The Texas Guide to Accepted Mobile Source Emission Reduction Strategies (MOSERS)

Third Edition 2021

Module 2: Methodologies

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Texas Department of Transportation

- William Knowles
- Laura Norton
- Janie Temple
- Tim Juarez

Texas A&M Transportation Institute

- Reza Farzaneh
- Robert Huch
- Chaoyi Gu
- Madhusudhan Venugopal

Table of Contents

Page

About This Guide

The third edition of the Texas Guide to Accepted Mobile Source Emission Reduction Strategies was developed by the Texas A&M Transportation Institute (TTI) for the Texas Department of Transportation (TxDOT) as part of the TTI-TxDOT "Air Quality and Conformity" Interagency Contract.

This guide is an updated and enhanced version of the 2007 edition of the Texas Guide to Accepted Mobile Source Emission Reduction Strategies, and is designed for use among Texas transportation practitioners who are undertaking air quality planning. The intent of this guidebook is to provide guidance and resources for practitioners to understand and evaluate mobile source emissions reduction strategies.

This third edition of the guidebook consists of two modules. Module 1 provides an overview of transportation and air quality planning, and discusses key topics relating to federal regulations, transportation conformity, mobile source emissions modeling, and transportation control measures. Module 2 contains a comprehensive set of analysis methods that can be used in the evaluation of emissions reductions achievable through the adoption of mobile source emission reduction strategies (MOSERS). This guidebook contains updated graphics, easy-to-navigate charts and comprehensive resource listings to help the reader gain an understanding of the subject matter and identify other resources for further reading.

Module 2
Generic Analysis for Evaluating MOSERS

In Module 1, the reader was provided a general background regarding the context of transportation and air quality planning. The concept of mobile source emissions reduction strategies is introduced, and commonly-used/accepted strategies are also discussed.

This module of the guidebook focuses on generic, standardized analysis methods for the estimation of various individual mobile source emission reduction strategies (MOSERS), also sometimes termed as "actions" or "measures." A total of 17 categories of strategies are presented in this module, several of which have different subtypes (measures) for which individual quantification approaches are discussed. All 16 of the 1990 Clean Air Act Amendments (CAAA) emission reduction measures (eligible transportation control measures [TCMs]) are included along with other categories of mobile source emission reduction strategies. The individual measures are described along with potential applications. An equation is then provided to derive the daily emission reduction of the strategy for analysis and reporting. The variables are described for each equation.

The analysis methods described herein are "off model" (i.e., computations performed outside of a travel demand model), applying generalized sketch-planning techniques. The methods are meant to assist with standardizing emissions estimation and evaluation approaches as well as documentation to aid the interagency review process.

The equations presented in this guide should be considered only as a starting point for the estimation of emissions reduction for various strategies. The results can serve as the basis for discussions between the interagency review partners and the nonattainment areas regarding mobile source emission reduction strategy use and implementation of these strategies as part of their SIP, conformity, and voluntary programs and actions. These equations can also be used by near nonattainment areas that are developing air quality plans and incorporating transportation emission reductions into their plans. Additional factors, such as the expected project life, and the overall cost-effectiveness of the strategy (as discussed in Module 1 of the guidebook) should also be taken into consideration.

Input Variables and Data Sources

The following sections introduce the various categories of mobile source emissions reduction measures and provide quantification equations for estimating effectiveness of individual measures under these categories. Input variables are defined for these equations and are necessary to analyze and document the emissions benefits of MOSERS. The input variables required for the quantification of emissions reductions achievable for various measures vary according to the type of measure. These variables are individually defined in the following sections and follow a consistent naming system based on the type of input variable. The types of inputs include:

- Scoping Inputs – are inputs relating to the scope and scale of the measure, such as lengths (of facilities, etc.) or numbers (such as usage levels, number of trips or number of households, etc.), times, or fees/charges associated with the measures.
- Traffic Inputs – include those related to traffic volumes/annual average daily traffic (AADT), delay, idling times, vehicle occupancies, mode shifts, trip lengths, parking facility utilization rates, vehicle miles of travel (VMT), or number of vehicle trips.
- Emissions Inputs – include exhaust emissions factors (such as running exhaust, start exhaust, and evaporative hot soak) and trip emissions factors.
- Factor Inputs – relate to percentage compliance or percentage usage of certain strategies or facilities, trip capture rates, and elasticities.

Detailed information about the input variables can be found in the appendix to this module. Locally specific data should be the preferred source for analysis, along with conservative, realistic assumptions applied where necessary. The equations documented in this module are a starting point. Users can make their case about data limitation and modify equations to get valid results. All assumptions and modifications should be documented for the benefit of review agencies.

Broadly speaking, data sources for these inputs range from those that are fairly easy to acquire from local data or knowledge to those that may require specialized surveys or field data collection. In the absence of local data, informed assumptions based on practitioner knowledge can be used. Default values should only be used if local-specific values are not available, too costly, or difficult to collect. The Texas Department of Transportation (TxDOT), metropolitan planning organizations (MPOs), transit agencies, city departments of transportation (DOTs), and other local agencies are all valuable sources of data and information. TxDOT, for example, performs local traffic counts statewide and is a valuable source of basic traffic volume information. City DOTs and MPOs may also have traffic volume data. Other important sources of data include regional travel demand model outputs, other traffic analysis data, census data, and local travel surveys. EPA's current emissions model (MOVES) can provide emissions factors needed for many of the emissions-related variables. The final unit of measure for each strategy is grams per day.

1.0 Improved Public Transit

Programs for improved public transit.
Section 108 (i), CAAA

Introduction

Improving public transit involves implementation of new or expanded public transit services or facilities. The improvements may be accomplished for all transit modes such as buses, light and heavy rail, and paratransit.

Main Components

- *System/service expansion projects* attempt to increase ridership by providing new rail system services and/or expanding bus services. For buses, the number of routes can be increased, higher service frequencies can be implemented, or routes can be extended to reflect new development. Express bus services can be an alternative to single occupancy vehicles (SOVs) by providing faster routes between suburban communities and downtown areas. In some cities, bus lanes on main highways enable people to save both time and money in their commute to work. In the rail system category, there are four major types of transit services:
  - Heavy rail rapid transit is characterized by high speeds (more than 70 mph) and high capacity (between 20,000 and 34,000 passengers per hour), and is considered to be most efficient when serving areas with more than 50 million square feet of nonresidential development.
  - Light rail transit systems are designed for medium capacity (ranging from 2,000 to 20,000 passengers per hour) and less developed urban areas.
  - Commuter rail is characterized by high-speed, station-to-station service and is designed to transport people from suburbs to downtown areas.
  - Fully automated rail systems circulate within urban areas and allow people easier access to congested facilities such as downtown areas or airports.
- *System/service operational improvements* focus on geographic coverage and scheduling changes that make mass transit a more attractive option to residents and commuters. Improved transfer procedures between transportation modes such as car/transit, pedestrian/transit, and bicycle/transit may encourage increased ridership on public transportation. An improved fleet maintenance program increases the efficiency of system operations and projects a perception of reliability to commuters.
- *Inducements* to potential transit users include:

- Improvements in fare structures and policies that include monthly or weekly passes, fare simplification (i.e., multiple operators accepting one fare medium), and fare reductions;
- Marketing programs that include customer service and intense marketing of transit services; and
- Passenger amenities that include provision of transit shelters, benches, maps, visually pleasing aesthetics, and improved comfort of buses and trains.

According to the EPA, air quality benefits from improving public transit are not difficult to estimate relative to other MOSERS because the number of new passengers utilizing the improved transit system can be easier to quantify. This information provides a basis for estimates of the number of vehicles, miles traveled, and air emissions reduced.

Other Considerations

There are several things to consider when considering improving public transit as an air emission reduction measure:

- Implementing changes to mass transit systems often requires substantial up-front investment of government resources. Projects may be extremely costly if they are capital intensive and rely on infrastructure changes. Many urban rail systems have cost several billion dollars to plan, design, construct, and implement, and may take a long time before they are fully operational. Timelines are very important since measures in an SIP must be funded and implemented in a timely manner. Nonattainment areas attempting to implement major transit projects into their air quality programs without adequate political and financial support may run into problems. At the other end of the cost range, system operational improvements and public awareness programs are less expensive. Improving bus shelters, instituting regional fare structures, and using better signage are examples of effective improvements that cost much less than the capital-intensive examples mentioned above.
- Improving transit systems is a complex process because of the extensive planning and coordination required.
    - Prior to extending rail or bus service, transportation departments need to secure adequate funding. This is often difficult because voter approval or permission from the state legislature is usually required.
    - To ensure the effectiveness of a public transit project, land use patterns in the region must be considered. For example, transit services should be designed in conjunction with urban development plans to ensure that new development is served by transit. Additional considerations should be made to provide minimal walking distances to transit corridors and adequately controlled parking. Transit expansions should be part of a larger, more complex urban design project.

Once projects are completed, aggressive marketing strategies should be initiated to encourage public utilization of the new or improved system. Improved public transit may not create immediate increased ridership despite the public awareness campaigns. Attempting to change people's behavior and attitude toward daily transportation can be a significant obstacle to a program's success. Public outreach materials and advertisements may be helpful in increasing voluntary ridership, but employer incentives are more likely to be effective.

1.1 System/Service Expansion

Increase ridership by providing new rail system services and/or expanding bus services.

Description

Expansion of a transit system or service can include the addition of rail services through increased frequency or route extension. Bus or paratransit services can be expanded with new vehicles and/or route extensions.

Application

Large cities or communities with enough population density to support reasonably frequent transit service.

Equation

Daily Emission Reduction (grams/day) = A + B – C – D

$A = VT_{R,\,P} * TEF_{AUTO} + VT_{R,\,OP} * TEF_{AUTO}$

Reduction in auto start emissions from trips reduced

$B = VMT_{R,\,P} * EF_{AUTO,\,P} + VMT_{R,\,OP} * EF_{AUTO,\,OP}$

Reduction in auto running exhaust emissions from VMT reductions

$C = VT_{BUS,\,P} * TEF_{BUS} + VT_{BUS,\,OP} * TEF_{BUS}$

Increase in emissions from additional bus starts

$D = VMT_{BUS,\,P} * EF_{BUS,\,P} + VMT_{BUS,\,OP} * EF_{BUS,\,OP}$

Increase in emissions from additional bus running exhaust emissions

Variables	(Unit)	Definitions
$EF_{AUTO, P}$	(grams/mile)	Speed-based running exhaust emission factor for affected roadway before implementation (NO_X, VOC, PM, or CO) during peak hours
$EF_{AUTO, OP}$	(grams/mile)	Speed-based running exhaust emission factor for affected roadway before implementation (NO_X, VOC, PM, or CO) during off-peak hours
$EF_{BUS, P}$	(grams/mile)	Speed-based running exhaust emission factor for transit vehicle (NO_X, VOC, PM, or CO) during peak hours
$EF_{BUS, OP}$	(grams/mile)	Speed-based running exhaust emission factor for transit vehicle (NO_X, VOC, PM, or CO) during off-peak hours
TEF_{AUTO}	(grams/trip)	Auto trip-end emission factor (NO_X, VOC, PM, or CO)
TEF_{BUS}	(grams/trip)	Bus (or other transit vehicle) trip-end emission factor (NO_X, VOC, PM, or CO)
$VMT_{BUS, P}$		VMT by transit vehicle during peak hours
$VMT_{BUS, OP}$		VMT by transit vehicle during off-peak hours
$VMT_{R, P}$		Reduction in automobile VMT during peak hours
$VMT_{R, OP}$		Reduction in automobile VMT during off-peak hours
$VT_{BUS, P}$	(trip)	Vehicle trips by bus or other transit vehicle during peak hours
$VT_{BUS, OP}$	(trip)	Vehicle trips by bus or other transit vehicle during off-peak hours
$VT_{R, P}$	(trip)	Reduction in number of automobile vehicle trips during peak hours
$VT_{R, OP}$	(trip)	Reduction in number of daily automobile vehicle trips during off-peak hours

Source: Texas A&M Transportation Institute

1.2 System/Service Operational Improvements

Increase ridership on existing transit systems.

Description

Operational improvements focus on enhancing the efficiency of a transit system and providing more effective service. These improvements are intended to attract new riders and reduce the number of vehicle trips. Improvements can be made, among others, in scheduling, routes, fleet maintenance programs, geographic coverage, improved mode transfer procedures, and monitoring operations.

Application

Cities and/or corridors with existing transit systems, new land development, limited parking, and heavy or increasing congestion.

Equation

$$\text{Daily Emission Reduction (grams/day)} = A + B - C - D$$

$$A = VT_{R,\ P} * TEF_{AUTO} + VT_{R,\ OP} * TEF_{AUTO}$$

Reduction in auto start emissions from trips reduced

$$B = VMT_{R,\ P} * EF_{AUTO,\ P} + VMT_{R,\ OP} * EF_{AUTO,\ OP}$$

Reduction in auto running exhaust emissions from VMT reductions

$$C = VT_{BUS,\ P} * TEF_{BUS} + VT_{BUS,\ OP} * TEF_{BUS}$$

Increase in emissions from additional bus starts

$$D = VMT_{BUS,\ P} * EF_{BUS,\ P} + VMT_{BUS,\ OP} * EF_{BUS,\ OP}$$

Increase in emissions from additional bus running exhaust emissions

Variables	(Unit)	Definitions
$EF_{AUTO, P}$	(grams/mile)	Speed-based running exhaust emission factor for affected roadway before implementation (NO_X, VOC, PM, or CO) during peak hours
$EF_{AUTO,OP}$	(grams/mile)	Speed-based running exhaust emission factor for affected roadway before implementation (NO_X, VOC, PM, or CO) during off-peak hours
$EF_{BUS, P}$	(grams/mile)	Speed-based running exhaust emission factor for transit vehicle (NO_X, VOC, PM, or CO) during peak hours
$EF_{BUS, OP}$	(grams/mile)	Speed-based running exhaust emission factor for transit vehicle (NO_X, VOC, PM, or CO) during off-peak hours
TEF_{AUTO}	(grams/trip)	Auto trip-end emission factor (NO_X, VOC, PM, or CO)
TEF_{BUS}	(grams/trip)	Bus (or other transit vehicle) trip-end emission factor (NO_X, VOC, PM, or CO)
$VMT_{BUS, P}$		VMT by transit vehicle during peak hours
$VMT_{BUS, OP}$		VMT by transit vehicle during off-peak hours
$VMT_{R, P}$		Reduction in automobile VMT during peak hours
$VMT_{R, OP}$		Reduction in automobile VMT during off-peak hours
$VT_{BUS, P}$		Vehicle trips by bus or other transit vehicle during peak hours
$VT_{BUS, OP}$		Vehicle trips by bus or other transit vehicle during off-peak hours
$VT_{R, P}$	(trip)	Reduction in number of automobile vehicle trips during peak hours
$VT_{R, OP}$	(trip)	Reduction in number of daily automobile vehicle trips during off-peak hours

Source: Texas A&M Transportation Institute

1.3 Marketing Strategies

Increase ridership by enhancing market demand for transit services.

Description

Marketing programs attempt to increase demand for a transit system. Programs can include improvements in fare structures and policies such as monthly or weekly passes, fare simplification (i.e., multiple operators accepting one fare medium), and fare reductions. Transit operators can promote customer service programs that enhance responsiveness to passenger concerns. Operators can also add or improve passenger amenities such as provision of transit shelters, benches, maps, visually pleasing aesthetics, and improved comfort of buses and trains. This strategy excludes adding more transit vehicles as a result of ridership increase. If additional buses are needed, use the equation in Section 3.1.

Application

Cities with existing and proposed transit systems.

Equation

Daily Emission Reduction (grams/day) = A + B

$A = VT_R * TEF_{AUTO}$

Reduction in auto start emissions from trips reductions

$B = VMT_R * EF_B$

Reduction in auto running exhaust emissions from trip reductions

$VT_R = N_{TR} * F_{T, SOV}$

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

$VMT_R = VT_R * TL_W$

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

Variables	(Unit)	Definitions
EF_B	(grams/mile)	Speed-based running exhaust emission factor before implementation (NO_X, VOC, PM, or CO)
$F_{T, SOV}$	(percent)	Percentage of people using a transit vehicle that previously were vehicle drivers
N_{TR}		New transit ridership
TEF_{AUTO}	(grams/trip)	Auto trip-end emission factor (NO_X, VOC, PM, or CO)
TL_W	(mile)	Average auto trip length
VMT_R		Reduction in daily automobile VMT
VT_R	(trip)	Reduction in number of daily automobile vehicle trips

Source: CalTrans

2.0 High-Occupancy Vehicle Facilities

Restriction of certain roads or lanes to, or construction of such roads or lanes for use by, passenger buses or high-occupancy vehicles.
Section 108 (ii), CAAA

Introduction

According to EPA, high-occupancy vehicle (HOV) lanes are one of the most frequently implemented mobile source emission reduction measures. HOV lanes are designated exclusively for use by vehicles with multiple occupants such as carpools, vanpools, and transit vehicles. Implementing HOV facilities can involve adding entirely new capacity or reallocating existing capacity. Along with a range of physical options, HOV facilities have operative options such as full-time HOV-only use, peak time use, and reversing the travel direction of facilities during peak times. HOV lanes can increase transit use and car occupancy for work-related trips in congested urban travel corridors.

Main Components

The most effective HOV lane improvements generally involve regional networks of linked lanes, with a system of supporting facilities and services. Historically, the most successful HOV applications have been along “radial” corridors into major central cities where HOV users can save at least 10 minutes of travel time compared to using mixed-traffic lanes. EPA studies show that HOV lanes are generally more effective if implemented along with transit improvements, park-and-ride facilities, employer-based transportation programs, and commuter parking subsidies.

Because of substantial physical and financial requirements, state departments of transportation (DOTs) usually are the agencies to implement HOV lanes. Historically, the EPA has found the typical time frame for implementing HOV lanes is three to eight years for planning, design, and construction. Private or nonprofit authorities may construct and operate HOV facilities along toll roads (high-occupancy toll [HOT] lanes). Operators can use discriminatory pricing strategies such as granting toll discounts to HOVs to promote utilization.

Potential land acquisition often determines feasibility and the time required to implement the project. Also, HOV project planning and design is a political process involving various parties, including political leaders, business groups, and citizen groups. Discussions and negotiation among them, while very important, may add time to the project.

HOV projects can be very expensive, depending on such factors as right-of-way acquisition or cost of land, bridge and overpass modifications, and interchange and ramp modifications to provide access. Total costs of some HOV projects have exceeded several hundred million dollars.

HOV impacts on air quality are fairly complex, but Los Angeles, San Francisco, Washington, D.C., and Portland have documented emissions impacts from their HOV projects. Assessments of the effectiveness of HOV lane facilities in reducing system-wide emissions have generally found reductions amounting to less than 1 percent.

HOV lanes reduce air pollution emissions by reducing running and trip-end emissions. Reductions in running emissions are derived by increasing average speeds from low speeds in congested traffic to 50 mph in HOV lanes, and increasing the use of buses, vanpools, and carpools results in less VMT. If riders do not take additional trips, HOV lanes will also reduce trip-end emissions. However, if users of HOV lanes meet their pool or bus through a park-and-ride arrangement, these trip-end emissions may offset the reduced air emissions benefits. When calculating the effectiveness of HOV lanes in reducing emissions, trip-end emissions resulting from using linkages must be considered.

Other Considerations

Two important factors in implementing a successful HOV program have been identified. Enforcement is critical. EPA studies show that early and substantial enforcement of HOV rules on a new facility is the best determinant of long-term public compliance. Also, education and marketing programs that promote the benefits and use of the HOV facilities, both during and after construction, increase the potential for users of the facility.

2.1 Freeway HOV Facilities

Reduce emissions by decreasing VMT and increase average speeds on the lane.

Description

Separate lanes on controlled access highways are created for vehicles containing a specified minimum number of passengers. The lane may be concurrent flow, be barrier/buffer separated, or have a separate right-of-way.

Application

Highways in areas of traffic congestion with sufficient available right-of-way.

Equation

Daily Emission Reduction (grams/day) = A + B + C + D

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

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

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

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

$$C = VT_R * TEF_{AUTO}$$

Reduction in auto start exhaust emissions from trip reductions

$$D = VMT_R * EF_B$$

Reduction in auto running exhaust emissions from trip reductions

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

Number of HOV users multiplied by the sum of the fraction of users selecting transit multiplied by the percentage that previously drove single-occupant vehicles added to the fraction of users selecting ridesharing multiplied by the percentage that previously drove single-occupant vehicles multiplied by the percentage of rideshare users that are passengers

$$VMT_R = VT_R * TL_W$$

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

Variables	(Unit)	Definitions
AVO_{RS}	(persons/vehicle)	Average vehicle occupancy of rideshare
EF_{B}	(grams/mile)	Speed-based running exhaust emission factor for affected roadway before implementation (NO_X, VOC, PM, or CO)
$EF_{GP, A}$		Speed-based running exhaust emission factor on general purpose lanes after implementation of HOV facility (NO_X, VOC, PM, or CO) (estimate)
$EF_{H, A}$		Speed-based running exhaust emission factor on HOV facility (NO_X, VOC, PM, or CO) (estimate)
F_{RS}	(percent)	Percentage of people attracted to the HOV facility using rideshare
$F_{RS, SOV}$	(percent)	Percentage of people attracted to the HOV facility using rideshare that previously were vehicle drivers
F_{T}	(percent)	Percentage of people attracted to the HOV facility using a transit vehicle
$F_{T, SOV}$	(percent)	Percentage of people using a transit vehicle that previously were vehicle drivers
L	(mile)	Length of HOV facility
N_{P}		Total number of expected people using the HOV lanes per day
N_{PH}		Number of peak hours (AM and/or PM)
TEF_{AUTO}	(grams/trip)	Auto trip-end emission factor (NO_X, VOC, PM, or CO)
TL_{W}	(mile)	Average auto trip length
$V_{GP, A}$		Average hourly volumes on general purpose lanes during peak hours after implementation of HOV facility
$V_{GP, B}$		Average hourly volumes on general purpose lanes during peak hours before implementation of HOV facility
$V_{H, A}$		Average hourly volumes on HOV lanes during peak hours
VMT_{R}		Reduction in daily automobile VMT
VT_{R}		Reduction in number of daily automobile vehicle trips (estimate)

Source: CalTrans (adapted by Texas A&M Transportation Institute)

2.2 Arterial HOV Facilities

Reduce emissions by decreasing VMT and increasing average speeds on the lane.

Description

Separate lanes on controlled access highways are created for vehicles containing a specified minimum number of passengers. The lane may be concurrent flow, be barrier/buffer separated, or have a separate right-of-way.

Application

Roadways in areas of traffic congestion with sufficient available right-of-way.

Equation

Daily Emission Reduction (grams/day) = A + B + C + D

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

Change in running exhaust emissions from vehicles shifting to HOV lane

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

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

$$C = VT_R * TEF_{AUTO}$$

Reduction in auto start exhaust emissions from trip reductions

$$D = VMT_R * EF_B$$

Reduction in auto running exhaust emissions from trip reductions

$$VT_R = N_P * (F_T * F_{T,SOV} + F_{RS} * F_{RS,SOV}) * 2 \text{ trips/day}$$

Number of HOV users multiplied by the sum of the fraction of users selecting transit multiplied by the percentage that previously drove SOVs added to the fraction of users selecting ridesharing multiplied by the percentage that previously drove single-occupant vehicles multiplied by two trips per day (round trip)

$$VMT_R = VT_R * TL_W$$

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

Variables	(Unit)	Definitions
EF_B	(gram/mile)	Speed-based running exhaust emission factor before implementation (NO_X, VOC, PM, or CO)
$EF_{GP, A}$		Speed-based running exhaust emission factor after implementation of HOV facility (general purpose lanes) (NO_X, VOC, PM, or CO) (estimate)
$EF_{H, A}$		Speed-based running exhaust emission factor on HOV facility (NO_X, VOC, PM, or CO) (estimate)
F_{RS}	(percent)	Percentage of people attracted to the HOV facility using rideshare
$F_{RS, SOV}$	(percent)	Percentage of people attracted to the HOV facility using rideshare that previously were vehicle drivers
F_T	(percent)	Percentage of people attracted to the HOV facility using a transit vehicle
$F_{T, SOV}$	(percent)	Percentage of people using a transit vehicle that previously were vehicle drivers
L	(mile)	Length of HOV facility
N_P		Total number of expected people using the HOV lanes per day
N_{PH}		Number of peak hours (AM and/or PM)
TEF_{AUTO}	(grams/trip)	Auto trip-end emission factor (NO_X, VOC, PM, or CO)
TL_W	(mile)	Average auto trip length
$V_{GP, A}$		Average hourly volumes on general purpose lanes during peak hours after implementation of HOV facility
$V_{GP, B}$		Average hourly volumes on general purpose lanes during peak hours before implementation of HOV facility
$V_{H, A}$		Average hourly volumes on HOV lanes during peak hours
VMT_R		Reduction in daily automobile VMT
VT_R	(trip)	Reduction in number of daily automobile vehicle trips (estimate)

Source: CalTrans (Texas A&M Transportation Institute)

2.3 Parking Facilities at Entrances to HOV Facilities

Reduce VMT.

Description

The transfer point between vehicle and HOV is made more efficient by constructing park-and-ride facilities at entrances to HOV facilities.

Application

Cities with HOV facilities and sufficient public transit systems. Planners should be cautious to avoid double-counting of benefits. Analyze parking related to new use of the HOV facility.

