors

The major input parameters used to generate running mobile emissions factors for CO, PM-10, PM-2.5, NOx, VOCs, SOx, and NH_3 are shown in the table below.

Table C-1. Major Input Parameters for MOBILE6.2 Emissions Factor Modeling

Parameter or Variable	Values or Sources
Vehicle Fleet and Activity Inputs	
VMT mix	EPA national average (default)
Mileage accrual rates	EPA national average (default)
Vehicle model year (registration) distribution	EPA national average (default)

Parameter or Variable	**Values or Sources**
Diesel sales fractions	EPA national average (default)
Soak time distribution	EPA national average (default), or All soak times >720 minutes (corresponds to 100percent cold starts).
Starts per day distribution	EPA national average (default), or Zero starts per day (for running emissions only)
Region	Low altitude
Vehicle speeds	Varied 2.5 mph and 3-65 mph by integers, with single average speed per scenario.
Roadway facility (functional classes)	Arterial (allows use of specific average speeds)
Seasonal/Meteorological Inputs	
Month of evaluation	July
Temperatures for all pollutants	Minimum: 68.0° F Maximum: 94.0° F (Representative summer temperatures only. Actual source for these values is high-ozone-day data from Boston, MA nonattainment area SIP.)
Absolute humidity	MOBILE6.2 default
Fuel Inputs	
ASTM Class	MOBILE6.2 default
Oxygenated fuels	No (MOBILE6.2 default)
Reformulated gasoline	No (MOBILE6.2 default)
Gasoline RVP	8.7 psi (Representative summer RVP only. Actual source for this value is Philadelphia, PA nonattainment area SIP.)
Diesel fuel sulfur content	15 ppm
State Program Inputs	
Inspection/Maintenance (I/M) Program	No program (MOBILE6.2 default)
Low Emitting Vehicle (LEV) Program	No program (MOBILE6.2 default)
Anti-tampering program (ATP)	No program (MOBILE6.2 default)
Stage II refueling controls	Not modeled (NO REFUELING command used).
Other Inputs	
Particulate matter emissions parameters	EPA national average (default)
All other inputs	EPA national average (default)