Equation 1

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

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

Variables	(Unit)	Definitions
EF_B	(grams/mile)	Speed-based running exhaust emission factor before implementation (NO_x , VOC, or CO)
N_{PK}		Number of parking spaces
U_P		Parking facility utilization rate (estimate)
TL_{PR}	(mile)	Average auto trip length from home to parking facility
TL_W	(mile)	Average length of affected auto trips

Source: Texas A&M Transportation Institute

For Long Waiting or Change Vehicle

Equation 2

$$\text{Daily Emission Reduction (grams/day)} = N_{PK} * U_P * (TL_W - TL_{PR}) * EF_B * 2 \text{ trips/day} - (N_{PK} * U_P / OCC) * TEF_{AUTO} * 2 \text{ trips/day}$$

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

Variables	(Unit)	Definitions
EF_B	(grams/mile)	Speed-based running exhaust emission factor before implementation (NO_X, VOC, PM, or CO)
N_{PK}		Number of parking spaces
U_P		Parking facility utilization rate (estimate)
TL_{PR}	(mile)	Average auto trip length from home to parking facility
TL_W	(mile)	Average length of affected auto trips
TEF_{AUTO}	(grams/trip)	Auto trip-end emission factor (NO_X, VOC, PM, or CO)
OCC_{HOV}	(persons/vehicle)	Average vehicle occupancy on HOV lanes

Source: Texas A&M Transportation Institute

For Short Waiting

Equation 3

$$\text{Daily Emission Reduction (grams/day)} = N_{PK} * U_P * (TL_W - TL_{PR}) * EF_B * 2 \text{ trips/day} - (N_{PK} * U_P / OCC) * EF_I * t * 2 \text{ trips/day}$$

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

Variables	(Unit)	Definitions
EF_B	(grams/mile)	Speed-based running exhaust emission factor before implementation (NO_X, VOC, PM, or CO)
EF_I	(grams/hour)	Idling emission factor (NO_X, VOC, PM, or CO)
N_{PK}		Number of parking spaces
U_P		Parking facility utilization rate (estimate)
TL_{PR}	(mile)	Average auto trip length from home to parking facility
TL_W	(mile)	Average length of affected auto trips
OCC_{HOV}	(persons/vehicle)	Average vehicle occupancy on HOV lanes
t	(hour)	Average waiting time at park and ride facility

Source: Texas A&M Transportation Institute

2.4 SOV Utilization of HOV Lanes

Reduce emissions by increasing average speed on the main lanes of a controlled access highway with an existing HOV facility.

Description

Areas can increase utilization of their HOV lanes by permitting SOVs to use the facility for a fee. The strategy will reduce the number of vehicles on the main lanes of the highway, leading to an increase in the average speed along the highway from the reduced congestion. SOVs may be allowed to use the HOV facility at certain times (peak hours) or throughout the day.

Application

Congested highways with existing HOV lanes operating under capacity.

Equation

Daily Emission Reduction (grams/day) = A – B

$$A = VMT_{GP,B} * EF_{GP,B} + VMT_{H,B} * EF_{H,B}$$

The running exhaust emissions of the affected highway before implementation of the strategy for both the general purpose and HOV lanes

$$B = VMT_{GP,A} * EF_{GP,A} + VMT_{H,A} * EF_{H,A}$$

The running exhaust emissions of the affected highway after implementation of the strategy for both the general purpose and HOV lanes

$$VMT_{GP,A} = VMT_{GP,B} - (VMT_{GP,B} * \epsilon)$$

The expected VMT on the general purpose lane after implementation is equal to the VMT of the lanes before implementation multiplied by the price elasticity subtracted from the VMT before implementation

$$VMT_{H,A} = VMT_{H,B} - (VMT_{H,B} * \epsilon)$$

The expected VMT on the HOV lane after implementation is equal to the VMT of the HOV lane before implementation multiplied by the price elasticity subtracted from the VMT before implementation

Variables	(Unit)	Definitions
$EF_{GP, A}$	(grams/mile)	Speed-based running exhaust emissions factor on general purpose lanes after implementation (NO_X, VOC, PM, or CO)
$EF_{GP, B}$	(grams/mile)	Speed-based running exhaust emissions factor on general purpose lanes before implementation (NO_X, VOC, PM, or CO)
$EF_{H, A}$	(grams/mile)	Speed-based running exhaust emissions factor on HOV lane after implementation (NO_X, VOC, PM, or CO)
$EF_{H, B}$	(grams/mile)	Speed-based running exhaust emissions factor on HOV lane before implementation (NO_X, VOC, PM, or CO) (grams/mile)
$VMT_{GP, A}$		VMT on general purpose lanes after implementation (estimate)
$VMT_{GP, B}$		VMT on general purpose lanes before implementation
$VMT_{H, A}$		VMT on HOV lane after implementation (estimate)
$VMT_{H, B}$		VMT on HOV facility before implementation of strategy
ϵ		Price elasticity of volume change due to facility charge

Source: Houston-Galveston Area Council

3.0 Employer-Based Transportation Management Programs

Employer-based transportation management programs, including incentives.
Section 108 (iii), CAAA

Introduction

Employer-based transportation management programs principally serve home-to-work trips in urban areas with populations of 250,000 or more. Primarily large employers, i.e., those having more than 100 employees at a single work site, have used employer-based transportation management programs. Employers provide information and incentives for employees who pool or use alternative forms of transportation for their daily commute.

Because home-to-work/work-to-home trips account for only 25 to 33 percent of all peak period trips made in most urban areas, the impact of commute management on area-wide VMT is limited. However, the commuter market represents the best potential for grouping riders, removing vehicle trips, and reducing VMT. Reducing commuter trips not only reduces emissions associated with VMT but also those associated with "cold starts," when commuters set out in the morning, and "hot soaks," when vehicles are parked at work and continue to produce evaporative emissions even after the engines are turned off.

Main Components

The 1990 CAAA required the implementation of employer-based transportation management programs in severe and extreme ozone nonattainment areas. The programs can consist of both voluntary and mandatory measures. According to EPA, a package of various complementary measures produces the greatest impacts. For an individual employer, trip-reduction effects can be seen immediately.

In addition to improving air quality primarily by reduced automobile trips and VMT, employer-based transportation management programs can provide savings benefits in the following areas:

- Vehicle expenses,
- Road construction and operation and maintenance (O&M) costs,
- Expenditures on public services devoted to vehicle traffic, and
- Resource consumption.

Employer-based transportation management programs can be highly cost-effective. Employers incur initial costs to design the program and to develop eligibility requirements for their employees. Monitoring and accounting costs are incurred periodically. Variation in costs of programs is based on the size of the employer, the nature and complexity of programs offered, and the amount of the subsidy offered.

The EPA has identified three types of employer-based transportation management programs with their associated costs:

- *General travel allowance programs* require considerable planning and promotional efforts before implementation, but ongoing administrative costs are relatively small. Employees can use general travel allowances for any transportation mode or for non–transportation purposes. Program monitoring costs are low, and accounting costs are negligible because the allowance is given out to all employees as a bonus. The only significant cost to the employer is the cost of the allowance itself. The cost can be at least partially offset because the reduction in the number of employees needing parking can generate savings in maintenance, monthly parking lease costs, and savings in future capital requirements.
- *Targeted or specific allowance programs*, such as transit and vanpool allowances, require ongoing administrative effort for accounting and monitoring eligibility requirements among employees.
- *Flexible use* of allowances for transportation services provided by many different operators is the largest and most complex program and may cost even more because of greater administrative, monitoring, and accounting needs.

Because employer-based transportation management programs are implemented by private entities, they do not require a substantial investment in government resources. The amount of time required to implement an incentive program is relative to the complexity of the measures offered. Some employer-based transportation management programs can be implemented almost immediately, while others require more time.

One significant concern for practitioners is the long-term sustainability of program impacts. Program effectiveness can diminish if management support or financial commitment wanes, or if employee turnover increases. The EPA has found programs that include financial incentives are more likely to have sustainable results. The following list summarizes three types of financial incentives and their goals:

- *Tax incentives* can allow employers and developers to provide facilities and equipment conducive to ridesharing. They may be in the form of investment tax credits or accelerated depreciation.
- *Subsidy programs* can help initiate a program by providing additional funding to enlist employer involvement and reduce the initial risk for employers in attempting a new program. The goal of the subsidies is for employers to see the benefits of the program and then continue subsidizing on their own to satisfy employee desire for using the program and/or to comply with regional or local mandates. Some subsidy programs target commuters directly when employer involvement is unlikely or impractical. For example, vanpool subsidies tied to corridor reconstruction projects

can aid in the formation of vanpools among commuters using the affected facilities, regardless of their particular job location.

- *Enabling legislation* can eliminate or minimize barriers to widespread implementation of employer-based trip-reduction programs. A legal requirement mandating employer or developer involvement is a powerful determinant of program effectiveness. Mandatory participation is essential to assuring widespread participation by enough employers to have an area-wide impact.

Other Considerations

The EPA has several observations regarding employer-based transportation management programs:

- Employer size and location do not seem to determine program effectiveness. Although downtown settings have an obvious potential to be effective, many successful programs have been located in large suburban activity centers. One possible explanation is that less ridesharing occurs naturally in those areas, which allows the program more opportunities to shift commuters' mode of transportation.
- The costs and benefits of employer-based transportation management programs are more difficult to measure than other mobile source emission reduction strategies. The primary area of uncertainty regarding these programs is the difficulty in determining causality between area-wide promotional efforts and VMT and emission impacts. It is a difficult task to separate out the impacts of these programs above and beyond those reported for employers or to speculate on the increase in VMT or emissions if these programs did not exist.
- It is difficult to separate out the impacts of any single trip-reduction strategy; and the techniques are not strictly additive due to the complementary nature of many strategies. Care must be taken not to double-count the effectiveness of employer-based transportation management programs with the benefits of area-wide rideshare incentives.
- The roles and responsibilities of the various public, nonprofit, and for-profit organizations involved in promoting ridesharing and other travel alternatives within a region need to be carefully delineated so that the various efforts are not perceived as either duplicative or conflicting by employers and individuals.

3.1 Transit/Rideshare Services

Reduce vehicle trips and emissions through increased use of transit, carpooling, or vanpooling.

Description

Employers or groups of employers in activity centers provide transportation service to and from the work site to transit facilities and homes. The services can include subscription buses, midday and park-and-ride shuttles, and guaranteed ride home programs.

Application

Large companies or groups of cooperating businesses.

Equation

Daily Emission Reduction (grams/day) = (A – B) + C – (D + E)

$A = VT_B * TL_B * EF_B$

Auto running exhaust emissions before strategy implementation

$B = VT_A * TL_A * EF_A$

Auto running exhaust emissions after strategy implementation

$C = (VT_B - VT_A) * TEF_{AUTO}$

Reduction in start exhaust emissions from reduction in vehicle trips to/from employment center

$VT_A = N_{VA} * 2 \text{ trips/day}$

$VT_B = N_{VB} * 2 \text{ trips/day}$

Number of vehicles before or after strategy implementation multiplied by two trips per day (round trip)

$D = VT_{BUS} * TL_{BUS} * EF_{BUS}$

Bus running exhaust emissions after strategy implementation

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

Increase in start exhaust emissions from increase in bus trips to/from employment center

Variables (Unit)		Definitions
EF_A	(grams/mile)	Speed-based running exhaust emission factor after implementation (NO_X, VOC, PM, or CO)
EF_B	(grams/mile)	Speed-based running exhaust emission factor before implementation (NO_X, VOC, PM, or CO)
EF_{BUS}	(grams/mile)	Speed-based running exhaust emission factor of buses after implementation (NO_X, VOC, PM, or CO)
N_{VA}		Number of vehicles after implementation
N_{VB}		Number of vehicles before implementation
TEF_{AUTO}	(grams/trip)	Auto trip-end emission factor (NO_X, VOC, PM, or CO)
TEF_{BUS}	(grams/trip)	Auto trip-end emission factor of buses (NO_X, VOC, PM, or CO)
TL_A	(mile)	Average auto trip length after implementation
TL_B	(mile)	Average auto trip length before implementation
TL_{BUS}	(mile)	Average bus trip length
VT_A	(trip)	Vehicle trips after implementation
VT_B	(trip)	Vehicle trips before implementation
VT_{BUS}	(trip)	New bus trips after adding bus service

Source: Texas A&M Transportation Institute

3.2 Bicycle and Pedestrian Programs

Reduce vehicle trips, VMT, and emissions through provision of bicycle and pedestrian support facilities and programs.

Description

Employers provide support facilities and/or services to encourage employees to bicycle or walk to work. The programs include credits to be used toward purchases of bicycles; bonus days off; shower and locker facilities; free reflective vest, helmet, nightlight, and mirror; reduced-cost purchase program for bicycles; onsite bicycle repair shop with mechanics and pick-up service; and forgiveness for occasional tardiness. In a Washington, D.C. area program, employers must provide at least one bicycle for every 50 employees for midday employee business and personal use.

Bicycle and pedestrian programs can be classified in three different TCMs under the 1990 CAAA. In this instance, the program is employer based and is placed in this category. This is a clear example of the overlap found amid the various mobile source emission reduction strategies.

Application

Areas with existing bicycle and/or pedestrian paths that can serve businesses or business centers.

Equation

Daily Emission Reduction (grams/day) = A + B

$$A = VT_R * TEF_{AUTO}$$

Reduction in auto start emissions from trip reductions

$$B = VMT_R * EF_B$$

Reduction in auto running exhaust emissions from trip reductions

$$VT_R = N_{BW} * F_{BW,\,SOV} * 2 \text{ trips/day}$$

Number of bike and pedestrian participants multiplied by the number of participants that previously drove SOVs multiplied by two trips per day (round trip)

$$VMT_R = VT_R * TL_{B,\,BW}$$

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

Variables	(Unit)	Definitions
EF_B	(grams/mile)	Speed-based running exhaust emission factor for the average speed of participants' trip before participating in the bike/pedestrian program (NO_X, VOC, PM, or CO)
$F_{BW, SOV}$	(percent)	Percentage of new cyclists who previously drove an SOV
N_{BW}		Number of participants in the bike/pedestrian program
TEF_{AUTO}	(grams/trip)	Auto trip-end emission factor (NO_X, VOC, PM, or CO)
$TL_{B, BW}$	(mile)	Average length of participants' trip before participating in the bike/pedestrian program (The National Personal Transportation Survey estimated 1.8 miles, yet MPOs may want to use a more regionally significant estimate.)
VMT_R		Reduction in daily auto vehicle miles traveled
VT_R	(trip)	Reduction in number of daily auto vehicle trips

Source: CalTrans/CARB and FHWA Southern Resource Center (modified by Texas A&M Transportation Institute)

3.3 Employee Financial Incentives

Reduce SOVs for commuting through provision of financial incentives to employees to use transportation alternatives.

Description

Employers can provide direct financial incentives to employees to use alternative forms of transportation in their commute. Carpooling, transit use, parking cash-out programs and parking subsidies for HOV lane users are examples of these types of incentives.

Application

Measure can be used in conjunction with carpool/vanpool programs or matching services in areas with adequate public transit and in areas with controlled or limited parking.

Equation

Daily Emission Reduction (grams/day) = A + B

$A = VT_R * TEF_{AUTO}$

Reduction in auto start emissions from trip reductions

$B = VMT_R * EF_B$

Reduction in auto running exhaust emissions from trip reductions

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

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

$VT_R = N_P * 2$ trips/day

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

$VMT_R = VT_R * TL_W$

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

Variables	(Unit)	Definitions
EF_B	(grams/mile)	Speed-based running exhaust emission factor before implementation (NO_X, VOC, PM, or CO)
$F_{BW, SOV}$	(percent)	Percentage of new participants in the bike/pedestrian programs who previously drove SOVs
$F_{RS, SOV}$	(percent)	Percentage of new participants in the rideshare programs who previously drove SOVs
$F_{T, SOV}$	(percent)	Percentage of new participants using transit facilities who previously drove SOVs
N_{BW}		Number of participants in bike/pedestrian programs
N_P		Total number of participants (estimate)
N_{RS}		Number of participants in rideshare programs
N_T		Number of participants using transit facilities
TEF_{AUTO}	(grams/trip)	Auto trip-end emission factor (NO_X, VOC, PM, or CO)
TL_W	(mile)	Average auto trip length
VMT_R		Reduction in daily auto vehicle miles traveled
VT_R	(trip)	Reduction in number of daily vehicle trips

Source: Texas A&M Transportation Institute

4.0 Trip-Reduction Ordinances

Trip-reduction ordinances.
Section 108 (iv), CAAA

Introduction

Trip-reduction ordinances (TROs) consist of regulations or similar measures requiring implementation of other mobile source emission reduction strategies. TROs may specify emission reduction strategies or simply require a set reduction in VMT, trips, or other measure of reduced travel.

TROs are applied in a variety of ways, depending upon the needs of a particular locality. The focus of these ordinances has been to encourage socially beneficial travel choices rather than controlling traveler behavior. Most TROs, therefore, offer a range of travel options, but the individual traveler's choice is voluntary. The most successful programs incorporate agencies, employees, and developers into the creation of TROs.

TROs have existed for well over a decade, with most early examples appearing in California. Due to a history of congestion and air quality problems, state legislative actions, and the interaction of CAAA requirements with the nonattainment status of its major urban areas, California remains the state with the most significant experience with TROs.

Main Components

TROs are applicable in large metropolitan areas and surrounding suburbs. Most measures are geared toward companies or developments of a minimum size. This size restriction reduces hardships on small companies and limits enforcement costs for the jurisdiction. The criterion often used for companies is the number of employees at a location. A TRO usually specifies that if a company has greater than the threshold number of employees (e.g., more than 50), it must begin complying with measures of the local TRO. In some jurisdictions, multiple thresholds exist. For example, a company with 50 employees might only have to provide preferred parking for carpools, while a company with 500 employees would be expected to provide a shuttle to the local subway station. Developers of residential, commercial, or mixed-use properties may be forced to adopt a series of measures, depending on the size of the facility. For example, a developer may need to provide vanpool parking if the office complex being built exceeds a certain size (e.g., 25,000 square feet) or if it will house more than a given number of workers.

Enforcement is another aspect of TROs that needs to be taken into consideration. Some TROs are purely voluntary, relying on the good will of businesses in achieving trip-reduction goals. In areas where compulsory TROs have been enacted, compliance is unavoidable for employers and developers. While some TROs specify no penalties, the majority of programs specify fines for given periods of noncompliance. Fines in one TRO study varied from $500 per month to $25,000 per day. In Sacramento County, California, noncompliance may be treated as a criminal misdemeanor. However, failing to fully implement TRO measures is rarely treated as a violation. This is especially true for first-time offenders or if the TRO has been recently implemented. Enforcement and punishment are usually reserved for organizations that display willful disregard toward the measure. The spirit of most TROs encourages participation rather than punishment of laggards.

Other Considerations

Some TRO measures affect only new developments/businesses. This leads to older businesses feeling no effects from a regulation, while similar organizations that are new to a community are faced with regulatory compliance efforts. Most TRO regulations, by their nature, affect businesses equally in the community. In most cases, good-faith compliance efforts by most organizations provide the important groundwork to achieve the desired environmental and social benefits, without placing undue burden on any one segment of the economy.

4.1 Negotiated Agreements

Achieve emission reduction goals through negotiation between local authorities and private companies or developers.

Description

Trip-reduction requirements can be used as a bargaining element in negotiations over re-zonings and/or as part of a public-private development agreement. Negotiated agreements allow the trip-reduction program to be formulated to mitigate the emission impacts of the specific project under consideration, but may also lead to considerable variation among the requirements imposed on similar projects.

Application

Large companies and development projects in large metropolitan areas and suburbs.

Equation

$$\text{Daily Emission Reduction (grams/day)} = A + B$$

$A = VT_R * TEF_{AUTO}$

Reduction in auto start emissions from trip reductions

$B = VMT_R * EF_B$

Reduction in auto running exhaust emissions from trip reductions

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

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

$VT_R = N_P * 2 \text{ trips/day}$

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

$VMT_R = VT_R * TL_W$

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

Variables	(Unit)	Definitions
EF_B	(grams/mile)	Speed-based running exhaust emission factor before implementation (NO_X, VOC, PM, or CO)
$F_{BW, SOV}$	(percent)	Percentage of new participants in the bike/pedestrian programs who previously drove SOVs
$F_{RS, SOV}$	(percent)	Percentage of new participants in the rideshare programs who previously drove SOVs
$F_{T, SOV}$	(percent)	Percentage of new participants using transit facilities who previously drove SOVs
N_{BW}		Number of participants in bike/pedestrian programs
N_P		Total number of participants
N_{RS}		Number of participants in rideshare programs
N_T		Number of participants using transit facilities
TEF_{AUTO}	(grams/trip)	Auto trip-end emission factor (NO_X, VOC, PM, or CO)
TL_W	(mile)	Average auto trip length
VMT_R		Reduction in daily auto vehicle miles traveled
VT_R	(trip)	Reduction in number of daily vehicle trips

Source: Texas A&M Transportation Institute

4.2 Trip-Reduction Programs

Achieve emission reduction goals by requiring specific reductions in the number of vehicle trips by employees of large companies.

Description

Trip-reduction programs require employers of specific-size companies to reduce the number of commute trips made by employees. Program goals can be mandatory or voluntary for employers. The program encourages use of alternative modes of travel including ridesharing, transit, walking/bicycling, and telecommuting among employees.

Application

Large companies and development projects in large metropolitan areas and suburbs.

Equation

Daily Emission Reduction (grams/day) = A + B

$A = VT_R * TEF_{AUTO}$

Reduction in auto start emissions from trip reductions

$B = VMT_R * EF_B$

Reduction in auto running exhaust emissions from VMT reductions

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

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

$VT_R = N_P * 2$ trips/day

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

$VMT_R = VT_R * TL_W$

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

Variables	(Unit)	Definitions
EF_B	(grams/mile)	Speed-based running exhaust emission factor before implementation (NO_X, VOC, PM, or CO)
$F_{BW, SOV}$	(percent)	Percentage of new participants in the bike/pedestrian programs who previously drove SOVs
$F_{RS, SOV}$	(percent)	Percentage of new participants in the rideshare programs who previously drove SOVs
$F_{T, SOV}$	(percent)	Percentage of new participants using transit facilities who previously drove SOVs
N_{BW}		Number of participants in bike/pedestrian programs
N_P		Total number of participants
N_{RS}		Number of participants in rideshare programs
N_T		Number of participants using transit facilities
TEF_{AUTO}	(grams/trip)	Auto trip-end emission factor (NO_X, VOC, PM, or CO)
TL_W	(mile)	Average auto trip length
VMT_R		Reduction in daily auto vehicle miles traveled (estimate)
VT_R	(trip)	Reduction in number of daily vehicle trips

Source: Texas A&M Transportation Institute

4.3 Mandated Ridesharing and Activity Programs

Decrease the number of commute trips by employees.

Description

Mandatory ridesharing programs require employers who employ more than a certain number of employees to implement ridesharing and/or related alternative commute programs. The reduction goals can vary according to the specific emission reduction needs of the locality. Program goals can be measured in various ways including improvement in employee average vehicle ridership or a decrease in employee home-based work trips.

Application

Large companies and development projects in large metropolitan areas and suburbs.

Equation

Daily Emission Reduction (grams/day) = A + B – (C + D)

$A = VT_R * TEF_{AUTO}$	
	Reduction in auto start emissions from trip reductions
$B = VMT_R * EF_B$	
	Reduction in auto running exhaust emissions from trip reductions
$C = VT_{BUS} * TEF_{BUS}$	
	Increase in bus start emissions from new bus trips
$D = VMT_{BUS} * EF_{BUS}$	
	Increase in bus running exhaust emissions from new bus trips
$N_P = (N_{RS} * F_{RS, SOV}) + (N_T * F_{T, SOV}) + (N_{BW} * F_{BW, SOV})$	
	Number of rideshare participants previously driving SOVs added to number of transit participants previously driving SOVs added to number of bike and pedestrian participants previously driving SOVs
$VT_R = N_P * 2$ trips/day	
	Number of participants multiplied by two trips per day (round trip)
$VT_{BUS} = N_{BUS} * 2$ trips/day	
	Number of buses multiplied by two trips per day (round trip)
$VMT_R = VT_R * TL_W$	
	The vehicle trips reduced multiplied by the average auto commute trip length
$VMT_{BUS} = VT_{BUS} * TL_{BUS}$	
	The bus trips increased multiplied by the average bus commute trip length

Variables	(Unit)	Definitions
EF_B	(grams/mile)	Speed-based running exhaust emission factor (NO_X, VOC, PM, or CO)
EF_{BUS}	(grams/mile)	Speed-based running exhaust emission factor of buses (NO_X, VOC, PM, or CO)
$F_{BW, SOV}$	(percent)	Percentage of new participants in the bike/pedestrian programs who previously drove SOVs
$F_{RS, SOV}$	(percent)	Percentage of new participants in the rideshare programs who previously drove SOVs
$F_{T, SOV}$	(percent)	Percentage of new participants using transit facilities who previously drove SOVs
N_{BW}		Number of participants in bike/pedestrian programs
N_{BUS}		Number of affected corridors
N_P		Total number of participants
N_{RS}		Number of participants in rideshare programs
N_T		Number of participants using transit facilities
TEF_{AUTO}	(grams/trip)	Auto trip-end emission factor (NO_X, VOC, PM, or CO)
TEF_{BUS}	(grams/trip)	Bus (or other transit vehicle) trip-end emission factor (NO_X, VOC, PM, or CO)
TL_{BUS}	(mile)	Average length of participants' trip before participating in the bike/pedestrian program
TL_W	(mile)	Average auto trip length
VMT_R		Reduction in daily auto vehicle miles traveled
VMT_{BUS}		Vehicle miles traveled by transit vehicle
VT_{BUS}	(trip)	Daily vehicle trips by bus or other transit vehicle
VT_R	(trip)	Reduction in number of daily vehicle trips

Source: Texas A&M Transportation Institute

4.4 Requirements for Adequate Public Facilities

Provide necessary infrastructure to implement emission reduction strategies.

Description

These policies require that adequate public facilities be in place (or at least programmed and funded) before additional development can be approved. They may call for developers to implement specific types of facilities and services (e.g., park-and-ride facilities at all major housing developments, sidewalks and bike paths, onsite transit pass sales, and rideshare matching) and/or may establish performance standards with the means of achieving those standards subject to negotiation.

Application

Large companies and development projects in large metropolitan areas and suburbs.

Equation

$$\text{Daily Emission Reduction (grams/day)} = A + B$$

$$A = VT_R * TEF_{AUTO}$$

Reduction in auto start emissions from trip reductions

$$B = VMT_R * EF_B$$

Reduction in auto running exhaust emissions from trip reductions

$$N_P = (N_{RS} * F_{RS,\,SOV}) + (N_T * F_{T,\,SOV}) + (N_{BW} * F_{BW,\,SOV})$$

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

$$VT_R = N_P * 2 \text{ trips/day}$$

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

$$VMT_R = VT_R * TL_W$$

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

Variables	(Unit)	Definitions
EF_B	(grams/mile)	Speed-based running exhaust emission factor (NO_X, VOC, PM, or CO)
$F_{BW, SOV}$	(percent)	Percentage of new participants in the bike/pedestrian programs who previously drove SOVs
$F_{RS, SOV}$	(percent)	Percentage of new participants in the rideshare programs who previously drove SOVs
$F_{T, SOV}$	(percent)	Percentage of new participants using transit facilities who previously drove SOVs
N_{BW}		Number of participants in bike/pedestrian programs
N_P		Total number of participants
N_{RS}		Number of participants in rideshare programs
N_T		Number of participants using transit facilities
TEF_{AUTO}	(grams/trip)	Auto trip-end emission factor (NO_X, VOC, PM, or CO)
TL_W	(mile)	Average auto trip length
VMT_R		Reduction in daily auto vehicle miles traveled
VT_R	(trip)	Reduction in number of daily vehicle trips

Source: Texas A&M Transportation Institute

4.5 Conditions of Approval for New Construction

Implement mandatory utilization of mobile source emission reduction strategies.

Description

Incorporation of mobile source emission reduction strategies in all new development projects over a certain size as a condition of approval. For example, a construction permit may require establishment of onsite parking spaces for high-occupancy vehicles; an occupancy permit may require an onsite transportation coordinator.

Application

Large companies and development projects in large metropolitan areas and suburbs.

Equation

$$\text{Daily Emission Reduction (grams/day)} = A + B$$

$$A = VT_R * TEF_{AUTO}$$

Reduction in auto start emissions from trip reductions

$$B = VMT_R * EF_B$$

Reduction in auto running exhaust emissions from trip reductions

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

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

$$VT_R = N_P * 2 \text{ trips/day}$$

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

$$VMT_R = VT_R * TL_W$$

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

Variables	(Unit)	Definitions
EF_B	(grams/mile)	Speed-based running exhaust emission factor (NO_X, VOC, PM, or CO)
$F_{BW, SOV}$	(percent)	Percentage of new participants in the bike/pedestrian programs who previously drove SOVs
$F_{RS, SOV}$	(percent)	Percentage of new participants in the rideshare programs who previously drove SOVs
$F_{T, SOV}$	(percent)	Percentage of new participants using transit facilities who previously drove SOVs
N_{BW}		Number of participants in bike/pedestrian programs
N_P		Total number of participants
N_{RS}		Number of participants in rideshare programs
N_T		Number of participants using transit facilities
TEF_{AUTO}	(grams/trip)	Auto trip-end emission factor (NO_X, VOC, PM, or CO)
TL_W	(mile)	Average auto trip length
VMT_R		Reduction in daily auto vehicle miles traveled
VT_R	(trip)	Reduction in number of daily vehicle trips

Source: Texas A&M Transportation Institute

5.0 Traffic Flow Improvements

Traffic flow improvement programs that achieve emission reductions.
Section 108 (v), CAAA

Introduction

Traffic flow improvements include a very wide range of measures for improving the operational efficiency of an intersection or corridor, generating small increases in capacity or delay reduction without the addition of extra lanes or new roads. The logic behind this emission reduction strategy is that reducing congestion and delays will also decrease congestion-related emissions. Traffic flow improvements have been used for decades, with projects becoming increasingly more complex as congestion on U.S. roadways has worsened.

Improvements generally provide a cost-effective method to reduce congestion although their effects on vehicular traffic can be difficult to quantify. Also, once traffic is less congested and flows more efficiently, motorists may increase vehicle trips, leading to increased VMT and increased emissions. *Planners should be aware of the difficulties in quantification of the benefits of the strategy because of the potential increases in VMT*.

Main Components

Strategies to improve traffic flow can be grouped into four general types:

- Traffic signalization,
- Traffic operations,
- Enforcement and management, and
- Intelligent Transportation Systems (ITS).

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

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

Traffic operations describe several types of roadway improvement projects, including:

- Converting two-way streets to one-way operation to improve corridor travel times and increase roadway capacity;
- Restricting left turns on two-way streets as a means of eliminating conflicts with left-turn movements, thereby reducing congestion and delay;
- Separating turning vehicles from through traffic with continuous median strip turn lanes;
- "Channelizing" roadways and intersections (i.e., clearly marking travel lanes and paths with striping and signage to reduce motorist confusion and uncertainty by channeling traffic into the proper position on the street) to improve vehicular flow and capacity; and
- Widening and reconstructing short sections of roadways and intersections to reduce bottlenecks along sections where traffic capacity is below that of the adjacent street (e.g., traffic islands, roundabouts, turning lanes, and signage).

Several types of programs fall under enforcement and management:

- Incident management systems consist of roving tow or service vehicles, motorist aid call boxes, incident teams, signage systems, contingency planning, and improved information availability to consumers through radio and television.
- Ramp metering, a technique for improving traffic flow on freeways, uses signals to regulate traffic entering the highway to pre-timed intervals or to intervals determined by traffic volumes on the ramp or the highway.
- Enforcement of traffic and parking program regulations necessary for individuals to adapt or adhere to particular travel and parking behaviors.

ITS applies information processing, communications technology, advanced control strategies, and electronics to improve the safety and efficiency of a transportation system. In the context of mobile source emission reduction strategies, ITS emphasizes advanced traffic control, incident management, and corridor management. This area includes the following:

- Transportation management centers (TMCs) contain closed-circuit monitors for observing traffic conditions. Cameras are placed along sections of freeways or arterials commonly congested during commute hours. These cameras enable TMC personnel to observe traffic and respond to situations in a timely manner, reducing adverse effects on the commuting traffic. TMCs serve as information and communication conduits between transportation personnel and law enforcement officials.

- The Congestion Management System (CMS), a decision support tool, provides an integrated approach to planning by assessing information on all asset inventories, including condition and operational performance. Designed to assist decision makers in choosing cost-effective strategies and actions, CMS is a systematic approach to improving the efficiency of transportation assets. CMS is a tool for data management, analysis, and deficiency identification for all state highway assets, as well as local roadways. CMS uses historic, current, and forecasted attributes to help identify current and future congested roadways. It also incorporates travel demand forecasting capabilities for urban and rural areas to assess transportation system performance, identifying areas where it is unacceptable. Performance measures with localized thresholds allow CMS to address movement of people, vehicles, and goods based on goals and objectives in specific areas.

Other Considerations

Typically, city and county public works departments implement traffic flow improvements with financial assistance provided by state and federal funding sources. Because these actions facilitate urban driving, there is usually little public opposition, except perhaps for local residents who may object to disruptions caused by construction.

Many small jurisdictions and even some large central cities have limited traffic engineering capabilities and budgets. In those cases, traffic signal management and roadway maintenance and design are often limited to the most basic or rudimentary installation and maintenance functions.

Implementing programs of interrelated traffic flow enhancement strategies can lead to substantial reductions in travel time and delay. Combined with signalization improvements and enforcement, traffic operations can fundamentally affect circulation in a relatively large area, improving system travel speed and efficiency overall. For any improvement to be successful, good coordination must exist between state and local traffic agencies and the police department assigned enforcement responsibilities.

5.1 Traffic Signalization

Decreasing vehicular stops and idling, which would in turn reduce travel times and traffic delays.

Description

Traffic signalization increases the efficiency of traffic flow at intersections by improving interconnection and coordination of signals, leading to reductions in travel times, delay, and stop-and-go driving. Traffic signalization can be as simple as updating equipment and/or software or improving the timing plan.

These projects are generally the most available tool for reducing congestion on local and arterial streets. Significant improvements in travel speed and/or time can be achieved.

Because signal improvements reduce travel times and stop-and-go driving conditions, they can measurably reduce CO and hydrocarbon emissions as well as reduce fuel consumption. The effects on vehicular emissions, however, can be difficult to quantify. Although system-wide air quality benefits might be low, measurable benefits to local air quality and congestion relief are common in downtown areas and major activity sites or corridors.

Traffic signalization improvements may encourage additional traffic, increasing VMT. An increase in VMT along a roadway with improved traffic flow would offset some of the short-term air quality improvements generated by faster, more consistent travel speeds. Also, by reducing travel time on affected corridors, traffic signalization may attract additional vehicles and divert motorists from alternative modes of transportation.

The costs of a traffic signalization program will vary depending on the type of improvement and number of signals involved. Updating a signalized intersection requires a new traffic controller or traffic control software strategy. Timing plan improvements entail a labor-intensive data collection effort to determine new signal timings and subsequent re-timing of signals at each location. Signal coordination and interconnection require cable installation, as well as a series of controllers or a centralized computer-based master control system. To remove signals, a field survey must be performed to substantiate the elimination of the signals. Fieldwork is also necessary to remove the equipment.

Application

Major arterials or high-capacity roadways with uncoordinated traffic signals.

Equation

Daily Emission Reduction (grams/day) = A + B

For corridors

$$A = V_{D,\,P} * (EF_{B,\,P} - EF_{A,\,P}) * L$$

Change in running exhaust emissions from improved traffic flow during the peak period

$$B = V_{D,\,OP} * (EF_{B,\,OP} - EF_{A,\,OP}) * L$$

Change in running exhaust emissions from improved traffic flow during the off-peak period

For individual intersection or grade separation

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

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

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

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

Variables	(Unit)	Definitions
D_A	(hour)	Average vehicle delay at intersection after implementation
D_B	(hour)	Average vehicle delay at intersection before implementation
$EF_{A, OP}$	(grams/mile)	Speed-based running exhaust emission factor during off-peak hours in affected corridor after implementation (NO_X, VOC, PM, or CO)
$EF_{A, P}$	(grams/mile)	Speed-based running exhaust emission factor during peak hours in affected corridor after implementation (NO_X, VOC, PM, or CO)
$EF_{B, OP}$	(grams/mile)	Speed-based running exhaust emission factor during off-peak hours in affected corridor before implementation (NO_X, VOC, PM, or CO)
$EF_{B, P}$	(grams/trip)	Speed-based running exhaust emission factor during peak hours in affected corridor before implementation (NO_X, VOC, PM, or CO)
EF_I	(grams/hour)	Idling emission factor (NO_X, VOC, PM, or CO)
L	(mile)	Length of corridor affected by signalization project
$V_{D, OP}$		Average daily volume for the corridor during off-peak hours
$V_{D, P}$		Average daily volume for the corridor during peak hours

Source: Federal Highway Administration Southern Resource Center & Texas A&M Transportation Institute

5.2 Traffic Operations

Reduce congestion in corridors and intersections, improving traffic speeds and reducing idling times, leading to lower emissions and improved traffic system efficiency.

Description

Traffic operation improvements, similar to traffic signalization improvements (see Section 5.1), primarily focus on reducing congestion on local and arterial streets by improving the system's efficiency. Generally, each action will improve traffic flow and safety. Many roadway changes require only signage and pavement marking changes with little new construction and are relatively quick to implement.

While costs vary, these projects are relatively inexpensive compared to other types of traffic flow solutions. Converting streets to one-way operations or implementing left-turn restrictions at intersections involves installing new signage and possibly removing or relocating existing signs and traffic signals. Implementing a continuous left-turn median lane requires new signage and lane markings and modifications to existing signage and signals. Similarly, improving the channelization of a roadway or intersection requires pavement striping, markings, and signage.

The system-wide air quality benefits are low and difficult to predict. However, in conjunction with their known effectiveness at improving traffic bottlenecks and flow, these programs should provide measurable reductions in localized CO and hydrocarbon emissions. Some EPA case studies cite reductions in CO and VOC emissions and decreasing hours of delay, along with increases in average speed and intersection capacity.

Combined with signalization improvements and enforcement, traffic operations can provide a plan that effectively improves circulation in a relatively large area, resulting in overall advancements in system travel speed and efficiency.

Application

Areas where changes in lane use are permitted, areas with sufficient right-of-way for roadway widening, and areas with adequate right-of-way at corners.

Equation

Daily Emission Reduction (grams/day) = A + B + C

$A = (I_P + I_{OP}) * EF_I$

Change in idling exhaust emissions from improved traffic flow during the peak and off-peak periods

$B = (EF_{B,P} - EF_{A,P}) * VMT_P$

Change in running exhaust emissions from improved traffic flow during the peak period

$C = (EF_{B,OP} - EF_{A,OP}) * VMT_{OP}$

Change in running exhaust emissions from improved traffic flow during the off-peak period

$I_P = (N_{PH} * V_{H,P} * DR_P)/3600$ seconds per hour
$I_{OP} = (N_{OPH} * V_{H,OP} * DR_{OP})/3600$ seconds per hour

Reduction of idling in the peak and off-peak period

$VMT_P = N_{PH} * V_{H,P} * L$
$VMT_{OP} = N_{OPH} * V_{H,OP} * L$

Vehicle miles traveled affected by the strategy in the peak and off-peak periods

Variables	(Unit)	Definitions
DR_{OP}		Estimated delay reduction during off-peak period (seconds)
DR_P		Estimated delay reduction during peak period (seconds)
$EF_{A, OP}$	(grams/mile)	Speed-based running exhaust emission factor during the off-peak period after implementation (NO_X, VOC, PM, or CO)
$EF_{A, P}$	(grams/mile)	Speed-based running exhaust emission factor during the peak period after implementation (NO_X, VOC, PM, or CO)
$EF_{B, OP}$	(g/mile)	Speed-based running exhaust emission factor during the off-peak period before implementation (NO_X, VOC, PM, or CO)
$EF_{B, P}$	(grams/mile)	Speed-based running exhaust emission factor during the peak period before implementation (NO_X, VOC, PM, or CO)
EF_I	(grams/hour)	Idling emission factor (NO_X, VOC, PM, or CO)
I_{OP}	(hour)	Off-peak hour reduction in idling emissions
I_P	(hour)	Peak hour reduction in idling emissions
L	(mile)	Length of affected roadway
N_{OPH}		Number of off-peak hours
N_{PH}		Number of peak hours
$V_{H, OP}$		Number of vehicles that pass through the intersection per hour during the off-peak period
$V_{H, P}$		Number of vehicles that pass through the intersection per hour during the peak period
VMT_{OP}		Off-peak hour reduction in speed emissions
VMT_P		Peak hour reduction in speed emissions

Source: Texas A&M Transportation Institute (modified from CARB and FHWA Southern Resource Center)

5.3 Enforcement and Management

Help reduce congestion and improve travel times on local and arterial roads and highways by consistent enforcement of road facility use and effective incident detection.

Description

Enforcement and management programs provide a variety of tools that, alone or in combination with other measures such as traffic operations and signalization improvements, can provide additional means to improve traffic flow conditions, both locally and at the corridor-wide level.

Many traffic flow improvements involve some modifications of driving behavior by local residents and commuters. As a result, the programs most likely to be successful are those providing the greatest incentives or disincentives to change. Strict enforcement of traffic flow improvements such as restricted left turns and parking limitations, for example, discourages violations. If initial enforcement of the programs is pursued vigorously, it can eventually be relaxed somewhat. Overly restrictive measures should be avoided. Very high fines, for instance, may be unacceptable to most users, fostering general resentment toward the program.

Enforcement and management strategies typically involve a substantial amount of time and planning to implement when compared to signalization or operations improvement programs.

Management measures can implement on-street parking and may involve establishing new no-stopping zones at select locations for the peak period or all day; relocation and consolidation of cab stands, tour bus stops, loading zones, and handicapped parking spaces; and removal of short-term parking meters.

Incident detection programs can significantly reduce the average duration of lane blockages. Roving tow or service vehicles can respond rapidly to traffic blockages. Using a surveillance and management system can increase the percentages of highway sections that are relatively free flowing versus those that are congested. Broad application of ramp metering can significantly benefit regional mobility by increasing average highway speeds, decreasing travel times, and reducing congestion on the corridor.

Enforcement activities feature a highly visible program that includes meter readers, motorcycle police officers, and tow trucks. For example, an intense enforcement policy would reduce the number of illegal long-term parking at metered spaces, increasing curb-side parking capacity, and would also reduce incidences of double parking, improving arterial capacity and decreasing travel times.

Enforcement and management activities impose capital, operating, and maintenance costs. For example, an enforcement program at a specific facility includes the labor costs associated with traffic control officers providing patrols and surveillance of the facility during its operation. Traffic and parking enforcement programs require meter readers, uniformed police officers, and tow trucks. However, the revenue generated by fines usually exceeds costs by a factor of seven or more.

An incident management system entails costs for embedded traffic detectors, changeable message signs, closed-circuit televisions, and central computer control. Metered ramps require additional signals and signage.

Application

Controlled access highways and arterials.

Incident Management

Equation 1

Daily Emission Reduction (grams/day) =

$$E_{REG} * F_{NR} * \sum_{i=1}^{n} F_{Eff\ i} * \left(\frac{ADT_i}{ADT_T} \right)$$

The amount of regional nonrecurring congestion emissions multiplied by the sum of each link's effectiveness and proportion to the total regional average daily traffic (ADT)

Variables	(Unit)	Definitions
ADT_i		Average daily traffic for each affected link
ADT_T	(vehicles/day)	Total average daily traffic for affected system
E_{REG}	(gram)	Regional freeway emissions
$F_{Eff\ i}$		Project effectiveness factor for each affected freeway
F_{NR}	(percent)	Nonrecurring emissions

Ramp Metering

Equation 2

Daily Emission Reduction (grams/day) = A – B

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

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

$B = N_V * t_q * EF_I$

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

Variables	(Unit)	Definitions
EF_A	(grams/mile)	Speed-based running exhaust emission factor for mainline after implementation (NO_X, VOC, PM, or CO)
EF_B	(grams/mile)	Speed-based running exhaust emission factor for mainline before implementation (NO_X, VOC, PM, or CO)
EF_I	(grams/hour)	Idling emission factor (NO_X, VOC, PM, or CO))
L	(mile)	Length of freeway corridor impacted by ramp metering (in hours)
N_V		Number of vehicles using metered ramps
t_q	(hour)	Average time spent in queue waiting to enter freeway
V_A		Average traffic volume per operating period on main lanes after implementing ramp metering
V_B		Average traffic volume per operating period on main lanes before implementing ramp metering

Source: Texas A&M Transportation Institute

5.4 Intelligent Transportation Systems (ITS)

Improve traffic speeds and reduce idling time through advanced traffic control systems and more efficient incident and corridor management.

Description

ITS combines the strengths of regional transportation planning models and traffic simulation models with overall transportation management strategies. It applies information technologies to the effective management of a traffic system and has received greater emphasis as a transportation planning concept since the Intermodal Surface Transportation Efficiency Act (ISTEA).

However, planners should be aware that some ITS methodologies require very detailed input data and complex computer models. Also, ITS entails potentially high costs to plan, implement, and utilize. Implementation of highway information management systems, from conceptual planning to the complete system, can require five to ten years.

Examples of ITS projects include transportation management centers. These centers contain closed-circuit monitors and many other data collection tools to observe traffic conditions. Cameras are placed along portions of freeways or arterials that commonly experience congestion difficulties during commute hours. These cameras enable personnel within the TMC to observe traffic and respond to situations in a timely manner, reducing the adverse effects on commuting traffic. TMCs serve as information and communication conduits between transportation personnel and law enforcement officials.

The Congestion Management System (CMS), a decision support tool, provides an integrated approach to planning by assessing information on all asset inventories, including condition and operational performance. Designed to assist decision makers in choosing cost-effective strategies and actions, CMS is a systematic approach to improving the efficiency of transportation assets. CMS is a tool for data management, analysis, and deficiency identification for all state highway assets as well as local roadways. CMS uses historic, current, and forecasted attributes to support identification of current and future congested roadways. It also incorporates travel demand forecasting capabilities for urban and rural areas to assess transportation system performance and identify areas with unacceptable performance. Performance measures with localized thresholds allow CMS to address movement of people, vehicles, and goods based on goals and objectives of specific areas.

In areas where ITS solutions are being considered and evaluated, researchers have found at least one out of three conditions exists:

- Cooperation and a partnership approach among all agencies involved in operating and enforcing laws on the transportation system.

- Improved communication and coordination across geographic boundaries and between agencies. ITS is a metropolitan and regional solution and requires a high level of cooperation among entities to be effective. ITS cannot be achieved by a single agency.
- Coordinated collection of data and use of information. ITS, especially TMCs, requires a larger amount of data collection, storage, and analysis than many agencies have previously amassed. Integration of the electronic systems that make up the different components is a key issue.

These conditions are considered preliminary but necessary steps that heighten awareness of the benefits of ITS solutions and allow for the consideration of ITS solutions. Without these conditions, planners should be cautious in considering ITS solutions as a MOSERS project in their area.

Application

Controlled-access highways and arterials.

Equation 1

$$\text{Daily Emission Reduction (grams/day)} = \sum_{i=1}^{n}[\mathbf{L}_i * \mathbf{ADT}_i * (\mathbf{EF}_B - \mathbf{EF}_A)_i]$$

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

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

Variables	(Unit)	Definitions
ADT_i		Average daily traffic for each affected roadway
EF_A	(grams/mile)	Speed-based running exhaust emission factor after implementation (NO_X, VOC, PM, or CO)
EF_B	(grams/mile)	Speed-based running exhaust emission factor before implementation (NO_X, VOC, PM, or CO)
L_i	(mile)	Length of each freeway affected by ITS
n		Number of affected corridors

Equation 2

Daily Emission Reduction (grams/day) = A + B + C + D

$A = E_{P} * F_{NR,\,P} * F_{ITS} * F_{EN,\,P}$

Change in emissions from alleviating peak hour nonrecurrent congestion

$B = E_{OP} * F_{OPH} * F_{NR,\,OP} * F_{ITS} * F_{EN,\,OP}$

Change in emissions from alleviating off-peak hour nonrecurrent congestion

$C = E_{P} * F_{ITS} * (1 - F_{NR,P}) * F_{ER,\,P}$

Change in emissions reduced from alleviating peak hour recurrent congestion

$D = E_{OP} * F_{OPH} * F_{ITS} * (1 - F_{NR,\,OP}) * F_{ER,\,OP}$

Change in emissions from alleviating off-peak hour recurrent congestion

Source: Texas A&M Transportation Institute & North Central Texas Council of Governments, 2006

Variables	(Unit)	Definitions
E_{OP}	(gram)	Emissions generated by congestion on affected roadway system during the off-peak period for each pollutant (NO_X, VOC, PM, or CO)
E_P	(gram)	Emissions generated by congestion on affected roadway system during the peak period for each pollutant (NO_X, VOC, PM, or CO)
$F_{EN, OP}$	(percent)	Percent of nonrecurrent congestion eliminated on roadways with ITS deployment, off-peak period
$F_{EN, P}$	(percent)	Percent of nonrecurrent congestion eliminated on roadways with ITS deployment, peak period
$F_{ER, OP}$	(percent)	Percent of recurrent congestion eliminated on roadways with ITS deployment, off-peak period
$F_{ER, P}$	(percent)	Percent of recurrent congestion eliminated on roadways with ITS deployment, peak period
F_{ITS}	(percent)	Percent of roadway system coverage with ITS deployment
$F_{NR, OP}$	(percent)	Percent of roadway system emissions caused by nonrecurring congestion in the off-peak period
$F_{NR, P}$	(percent)	Percent of roadway system emissions caused by nonrecurring congestion in the peak period
F_{OPH}	(percent)	Percent of off-peak hours/emissions affected by ITS deployment

5.5 Railroad Grade Separation

Reduce idling times to lower emissions and improved traffic system efficiency.

Description

Railroad grade separations remove periodic traffic delays on major roadways by raising or lowering either the rail line or the roadway and permitting more efficient flow of traffic at major rail crossings.

This strategy can be a large-scale project and may require high costs in right-of-way and construction. Close cooperation must be gained with the affected railroad company. The system-wide air quality benefits are low and difficult to predict. However, these programs should provide measurable reductions in localized CO and hydrocarbon emissions. Delay time is eliminated at the rail grade separation.

Application

Arterials with delays caused by at-grade rail crossings.

Equation

$$\text{Daily Emission Reduction (grams/day)} = A * B$$

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

The number of vehicles affected by rail crossing delays

$$B = t_C / 2 * EF_I$$

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

Variables	(Unit)	Definitions
EF_I	(grams/hour)	Idling emission factor (NO_X, VOC, PM, or CO)
t_C	(hours/crossing)	Average amount of time rail crossing is closed due to train crossing
t_H	(hour)	Duration of analysis period
$t_{H,C}$		Hours per analysis period roadway is closed due to train crossing
V		Bi-directional arterial volume for analysis period

Source: Texas A&M Transportation Institute

5.6 General Intersection Improvements

Reduce emissions by reducing idling time at intersection with roundabouts.

Description

The general intersection improvements increase the efficiency of traffic flow at intersections by improving roadway capacity and interconnection, leading to reductions in travel times, delay, and stop-and-go driving.

Application

Major Arterials or high-capacity roadways with traffic signals.

Equation

$$\text{Daily Emission Reduction (grams/day)} = A + B$$

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

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

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

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

Variables	(Unit)	Definitions
D_A	(hour)	Average vehicle delay at intersection after implementation
D_B	(hour)	Average vehicle delay at intersection before implementation
EF_I	(grams/hour)	Idling emission factor (NO_X, VOC, PM, or CO)
$V_{D,\,P}$		Average daily volume for the corridor during peak hours
$V_{D,\,OP}$		Average daily volume for the corridor during off-peak hours

Source: Federal Highway Administration Southern Resource Center & Texas A&M Transportation Institute

5.7 Shoulder Lane Application

Reduce emissions by decreasing VMT and increase average speeds on the lane.

Description

Shoulder lanes on controlled access highways are created for vehicles during peak hours when demand heavily exceeds the highway capacity. The approach in this project evaluates the shoulder lane facility improvements that are parallel to a freeway.

Application

Highways in areas of traffic congestion with sufficient available right-of-way.

Equation

Daily Emission Reduction (grams/day) = A + B

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

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

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

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

Variables (Unit)		Definitions
EF_B	(grams/mile)	Speed-based running exhaust emission factor for affected roadway before implementation (NO_X, VOC, PM, or CO)
$EF_{GP, A}$		Speed-based running exhaust emission factor after implementation of HOV facility (general purpose lanes) (NO_X, VOC, PM, or CO) (estimate)
$EF_{S, A}$		Speed-based running exhaust emission factor on shoulder lane facility (NO_X, VOC, PM, or CO) (estimate)
L	(mile)	Length of shoulder lane facility
N_{PH}		Number of peak hours (AM and/or PM)
$V_{GPL, A}$		Average hourly volumes on general purpose lanes during peak hours after implementation of shoulder lane facility
$V_{GPL, B}$		Average hourly volumes on general purpose lanes during peak hours before implementation of shoulder lane facility
$V_{S, A}$		Average hourly volumes on shoulder lanes during peak hours

Source: CalTrans (adapted by Texas A&M Transportation Institute)

5.8 Roundabouts

Reduce emissions by reducing idling time at intersection with roundabouts.

Description

Roundabouts are intersections that circulate traffic flow around a central island with yield on entry traffic control. Roundabouts smooths traffic from all directions with less average time spent on idling, which may lead to less idling emissions.

Application

Arterials or low to medium-capacity roadways with traffic signals or stop signs. Equation is for individual intersections.

Equation

$$\text{Daily Emission Reduction (grams/day)} = A + B$$

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

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

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

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

Variables	(Unit)	Definitions
D_A	(hour)	Average vehicle delay at intersection after implementation
D_B	(hour)	Average vehicle delay at intersection before implementation
EF_I	(grams/hour)	Idling emission factor (NO_X, VOC, PM, or CO)
$V_{D,\,OP}$		Average daily volume for the corridor during off-peak hours
$V_{D,\,P}$		Average daily volume for the corridor during peak hours

Source: Federal Highway Administration Southern Resource Center & Texas A&M Transportation Institute

6.0 Park-and-Ride/Fringe Parking

Fringe and transportation corridor parking facilities serving multiple-occupancy vehicle programs or transit service.
Section 108 (vi), CAAA

Introduction

Park-and-ride/fringe parking facilitates passenger transfer to transit services, carpooling, and vanpooling. The facilities are usually located at key highway interchanges or along heavily traveled corridors remote from the central business district or major activity centers. Their availability promotes the use of transit services and the implementation of rideshare programs.

Main Components

The parking facilities accommodate drivers who wish to use transit or join carpools or vanpools at the facilities to complete their trips to the work site. This results in decreases in the number of vehicles entering congested areas and, as a result, reduces emissions. State or local transportation agencies may informally designate or formally establish these parking facilities.

The costs of this emission reduction strategy are relatively high but not as expensive as HOV facilities. Design and construction of the site and operation and maintenance after it is built are the main investments. Land acquisition costs may be significant, but many facilities are built in system highway or transit right-of-way next to transit stations or centers.

Other Considerations

Key issues in considering park-and-ride and fringe facilities include:

- Consideration of local traffic conditions around potential sites should be given to avoid intensifying local traffic or air quality problems.
- Facilities should have adequate pedestrian and bicycle access.
- Planners should consider the availability of personal services such as banks, cleaners, convenience stores, and daycare at or near the facility.

6.1 New Facilities

Reduce vehicle trips and VMT by enhancements of transit system and ridesharing.

Description

Construction of new park-and-ride facilities in locations remote from the central city area or major business activity centers or on the fringes of major employment centers. Parking facilities or garages are constructed adjacent to or very near transit facilities or heavily traveled corridors. These facilities are designed to be conducive to several modes of transportation including pedestrian and bicycle facilities.

Application

Cities with HOV facilities or public transit systems.

Equation

Daily Emission Reduction (grams/day) = A - B - C

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

Change in idling emissions from reduced vehicle trips of SOV vehicles

$$B = (T_C + T_T + T_V) * EF_I$$

Change in idling emissions from carpool, vanpool and transit vehicles

$$C = (S_C + S_T + S_V) * TEF$$

Change in start emissions from carpool, vanpool and transit vehicles

Variables	(Unit)	Definitions
EF_B	(grams/mile)	Speed-based running exhaust emission factor before implementation (NO_X, VOC, PM, or CO)
EF_I	(grams/hour)	Idling emission factor (NO_X, VOC, PM, or CO)
N_{PK}	(parking spaces)	Number of spaces in parking facility
S_C		Number of SOV vehicle starts of carpool users
S_T		Number of SOV vehicle starts of transit users
S_V		Number of SOV vehicle starts of vanpool users
TEF	(grams/trip)	Auto trip-end emission factor (NO_X, VOC, PM, or CO)
TL_{PR}	(mile)	Average trip length to park-and-ride facility
TL_W	(mile)	Average trip length to work places
T_C		Number of SOV vehicle trips of carpool users
T_T		Number of SOV vehicle trips of transit users
T_V		Number of SOV vehicle trips of vanpool users
U_P	(percent)	Parking facility utilization rate (estimate)

6.2 Improved Connections to Freeway System

Enhance the attraction of using park-and-ride facilities.

Description

A direct connector ramp between park-and-ride facilities and a freeway is an enhancement of the service provided by the parking facility. Some emissions will be reduced as buses, vans, and carpools idle less while waiting to enter and exit the freeway. This strategy serves to enable park-and-ride facilities and improves public transit.

This measure is also more expensive than others. The location of the parking facility relative to the freeway will determine the cost of constructing the ramp. Parking facilities adjacent to highways, requiring little site preparation, should demand less funding than others in more remote locations.

Application

Urban areas with park-and-ride facilities, transit service, and rideshare programs.

Equation

Daily Emission Reduction (grams/day) = A + B

$$A = (VMT_{BUS,B} * EF_B - VMT_{BUS,A} * EF_A) + (VMT_{AUTO,B} * EF_B - VMT_{AUTO,A} * EF_A)$$

Reduction in vehicle running exhaust emissions from improved travel time from park-and-ride facility to freeway entrance

$$B = N_P * F_{AT} * TL_{PR} * EF_B * 2 \text{ trips/day}$$

Reduction in auto running exhaust emissions from a reduction in commute trip length multiplied by two trips per day (round trip)

Variables	(Unit)	Definitions
EF_A	(grams/mile)	Speed-based running exhaust emission factor after implementation (NO_X, VOC, PM, or CO)
EF_B	(grams/mile)	Speed-based running exhaust emission factor before implementation (NO_X, VOC, PM, or CO)
F_{AT}	(percent)	Percentage of participants who previously drove single-occupancy vehicles (SOVs)
N_P		Number of new park-and-ride participants
TL_{PR}	(mile)	Average trip length to park-and-ride facility
$VMT_{AUTO, A}$		Vehicle miles traveled by auto after implementation
$VMT_{AUTO, B}$		Vehicle miles traveled by auto before implementation
$VMT_{BUS, A}$		Vehicle miles traveled by transit vehicle after implementation
$VMT_{BUS B}$		Vehicle miles traveled by transit vehicle before implementation

Source: Texas A&M Transportation Institute

6.3 Onsite Support Services

Reduce VMT through clustering of personal services at park-and-ride/fringe parking facilities.

Description

Park-and-ride/fringe parking facilities that provide personal support services enhance passenger use of the facility. Riders are able to conduct personal business in one place, which reduces VMT.

Some services and amenities provided at park-and-ride/fringe parking facilities include convenience stores, financial services, child-care centers, postal services, laundry/dry cleaning, and food services.

Application

Urban areas with existing park-and-ride/fringe parking facilities.

Equation

Daily Emission Reduction (grams/day) = A + B + C

$$A = (N_{PK} * U_P * F_{USE}) * N_{HBO} * TL_{HBO} * EF_B$$

Reduction in auto running exhaust emissions from a reduction in home-based other trips

$$B = (N_{PK} * U_P * F_{USE}) * N_{HBO} * TEF_{AUTO}$$

Reduction in auto start exhaust emissions from a reduction in home-based other trips

$$C = N_P * F_{AT} * TL_{PR} * EF_B * 2 \text{ trips/day}$$

Reduction in auto running exhaust emissions from a reduction in commute trip length multiplied by two trips per day (round trip)

Variables	(Unit)	Definitions
EF_B	(grams/mile)	Speed-based running exhaust emission factor before implementation (NO_X, VOC, PM, or CO)
F_{AT}	(percent)	Percentage of participants who previously drove SOVs
F_{USE}	(percent)	Percentage of park-and-ride users that utilize the facilities
N_{HBO}		Average number of home-based other trips
N_P		Number of new participants using onsite services at the park-and-ride/fringe parking facilities
N_{PK}		Number of parking spaces
TEF_{AUTO}	(grams/trip)	Auto trip-end emission factor (NO_X, VOC, PM, or CO)
TL_{HBO}	(mile)	Average trip length of home-based other
TL_{PR}	(mile)	Average trip length to facility
U_P		Parking facility utilization rate (estimate)

Source: Texas A&M Transportation Institute

6.4 Shared-Use Parking

Enhance park-and-ride services and subsequent reduced VMT and vehicle trips.

Description

In some urban locations, it may be more cost-efficient for a city to establish park-and-ride service at an existing parking facility. Joint use of parking facilities at shopping malls, theaters, churches, or stadiums can be negotiated with property owners or management companies.

Application

Cities with transit service.

Equation

Daily Emission Reduction (grams/day) =

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

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

Variables	(Unit)	Definitions
EF_B	(grams/mile)	Speed-based running exhaust emission factor before implementation (NO_X, VOC, PM, or CO)
N_{PK}		Number of parking spaces
TL_{PR}	(mile)	Average auto trip length from home to parking facility
TL_W	(mile)	Average auto work trip length
U_P		Parking facility utilization rate (estimate)

Source: Texas A&M Transportation Institute

7.0 Vehicle Use Limitations and Restrictions

Programs to limit or restrict vehicle use in downtown areas or other areas of emission concentration particularly during periods of peak use.
Section 108 (vii), CAAA

Introduction

Vehicle use limitations/restrictions are techniques for restricting the use of certain types of vehicles in a given geographic area or specified time period.

Main Components

There are three major categories of vehicle use restrictions:

- No-drive days
- Control of truck movements, and
- Truck Lane Restrictions

Other Considerations

Although pedestrian and transit malls have been created in many downtown areas in the United States and auto-restricted zones have been used in Europe and Asia, vehicle use limitations and restrictions are still a potentially debatable technique for a local government or agency to implement. All these program types should accommodate the needs of commercial interests requiring accessibility by customers/clients for goods delivery in designated areas. Clear and careful consideration of an area's economic strengths and weaknesses should be made before restricting vehicle use. Regardless of the final policy, alternative means of providing access to, and circulation within, the area affected by the program should be developed.

7.1 No-Drive Days

Reduce vehicle trips and vehicle miles traveled.

Description

No-drive days request or require identified individuals to not operate their vehicles on designated days, reducing the number of vehicles on roads. A particular letter or number on their license plates usually identifies the individuals. The program can be mandatory or voluntary. In the United States, no-drive days are currently all voluntary.

Alternative transportation on no-drive days must be available to drivers and coordinated with the program. This measure may be difficult to initiate without an existing transit system, rideshare, or employer-based programs.

No-drive day programs require significant marketing efforts and cooperation of local media.

Application

Cities or areas that are well served by transit or where alternate transportation is available.

Equation

Daily Emission Reduction (grams/day) = A + B + C

$A = VMT_{R,P} * EF_{B,P}$

Reduction in auto running exhaust emissions resulting from reduced peak period VMT multiplied by the average peak period running exhaust emission factor

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

Reduction in auto running exhaust emissions resulting from reduced off-peak period VMT multiplied by the average off-peak period running exhaust emission factor

$C = (VT_{R,P} + VT_{R,OP}) * TEF_{AUTO}$

Reduction in auto start emissions from trip reductions

$VT_{R,P} = N_V * F_{CND} * F_W * 2 \text{ trips/day}$

The number of vehicles affected by the program multiplied by the compliance rate with the program multiplied by the fraction of vehicle use for commute trips multiplied by two trips per day (round trip)

$VT_{R,OP} = N_V * F_{CND} * (1 - F_W) * N_{NW}$

The number of vehicles affected by the program multiplied by the compliance rate with the program multiplied by the fraction of vehicle use for noncommute trips multiplied by the average number of noncommute auto trips per day

$VMT_{R,P} = VT_{R,P} * TL_W$
$VMT_{R,OP} = VT_{R,OP} * TL_{NW}$

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

Variables	(Unit)	Definitions
$EF_{B, OP}$	(grams/mile)	Speed-based running exhaust emission factor on roadway during off-peak period before no-drive days implemented (NO_X, VOC, PM, or CO)
$EF_{B, P}$	(grams/mile)	Speed-based running exhaust emission factor on roadway during peak period before no-drive days implemented (NO_X, VOC, PM, or CO)
F_{CND}	(percent)	Percent compliance of the no-drive days program
F_W	(percent)	Percentage of participating vehicles commuting to work
N_{NW}		Average number of nonwork trips
N_V		Number of vehicles participating
TEF_{AUTO}	(grams/trip)	Auto trip-end emission factor (NO_X, VOC, PM, or CO)
TL_{NW}	(mile)	Average nonwork trip length
TL_W	(mile)	Average work trip length
$VMT_{R, OP}$		Reduction in regional off-peak period VMT after no-drive days implemented
$VMT_{R, P}$		Reduction in regional peak period VMT after no-drive days implemented
$VT_{R, OP}$	(trip)	Reduction in regional number of off-peak period vehicle trips after no-drive days implemented
$VT_{R, P}$	(trip)	Reduction in regional number of peak period vehicle trips after no-drive days implemented

Source: Texas A&M Transportation Institute

7.2 Control of Truck Movement

Reduce congestion along corridors and reduce idling. Reduce ozone formation through an offset in emission times.

Description

Cities can regulate the movement of trucks within some areas at certain times. 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. However, controlling truck movements requires various legal restrictions that practitioners should definitely consider when proposing such measures. The cooperation and support of the trucking industry are crucial to program success.

Implementation of controls must involve consideration of time periods and routes currently being used for movements, direct costs to businesses for the controls, and indirect costs to the economy for changing truck movement patterns. Therefore, local traffic and economic data are essential to planning controls.

Application

Downtown areas or major business activity centers with alternate freeway and arterial routes available.

Equation

$$\text{Daily Emission Reduction (grams/day)} = \sum (VMT_B * EF_{B.i} - VMT_A * EF_{A.i})$$

The change in running exhaust emissions of trucks on the affected links before control subtracted by the running exhaust emissions of these trucks after control by reroute to alternative routes or reschedule to off-peak period.

Variables	(Unit)	Definitions
$EF_{A,}$	(grams/mile)	Speed-based running exhaust emission factor for fleet composite with time period specific truck mix (NO_X, VOC, PM, or CO)
$EF_{B,}$	(grams/mile)	Speed-based running exhaust emission factor for defined fleet composite with time period specific truck mix (NO_X, VOC, PM, or CO)
i		Time period
VMT_B		Vehicle miles traveled by truck fleet during peak period before control of truck movement
VMT_A		Vehicle miles traveled by truck fleet after control of truck movement

Source: Texas A&M Transportation Institute

7.3 Truck Lane Restrictions

Reduce congestion along corridors and improves operational efficiency.

Description

Transportation agencies can restrict the movement of heavy-duty trucks to two or more designated lanes of a highway. This ensures that at least one of the highway lanes (normally the left lane or inside lane) is used only by passenger vehicles. Trucks are often slower-moving than the passenger vehicles in these lanes. Therefore, controlling truck use of these lanes improves operational efficiency and highway safety. Truck lane restrictions should only be considered where there is a minimum of four percent trucks in the traffic stream over a 24-hour period and when approximately 10 percent of the total truck traffic is currently using the lanes on which the restrictions are to apply.

Application

The roadway section to be restricted should be at least six miles long and should have at least three lanes on each side of the freeway.

For Corridors

Equation

$$\text{Daily Emission Reduction (grams/day)} = A + B + C + D$$

$$A = V_{DA,\ P} * (EF_{B\text{-}Auto,\ P} - EF_{A\text{-}Auto,\ P}) * L$$

Change in auto running exhaust emissions during the peak period

$$B = V_{DA,\ OP} * (EF_{B\text{-}Auto,\ OP} - EF_{A\text{-}Auto,\ OP}) * L$$

Change in auto running exhaust emissions during the off-peak period

$$C = V_{DT,\ P} * (EF_{B\text{-}Truck,\ P} - EF_{A\text{-}Truck,\ P}) * L$$

Change in truck running exhaust emissions during the peak period

$$D = V_{DT,\ OP} * (EF_{B\text{-}Truck,\ OP} - EF_{A\text{-}Truck,\ OP}) * L$$

Change in truck running exhaust emissions during the off-peak period

Variables	(Unit)	Definitions
$EF_{A\text{-}Auto,\ OP}$	(grams/mile)	Speed-based auto running exhaust emission factor during off-peak hours in affected corridor after implementation (NO_X, VOC, PM, or CO)
$EF_{A\text{-}Auto,\ P}$	(grams/mile)	Speed-based auto running exhaust emission factor during peak hours in affected corridor after implementation (NO_X, VOC, PM, or CO)
$EF_{B\text{-}Auto\ OP}$	(grams/mile)	Speed-based auto running exhaust emission factor during off-peak hours in affected corridor before implementation (NO_X, VOC, PM, or CO)
$EF_{B\text{-}Auto,\ P}$	(grams/trip)	Speed-based auto running exhaust emission factor during peak hours in affected corridor before implementation (NO_X, VOC, PM, or CO)
$EF_{A\text{-}Truck,\ OP}$	(grams/mile)	Speed-based truck running exhaust emission factor during off-peak hours in affected corridor after implementation (NO_X, VOC, PM, or CO)
$EF_{A\text{-}Truck,\ P}$	(grams/mile)	Speed-based truck running exhaust emission factor during peak hours in affected corridor after implementation (NO_X, VOC, PM, or CO)
$EF_{B\text{-}Truck,\ OP}$	(grams/mile)	Speed-based truck running exhaust emission factor during off-peak hours in affected corridor before implementation (NO_X, VOC, PM, or CO)
$EF_{B\text{-}Truck,\ P}$	(grams/trip)	Speed-based truck running exhaust emission factor during peak hours in affected corridor before implementation (NO_X, VOC, PM, or CO)
L	(mile)	Length of the roadway(s) implementing truck restriction strategy
$V_{DA,\ OP}$		Average daily auto volume for the corridor during off-peak hours
$V_{DA,\ P}$		Average daily auto volume for the corridor during peak hours
$V_{DT,\ OP}$		Average daily truck volume for the corridor during off-peak hours
$V_{DT,\ P}$		Average daily truck volume for the corridor during peak hours

Source: Texas A&M Transportation Institute
Resource: Truck Lane Pilot Study, https://resources.nctcog.org/trans/goods/trucklane/

8.0 Area-Wide Rideshare Incentives

Programs for the provision of all forms high-occupancy, shared-ride services.
Section 108 (viii), CAAA

Introduction

Area-wide rideshare incentives promote and assist state, regional, and local efforts aimed at encouraging commuters to use alternatives to SOVs in traveling to work and encourage employers to provide in-house programs that promote ridesharing, transit, bicycling, and walking among employees. This strategy facilitates most employer-based transportation management programs and provides another example of the overlap between individual emission reduction strategies. The EPA has found that these programs are effective in enhancing the emission reduction efforts of small- and medium-sized businesses in an area.

Main Components

The three main categories of area-wide rideshare incentives include the following:

- *Commute management organizations* are third-party ridesharing agencies that provide rideshare matching or alternative commute organization or incentive programs. The programs focus largely on employers, given their influence over employee commute and working patterns.
- *Transportation management associations* (TMAs) provide a structure for developers, property managers, employers, and public officials to cooperatively promote programs that mitigate traffic congestion, assist commuters, and encourage particular modes of travel in specific areas. TMAs can also provide government and private industry with a forum for discussion of current and future roadway and transit needs in an area.
- *State and local tax incentive and subsidy programs* provide incentives and disincentives for employers and employees to consider and utilize alternative modes of transportation to commute instead of SOVs.

Other Considerations

The costs and benefits of area-wide rideshare incentive programs are difficult to measure. The EPA has found it difficult to establish causality between area-wide incentives and reduced VMT and emissions. Commute management organizations, TMAs, and state and local tax incentives and subsidies are supportive of in-house employer programs, but the agency has concluded that there appears to be no evaluation that has estimated the impact of these programs above and beyond that attributable to the employer programs. The programs do improve the effectiveness of employer-based ridesharing programs, produce results among unaffiliated commuters, and serve to maintain existing levels of shared ride modes. It is a difficult task to separate the impacts of these programs above and beyond those reported for employers or to speculate on the increase in VMT or emissions if these programs did not exist.

As noted in Section 4 (employer-based transportation management programs), care must be taken not to double-count the effectiveness of area-wide rideshare incentives with the benefits of employer-based transportation management programs. The roles and responsibilities of various public, nonprofit, and for-profit organizations involved in promoting ridesharing and other travel alternatives within a region must be carefully delineated so their various efforts are not perceived as either duplicative or conflicting by employers and individuals.

8.1 Commute Management Organizations

Facilitate and promote ridesharing activities to reduce vehicle trips and VMT.

Description

Commute management organizations are third-party ridesharing agencies that provide rideshare matching or alternative commute organization or incentive programs. The programs focus largely on employers, given their influence over employee commute and working patterns. Organization services can include computerized carpool matching, vanpool managing, and providing vanpool vehicles, marketing, and technical assistance to employers.

Application

Urban areas with populations of 50,000 or more where taxes or other public funding can be obtained for transportation/air quality purposes.

Equation

Daily Emission Reduction (grams/day) = A + B

$$A = \sum VT_R * TEF_{AUTO}$$

Reduction in auto start emissions from trip reductions

$$B = \sum VMT_R * EF_B$$

Reduction in auto running exhaust emissions from trip reductions

$$1 = F_{T,\, SOV} + F_{RS,\, SOV} + F_{BW,\, SOV}$$

The fractions of strategy participants that shift to other modes from single-occupant vehicles

$$VT_{R,\, T} = N_T * F_{T,\, SOV} * 2 \text{ trips/day}$$
$$VT_{R,\, RS} = N_{RS} * (1 - 1 / AVO_{RS}) * F_{RS,\, SOV} * 2 \text{ trips/day}$$
$$VT_{R,\, BW} = N_{BW} * F_{BW,\, SOV} * 2 \text{ trips/day}$$

The number of participants multiplied by the fraction of SOV drivers that switch to another mode multiplied by two trips per day (round trip)

$$VMT_{R,\, T} = VT_{R,\, T} * (TL_W - TL_T)$$
$$VMT_{R,\, RS} = VT_{R,\, RS} * (TL_W - TL_{RS})$$
$$VMT_{R,\, BW} = VT_{R,\, BW} * TL_W$$

The vehicle trip reduction multiplied by the change in average trip length after the mode switch

Variables	(Unit)	Definitions
AVO_{RS}	(person/vehicle)	Average vehicle occupancy of rideshare
EF_B	(grams/mile)	Speed-based running exhaust emission factor before implementation (NO_X, VOC, PM, or CO)
$F_{BW, SOV}$	(percent)	Percentage of new participants in the bike/pedestrian programs who previously drove SOVs
$F_{RS, SOV}$	(percent)	Percentage of new participants in the rideshare programs who previously drove SOVs
$F_{T, SOV}$	(percent)	Percentage of new participants using transit facilities who previously drove SOVs
N_{BW}		Number of participants in bicycle/pedestrian programs
N_{RS}		Number of participants in rideshare
N_T		Number of participants using transit facilities
TEF_{AUTO}	(grams/trip)	Auto trip-end emission factor (NO_X, VOC, PM, or CO)
TL_{RS}	(mile)	Average auto trip length to rideshare facility
TL_T	(mile)	Average auto trip length to transit facility
TL_W	(mile)	Average auto trip length to work
VMT_R		Reduction in daily auto vehicle miles traveled
$VMT_{R, BW}$		Reduction in daily auto vehicle miles traveled by bike/pedestrian mode
$VMT_{R, RS}$		Reduction in daily auto vehicle miles traveled by rideshare mode
$VMT_{R, T}$		Reduction in daily auto vehicle miles traveled by transit mode
VT_R	(trip)	Reduction in number of daily vehicle trips
$VT_{R, BW}$	(trip)	Reduction in number of daily vehicle trips by bike/pedestrian mode
$VT_{R, RS}$	(trip)	Reduction in number of daily vehicle trips by rideshare mode
$VT_{R, T}$	(trip)	Reduction in number of daily vehicle trips by transit mode

Source: CalTrans/CARB (adapted by Texas A&M Transportation Institute)

8.2 Transportation Management Associations

Facilitate efforts by private industry and government to effectively manage local, metropolitan, and county transportation issues.

Description

Transportation management associations are private organizations that provide a structure for developers, property managers, employers, and public officials to cooperatively promote programs that mitigate traffic congestion, assist commuters, and encourage particular modes of travel in specific areas. TMAs can also provide government and private industry with a forum for discussion of current and future roadway and transit needs in an area. TMAs are implemented by private entities and therefore do not require a substantial investment from government resources. California has the largest number of TMAs in the nation.

According to the EPA, TMA development activities can be very time consuming, often requiring one to two years before the TMA is fully operational.

Application

Urban areas with large groups of individual employers.

Equation

Daily Emission Reduction (grams/day) = A + B

$A = \sum VT_R * TEF_{AUTO}$

Reduction in auto start emissions from trip reductions

$B = \sum VMT_R * EF_B$

Reduction in auto running exhaust emissions from trip reductions

$1 = F_{T,\ SOV} + F_{RS,\ SOV} + F_{BW,\ SOV}$

The fractions of strategy participants that shift to other modes from single-occupant vehicles

$VT_{R,\ T} = N_T * F_{T,\ SOV} * 2\ trips/day$
$VT_{R,\ RS} = N_{RS} * (1 - 1/AVO_{RS}) * F_{RS,\ SOV} * 2\ trips/day$
$VT_{R,\ BW} = N_{BW} * F_{BW,\ SOV} * 2\ trips/day$

The number of participants multiplied by the fraction of SOV drivers that switch to another mode multiplied by two trips per day (round trip)

$VMT_{R,\ T} = VT_{R,\ T} * (TL_W - TL_T)$
$VMT_{R,\ RS} = VT_{R,\ RS} * (TL_W - TL_{RS})$
$VMT_{R,\ BW} = VT_{R,\ BW} * TL_W$

The vehicle trip reduction multiplied by the change in average trip length after the mode switch

Variables	(Unit)	Definitions
AVO_{RS}	(person/vehicle)	Average vehicle occupancy of rideshare
EF_B	(grams/mile)	Speed-based running exhaust emission factor before implementation (NO_X, VOC, PM, or CO)
$F_{BW, SOV}$	(percent)	Percentage of new participants in the bike/pedestrian programs who previously drove SOVs
$F_{RS, SOV}$	(percent)	Percentage of new participants in the rideshare programs who previously drove SOVs
$F_{T, SOV}$	(percent)	Percentage of new participants using transit facilities who previously drove SOVs
N_{BW}		Number of participants in bicycle/pedestrian programs
N_{RS}		Number of participants in rideshare
N_T		Number of participants using transit facilities
TEF_{AUTO}	(grams/trip)	Auto trip-end emission factor (NO_X, VOC, PM, or CO)
TL_{RS}	(mile)	Average auto trip length to rideshare facility
TL_T	(mile)	Average auto trip length to transit facility
TL_W	(mile)	Average auto trip length to work
VMT_R		Reduction in daily auto vehicle miles traveled
$VMT_{R, BW}$		Reduction in daily auto vehicle miles traveled by bike/pedestrian mode
$VMT_{R, RS}$		Reduction in daily auto vehicle miles traveled by rideshare mode
$VMT_{R, T}$		Reduction in daily auto vehicle miles traveled by transit mode
VT_R	(trip)	Reduction in number of daily vehicle trips
$VT_{R, BW}$	(trip)	Reduction in number of daily vehicle trips by bike/pedestrian mode
$VT_{R, RS}$	(trip)	Reduction in number of daily vehicle trips by rideshare mode
$VT_{R, T}$	(trip)	Reduction in number of daily vehicle trips by transit mode

Source: CalTrans/CARB (adapted by Texas A&M Transportation Institute)

8.3 Tax Incentives and Subsidy Programs

Use taxes and subsidies to provide disincentives to SOVs and incentives to alternative commute modes, thereby reducing vehicle trips and VMT.

Description

State and local tax incentive and subsidy programs provide incentives and/or disincentives for employers and employees to consider and utilize alternative modes of transportation to commute instead of SOVs.

Three types of financial incentives and their goals are summarized below:

- *Tax incentives* can allow employers and developers to provide facilities and equipment conducive to ridesharing. They may be in the form of investment tax credits or accelerated depreciation of facilities.
- *Subsidy programs* can help initiate a program by providing additional funding to enlist employer involvement and improve the preliminary risk to employers attempting a new program. The goal of the subsidies is for employers to see the benefits of the program and then continue the subsidies on their own to satisfy employee desire and/or to comply with regional or local mandates. Some subsidy programs target commuters directly, when employer involvement is unlikely or impractical. For example, vanpool subsidies tied to corridor reconstruction projects can aid in the formation of vanpools among commuters using the affected facilities regardless of their particular job location.
- *Enabling legislation* can eliminate or minimize barriers to widespread implementation of employer-based trip-reduction programs. A legal requirement mandating employer or developer involvement is a powerful determinant of program effectiveness. Mandatory participation is key to assuring widespread participation by enough employers to have an area-wide impact.

Application

Areas where taxes and public funding can be obtained for this purpose.

Equation

Daily Emission Reduction (grams/day) = A + B

$A = \sum VT_R * TEF_{AUTO}$

Reduction in auto start emissions from trip reductions

$B = \sum VMT_R * EF_B$

Reduction in auto running exhaust emissions from trip reductions

$1 = F_{T, SOV} + F_{RS, SOV} + F_{BW, SOV}$

The fractions of strategy participants that shift to other modes from single-occupant vehicles

$VT_{R, T} = N_T * F_{T, SOV} * 2 \text{ trips/day}$
$VT_{R, RS} = N_{RS} * (1 - 1/AVO_{RS}) * F_{RS, SOV} * 2 \text{ trips/day}$
$VT_{R, BW} = N_{BW} * F_{BW, SOV} * 2 \text{ trips/day}$

The number of participants multiplied by the fraction of SOV drivers that switch to another mode multiplied by two trips per day (round trip)

$VMT_{R, T} = VT_{R, T} * (TL_W - TL_T)$
$VMT_{R, RS} = VT_{R, RS} * (TL_W - TL_{RS})$
$VMT_{R, BW} = VT_{R, BW} * TL_W$

The vehicle trip reduction multiplied by the change in average trip length after the mode switch

Variables	(Unit)	Definitions
AVO_{RS}	(person/vehicle)	Average vehicle occupancy of rideshare
EF_B	(grams/mile)	Speed-based running exhaust emission factor before implementation (NO_X, VOC, PM, or CO)
$F_{BW, SOV}$	(percent)	Percentage of new participants in the bike/pedestrian programs who previously drove SOVs
$F_{RS, SOV}$	(percent)	Percentage of new participants in the rideshare programs who previously drove SOVs
$F_{T, SOV}$	(percent)	Percentage of new participants using transit facilities who previously drove SOVs
N_{BW}		Number of participants in bicycle/pedestrian programs
N_{RS}		Number of participants in rideshare
N_T		Number of participants using transit facilities
TEF_{AUTO}	(grams/trip)	Auto trip-end emission factor (NO_X, VOC, PM, or CO)
TL_{RS}	(mile)	Average auto trip length to rideshare facility
TL_T	(mile)	Average auto trip length to transit facility
TL_W	(mile)	Average auto trip length to work
VMT_R		Reduction in daily auto vehicle miles traveled
$VMT_{R, BW}$		Reduction in daily auto vehicle miles traveled by bike/pedestrian mode
$VMT_{R, RS}$		Reduction in daily auto vehicle miles traveled by rideshare mode
$VMT_{R, T}$		Reduction in daily auto vehicle miles traveled by transit mode
VT_R	(trip)	Reduction in number of daily vehicle trips
$VT_{R, BW}$	(trip)	Reduction in number of daily vehicle trips by bike/pedestrian mode
$VT_{R, RS}$	(trip)	Reduction in number of daily vehicle trips by rideshare mode
$VT_{R, T}$	(trip)	Reduction in number of daily vehicle trips by transit mode

Source: CalTrans/CARB (adapted by Texas A&M Transportation Institute)

9.0 Bicycle and Pedestrian Lanes, Support Facilities, and Programs

Programs to limit portions of road surfaces or certain sections of the metropolitan area to the use of nonmotorized vehicles or pedestrian use, both as to time and place.
Section 108 (ix),

Programs for secure bicycle storage facilities and other facilities, including bicycle lanes, for the convenience and protection of bicyclists, in both public and private areas.
Section 108 (x), CAAA

Programs for new construction and major reconstructions of paths, tracks, or areas solely for the use by pedestrian or other nonmotorized means of transportation when economically feasible and in the public interest. For purposes of this clause, the Administrator shall also consult with the Secretary of the Interior.
Section 108 (xv), CAAA.

Introduction

Bicycling and walking represent viable alternatives to most SOV trips. Every trip shifted from an SOV to a bicycle or walking results in a 100 percent reduction in vehicle emissions for that trip.

Main Components

Bicycle and pedestrian programs can be adapted to a community's characteristics (e.g., topography, population, and existing infrastructure) and the budget of the administering agency. Common types of bicycle and pedestrian facilities include the following:

- Routes, lanes, and paths;
- Sidewalks and walkways;
- Plans and maps;
- Bicycle coordinators;
- Racks and other storage facilities;
- Shower facilities and clothing lockers;
- Connections with transit;
- Ordinances for bicycle parking;
- Education, media, and promotions;
- Sidewalk furniture; and
- Pedestrian safety modifications.

According to the EPA studies, bicycling and walking can substitute for short trips, 5 miles or less in length for bicycle trips and less than one-half mile for walking trips. The amount of VMT reduced may be small, but the air emissions benefits can be much greater because cold-start and hot-soak emissions comprise a large portion of the total emissions per vehicle trip.

Bicycle and pedestrian programs are often packaged with other strategies. The EPA notes that many employers provide bike and pedestrian facilities as part of their employer-based transportation management program. Many public transit improvement plans also support bicycle and pedestrian programs by incorporating elements to improve access to transit facilities. Municipal and regional trip-reduction ordinances can mandate these types of programs. Traffic flow improvements may indirectly support bicycle and pedestrian programs by improving signal intersections and increasing safety for bicyclists and pedestrians.

Costs for developing, maintaining, and operating a bicycle or pedestrian program may include the following:

- Salary and benefits for a program coordinator and staff,
- Land acquisition,
- Bike lane construction,
- Bike path construction,
- Bicycle lockers and racks,
- Publications,
- Signage striping,
- Maintenance,
- Enforcement, and
- Educational materials.

Except for equipment, direct cost to travelers is minimal.

Other Considerations

Three main factors affect the viability of bicycling and walking as alternative transportation:

- Trip distance, defined above as 5 miles or less for bicycles and less than one-half mile for pedestrians,
- Safety, both along the path or lane and at the destination site, and
- Weather conditions, since inclement weather is not conducive to either mode.

The EPA reports that the following local factors help to ensure a successful program:

- Short travel distances between residential areas and key trip attractions;
- High concentrations of people under age 40;
- Compatible infrastructure that can be modified into appropriate facilities;
- Areas with localized congestion or crowded parking facilities; and
- Marketing and education efforts including maps and plans, safety training, promotions, and media events.

Factors that negatively affect bicycle and pedestrian programs are:

- Missing links in the network of lanes and trails,
- Lack of safe routes to work destinations,
- Conflicts with traffic laws that give preference to autos, and
- Lack of facilities to accommodate activities.

9.1 Bicycle and Pedestrian Lanes or Paths

Replace vehicle trips and VMT with bicycle and pedestrian travel.

Description

A large number of bicycle and pedestrian projects are available to practitioners for implementation in air quality mitigation efforts. With ISTEA, the Transportation Equity Act for the 21st Century (TEA-21), and the Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users (SAFETEA-LU), funding for these types of programs has increased dramatically in the last decade. They include:

- Reallocation of right-of-way to accommodate bicycles and pedestrians,
- Traffic calming programs,
- Median refuges at key minor street crossings and bike-friendly signals,
- Independent bicycle/pedestrian structures or those in conjunction with other existing or planned transportation facilities
- New trails, connecting existing trail segments, and encouraging developers to include trails in their developments,
- Improved connections between residential areas and transit stops, providing secure bicycle parking at stops and providing for carrying bicycles on the system,
- On bridges, reallocation of bridge deck width by shifting lane lines, modifying surface for better bicycle stability, modifying ramps to discourage high-speed turning movements, and, as a last resort, developing bicycle connections independent of the bridge in question,
- Safety upgrades at intersections,
- Bicycle-sensitive loop detectors in new installations and existing installations retrofitted where needed,
- Replacing bad drain grate standards with bicycle-safe models, replacing or modifying existing installations, and, as a routine practice, considering bicyclists when locating new utilities,
- Providing smooth paved shoulders on all new construction and reconstruction, and
- Increasing bike parking regularly.

Application

Areas where travel distances (residential/work or retail sites, for example) are short enough for bicycle/pedestrian travel to be practical.

For a Facility Located Parallel to an Existing Roadway

Equation 1

$$\text{Daily Emission Reduction (grams/day)} = AADT * PMS * L * EF_B$$

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

Variables	(Unit)	Definitions
AADT	(vehicles/day)	Average annual daily traffic in corridor
EF_B	(grams/mile)	Speed-based running exhaust emission factor for participants' trip before participating in the bike/pedestrian program (NO_X, VOC, PM, or CO)
L	(mile)	Length of facility
PMS	(percent)	Percentage mode shift from driving to bike/pedestrian
PMS	(percent)	Percentage mode shift from driving to bike/pedestrian

For a Facility without a Parallel Roadway

Equation 2

Daily Emission Reduction (grams/day) =

$$HH_{AREA} * HH_{TRIPS} * PMS * TL_{B} * EF_{B}$$

The number of households in the area affected by the strategy multiplied by the average number of household trips in the strategy area by the percentage of drivers shifting to bike/pedestrian multiplied by the length of the project facility multiplied by the speed based running exhaust emission factor for participants' trip before participating in the bike/pedestrian program

Variables	(Unit)	Definitions
EF_B	(grams/mile)	Speed-based running exhaust emission factor for participants' trip before participating in the bike/pedestrian program (NO_X, VOC, PM, or CO)
HH_{AREA}		Number of households in strategy area
HH_{TRIPS}		Average number of trips per household in strategy area
PMS	(percent)	Percentage mode shift from driving to bike/pedestrian
TL_B	(mile)	Average auto trip length before implementation

For a Facility without a Parallel Roadway

Equation 3

Daily Emission Reduction (grams/day) = A + B

$A = N_{BW} * TL_{B} * EF_{B}$

The number of new bicycle/pedestrian facility users multiplied by the bicycle and/or pedestrian trip length multiplied by the speed-based running exhaust emission factor for participants' trip before participating in the bicycle/pedestrian program

$B = N_{BW} * TEF_{AUTO}$

The number of new bicycle/pedestrian facility users multiplied by the trip-end emission factor

Variables	(Unit)	Definitions
EF_{B}	(grams/mile)	Speed-based running exhaust emission factor for participants' trip before participating in the bike/pedestrian program (NO_X, VOC, PM, or CO)
N_{BW}		Number of new participants on the bike/pedestrian facility
TEF_{AUTO}	(grams/trip)	Auto trip-end emission factor (NO_X, VOC, PM, or CO)
TLB	(mile)	Average auto trip length before implementation

Source: Capitol Area MPO (CAMPO) & EL Paso MPO & North Central Texas Council of Governments, 2006

9.2 Bicycle and Pedestrian Support Facilities and Programs

Enhance replacement of vehicle trips and VMT through provision of facilities for bicycle and pedestrian travel.

Description

Many support facilities are provided as part of employer-based transportation management programs and improving transit. They can include sidewalks, intersection improvements, sidewalk furniture, bicycle racks on buses, lockers and shower facilities, education, and promotions.

Application

Areas where travel distances (residential/work or retail sites, for example) are short enough for bicycle/pedestrian travel to be practical.

Equation

Daily Emission Reduction (grams/day) = A + B

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

Reduction in auto start emissions from trip reductions

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

Reduction in auto running exhaust emissions from trip reductions

$$VT_{R} = N_{BW} * F_{BW,\ SOV} * 2\ \text{trips/day}$$

The number of bicycle and pedestrian program participants multiplied by the fraction of participants that shifted from single-occupant vehicle use multiplied by two trips per day (round trip)

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

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

Variables	(Unit)	Definitions
EF_B	(grams/mile)	Speed-based running exhaust emission factor for the average speed of participants' trip before participating in the bike/pedestrian program (NO_X, VOC, PM, or CO)
$F_{BW, SOV}$	(percent)	Percentage of new participants in the bike/pedestrian programs who previously drove SOVs
N_{BW}		Number of new participants in the bike/pedestrian programs
TEF_{AUTO}	(grams/trip)	Auto trip-end emission factor (NO_X, VOC, PM, or CO)
TL_W	(mile)	Average auto trip length to work
VMT_R		Reduction in daily auto vehicle miles traveled
VT_R	(trip)	Reduction in number of daily auto vehicle trips

Source: CalTrans/CARB

10.0 Extended Vehicle Idling

Programs to control extended idling of vehicles.
Section 108 (xi), CAAA

Introduction

Extended vehicle idling strategy attempts to reduce the amount of time that vehicles spend in idle mode as part of their overall operation. Idling restrictions primarily lower CO emissions from both gasoline-powered and diesel-powered motor vehicles in affected areas. The restrictions do provide for some NO_x emission reductions.

Main Components

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.

Exemptions are usually provided for emergency vehicles or idling required by traffic delays, for refrigerated cargo, and for driver sleep breaks.

The time threshold for requiring idling restriction varies across programs and urban contexts. Some programs set the limit at 30 minutes for combustion engines in cars and trucks. In Houston, vehicles over 14,000 pounds are limited to five minutes of idling when operating in the nonattainment area. In Texas, The Locally Enforced Motor Vehicle Idling Limitations rule, which was first established in December 2004, places time limits on the idling of gasoline and diesel-powered engines of heavy-duty motor vehicles within the jurisdiction of any local government that has signed a MOA with the TCEQ to delegate enforcement of the state's motor vehicle idling limitations to that local government. This rule prohibits any person in the affected local jurisdiction from permitting the primary propulsion engine of a heavy-duty motor vehicle to idle for more than five consecutive minutes when the vehicle is not in motion. The goal of this air quality control program is to lower NO_X and other pollutant emissions from fuel combustion by heavy-duty motor vehicles.

Other Considerations

Implementation of these types of controls on vehicle operations should be conducted at the regional or state level, except for restrictions on drive-through facilities, which are a local responsibility enforced through the zoning code. Individual attempts at restrictions could result in a confusing patchwork of regulations in a nonattainment area and may not provide an effective reduction measure.

In California, negative experience with idling restrictions at rail crossings suggested that an enforcement mechanism is required for these programs but did not specify the types of penalties needed.

Public education campaigns regarding the need for controls on idling emissions should be considered when implementing idling restriction measures.

10.1 Controls on Drive-Through Facilities

Reduce vehicle emissions.

Description

This measure involves limitations on the operation of drive-through facilities at businesses that provide drive-through service. Examples of these types of businesses are fast food restaurants, banks, and dry cleaners. Limitations may be placed on the operating hours of the facility, usually at peak traffic hours or peak restaurant hours. Prohibitions on construction of new facilities may also be implemented.

Application

Large urban areas.

Equation

Daily Emission Reduction (grams/day) = A – B + C

$$A = N_V * t_B * EF_I$$

The amount of idling exhaust emissions generated before the control

$$B = (1 - F_{PARK}) * N_V * t_A * EF_I$$

The idling exhaust emissions after the control is in place

$$C = F_{PARK} * N_V * (TEF_{AUTO})$$

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

Variables	(Unit)	Definitions
EF_I	(grams/hour)	Idling emission factor (NO_X, VOC, PM, or CO)
F_{PARK}	(percent)	Percent of vehicles that park instead of using the drive-through facility due to imposed control
N_V		Average number of vehicles using the drive-through facility
t_A	(hour)	Time spent in queue after implementation of control
t_B	(hour)	Time spent in queue before implementation of control
TEF_{AUTO}	(grams/trip)	Auto trip-end emission factor (NO_X, VOC, PM, or CO)

Source: Texas A&M Transportation Institute

10.2 Controls on Idling – Idling Restrictions

Reduce vehicle emissions through idling restrictions.

Description

This measure places restrictions on idling time for trucks, buses, construction equipment, and other heavy-duty on-road vehicles in the nonattainment area. The restriction may be automatic or manually implemented. Automatic restrictions would require a modification to a vehicle engine design that shuts off an idling vehicle engine after a set time limit. Manual restrictions would require the operator of the vehicle to shut off the engine.

The primary attraction of this measure to the regulated community is that it provides emission reduction benefits while also providing a cost savings through reduction in motor fuel consumption.

Application

Medium-sized and large urban areas with significant number of heavy-duty vehicles and equipment operating in the area.

Equation

$$\text{Daily Emission Reduction (grams/day)} = A * (B - C)$$

$$A = N_V * F_{PARK}$$

The number of vehicles in compliance with idling restrictions

$$B = EF_I * (t_B - t_A)$$

The reduction in idling exhaust emissions from reduced time spent in idling

$$C = N_{RSt} * TEF_{TRK}$$

The increase in start exhaust emissions resulting from engine restarts

Variables	(Unit)	Definitions
EF_I	(grams/hour)	Idling emission factor for trucks (NO_X, VOC, PM, or CO)
F_{PARK}	(percent)	Compliance factor (percentage of vehicles that park instead of idling)
N_{RSt}		Average number of times vehicle is restarted
N_V		Number of vehicles with restricted idling time
t_A	(hour)	Time per truck heavy-duty vehicles are allowed to spend idling after restriction
t_B	(hour)	Average time per truck heavy-duty vehicles spend idling before restriction
TEF_{TRK}	(grams/trip)	Engine start emission factor (NO_X, VOC, PM, or CO)

Source: Texas A&M Transportation Institute

10.3 Controls on Idling – Idle Reduction Technologies

Reduce vehicle idle emissions through the use of idle reduction technologies.

Description

This measure achieves emission reduction through the use of idle reduction technologies for heavy duty vehicles and equipment including trucks, buses, construction equipment, and other heavy-duty on-road vehicles in the nonattainment area. Idle reduction technologies can include:

- Diesel- and battery-powered auxiliary power units (APUs);
- Direct-fire heaters (DFH);
- automatic engine shut down and start-up (ESS); and
- Truck stop electrification (TSE).

The equations provided here may be used for projects in which heavy-duty vehicles shut down the main engine and apply power using an idle reduction technology. The equations quantify the reduction in heavy-duty vehicle emissions and adjust the emissions for the emissions produced by fuel-operated idle reduction technologies.

The primary attraction of this measure is that it provides emission reduction benefits while also providing a cost savings through reduction in motor fuel consumption. A limitation of this measure is that it is equipment dependent, requiring either the heavy-duty vehicle to be equipped with an idle reduction technology, or the facilities that idling occur provide TSE option.

Application

Medium-sized and large urban areas with significant number of heavy-duty vehicles and equipment operating in the area.

Equation

Daily Emission Reduction (grams/day) = $\sum A * (B - C - D)$

$A = N_{VT}$

The number of vehicles equipped with each type of idle reduction technology T (APU, DFH, ESS, and TSE)

$B = EF_I * t_T$

The reduction in idling exhaust emissions from reduced time spent idling as a result of operating idle reduction technology T

$C = N_{RSt} * TEF_{TRK}$

The increase in start exhaust emissions resulting from engine restarts
Applicable to automatic engine shut-off and restart
For other technologies, C = 0

$D = EF_T * t_T$

The increase in emissions from operating idle reduction technology
Applicable to APU and direct-fired heaters
For TSE and battery-powered APU, D = 0

Variables	(Unit)	Definitions
EF_I	(grams/hour)	Idling emission factor for trucks (NO_X, VOC, PM, or CO)
EF_T	(grams/hour)	Running emission factor for idle reduction technology T (NO_X, VOC, PM, or CO)
N_{RSt}		Average number of times vehicle is restarted
$N_{V,T}$		Number of vehicles equipped with idle reduction technology T
t_T	(hour)	Average time per heavy-duty vehicles that idle reduction technology T is used instead of engine idling
TEF_{TRK}	(grams/trip)	Engine start emission factor (NO_X, VOC, PM, or CO)

Source: Texas A&M Transportation Institute

11.0 Extreme Low Temperature Cold Starts

Programs to reduce motor vehicle emissions that are caused by extreme cold-start conditions.
Section 108 (xii), CAAA

Introduction

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

Since the required climactic conditions occur very rarely in southern states, this strategy is not recommended for consideration in the state of Texas.

12.0 Work Schedule Changes

Employer-sponsored programs to permit flexible work schedules.
Section 108 (xiii), CAAA

Introduction

The goal of implementing work schedule changes is to reduce the volume of commute traffic during peak traveling times by spreading or moving those trips to other times of day. The programs may be voluntary, mandatory, or used by employers to satisfy trip-reduction ordinances or air quality regulations. The EPA Office of Mobile Sources has found that schedule change programs achieve greater success and gain employee approval if employers adopt the changes voluntarily with employee input.

Main Components

There are three main types of changes to work schedules:

- *Telecommuting* is work done on a regular basis from daily to once a week at an alternative work site such as the employee's home or a telecommuting center. A center is a facility that provides the employer, employee, and customers with all requirements to perform work and services without traveling to the employee's main work site and may be operated by a single or consortium of businesses.
- *Flextime* allows employees to set arrival and/or departure times with the approval of the employer in order to avoid traveling at peak traffic times, but all employees are present for some core period of the workday.
- *Compressed work weeks* are work scheduling programs that condense a standard number of work hours into fewer than five days per week or fewer than 10 days per two-week period. For example, four days at 10 hours per day or 80 hours over nine days.

Work schedule changes are relatively easy to establish for several reasons, including the following:

- No infrastructure costs or front-end investment of government resources is required.
- These measures can be adopted voluntarily and require no approval from government agencies: there is no potentially lengthy process of obtaining funds and/or government approval.
- The measures can be easily explained to and understood by employees.

Although work schedule changes are relatively easy to administer, they require careful planning and coordination to be successful. Transportation planners need to be aware of employer issues with implementing work schedule changes. In terms of cost, businesses planning and implementing the policies must be compared to the potential savings that employees will gain with costs to implement and maintain them. Labor hours will be required to plan and implement the changes, increased facility security may be required since some workers will stay later or arrive earlier, and there may be increased utility needs as the facility is used longer in the day. Client relations and intra-department activities within the business or agency accustomed to the previous work hours need to be considered. Businesses must also ensure that the programs are consistent with union agreements.

Other Considerations

The EPA Office of Mobile Sources has found that several factors should be considered when attempting to use work schedule changes as a mobile emission reduction strategy:

- *Diminished benefits* as the decrease in work trip VMT may be mitigated to some extent by increased nonwork travel for people working compressed work weeks. The potential exists that although employees may benefit from driving on their day off, congestion and air quality may not significantly improve overall. However, more trips are likely to be taken during off-peak congestion hours so that the time distribution of ozone precursors is widened, and ozone formation is retarded.
- *Potential reduction in ridesharing and transit use by employees* may occur because of variable work hours. Businesses should coordinate the schedule changes, whenever possible, with transit and ridesharing services. Schedules for these services may need to be modified as a response to new arrival and departure times.
- *Pilot programs are recommended* for three to six months before committing to the changed hours so that the policies can be evaluated in terms of employee morale, productivity, and financial ramifications.
- *Applicability* of variable work hour strategies can be an issue for businesses. Organizations that rely heavily on process manufacturing usually need all workers to be present at the same time to work efficiently. Compressed work weeks may be a more suitable option for manufacturing plants than a flextime or staggered hours policy. Service businesses may be more able to rotate worker schedules and permit flextime policies.
- *Location* of the organization implementing a work schedule change may be a factor influencing success. Flextime policies may be more successful in areas of greater workplace density where associated traffic is highly concentrated around peak periods.

12.1 Telecommuting

Reduce vehicle trips and work trip VMT.

Description

Telecommuting involves employees working at home or at satellite work centers with approval of employers for one or more days per week. Satellite work centers are constructed and maintained by employers or agencies and provide the required work tools for an employee to perform his or her tasks. Telecommuting has grown with the rise and adoption of information technology in the last two decades. The use of centers does not reduce trips but can significantly decrease VMT.

Application

Organizations that do not require daily face-to-face customer or coworker interaction or that otherwise require the constant physical presence of the employee.

Telecommuting (Home)

Equation 1

$$\text{Daily Emission Reduction (grams/day)} = A + B$$

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

Reduction in auto start emissions from trips reductions

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

Reduction in auto running exhaust emissions from trips reductions

$$VT_{R} = N_{P} * N_{D} / 5 * 2 \text{ trips/day}$$

Number of people working at home multiplied by the average number of days worked at home per work week multiplied by two trips per day (round trip)

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

The vehicle trips reduced multiplied by the auto commute trip length

Telecommuting (Center)

Equation 2

Daily Emission Reduction (grams/day) = $VMT_R * EF_B$

Reduction in auto running exhaust emissions from trip reductions

$$VMT_R = VT_R * (TL_W - TL_{TC})$$

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

Variables	(Unit)	Definitions
EF_B	(grams/mile)	Speed-based running exhaust emission factor before implementation (NO_X, VOC, PM, or CO)
N_D		Number of days in program
N_P		Number of participants
TEF_{AUTO}	(grams/trip)	Auto trip-end emission factor (NO_X, VOC, PM, or CO)
TL_{TC}	(mile)	Average auto trip length to the telecommuting center
TL_W	(mile)	Average auto trip length
VMT_R		Reduction in daily VMT
VT_R	(trip)	Reduction in number of daily auto vehicle trips

Source: CalTrans/CARB

12.2 Flextime

Reduce peak hour congestion.

Description

Flextime allows employees to set arrival and/or departure times with the approval of the employer in order to avoid traveling at peak traffic times, but all employees are present for some core period of the workday.

Application

Businesses or agencies that do not require specific hours of employee availability.

Equation

Daily Emission Reduction (grams/day) =

$$(N_P * TL_W) * (EF_B - EF_A) * N_D/5$$

Number of vehicle trips reduced multiplied by the average auto trip length. The number of flextime participants multiplied by the average auto commute trip length multiplied by the change in auto running exhaust emission factors due to improved average travel speed multiplied by the percentage of the work week affected by the strategy

Variables	(Unit)	Definitions
EF_A	(grams/mile)	Speed-based running exhaust emission factor for participants after implementation (NO_X, VOC, PM, or CO)
EF_B	(grams/mile)	Speed-based running exhaust emission factor for participants before implementation (NO_X, VOC, PM, or CO)
N_D		Number of days in program
N_P		Number of participants
TL_W	(mile)	Average auto trip length of commute to work

Source: Texas A&M Transportation Institute

12.3 Compressed Work Week

Reduce work trips, VMT, and traffic volume by reducing days of travel to work site by employees and spreading trips outside the peak period.

Description

Compressed work weeks are work scheduling programs that condense a standard number of work hours into fewer than five days per week or fewer than 10 days per two-week period (e.g., four days at 10 hours per day or 80 hours over nine days).

Application

Employers who determine that productivity and services by their organization can be maintained by a compressed work schedule.

Equation

Daily Emission Reduction (grams/day) = A + B + C

$A = VT_R * TEF_{AUTO}$

Reduction in auto start emissions from trips reductions

$B = VMT_R * EF_B$

Reduction in auto running exhaust emissions from trip reductions

$C = N_P * TL_W * (EF_B * EF_A) * N_D / N_{D, PRG}$

The number of participants multiplied by the average auto commute trip length multiplied by the change in auto running exhaust emission factors due to improved average travel speed multiplied by the percentage of the work week affected by the strategy

$VT_R = N_P * N_D / N_{D, PRG} * 2$ trips/day

The number of program participants multiplied by the number of work days eliminated divided by the number of work days within the scheduling program multiplied by two trips per day (round trip)

$VMT_R = VT_R * TL_W$

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

Variables	(Unit)	Definitions
EF_A	(grams/mile)	Speed-based running exhaust emission factor after implementation (NO_X, VOC, PM, or CO)
EF_B	(grams/mile)	Speed-based running exhaust emission factor for participants before implementation (NO_X, VOC, PM, or CO)
N_D		Number of work days eliminated
$N_{D, PRG}$		Number of work days in the scheduling program (five or ten days)
N_P		Number of participants
TEF_{AUTO}	(grams/trip)	Auto trip-end emission factor (NO_X, VOC, PM, or CO)
TL_W	(mile)	Average auto trip length of commute to work
VMT_R		Reduction in daily automobile VMT
VT_R	(trip)	Reduction in number of daily vehicle trips

Source: CalTrans/CARB

13.0 Activity Centers

Programs and ordinances to facilitate non-automobile travel, provision, and utilization of mass transit, and to generally reduce the need for single-occupant vehicle travel, as part of transportation planning and development efforts of a locality, including programs and ordinances applicable to new shopping centers, special events, and other centers of vehicle activity.
Section 108 (xiv), CAAA

Introduction

Programs to reduce vehicular travel in activity centers are another mobile source emission reduction strategy that enables other more specific emission reduction strategies to occur. Activity center measures involve urban design and transportation measures, guidelines, and regulations designed to reduce automobile trips and to promote non-automobile travel associated with the use of a cohesive nexus of activity such as office parks, shopping centers, mixed-use developments, and other areas of vehicle activity.

Main Components

The guidelines and regulations may take a number of forms, including:

- Transit-friendly design guidelines and ordinances,
- Vanpool and carpool considerations,
- Pedestrian and bicycle design considerations,
- Parking management,
- Mixed-use development ordinances and zones,
- Site plan review ordinances, and
- Higher density land development.

By incorporating opportunities for alternative travel modes such as transit, HOVs, bicycles, and walking into the overall design of new development, the desirability of these alternative modes is enhanced. Higher density development encourages transit and HOV use. A balanced mix of land uses in denser areas can reduce the need for certain types of vehicle trips if the need can be met in the immediate vicinity of residence or place of work.

Other Considerations

The use of activity centers for emission reduction is a long-term strategy. The development of new or greatly modified urban design codes and regulations requires a significant amount of time and political discussion. If approved, new infrastructure and public services for the activity centers must then be designed and implemented.

13.1 Design Guidelines and Regulations

Reduce vehicle trips and VMT.

Description

Land use design guidelines and regulations used in the context of this strategy require HOV/transit/bicycle/pedestrian access in the design of facilities within land developments. Unless similar guidelines or regulations have been adopted by a city within an area, creation and adoption of these regulations will take significant periods of time. Changes in development codes are a politically contentious issue in any municipality, requiring much discussion and debate.

The last decade has seen greater interest in transit-oriented development, sustainable development, and New Urbanism in urban planning, ranging from sites within urban areas such as Sacramento, California, or new cities such as Celebration, Florida. Their present success is indicative of an available market for these types of design guidelines.

Application

Cities with transit service or areas available for higher density development.

Equation

Daily Emission Reduction (grams/day) =

$$\sum BASE * CAP * F_{PURi} * TL_{PURi} * EF_{PURi}$$

The number of trips reduced as a result of the mixed-use development multiplied by fraction of trips by purpose multiplied by the associated average trip length and speed-based emission factor

$$BASE = \sum N_{DUi} * TR_{Dui}$$

The number of daily trips generated by non-mixed residential and commercial uses equals number of units generated by a typical development times the trip rate by purpose

Variables	(Unit)	Definitions
BASE	(trip)	Number of daily trips generated by nonregulated residential and commercial uses
CAP	(percent)	Internal capture rate of regulated development
EF_{PURi}	(grams/mile)	Speed-based running exhaust emission factor by trip purpose (NO_X, VOC, PM, or CO)
F_{PURi}	(percent)	Percentage of trips saved by trip purpose
N_{DUi}		Number of development units by type
TL_{PURi}	(mile)	Average trip length by trip purpose
TR_{DUi}		Daily trip rate by development unit type

Source: CAMPO

13.2 Parking Regulations and Standards

Reduce vehicle trips and VMT.

Description

This emission reduction strategy is very similar to those found in Section 17 ("Parking Management"), and the reader is referred to that section for greater detail. In this specific case, the use of the limitations on parking is to encourage and enforce the development of high-density activity centers.

Application

Cities developing activity centers.

Equation

$$\text{Daily Emission Reduction (grams/day)} = A + B$$

$$A = \sum VT_R * TEF_{AUTO}$$

Reduction in auto start emissions from trips reductions

$$B = \sum VMT_R * EF_B$$

Reduction in auto running exhaust emissions from trip reductions

$$1 = F_{T,\,SOV} + F_{RS,\,SOV} + F_{BW,\,SOV}$$

The fractions of strategy participants that shift to other modes from SOVs

$$VT_{R,\,T} = N_T * F_{T,\,SOV} * 2 \text{ trips/day}$$
$$VT_{R,\,RS} = N_{RS} * (1 - 1/AVO_{RS}) * F_{RS,\,SOV} * 2 \text{ trips/day}$$
$$VT_{R,\,BW} = N_{BW} * F_{BW,\,SOV} * 2 \text{ trips/day}$$

The number of participants multiplied by the fraction of SOV drivers that switch to another mode multiplied by two trips per day (round trip)

$$VMT_{R,\,T} = VT_{R,\,T} * (TL_W - TL_T)$$
$$VMT_{R,\,RS} = VT_{R,\,RS} * (TL_W - TL_{RS})$$
$$VMT_{R,\,BW} = VT_{R,\,BW} * TL_W$$

The vehicle trip reduction multiplied by the change in average trip length after the mode switch

Variables	(Unit)	Definitions
AVO_{RS}	(persons/vehicle)	Average vehicle occupancy of rideshare
EF_B	(grams/mile)	Speed-based running exhaust emission factor before implementation (NO_X, VOC, PM, or CO)
$F_{BW, SOV}$	(percent)	Percentage of new participants in the bike/pedestrian programs who previously drove SOVs
$F_{RS, SOV}$	(percent)	Percentage of new participants in the rideshare programs who previously drove SOVs
$F_{T, SOV}$	(percent)	Percentage of new participants using transit facilities who previously drove SOVs
N_{BW}		Number of participants in bicycle/pedestrian programs
N_{RS}		Number of participants in rideshare
N_T		Number of participants using transit facilities
TEF_{AUTO}	(grams/trip)	Auto trip-end emission factor (NO_X, VOC, PM, or CO)
TL_{RS}	(mile)	Average auto trip length to rideshare facility
TL_T	(mile)	Average auto trip length to transit facility
TL_W	(mile)	Average auto trip length to work
VMT_R		Reduction in daily auto vehicle miles traveled
$VMT_{R, BW}$		Reduction in daily auto vehicle miles traveled by bike/pedestrian mode
$VMT_{R, RS}$		Reduction in daily auto vehicle miles traveled by rideshare mode
$VMT_{R, T}$		Reduction in daily auto vehicle miles traveled by transit mode
VT_R	(trip)	Reduction in number of daily vehicle trips
$VT_{R, BW}$	(trip)	Reduction in number of daily vehicle trips by bike/pedestrian mode
$VT_{R, RS}$	(trip)	Reduction in number of daily vehicle trips by rideshare mode
$VT_{R, T}$	(trip)	Reduction in number of daily vehicle trips by transit mode

Source: CalTrans/CARB (adapted by Texas A&M Transportation Institute)

13.3 Mixed-Use Development

Reduce vehicle trips and VMT through high-density development of mixed-use land developments.

Description

Mixed-use development is a broad range of land use regulations, ordinances, and guidelines that require a variety of residential, retail, and other land uses clustered together in a limited land space rather than segregated and spread in a larger area. This is a long-term strategy to be implemented in significant magnitude over a long period of time.

Mixed-use developments fulfill the following criteria:

- Three or more significant revenue-producing uses (such as office, retail, residential, hotel/motel, entertainment, cultural, recreation, etc.) that in well-planned projects are mutually supporting;
- Significant physical and functional integration of project components (and thus a relatively intensive use of land), including uninterrupted pedestrian connections; and
- Development in conformance with a coherent plan (which frequently stipulates the type and scale of uses, permitted densities, and related developmental consideration).

Many terms can be used to describe this measure such as New Urbanism, transit-oriented development, sustainable development, and cluster development. All generally require greater density requirements, smaller lots, less segregation of land use with a mix of housing, business, recreation, and retail industries. Mixed-use development is intended to provide site amenities that encourage ridesharing or transit use, thus decreasing reliance on SOV use.

Application

New developments or redevelopment in urban areas.

Equation

Daily Emission Reduction (grams/day) =

$$\sum BASE * CAP * F_{PURi} * TL_{PURi} * EF_{PURi}$$

The number of trips reduced as a result of the mixed-use development multiplied by the reduction in auto running exhaust emissions from the trips reduced

$$BASE = \sum N_{DUi} * TR_{Dui}$$

The number of daily trips generated by non-mixed residential and commercial uses equals number of units generated by a typical development times the trip rate by purpose

Variables	(Unit)	Definitions
BASE	(trip)	Number of daily trips generated by non-mixed residential and commercial uses
CAP	(percent)	Internal capture rate of mixed-use development
EF_{PURi}	(grams/mile)	Speed-based running exhaust emission factor by trip purpose (NO_X, VOC, PM, or CO)
F_{PURi}	(percent)	Percentage of trips saved by trip purpose
TL_{PURi}	(mile)	Average trip length by trip purpose
N_{DUi}		Number of development units by type
TR_{DUi}		Daily trip rate by development unit type

Source: CAMPO

14.0 Accelerated Vehicle Retirement

Program to encourage the voluntary removal from use and the marketplace of pre-1980 model year light-duty vehicles and pre-1980 model light-duty trucks.
Section 108 (xvi), CAAA

Introduction

Accelerated vehicle retirement, or vehicle scrappage, involves an offer to purchase older vehicles having high emission rates to remove these vehicles from the active vehicle fleet in an area. The program operates by an organization, usually private, paying a fee to owners of older, high-emission vehicles who voluntarily turn in their vehicle. The vehicle is then scrapped, removing it from use. The fee for the vehicle, also called a bounty, is usually a fixed price per scrapped vehicle although different amounts can be offered for different model years. Individual vehicle emissions characteristics might also be used as a criterion for scrappage.

Main Components

A scrappage program requires a funding source before it can be initiated. Public agencies may find this initial cost prohibitive, either in amount or difficulty obtaining approval. Private companies looking to offset emissions elsewhere in their company with the emissions reductions from the program may implement scrappage programs.

According to the EPA Office of Mobile Sources, vehicle retirement programs can be made more cost-effective by linking them to regional programs that are designed to measure the emissions of individual vehicles, such as inspection and maintenance (I/M) programs and remote sensing programs. The advantage of this linkage is that vehicles can be screened to help ensure that only vehicles that emit above the applicable standards and cannot be repaired at reasonable cost are scrapped.

Other Considerations

The cost-effectiveness of a scrappage program is likely to decline over time as the pool of older, high-emission vehicles is reduced. Vehicle owners wishing to participate may hold onto their vehicles and scrap them at the end of a continuous or long-running program. The program is more effective if limited in duration.

The amount of the bounty is a critical variable in a scrappage program. If the bounty is too low, the program will not attract enough vehicles to have any real impact on air quality. If the bounty is too high, the program will attract vehicles that are newer and cleaner, which would limit the program's overall impact and reduce its cost-effectiveness. Also, the program would not be able to remove as many vehicles out of the fleet. For the most part, actual scrappage programs have offered somewhere between $500 and $1000 per scrapped vehicle, with the most common bounty being $700.

Vehicle eligibility for scrappage programs must be well defined. A basic criterion is vehicle age and/or model year. The vehicle should also be operational. Requiring that it be driven to the program site ensures this criterion. Registration of the vehicle should reflect origin within the program area so that emissions reductions are actually achieved in the area.

The costs of an accelerated vehicle retirement program to the implementing agency are equal to the bounty price per vehicle, plus any administrative costs per vehicle, multiplied by the number of vehicles scrapped by the program.

14.1 Cash Payments

Reduce fleet vehicle emissions.

Description

Cash payment, or a bounty, is offered for older, high-emission vehicles. The vehicles are then scrapped. In some instances, non-emission-related parts from the vehicles may be salvaged for use as replacement parts. Cash payment programs should include follow-up and evaluation procedures to minimize any uncertainty in emission benefits.

Application

Best when utilized in conjunction with a regional inspection and maintenance (I/M) program. Congestion Mitigation and Air Quality Improvement Program (CMAQ) funds cannot be used for this strategy.

Equation

Daily Emission Reduction (grams/day) =

$$VMT_B * EF_O - VMT_A * EF_N + (VT_B * TEF_O - VT_A * TEF_N)$$

The average daily VMT of vehicles removed from service multiplied by the average daily composite emission factor for vehicles removed from service subtracted by the average daily VMT of new vehicles multiplied by the average daily composite emission factor for the replacement vehicles.

Variables	(Unit)	Definitions
VMT_A	(grams/mile)	VMT by the vehicle (estimate)
VMT_B	(grams/mile)	VMT by the vehicle to be replaced (estimate)
EF_N	(grams/mile)	Replacement vehicle speed-based running exhaust emission factor (NO_X, VOC, PM, or CO)
EF_O	(grams/mile)	Retired vehicle speed-based running exhaust emission factor (NO_X, VOC, PM, or CO)
VT_B	(trip)	Number of trips of retired vehicle (estimate)
VT_A	(trip)	Number of trips of replacement vehicle (estimate)
TEF_O	(grams/trip)	Trip end emission factor of retired vehicle (NO_X, VOC, PM, or CO)
TEF_N	(grams/trip)	Trip end emission factor of replacement vehicle (NO_X, VOC, PM, or CO)

Source: Texas A&M Transportation Institute

15.0 Parking Management

Reduce vehicle trips and VMT by disincentivizing SOV travel to a target area.

Introduction

The management of parking supply and demand is not a mobile source emission reduction strategy created specifically by the CAAA, but is usually implemented in conjunction with other congestion management and emission reduction measures. Most urban areas have some form of parking management.

Parking management efforts attempt to reduce vehicle trips and VMT by providing disincentives to SOV travel to an area of a city. Strategies favor carpools and vanpools. Increases in parking costs or decreases in availability encourage use of alternative modes. Air quality benefits through parking management strategies are derived when travelers choose an alternative method to SOV travel because of preferential parking for that mode or limited parking availability in an area for SOV travel.

Main Components

Examples of management strategies include:

- Preferential parking pricing programs for high-occupancy vehicles (HOVs),
- Preferential parking for HOVs,
- Parking fee structures that discourage long-term parking,
- Increased parking fees,
- Limitations on new public and private spaces, and
- Zoning regulations with parking controls for new developments.

Since these strategies are implemented as one part of a larger package of measures, the actual impact of parking management measures on SOV travel is difficult to quantify. It is difficult to separate the impacts of this measure itself from the overall program.

Parking management measures may be voluntary or required by ordinance. The measure does not require a substantial amount of financial resources to implement (administration, signage, enforcement, and surveys, if needed), but it is possible that a large amount of political capital may be required to overcome possible business and employer objections to reducing or limiting available parking. Implementing mandatory parking supply reductions may be unpopular with merchants, employers, or residents and require consensus building to implement a policy that is generally accepted. The EPA Office of Mobile Sources reports that cities that already have a comprehensive parking plan for downtown or suburban areas may already have the necessary experience, personnel, and resources to effectively implement a parking supply program.

Other Considerations

Policies that limit available parking supply have a greater chance of success if the following aspects are evident:

- Current parking is well utilized.
- Transit, bicycle and pedestrian, and ridesharing facilities and programs exist to absorb commuters that no longer drive.
- High-density central business districts or activity centers are present.
- The area has high land values and strong economic development.
- Vacant land and neighborhoods in the area do not have the capacity to absorb the parking overflow or are well controlled by parking restrictions.

15.1 Preferential Parking for HOVs

Reduce vehicle trips and VMT by providing incentives for HOV travel.

Description

Incentives are provided to HOV travelers by providing cost-free and/or reserved HOV parking spaces in an area or specific site. The incentives can also be indirect. For example, increased parking fees at the destination for SOVs discourage SOV travel but do not directly promote HOVs.

Application

Cities and the areas within them with controlled parking.

Equation

Daily Emission Reduction (grams/day) = A + B

$$A = VT_R * TEF_{AUTO}$$

Reduction in auto start emissions from trips reductions

$$B = VMT_R * EF_B$$

Reduction in auto running exhaust emissions from trips reductions

$$VT_R = N_{PPK} * U_{PPK} * (1 - F_{ECP}) * (OCC - 1) * 2 \text{ trips/day}$$

Number of preferential parking spaces multiplied by the parking utilization rate of the preferential parking spaces multiplied by the fraction of new carpools multiplied by the average number of passengers after implementation multiplied by two trips per day (round trip)

$$VMT_R = VT_R * TL_W$$

The vehicle trip reduction multiplied by the average auto commute trip length

Variables	(Unit)	Definitions
EF_B	(grams/mile)	Speed-based running exhaust emission factor before implementation (NO_X, VOC, PM, or CO)
F_{ECP}	(percent)	Percentage of existing carpools
N_{PPK}		Number of preferential spaces in parking facility
OCC_{HOV}	(persons/vehicle)	Average vehicle occupancy of HOV lanes
TEF_{AUTO}	(grams/trip)	Auto trip-end emission factor (NO_X, VOC, PM, or CO)
TL_W	(mile)	Average auto trip length to work before implementation of measure
U_{PPK}	(percent)	Utilization rate of preferential parking spaces
VMT_R		Reduction in daily automobile VMT
VT_R	(trip)	Reduction in number of daily vehicle trips

Source: Texas A&M Transportation Institute

15.2 Public Sector Parking Pricing

Reduce vehicle trips and VMT through disincentives.

Description

Cities modify parking fee and time structures at municipal facilities to discourage use of the facility. The measure can include increasing charges for peak hour parking, raising parking fees equivalent to commercial facilities, or not having a daily maximum parking fee.

Application

Cities and the areas within them with controlled parking.

Equation

Daily Emission Reduction (grams/day) = A + B

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

Reduction in auto start emissions from trips reductions

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

Reduction in auto running exhaust emissions from trip reductions

$$1 = F_{SOV} + F_{T,\,SOV} + F_{RS,\,SOV} + F_{BW,\,SOV}$$

The fractions of affected drivers that will continue to drive SOVs and those that shift to other available modes

$$VT_{R} = (\Delta P_{fee} * \epsilon_{fee} * N_{PK} * U_{P}) * (1 - F_{SOV}) * 2 \text{ trips/day}$$

Change in parking fees multiplied by a price elasticity multiplied by the number of affected parking spaces and their utilization rate multiplied by the fraction of SOVs that make a mode switch multiplied by two trips per day (round trip)

$$VMT_{R,\,T} = VT_{R} * F_{T,\,SOV} * (TL_{W} - TL_{T})$$
$$VMT_{R,\,RS} = VT_{R} * (1 - 1/AVO_{RS}) * F_{RS,\,SOV} * 2 \text{ trips/day}$$
$$VMT_{R,\,BW} = VT_{R} * F_{BW,\,SOV} * TL_{W}$$

The vehicle trip reduction multiplied by the fraction of SOV drivers that switch to another mode multiplied by the change in average trip length after the mode switch

Variables	(Unit)	Definitions
AVO_{RS}	(persons/vehicle)	Average vehicle occupancy of rideshare
EF_{B}	(grams/mile)	Speed-based running exhaust emission factor before implementation (NO_X, VOC, PM, or CO)
$F_{BW, SOV}$	(percent)	Percentage of new participants in the bike/pedestrian programs who previously drove SOVs
$F_{RS, SOV}$	(percent)	Percentage of new participants in the rideshare programs who previously drove SOVs
F_{SOV}	(percent)	Percentage of those people continuing to use an SOV for their full commute
$F_{T, SOV}$	(percent)	Percentage of new participants using transit facilities who previously drove SOVs
N_{PK}		Number of spaces in parking facility
TEF_{AUTO}	(grams/trip)	Auto trip-end emission factor (NO_X, VOC, PM, or CO)
TL_{T}	(mile)	Average auto trip length to transit location
TL_{W}	(mile)	Average auto trip length of commute to work
U_{P}		Utilization rate of parking facility
VMT_{R}		Reduction in daily automobile VMT
$VMT_{R, BW}$		Reduction in daily auto vehicle miles traveled by bike/pedestrian mode
$VMT_{R, RS}$		Reduction in daily auto vehicle miles traveled by rideshare mode
$VMT_{R, T}$		Reduction in daily auto vehicle miles traveled by transit mode
VT_{R}	(trip)	Reduction in number of daily vehicle trips
ΔP_{fee}	(percent)	Percentage change in parking fee structure
ϵ_{fee}		Price elasticity for mode shift

Source: Texas A&M Transportation Institute

15.3 Parking Requirements in Zoning Ordinances

Limit parking supply through land use controls.

Description

Areas can provide limits on the amount of parking available in new land development within the city or area through their zoning ordinances or other land use controls. The main technique is to establish a maximum amount of parking that a developer cannot exceed, rather than a traditional minimum parking supply for a new project. Changes to land use regulations may cause a potentially contentious political debate among citizens. Transportation planners should be aware of the possibility.

Application

New land use developments in high-density urban areas with adequate public transit access.

Equation

Daily Emission Reduction (grams/day) = A + B

$$A = \sum VT_R * TEF_{AUTO}$$

Reduction in auto start emissions from trips reductions

$$B = \sum VMT_R * EF_B$$

Reduction in auto running exhaust emissions from trip reductions

$$1 = F_{SOV} + F_{T,\,SOV} + F_{RS,\,SOV} + F_{BW,\,SOV}$$

The fractions of affected drivers that will continue to drive SOVs and those that shift to other available modes

$$N_P = (N_{PK,\,B} * U_{P,\,B} - N_{PK,\,A} * U_{P,\,A}) * OCC * (1 - F_{SOV})$$

The difference between the number of parking spaces affected before the control multiplied by the parking utilization rate before the control and the number of parking spaces affected after the control multiplied by the parking utilization rate after the control multiplied by the average vehicle occupancy multiplied by the fraction of single-occupant vehicles that make a mode switch multiplied by two trips per day (round trip)

$$VT_{R,\,T} = N_P * F_{T,\,SOV} * 2 \text{ trips/day}$$
$$VT_{R,\,RS} = N_P * (1 - 1/AVO_{RS}) * F_{RS,\,SOV} * 2 \text{ trips/day}$$
$$VT_{R,\,BW} = N_P * F_{BW,\,SOV} * 2 \text{ trips/day}$$

The number of participants multiplied by the fraction of single-occupant vehicle drivers that switch to another mode multiplied by two trips per day (round trip)

$$VMT_{R,\,T} = VT_{R,\,T} * (TL_W - TL_T)$$
$$VMT_{R,\,RS} = VT_{R,\,RS} * (TL_W - TL_{RS})$$
$$VMT_{R,\,BW} = VT_{R,\,BW} * TL_W$$

The vehicle trip reduction multiplied by the change in average trip length after the mode switch

Variables	(Unit)	Definitions
AVO_{RS}	(persons/vehicle)	Average vehicle occupancy of rideshare
EF_{B}	(grams/mile)	Speed-based running exhaust emission factor before implementation (NO_X, VOC, PM, or CO)
$F_{BW, SOV}$	(percent)	Adjustment factor for people who previously drove an SOV for their full commute and shift to bike/pedestrian
$F_{RS, SOV}$	(percent)	Adjustment factor for people who previously drove an SOV for their full commute and shift to rideshare
F_{SOV}	(percent)	Percentage of those people continuing to use an SOV for their full commute
$F_{T, SOV}$	(percent)	Adjustment factor for people who drove an SOV for their full commute and shift to transit
N_{P}		Number of participants
$N_{PK, A}$		Number of parking spaces allowed after implementation of control
$N_{PK, B}$		Number of parking spaces allowed before implementation of control
OCC	(persons/vehicle)	Average vehicle occupancy
TEF_{AUTO}	(grams/trip)	Auto trip-end emission factor (NO_X, VOC, PM, or CO)
TL_{RS}	(mile)	Average auto trip length to rideshare location
TL_{T}	(mile)	Average auto trip length to transit location
TL_{W}	(mile)	Average auto trip length of commute to work
$U_{P, A}$	(percent)	Utilization rate of parking facility after implementation
$U_{P, B}$	(percent)	Utilization rate of parking facility before implementation
VMT_{R}		Reduction in daily automobile VMT
$VMT_{R, BW}$		Reduction in daily auto vehicle miles traveled by bike/pedestrian mode
$VMT_{R, RS}$		Reduction in daily auto vehicle miles traveled by rideshare mode
$VMT_{R, T}$		Reduction in daily auto vehicle miles traveled by transit mode
VT_{R}	(trip)	Reduction in number of daily vehicle trips
$VT_{R, BW}$	(trip)	Reduction in number of daily vehicle trips by bike/pedestrian mode
$VT_{R, RS}$	(trip)	Reduction in number of daily vehicle trips by rideshare mode
$VT_{R, T}$	(trip)	Reduction in number of daily vehicle trips by transit mode

Source: Texas A&M Transportation Institute

15.4 On-Street Parking Controls

Reduce vehicle trips and VMT by providing disincentives to on-street parking in urban areas.

Description

Cities can utilize several techniques to limit on-street parking in urban areas, including increased meter fees that discourage long-term parking, curb parking restrictions, peak hour parking bans, and residential parking controls. In addition, parking times can be decreased. Enforcement of the parking regulations should be strengthened. Planners should keep in mind that this measure is more effective in high-density areas such as central business districts or activity centers with limited available parking. Applied to areas with excess parking supply or dispersed development, this measure may simply reallocate the parking and not aid in encouraging alternative modes of travel.

Application

Areas of higher density, activity centers, or congested roadways with limited parking.

For Parking Fee Increases

Equation 1

Daily Emission Reduction (grams/day) = A + B

$A = \sum VT_R * TEF_{AUTO}$

Reduction in auto start emissions from trips reductions

$B = \sum VMT_R * EF_B$

Reduction in auto running exhaust emissions from trip reductions

$1 = F_{SOV} + F_{T, SOV} + F_{RS, SOV} + F_{BW, SOV}$

The fractions of affected drivers that will continue to drive SOVs and those that shift to other available modes

$VT_R = (\Delta P_{fee} * \epsilon_{fee} * N_{PK} * U_P) * (1 - F_{SOV}) * 2 \text{ trips/day}$

The change in parking fees multiplied by a price elasticity multiplied by the number of affected parking spaces and their utilization rate multiplied by the fraction of SOVs that make a mode switch multiplied by two trips per day (round trip)

$VMT_{R, T} = VT_R * F_{T, SOV} * (TL_W - TL_T)$
$VMT_{R, RS} = VT_R * (1 - 1/AVO_{RS}) * F_{RS, SOV} * (TL_W - TL_{RS})$
$VMT_{R, BW} = VT_R * F_{BW, SOV} * TL_W$

The vehicle trip reduction multiplied by the fraction of SOV drivers that switch to another mode multiplied by the change in average trip length after the mode switch

For Parking Controls

Equation 2

Daily Emission Reduction (grams/day) = A + B

$A = \sum VT_R * TEF_{AUTO}$

Reduction in auto start emissions from trips reductions

$B = \sum VMT_R * EF_B$

Reduction in auto running exhaust emissions from trip reductions

$1 = F_{SOV} + F_{T, SOV} + F_{RS, SOV} + F_{BW, SOV}$

The fractions of affected drivers that will continue to drive SOVs and those that shift to other available modes

$N_P = (N_{PK, B} * U_{P, B} - N_{PK, A} * U_{P, A}) * OCC * (1 - F_{SOV})$

The difference between the number of parking spaces affected before the control multiplied by the parking utilization rate before the control and the number of parking spaces affected after the control multiplied by the parking utilization rate after the control multiplied by the average vehicle occupancy multiplied by the fraction of single-occupant vehicles that make a mode switch multiplied by two trips per day (round trip)

$VT_{R, T} = N_P * F_{T, SOV} * 2$ trips/day
$VT_{R, RS} = N_P * (1 - 1/AVO_{RS}) * F_{RS, SOV} * 2$ trips/day
$VT_{R, BW} = N_P * F_{BW, SOV} * 2$ trips/day

The number of participants multiplied by the fraction of single-occupant vehicle drivers that switch to another mode multiplied by two trips per day (round trip)

$VMT_{R, T} = VT_{R, T} * (TL_W - TL_T)$
$VMT_{R, RS} = VT_{R, RS} * (TL_W - TL_{RS})$
$VMT_{R, BW} = VT_{R, BW} * TL_W$

The vehicle trip reduction multiplied by the change in average trip length after the mode switch

Variables	(Unit)	Definitions
AVO_{RS}	(persons/vehicle)	Average vehicle occupancy of rideshare
EF_{B}	(grams/mile)	Speed-based running exhaust emission factor before implementation (NO_X, VOC, PM, or CO)
$F_{BW, SOV}$	(percent)	Adjustment factor for people who previously drove an SOV for their full commute and shift to bike/pedestrian
$F_{RS, SOV}$	(percent)	Adjustment factor for people who previously drove an SOV for their full commute and shift to rideshare
F_{SOV}	(percent)	Percentage of those people continuing to use an SOV for their full commute
$F_{T, SOV}$	(percent)	Adjustment factor for people who drove an SOV for their full commute and shift to transit
N_{P}		Number of participants
N_{PK}		Number of spaces in parking facility
$N_{PK, A}$		Number of parking spaces allowed after implementation of control
$N_{PK, B}$		Number of parking spaces allowed before implementation of control
OCC	(persons/vehicle)	Average vehicle occupancy
TEF_{AUTO}	(grams/trip)	Auto trip-end emission factor (NO_X, VOC, PM, or CO)
TL_{RS}	(mile)	Average auto trip length to rideshare location
TL_{T}	(mile)	Average auto trip length to transit location
TL_{W}	(mile)	Average auto trip length of commute to work
U_{P}	(percent)	Utilization rate of parking facility
$U_{P, A}$	(percent)	Utilization rate of parking facility after implementation
$U_{P, B}$	(percent)	Utilization rate of parking facility before implementation
VMT_{R}		Reduction in daily automobile VMT
$VMT_{R, BW}$		Reduction in daily auto vehicle miles traveled by bike/pedestrian mode
$VMT_{R, RS}$		Reduction in daily auto vehicle miles traveled by rideshare mode
$VMT_{R, T}$		Reduction in daily auto vehicle miles traveled by transit mode
VT_{R}	(trip)	Reduction in number of daily vehicle trips
$VT_{R, BW}$	(trip)	Reduction in number of daily vehicle trips by bike/pedestrian mode
$VT_{R, RS}$	(trip)	Reduction in number of daily vehicle trips by rideshare mode
$VT_{R, T}$	(trip)	Reduction in number of daily vehicle trips by transit mode
ΔP_{fee}	(percent)	Percentage change in parking fee structure
ϵ_{fee}		Price elasticity for mode shift

Source: Texas A&M Transportation Institute

16.0 Vehicle Replacement, Retrofits, and Repowering

Programs to encourage emissions reduction by the “3Rs” - the replacement of existing vehicles with lower-emitting ones, or the use of repowering or retrofits to reduce vehicle emissions.

Introduction

Vehicle emission rates can be reduced through the purchase of motor vehicles, including hybrids, electric, or alternative fuel vehicles certified to pollute less than typical new vehicles. Programs that provide complete engine replacements or retrofits that result in lower pollution may also be implemented. This measure has received emphasis in federal transportation legislation, and can be funded through CMAQ in eligible areas.

Clean vehicle programs are often instituted to take advantage of available funding and improve existing fleets.

Truck fleets also incorporate some elements of vehicle retrofits and replacement strategies into *truck efficiency programs*. These programs usually include a broader range of emissions reduction and fuel-saving strategies including operational measures, trailer lightweighting and aerodynamic devices.

16.1 Clean Vehicle Program

Reduce vehicle emissions through new vehicle technology.

Description

This method is designed to evaluate the benefits of clean vehicle program, which is to reduce emissions by replacing old vehicles with newer, cleaner vehicles, or providing complete engine replacement or retrofits that result in lower emissions. The method estimates daily activity change if there is difference in number of vehicles and the difference in the average daily distance traveled between old and new vehicles.

Application

Cities, agencies, and employers with a vehicle fleet.

Equation

$$\text{Daily Emission Reduction (grams/day)} = VMT_{REP} * (EF_B - EF_A) + VT_{REP} * (TEF_B - TEF_A)$$

Average daily VMT of the replaced vehicle multiplied by the change in pre-replacement and post-replacement composite emission factors

Variables	(Unit)	Definitions
EF_A	(grams/mile)	Speed-based running exhaust emission factor after replacement (NO_X, VOC, PM, or CO)
EF_B	(grams/mile)	Speed-based running exhaust emission factor before replacement (NO_X, VOC, PM, or CO)
TEF_A	(grams/trip)	Trip end emission factor after replacement (NO_X, VOC, PM, or CO)
TEF_B	(grams/trip)	Trip end emission factor before replacement (NO_X, VOC, PM, or CO)
VMT_{REP}		Average Daily VMT of the vehicle to be replaced
VT_{REP}		Average Daily Trips of the vehicle to be replaced

Source: CalTrans/CARB

16.2 Truck Efficiency Program

Reduce vehicle emissions by improving operating efficiency.

Description

Truck efficiency program such as SmartWay Transport Partnership (SmartWay), established by EPA in 2004, is a voluntary, public-private partnership with the ground freight industry. Truck and rail freight are integral to the nation's economy; however, heavy-duty diesel vehicles are major consumers of fossil fuels and major contributors to air pollution. Truck efficiency programs promote a variety of strategies designed to reduce energy consumption and vehicle emissions that also lead to a reduction in costs for freight operators. Improvements in fuel efficiency will be directly proportional to reduced fuel use and emissions.

The primary attraction of this measure to the regulated community is that it provides emission reduction benefits while also providing a cost savings through reduction in motor fuel consumption.

Application

Individuals or fleet companies with significant fleets of heavy-duty vehicles.

Equation

Daily Emission Reduction (grams/day) =

$$\sum_{i=1}^{n}[N_{Vi} * P_{Ri} * EF * TL_D]$$

Reduction in auto running exhaust emissions, where percentage reduction of emissions varies with the kit(s) installed on the truck

Variables	(Unit)	Definitions
EF	(grams/mile)	Truck exhaust emission factor based on average daily speed (NO_X, VOC, PM, or CO)
N_{Vi}		Number of vehicles adopting individual operating efficiency improving technologies
P_{Ri}	(percent)	Percent reduction in emissions after adopting individual operating efficiency improving technologies
TL_D	(mile)	Average daily truck travel

Source: Texas A&M Transportation Institute
Note: SmartWay Tractors and Trailers meet voluntary equipment specifications that can reduce fuel consumption by 10 to 20 percent for 2007 and newer long-haul tractors and trailers.
http://arlnetwork.com/smartway.php

17.0 Pricing Strategies

Reduce vehicle trips and VMT by disincentivizing driving, including in congested zones or on congested roadways.

Introduction

Pricing strategies disincentivize driving, with a view of reducing congestion and also reducing overall vehicle miles of travel. Congestion pricing, specifically, is the imposition of fees, in differential rates varying by time of day and/or location depending on the level of congestion, on road users in congested zones or traveling on congested roadways.

Main Components

Congestion pricing is the most common approach to implementation of pricing strategies. Depending on the scope of the project, there are three types of congestion pricing policies:

- *Facility pricing* is levied on one or several roadways that link residential areas to downtown commercial districts. Fees may be imposed on new or existing roads, but it is usually more politically acceptable to impose fees on new facilities because people would view the policy as taking away a free service. In order for a pricing measure to be considered an application of facility pricing, the purpose of the measure must be to reduce congestion.
- *Regional network pricing* levies fees on drivers traveling on a network of similar roads (e.g., highways). Unlike facility pricing, network pricing applies fees on multiple roads going in many directions. This fee structure results in a more accurate fee for vehicle use than facility pricing because more of the trip is included within the boundary of the system. Fees may be collected from a series of tollbooths along the network or from entrance and exit ramps on controlled access facilities.
- *Cordon pricing* charges vehicles that enter high-activity areas such as central business districts. Areas of high congestion are identified and encircled with one or more cordons (lines). Vehicles may enter the area on different types of roads (e.g., arterials or highways). Fees are then collected from drivers through tollbooths at the cordon, special area permits, or parking permits. Prices may vary by time of day so that drivers may be reluctant to enter the cordoned areas during typical peak congestion periods. Although this pricing measure has been successfully implemented in such countries as Singapore, Norway, and England, it has yet to be implemented in the United States.

In addition to congestion pricing approaches, *mileage-based user fees* are also increasingly being promoted as a means of mitigating congestion and reducing auto trips and VMT. Mileage-based fees (such as pay-as-you-drive insurance) vary based on distance driven, and therefore provide drivers with an incentive to drive less.

Other Considerations

Congestion pricing policies and mileage-based user fees are only in the pilot program stage of development in the United States, so there is little empirical evidence on the extent to which VMT and emissions are reduced. Theoretically, emissions will be reduced considerably because VMT and idling will decrease. The imposed fees will provide an incentive for people to switch from SOVs to HOVs or mass transit. Therefore, fewer total VMT will accumulate, directly eliminating emissions. Fewer VMT will occur during peak periods, which results in less idling. Moreover, the revenue generated by the pricing policy may be used for transportation improvements.

Many existing toll roads cannot be considered examples of congestion pricing policies because their purpose is largely to raise revenue. Toll roads may be viewed as congestion pricing mechanisms if the fees are structured in such a manner as to influence demand.

Although implementing congestion pricing policies is not typically as expensive as other emission reduction strategies such as building rail lines, there are important cost considerations such as:

- Financial and human resources for planning phases,
- Implementing tolls and HOV fees,
- Public education and marketing campaigns, and
- Ongoing operations and maintenance.

The scope of the pricing policy greatly determines program cost. Facility pricing programs generally cost significantly less than regional network pricing and cordon pricing because as little as one roadway is affected.

Congestion pricing is relatively risky to implement because:

- Citizens will be paying for a service they had perceived to be receiving free of charge.
- The policy may be politically unpopular, especially if people are willing to endure congestion rather than pay more out-of-pocket expense to lessen it.
- Because congestion pricing is still in the pilot stage, the amount of emissions reductions from these measures cannot be projected with great certainty.

17.1 Facility Pricing

Mitigate congestion through reduction of trips and VMT.

Description

Facility pricing is levied on one or several roadways that link residential areas to downtown commercial districts. Fees may be imposed on new or existing roads, but it is usually more politically acceptable to impose fees on new facilities because people would not view the policy as taking away a free service. In order for a pricing measure to be considered an application of facility pricing, the purpose of the measure must be to reduce congestion.

Single facility projects are best suited for a corridor connecting residential neighborhoods with downtown areas. However, there are at least two disadvantages to this option, increasing VMT and moving congestion.

Total VMT may actually increase as a consequence of imposing fees on the most direct route that people travel due to drivers diverting to nontoll alternate routes. Drivers may continue to avoid the fees by driving on the alternate routes, thereby merely shifting congestion to nonpriced areas of the city.

Among the congestion pricing measures, single facility projects are generally the easiest type of policy to enact according to the EPA Office of Mobile Sources. Some of the reasons that single facility projects are easy to implement include:

- Simplest to design and require the least up-front investment of government resources;
- Easily monitored and evaluated, especially if the facility has few entrances, exits, and alternate routes; and
- Relatively more politically acceptable because they focus on only one route. Under single facility programs, there may be alternative free routes people can choose, whereas regional network pricing projects may result in people being charged no matter which route they use.

Regional network pricing levies fees on drivers traveling on a network of similar roads (e.g., highways). Unlike facility pricing, network pricing applies fees on multiple roads going in many directions. This fee structure results in a more accurate cost for vehicle use than facility pricing because more of the trip is included within the boundary of the system. Fees may be collected from a series of tollbooths along the network or from entrance and exit ramps on controlled access facilities.

Because regional network pricing is more comprehensive than facility pricing, it has a greater potential to eliminate many free alternative routes. However, if a viable public transit system is unavailable in the area, then this measure could be difficult to implement.

If drivers have a choice in choosing one mode of transit over another, regional network pricing may be very effective in reducing congestion and improving air quality because of its comprehensiveness. The measure can provide strong incentive for people to ride in carpools, use public transit, or adjust their travel time in the face of high tolls.

If the network of roads to be priced encompasses several jurisdictions, coordination among transportation officials and agencies is crucial to implementation and success of the measure.

A regional pricing strategy may be analyzed in the same way as facility pricing with the analysis conducted for each roadway affected by the strategy.

Application

Highways or controlled access facilities between residential areas and central commercial areas. This strategy should only be used for CMAQ purposes.

Equation

Daily Emission Reduction (grams/day) = A + B + C + D

$A = (VT_R * TEF_{AUTO}) + (VMT_R * EF_B)$

Reduction in auto start emissions from trip reductions plus the reduction in auto running exhaust emissions from trip reductions

$B = VT_S * TL_B * (EF_B – EF_A)$

Reduction in auto running exhaust emissions from trips shifted to a no cost or lower cost time period

$C = VT_{ALT} * (TL_B * EF_B – TL_A * EF_A)$

Reduction in auto running exhaust emissions from trips on an alternate facility during the same time period

$D = VT_{NC} * TL_B * (EF_B – EF_A)$

Reduction in auto running exhaust emissions due to a speed change for trips remaining on the facility after implementation

$VMT_R = VT_R * TL_B$
$VT_R = Є * (FEE_B – FEE_A) * VT_B$
$VT_S = Є * (FEE_B – FEE_A) * VT_B$

The price elasticity for use of the facility multiplied by the difference in the fee for use of the facility before and after strategy implementation multiplied by the number of vehicle trips before implementation

$VT_B = VT_R + VT_S + VT_{ALT} + VT_{NC}$

Vehicle trips on facility before implementation of measure mathematically equals to remaining vehicle trips on the facility after implementation plus resulting trip changes ($VT_S + VT_{ALT} + VT_{NC}$)

Variables	(Unit)	Definitions
EF_A	(grams/mile)	Speed-based running exhaust emission factor after implementation on affected roadway
EF_B	(grams/mile)	Speed-based running exhaust emission factor on affected roadway before implementation
FEE_A	(percent)	Price for facility use after implementation of measure
FEE_B	(percent)	Price for facility use before implementation of measure
TEF_{AUTO}	(grams/trip)	Auto trip-end emission factor (NO_X, VOC, PM, or CO)
TL_A	(mile)	Average auto trip length after implementation of measure
TL_B	(mile)	Average auto trip length before implementation of measure
VMT_R		Reduction in daily automobile VMT
VT_{ALT}	(trip)	Vehicle trips on alternate facility
VT_B	(trip)	Vehicle trips on facility before implementation of measure
VT_{NC}	(trip)	Vehicle trips remaining on facility after implementation
VT_R	(trip)	Reduction in number of daily automobile vehicle trips
VT_S	(trip)	Vehicle trips on facility shifted to no cost or lower cost time period
ϵ		Price elasticity for mode and time shift

Source: Texas A&M Transportation Institute

17.2 Cordon Pricing

Mitigate congestion through fees for operating vehicles in high activity areas.

Description

Cordon pricing charges vehicles that enter high-activity areas such as central business districts. Areas of high congestion are identified and encircled with one or more cordons (lines). Vehicles may enter the area on different types of roads (e.g., arterials or highways). Fees are then collected from drivers through tollbooths at the cordon, special area permits, or parking permits. Prices may vary by time of day so that drivers may be reluctant to enter the cordoned areas during typical peak congestion periods.

Cordon pricing has potential disadvantages:

- Although it may relieve inner-city congestion, cordon pricing policy may not reduce traffic on the region's freeway system leading into the city.
- Once vehicles pay the fee for entering the area, there is no price difference for people who drive for a longer period of time than others.
- Cordon pricing may also result in the unintended consequence of congestion moving into streets adjacent to the cordoned area. Similar to single facility pricing, congestion may simply shift from the priced roadways to other nontoll alternative routes.
- An inequitable situation for businesses within the affected district may result if people choose to avoid fees and do business elsewhere. Commercial delivery businesses and companies in the transportation industry that need access to affected areas may also be negatively affected if not exempted.

Application

Major business districts or other concentrated congested areas.

Equation

Daily Emission Reduction (grams/day) = A + B + C + D

$A = (VT_R * TEF_{AUTO}) + (VMT_R * EF_B)$

Reduction in auto start emissions from trip reductions plus the reduction in auto running exhaust emissions from trip reductions

$B = VT_S * TL_B * (EF_B - EF_A)$

Reduction in auto running exhaust emissions from trips shifted to a no cost or lower cost time period

$C = VT_{ALT} * (TL_B * EF_B - TL_A * EF_A)$

Reduction in auto running exhaust emissions from trips shifted to an alternate destination during the same time period

$D = VT_{NC} * TL_B * (EF_B - EF_A)$

Reduction in auto running exhaust emissions from trips remaining on the same routes after implementation

$VMT_R = VT_R * TL_B$
$VT_R = \epsilon * (FEE_B - FEE_A) * VT_B$
$VT_S = \epsilon * (FEE_B - FEE_A) * VT_B$

The price elasticity for use of the facility multiplied by the difference in the fee for use of the facility before and after strategy implementation multiplied by the number of vehicle trips before implementation

$VT_B = VT_R + VT_S + VT_{ALT} + VT_{NC}$

Vehicle trips on facility before implementation of measure mathematically equals to remaining vehicle trips on the facility after implementation plus resulting trip changes ($VT_S + VT_{ALT} + VT_{NC}$)

Variables	(Unit)	Definitions
EF_A	(grams/mile)	Speed-based running exhaust emission factor after implementation on affected roadway
EF_B	(grams/mile)	Speed-based running exhaust emission factor on affected roadway before implementation (NO_X, VOC, PM, or CO)
FEE_A	(percent)	Price for facility use after implementation of measure
FEE_B	(percent)	Price for facility use before implementation of measure
TEF_{AUTO}	(grams/trip)	Auto trip-end emission factor (NO_X, VOC, PM, or CO)
TL_A	(mile)	Average auto trip length after implementation of measure
TL_B	(mile)	Average auto trip length before implementation of measure
VMT_R		Reduction in daily automobile VMT
VT_{ALT}	(trip)	Vehicle trips on alternate facility
VT_B	(trip)	Vehicle trips on facility before implementation of measure
VT_{NC}	(trip)	Vehicle trips remaining on facility after implementation
VT_R	(trip)	Reduction in number of daily automobile vehicle trips
VT_S	(trip)	Vehicle trips on facility shifted to no cost or lower cost time period
ϵ		Price elasticity for mode and time shift

Source: Texas A&M Transportation Institute

17.3 Pay-As-You-Drive (PAYD) Insurance Program

Mitigate congestion through reduction of auto trips and VMT.

Description

A mileage-based vehicle insurance program permits drivers to pay their automobile insurance premiums on a variable scale, dependent upon how much they drive each vehicle. Since the cost of coverage is directly tied to use of the vehicles, PAYD insurance provides incentive to drive less.

Application

Individuals or companies with fleet can participate in this program.

Equation

Daily Emission Reduction (grams/day) = A + B

$$A = Nv * (TL_B - TL_A) * EF_B$$

Reduction in auto running exhaust emissions from trip reductions

$$B = (VT_B - VT_A) * TEF_{AUTO}$$

Reduction in auto start exhaust emissions from reduction in vehicle trips

$$VT_A = N_V * N_{TA}$$
$$VT_B = N_V * N_{TB}$$

Number of auto trips before and after strategy implementation

Variables	(Unit)	Definitions
EF_B	(grams/mile)	Speed-based running exhaust emission factor (NO_X, VOC, PM, or CO)
N_V		Number of vehicles participating in the program
N_{TB}		Average number of auto trips per day before participating in the program
N_{TA}		Average number of auto trips per day after participating in the program
TEF_{AUTO}	(grams/trip)	Auto trip-end emission factor (NO_X, VOC, PM, or CO)
TL_A	(mile)	Average daily travel after participating in the program
TL_B	(mile)	Average daily travel before participating in the program
VT_A	(trip)	Number of daily vehicle trips after implementation
VT_B	(trip)	Number of daily vehicle trips before implementation

Source: Texas A&M Transportation Institute
Resource: Pay-As-You-Drive Automobile Insurance Pilot Program,
https://mobility.tamu.edu/mip/strategies-pdfs/travel-options/technical-summary/pay-as-you-drive-insurance-4-pg.pdf

Appendix. Summary of Input Variables

The input variables are listed below in alphabetical order by category. A description of potential sources for the variables is given within each category.

Type of Input	Variables	(Unit)	Description	Comments
Scoping	HH_{AREA}		Number of households in strategy area	Length and numbers are fairly easy to acquire although some variables such as number of participants in a strategy may require surveys of commuters or local businesses.
	i		Time Period	
	L	(mile)	Length of affected roadway	
	L_i	(mile)	Length of each freeway affected by intelligent transportation systems (ITS)	
	N		Number of affected corridors	
	N_{BUS}		Number of buses	
	N_{BW}		Number of participants in bike/pedestrian programs	
	$N_{BW, SOV}$		Number of participants in bike/pedestrian programs who previously used single-occupancy vehicles	
	N_D		Number of days in the program	
	$N_{D, PRG}$		Number of work days in the scheduling program (five or 10 days)	
	N_{DUi}		Number of development units by type	
	N_{HBO}		Average number of home-based other trips	
	N_{ND}		Number of people using the park-and-ride facility but not driving to it	
	N_{NW}		Average number of nonwork trips	

Type of Input	Variables	(Unit)	Description	Comments
Scoping	N_{OPH}		Number of off-peak hours	Length and numbers are fairly easy to acquire although some variables such as number of participants in a strategy may require surveys of commuters or local businesses.
	N_P		Number of participants	
	N_{PH}		Number of peak hours (AM and/or PM)	
	N_{PK}		Number of spaces in parking facility	
	$N_{PK,\ A}$		Number of parking spaces allowed after implementation of control	
	$N_{PK,\ B}$		Number of parking spaces allowed before implementation of control	
	N_{PPK}		Number of preferential spaces in parking facility	
	$N_{PR,\ HOV}$		Number of high-occupancy vehicle (HOV) parking spaces at the park-and-ride facility	
	N_{RS}		Number of participants in rideshare programs	
	N_{RSt}		Average number of times the vehicle is restarted	
	N_{TA}		Average number of auto trips per day after participating in the program	
	N_{TB}		Average number of auto trips per day before participating in the program	
	N_T		Number of participants using transit facilities	
	N_{TR}		Number of new transit ridership	
	N_V		Number of vehicles	
	$N_{V,\ PRI}$		Number of HOVs using prioritized lane	
	N_{VA}		Number of vehicles after implementation	
	N_{VB}		Number of vehicles before implementation	
	N_{VT}		Number of vehicles equipped the specific idle reduction technology	
	N_{Vi}		Number of vehicles adopting individual operating efficiency improving technologies	

Type of Input	Variables	(Unit)	Description	Comments
Scoping	t		Average waiting time at Park and Ride facility	Time can be easily computed and estimated from available data and field collection.
	t_A	(hour)	Time after implementation of strategy	
	t_B	(hour)	Time before implementation of strategy	
	t_C	(hours/ crossing)	Average amount of time rail crossing is closed due to train crossing	
	t_H	(hour)	Duration of analysis period	
	$t_{H,C}$		Hours per analysis period roadway is closed due to train crossing	
	t_q	(hour)	Average time spent in queue waiting to enter freeway	
	t_T	(hour)	Average time per heavy-duty vehicles that idle reduction technology T is used	
	FEE_A		Price for facility use after implementation of measure (decimal)	Fees for use of road facilities can be easily obtained.
	FEE_B		Price for facility use before implementation of measure (decimal)	
	ΔP_{fee}		Percentage change in parking fee structure (decimal)	Parking fee structure changes will require field collection through surveys of parking facilities in affected areas.

Type of Input	Variables	(Unit)	Description	Comments
Traffic	AADT	(vehicles/ day)	Annual average daily traffic in corridor	Average daily traffic (ADT) in areas affected by an implemented emission reduction strategy can be derived from local traffic counts conducted by the Texas Department of Transportation (TxDOT) or other local sources. For specific HOV facilities related to individual strategies, some data may need to be field collected by the local agency. Conservative estimates should be given for ADT after implementation of strategies (lower instead of higher).
	ADT_A	(vehicles/ day)	Average daily traffic on facility after implementation	
	$ADT_{A, ALT}$	(vehicles/ day)	Average daily traffic on alternate route(s) after implementation	
	ADT_B	(vehicles/ day)	Average daily traffic on facility before implementation	
	$ADT_{B, ALT}$	(vehicles/ day)	Average daily traffic on alternate route(s) before implementation	
	ADT_i		Average daily traffic for each affected link	
	ADT_T	(vehicles/ day)	Total average daily traffic for affected system	
	D_A	(hour)	Average vehicle delay at intersection after implementation	Delay and delay reduction can be estimated from the regional travel demand model, stopped delay studies, and average speeds derived from TxDOT traffic analysis.
	D_B	(hour)	Average vehicle delay at intersection before implementation	
	DR_{OP}	(second)	Estimated delay reduction during off-peak period	
	DR_P	(second)	Estimated delay reduction during peak period	

Type of Input	Variables	(Unit)	Description	Comments
Traffic	I_{OP}	(hour)	Off-peak hour reduction in idling emissions	Idling may be inferred from stopped delay studies.
	I_P	(hour)	Peak hour reduction in idling emissions	
	AVO_{RS}	(persons/ vehicle)	Average vehicle occupancy of rideshare	Vehicle occupancy can be derived from occupancy surveys, transit ridership data, and business or commuter surveys. Metropolitan planning organizations (MPOs), rideshare agencies, and local transit agencies are potential sources of these data.
	OCC	(persons/ vehicle)	Average vehicle occupancy	
	OCC_{HOV}	(persons/ vehicle)	Average vehicle occupancy on HOV lanes	
	PMS		Percentage mode shift from driving to bike/pedestrian (decimal)	The percentage of drivers shifting to bike or pedestrian mode can be estimated through surveys in the area affected by the strategy.
	S_C		Number of SOV vehicle starts of carpool users	Start emissions for carpool, transit and vanpool vehicles can be derived from local data.
	S_T		Number of SOV vehicle starts of transit users	
	S_V		Number of SOV vehicle starts of vanpool users	

Type of Input	Variables	(Unit)	Description	Comments
Traffic	T_C		Number of SOV vehicle trips of carpool users	Trip length variables can be acquired from the regional travel demand model, census data, or local travel surveys. MPOs, TxDOT, and rideshare agencies may be able to provide these data. Trip length varies by purpose; pick the one that is most appropriate to the strategy.
	TL_A	(mile)	Average auto trip length after implementation	
	TL_B	(mile)	Average auto trip length before implementation	
	$TL_{B,\ BW}$	(mile)	Average length of participants' trip before participating in the bike/pedestrian program	
	TL_{BUS}	(mile)	Average bus trip length	
	TL_D	(mile)	Average daily truck travel	
	TL_{HBO}	(mile)	Average trip length of home-based other	
	TL_{NW}	(mile)	Average nonwork trip length	
	TL_{PR}	(mile)	Average auto trip length to the park-and-ride facility	
	TL_{PURi}	(mile)	Average trip length by trip purpose	
	TL_{RS}	(mile)	Average auto trip length to rideshare location	
	TL_T	(mile)	Average auto trip length to transit facility	
	TL_{TC}	(mile)	Average auto trip length to the telecommuting center	
	TL_W	(mile)	Average auto trip length	
	TR_{DUi}		Daily trip rate by development unit type	
	T_T		Number of SOV vehicle trips of transit users	
	T_V		Number of SOV vehicle trips of vanpool users	

Type of Input	Variables	(Unit)	Description	Comments
Traffic	U_P		Parking facility utilization rate (estimate)	Utilization rate of a parking facility may require field observation but can also be derived through business surveys.
	$U_{P, A}$		Utilization rate of parking facility after implementation (decimal)	
	$U_{P, B}$		Utilization rate of parking facility before implementation (decimal)	
	$U_{P, HOV}$		Utilization rate of parking spaces by HOVs (decimal)	
	U_{PPK}		Utilization rate of preferential parking spaces (decimal)	
	V		Bi-directional arterial volume for analysis period	Traffic volume can be computed through traffic counts, both automated and manual.
	V_A		Average traffic volume per operating period on main lanes after implementing ramp metering	
	V_B		Average traffic volume per operating period on main lanes before implementing ramp metering	
	$V_{D, OP}$		Average daily volume for the corridor during off-peak hours	
	$V_{D, P}$		Average daily volume for the corridor during peak hours	
	$V_{DA, OP}$		Average daily auto volume for the corridor during off-peak hours	
	$V_{DA, P}$		Average daily auto volume for the corridor during peak hours	
	$V_{DT, OP}$		Average daily truck volume for the corridor during off-peak hours	
	$V_{DT, P}$		Average daily truck volume for the corridor during peak hours	
	$V_{GP, A}$		Average hourly volumes on general purpose lanes during peak hours after implementation of HOV facility	
	$V_{GP, B}$		Average hourly volumes on general purpose lanes during peak hours before implementation of HOV facility	
	$V_{GPL, A}$		Average hourly volumes on general purpose lanes during peak hours after implementation of shoulder lane facility	

Type of Input	Variables	(Unit)	Description	Comments
Traffic	$V_{GP, B}$		Average hourly volumes on general purpose lanes during peak hours before implementation of shoulder lane facility	Traffic volume can be computed through traffic counts, both automated and manual.
	$V_{H, A}$		Average hourly volumes on HOV lanes during peak hours	
	$V_{H, OP}$		Number of vehicles that pass through the intersection per hour during the off-peak period	
	$V_{H, P}$		Number of vehicles that pass through the intersection per hour during the peak period	
	VMT_{A}		Vehicle miles traveled by truck fleet during peak period after control of truck movement	Vehicle miles traveled can be derived from the regional travel demand model or calculation of products of trip lengths and volumes. TxDOT, census data, travel surveys, and local MPOs are sources for these data.
	$VMT_{AUTO, A}$		Vehicle miles traveled by auto after implementation	
	$VMT_{AUTO, B}$		Vehicle miles traveled by auto before implementation	
	VMT_{B}		Vehicle miles traveled by truck fleet before control of truck movement	
	VMT_{BUS}		Vehicle miles traveled by transit vehicle	
	$VMT_{BUS, A}$		Vehicle miles traveled by transit vehicle after implementation (estimate)	
	$VMT_{BUS, B}$		Vehicle miles traveled by transit vehicle before implementation	
	$VMT_{BUS, OP}$		Vehicle miles traveled by transit vehicle during off-peak hours	
	$VMT_{BUS, P}$		Vehicle miles traveled by transit vehicle during peak hours	
	$VMT_{GP, A}$		Vehicle miles traveled on general purpose lanes after implementation (estimate)	
	$VMT_{GP, B}$		Vehicle miles traveled on general purpose lanes before implementation	
	$VMT_{H, A}$		Vehicle miles traveled on HOV lane after implementation (estimate)	
	$VMT_{H, B}$		Vehicle miles traveled on HOV lane before implementation of strategy	

Type of Input	Variables	(Unit)	Description	Comments
Traffic	VMT_{OP}		Off-peak hour reduction in speed emissions	Vehicle miles traveled can be derived from the regional travel demand model or calculation of products of trip lengths and volumes. TxDOT, census data, travel surveys, and local MPOs are sources for these data.
	VMT_{P}		Peak hour reduction in speed emissions	
	VMT_{R}		Reduction in daily automobile vehicle miles traveled	
	$VMT_{R,\ BW}$		Reduction in daily auto vehicle miles traveled by bike/pedestrian mode	
	$VMT_{R,\ OP}$		Reduction in regional off-peak period VMT after no-drive days implemented	
	$VMT_{R,\ P}$		Reduction in regional peak period VMT after no-drive days implemented	
	$VMT_{R,\ RS}$		Reduction in daily auto vehicle miles traveled by rideshare mode	
	$VMT_{R,\ T}$		Reduction in daily auto vehicle miles traveled by transit mode	
	VMT_{REP}		VMT of the vehicle to be replaced	
	$V_{S,\ A}$		Average hourly volumes on shoulder lanes during peak hours	
	BASE	(trip)	Number of daily trips generated by nonregulated residential and commercial uses	Vehicle trips can be derived from traffic data from local MPOs and TxDOT, supplemented by local surveys or counts if determined to be feasible and required.
	HH_{TRIPS}		Average number of trips per household in strategy area	
	VT_{A}	(trip)	Average daily vehicle trips after implementation	
	VT_{ALT}	(trip)	Vehicle trips on alternate facility	
	VT_{B}	(trip)	Average daily vehicle trips before implementation	

Type of Input	Variables	(Unit)	Description	Comments
Traffic	VT_{BUS}	(trip)	Daily vehicle trips by bus or other transit vehicle	Vehicle trips can be derived from traffic data from local MPOs and TxDOT, supplemented by local surveys or counts if determined to be feasible and required.
	$VT_{BUS, OP}$	(trip)	Vehicle trips by bus or other transit vehicle during off-peak hours	
	$VT_{BUS, P}$	(trip)	Vehicle trips by bus or other transit vehicle during peak hours	
	VT_{NC}	(trip)	Vehicle trips remaining on facility after implementation	
	VT_{R}	(trip)	Reduction in number of daily automobile vehicle trips	
	$VT_{R, BW}$	(trip)	Reduction in number of daily vehicle trips by bike/pedestrian mode	
	$VT_{R, OP}$	(trip)	Reduction in regional number of off-peak period vehicle trips after no-drive days implemented	
	$VT_{R, P}$	(trip)	Reduction in regional number of peak period vehicle trips after no-drive days implemented	
	$VT_{R, RS}$	(trip)	Reduction in number of daily vehicle trips by rideshare mode	
	$VT_{R, T}$	(trip)	Reduction in number of daily vehicle trips by transit mode	
	VT_{REP}	(trip)	Average Daily Trips of the vehicle to be replaced	
	VT_{S}	(trip)	Vehicle trips on facility shifted to no cost or lower cost time period	

Type of Input	Variables	(Unit)	Description	Comments
Emissions	E_{OP}	(gram)	Emissions generated by congestion on affected roadway system during the off-peak period for each pollutant (oxides of nitrogen [NO_x], volatile organic compound [VOC], or carbon monoxide [CO])	A variety of vehicle emission sources can be used during analysis. The most used sources are running exhaust, start exhaust, and evaporative hot soak. Running exhaust emissions are influenced by vehicle operating speeds. Start exhaust and evaporative hot soak emissions are influenced by engine on/off activity. Most of the emission variables can be derived directly using the MOtor Vehicle Emission Simulator (MOVES) model and its output. In some cases, additional processing may be required to aggregate to the level specified by the variable. Where speed emission factor is used in this guide, this refers to the speed-dependent running exhaust emission factor output by MOVES.
	E_P	(gram)	Emissions generated by congestion on affected roadway system during the peak period for each pollutant (NO_x, VOC, PM, or CO)	
	E_{REG}	(gram)	Regional freeway emissions	
	EF	(grams/ mile)	Truck exhaust emission factor based on average daily speed (NOx, VOC, PM, or CO)	
	EF_A	(grams/ mile)	Speed-based running exhaust emission factor after implementation (NOx, VOC, PM, or CO)	
	$EF_{A, ALT}$	(grams/ mile)	Speed-based running exhaust emission factor on alternate route after implementation (NOx, VOC, PM, or CO)	
	$EF_{A, i}$	(grams/ mile)	Speed-based running exhaust emission factor for fleet composite (including trucks) (NOx, VOC, PM, or CO)	
	$EF_{A, OP}$	(grams/ mile)	Speed-based running exhaust emission factor during off-peak hours in affected corridor after implementation (NOx, VOC, PM, or CO)	
	$EF_{A, P}$	(grams/ mile)	Speed-based running exhaust emission factor during peak hours in affected corridor after implementation (NO_x, VOC, PM, or CO)	
	$EF_{A\text{-}Auto, OP}$	(grams/ mile)	Speed-based auto running exhaust emission factor during off-peak hours in affected corridor after implementation (NOx, VOC, PM, or CO)	
	$EF_{A\text{-}Auto, P}$	(grams/ mile)	Speed-based auto running exhaust emission factor during peak hours in affected corridor after implementation (NOx, VOC, PM, or CO)	
	$EF_{A\text{-}Truck, OP}$	(grams/ mile)	Speed-based truck running exhaust emission factor during off-peak hours in affected corridor after implementation (NOx, VOC, PM, or CO)	

Type of Input	Variables	(Unit)	Description	Comments
Emissions	$EF_{A\text{-}Truck,\ P}$	(grams/ mile)	Speed-based truck running exhaust emission factor during peak hours in affected corridor after implementation (NOx, VOC, PM, or CO)	A variety of vehicle emission sources can be used during analysis. The most used sources are running exhaust, start exhaust, and evaporative hot soak. Running exhaust emissions are influenced by vehicle operating speeds. Start exhaust and evaporative hot soak emissions are influenced by engine on/off activity. Most of the emission variables can be derived directly using the MOVES model and its output. In some cases, additional processing may be required to aggregate to the level specified by the variable. Where speed emission factor is used in this guide, this refers to the speed-dependent running exhaust emission factor output by MOVES.
	EF_{B}	(grams/ mile)	Speed-based running exhaust emission factor for affected roadway before implementation (NOx, VOC, PM, or CO)	
	$EF_{B,\ ALT}$	(grams/ mile)	Speed-based running exhaust emission factor on alternate route before implementation (NOx, VOC, PM, or CO)	
	$EF_{B,\ i}$	(grams/ mile)	Speed-based running exhaust emission factor for defined fleet composite (excluding trucks) (NOx, VOC, PM, or CO)	
	$EF_{B,\ OP}$	(grams/ mile)	Speed-based running exhaust emission factor during off-peak hours in affected corridor after before implementation (NOx, VOC, PM, or CO)	
	$EF_{B,\ P}$	(grams/ mile)	Speed-based running exhaust emission factor during peak hours in affected corridor before implementation (NOx, VOC, PM, or CO)	
	$EF_{B\text{-}Auto,\ OP}$	(grams/ mile)	Speed-based auto running exhaust emission factor during off-peak hours in affected corridor before implementation (NOx, VOC, PM, or CO)	
	$EF_{B\text{-}Auto,\ P}$	(grams/ mile)	Speed-based auto running exhaust emission factor during peak hours in affected corridor before implementation (NOx, VOC, PM, or CO)	
	$EF_{B\text{-}Truck,\ OP}$	(grams/ mile)	Speed-based truck running exhaust emission factor during off-peak hours in affected corridor before implementation (NOx, VOC, PM, or CO)	

Type of Input	Variables	(Unit)	Description	Comments
Emissions	$EF_{B\text{-}Truck, P}$	(grams/ mile)	Speed-based truck running exhaust emission factor during peak hours in affected corridor before implementation (NOx, VOC, PM, or CO)	A variety of vehicle emission sources can be used during analysis. The most used sources are running exhaust, start exhaust, and evaporative hot soak. Running exhaust emissions are influenced by vehicle operating speeds. Start exhaust and evaporative hot soak emissions are influenced by engine on/off activity. Most of the emission variables can be derived directly using the MOVES model and its output. In some cases, additional processing may be required to aggregate to the level specified by the variable. Where speed emission factor is used in this guide, this refers to the speed-dependent running exhaust emission factor output by MOVES.
	EF_{BUS}	(grams/ mile)	Speed-based running exhaust emission factor for transit vehicle	
	$EF_{GP, A}$	(grams/ mile)	Speed-based running exhaust emission factor on general purpose lanes after implementation (NOx, VOC, PM, or CO)	
	$EF_{GP, B}$	(grams/ mile)	Speed-based running exhaust emissions factor on general purpose lanes before implementation (NOx, VOC, PM, or CO)	
	$EF_{H, A}$	(grams/ mile)	Speed-based running exhaust emission factor on HOV lane after implementation (NOx, VOC, PM, or CO)	
	$EF_{H, B}$	(grams/ mile)	Speed-based running exhaust emissions factor on HOV lane before implementation (NOx, VOC, PM, or CO)	
	EF_{I}	(grams/ hour)	Emission factor for idling (NO_x, VOC, PM, or CO)	
	EF_{N}	(grams/ mile)	Replacement vehicle speed-based running exhaust emission factor (NOx, VOC, PM, or CO)	
	EF_{O}	(grams/ mile)	Retired vehicle speed-based running exhaust emission factor (NOx, VOC, PM, or CO)	
	EF_{PURi}	(grams/ mile)	Speed-based running exhaust emission factor by trip purpose (NOx, VOC, PM, or CO)	
	$EF_{S, A}$	(grams/ mile)	Speed-based running exhaust emission factor on shoulder lane facility (NOx, VOC, PM, or CO) (estimate)	
	EF_{T}	(grams/ hour)	Idling emission factors for idle reduction technologies (NOx, VOC, PM, or CO)	

Type of Input	Variables	(Unit)	Description	Comments
Emissions	TEF	(grams/trip) (grams/start)	Auto trip-end emission factor (NOx, VOC, PM, or CO)	This guide uses trip end factors to represent all associated vehicle engine start/stop emissions (includes start emissions at a minimum and may include hot soak emissions) of a vehicle trip measured in grams per trip. This factor can be calculated by using information from MOVES database output.
	TEF_{A}	(grams/trip) (grams/start)	Trip end emission factor after replacement (NO_x, VOC, PM, or CO)	
	TEF_{AUTO}	(grams/trip) (grams/start)	Auto trip-end emission factor (NO_x, VOC, PM, and CO)	
	TEF_{B}	(grams/trip) (grams/start)	Trip end emission factor before replacement (NO_x, VOC, PM, or CO)	
	TEF_{BUS}	(grams/trip) (grams/start)	Bus (or other transit vehicle) trip-end emission factor (NOx, VOC, PM, or CO)	
	TEF_{N}	(grams/trip) (grams/start)	Trip end emission factor of replacement vehicle (NOx, VOC, PM, or CO)	
	TEF_{O}	(grams/trip) (grams/start)	Trip end emission factor of retired vehicle (NOx, VOC, PM, or CO)	
	TEF_{TRK}	(grams/trip) (grams/start)	Truck trip-end emission factor (NO_x, VOC, PM, or CO)	
Factor	CAP		Internal capture rate of regulated development (decimal)	Design guidelines and mixed-use developments will require an estimate of vehicle trips saved as a result of the design and/or regulation.
	F_{AT}	(percent)	Percentage of participants who previously drove SOVs (decimal)	The various factor variables (F) can be derived from multiple sources: travel demand models, emissions inventories, fleet inventories, rideshare agencies, and local surveys conducted by agency staff.
	$F_{BW, SOV}$	(percent)	Percentage of new participants in the bike/pedestrian programs who previously drove SOVs (decimal)	
	F_{CND}	(percent)	Percent compliance of the no-drive days program	
	F_{ECP}	(percent)	Percentage of existing carpools (decimal)	
	F_{Eff}		Project effectiveness factor for each affected freeway	
	$F_{EN, OP}$	(percent)	Percent of nonrecurrent congestion eliminated on roadways with ITS deployment, off-peak period (decimal)	

Type of Input	Variables	(Unit)	Description	Comments
Factor	$F_{EN, P}$	(percent)	Percent of nonrecurrent congestion eliminated on roadways with ITS deployment, peak period (decimal)	The various factor variables (**F**) can be derived from multiple sources: travel demand models, emissions inventories, fleet inventories, rideshare agencies, and local surveys conducted by agency staff.
	$F_{ER, OP}$	(percent)	Percent of recurrent congestion eliminated on roadways with ITS deployment, off-peak period (decimal)	
	$F_{ER, P}$	(percent)	Percent of recurrent congestion eliminated on roadways with ITS deployment, peak period (decimal)	
	F_{ITS}	(percent)	Percent of roadway system coverage with ITS deployment (decimal)	
	F_{NR}		Nonrecurring emissions (decimal)	
	$F_{NR, OP}$	(percent)	Percent of roadway system emissions caused by nonrecurring congestion in the off-peak period (decimal)	
	$F_{NR, P}$	(percent)	Percent of roadway system emissions caused by nonrecurring congestion in the peak period (decimal)	
	F_{OPH}	(percent)	Percent of off-peak hours/emissions affected by ITS deployment (decimal)	
	F_{PARK}	(percent)	Percent of vehicles that park instead of using the drive-through facility due to imposed control (decimal)	
	F_{PURi}	(percent)	Percentage of trips saved by trip purpose (decimal)	

Type of Input	Variables	(Unit)	Description	Comments
Factor	F_{RS}	(percent)	Percentage of people attracted to the HOV facility using rideshare (decimal)	The various factor variables (**F**) can be derived from multiple sources: travel demand models, emissions inventories, fleet inventories, rideshare agencies, and local surveys conducted by agency staff.
	$F_{RS, SOV}$	(percent)	Percentage of people attracted to the HOV facility using rideshare that previously used an SOV (decimal)	
	F_{SOV}	(percent)	Percentage of those people continuing to use an SOV for their full commute (decimal)	
	F_{T}	(percent)	Percentage of people attracted to the HOV facility using a transit vehicle (decimal)	
	$F_{T, SOV}$	(percent)	Percentage of people using a transit vehicle that previously were vehicle drivers (decimal)	
	F_{USE}	(percent)	Percentage of park-and-ride users that utilize the facilities (decimal)	
	F_{W}	(percent)	Percentage of participating vehicles commuting to work (decimal)	
	P_{Ri}	(percent)	Percent reduction in emissions after adopting individual operating efficiency improving technologies	
	ϵ	(mile)	Price elasticity for mode and time shift or facility charge	The elasticity variable can be determined from data from TxDOT or local MPOs. Regional travel demand models rely on these elasticities in the mode choice module.
	ϵ_{fee}		Price elasticity for mode shift	