Performance Review of Transportation Fund for Clean Air Projects

Literature Review

Prepared for

Bay Area Air Quality Management District

Prepared by

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EXECUTIVE SUMMARY

This document summarizes existing literature on the transportation and emission reduction impacts of selected transportation control measures (TCMs). The document focuses on selected TCMs funded by BAAQMD's Transportation Fund for Clean Air (TFCA) program for which emission reduction effectiveness appears to be the most uncertain. Specifically, literature was reviewed on the following ten types of TFCA projects:

- Regional rideshare programs
- Vanpool/buspool programs
- Traffic signal timing
- Incident management
- Transit signal priority
- Bicycle paths, lanes, and routes
- Bicycle racks, lockers, and parking stations
- Bicycle racks on buses
- Pedestrian facility improvements
- Traffic calming

For each of the project types of interest, we assessed transportation impacts, emissions impacts, and other health and economic impacts. For emission reduction cost effectiveness, the literature review relies heavily on Transportation Research Board (TRB) Special Report 264, entitled *The Congestion Mitigation and Air Quality Improvement Program: Assessing 10 Years of Experience*. This comprehensive report reviewed and summarized all relevant literature published before 2002 (more than 80 sources), and also adjusts estimated emission impacts from different studies so they are in comparable terms. Because the methodology used in the TRB report differs from that currently used by the Air District in several respects, the cost effectiveness figures presented in this review cannot be directly compared to current Air District TFCA cost effectiveness estimates.

There is evidence that all types of ridesharing, bicycle, and pedestrian projects can reduce automobile use and associated emissions. Signal timing and incident management projects can reduce congestion and associated emissions. All project types can also generate other public health and economic benefits.

- There is extensive evidence that **regional ridesharing** programs and **vanpool/buspool** programs reduce vehicle use and emissions. The literature suggests these projects are often highly cost effective at reducing emissions, although transportation and emissions impacts can vary widely by project.
- **Traffic signal timing** and **incident management** projects reduce vehicle idling and smooth traffic flow. Many studies have documented congestion reduction, emission reduction, and economic benefits resulting from these projects. Some beneficial impacts of these projects may be offset due to higher speeds (which can lead to greater NOx emissions and discourage non-motorized travel) and induced traffic.
- **Transit signal priority** (TSP) projects have been demonstrated to reduce bus travel time and improve service reliability, which can lead to greater transit ridership and less auto travel. Research to date has

not been able to isolate the ridership and emissions benefits of these projects because they are often bundled with other transit improvements.

- A variety of research suggests that the provision of **bicycle paths and lanes** induces drivers to switch to bicycling mode. Few studies have quantified automobile travel and emission reduction benefits from these projects. These projects have other public health benefits related to increases in physical activity.
- Several studies have calculated the emission reduction cost effectiveness of **bicycle racks, lockers, and parking stations**, with widely varying results. Much of the research to date has focused on more expensive bicycle lockers rather than inexpensive bicycle racks.
- Many transit agencies have reported increased bicycle usage following installation of **bike racks on buses**. A recent survey of transit agencies suggests that these projects lead to increased transit usage. There is very little research on the trip reduction and emissions impacts of bike racks on buses.
- There is clear evidence that **pedestrian facility improvements** and, in some cases, **traffic calming** are associated with increased pedestrian activity. There is more limited evidence that pedestrian facility improvements reduce automobile use and emissions. Recent studies of Safe Routes to School programs have found that pedestrian facility improvements (such as sidewalk gap closure) result in more children walking to school. These projects typically create public health benefits by encouraging physical activity and improving pedestrian safety.

For six of the ten project types, we identified calculations of emission reduction cost effectiveness in the literature, summarized in Table ES-1. Among these six project types, regional ridesharing and traffic signal timing projects appear to be the most cost-effective, followed closely by vanpool/buspool projects. Bicycle parking projects appear to be less cost effective, among the project types for which information is available. No comparable cost effectiveness estimates are available for four of the project types considered, and two others (incident management and bicycle path/lane/route projects) have only one or two examples in the literature. While there is evidence that these six project types can reduce emissions, it is difficult to draw firm conclusions about their cost effectiveness.

Table ES-1: Summary of Annual Cost Effectiveness by Project Type (thousands of $/ton)

Project Type	Number of Projects	Low	High	Mean	Median
Regional Ridesharing	3	$1.2	$16.0	$8.2	$7.4
Vanpool/Buspool	6	$5.2	$89.0	$24.3	$10.5
Signal Timing	3	$6.0	$27.2	$13.7	$7.9
Incident Management	2	$2.4	$199.8	$101.1	$101.1
Transit Signal Priority	0	N/A	N/A	N/A	N/A
Bicycle Paths, Lanes, and Routes	1	$67.5	$67.5	$67.5	$67.5
Bicycle Racks, Lockers, Parking Stations	5	$10.4	$295.6	$123.1	$98.8
Bicycle Racks on Buses	0	N/A	N/A	N/A	N/A
Pedestrian Facility Improvements	0	N/A	N/A	N/A	N/A
Traffic Calming	0	N/A	N/A	N/A	N/A

Note: $/ton adjusted to the year 2000.
Source: Transportation Research Board, *The Congestion Mitigation and Air Quality Improvement Program: Assessing 10 Years of Experience*, Special Report 264, 2002.

In order to put the Table ES-1 results in a broader context, Table ES-2 summarizes the cost effectiveness of other projects types reviewed in TRB Special Report 264, ranked by median cost-effectiveness. These findings suggest that regional ridesharing, traffic signal timing, and vanpool/buspool projects are among the most cost-effective of all 20 project types reviewed in the report. Only inspection and maintenance programs (which are not funded by the TFCA program) appear to more cost-effective. Projects involving charges and fees appear to be one of the most cost-effective types of projects; such projects are eligible for TFCA funding but none have been implemented to date.

Table ES-2: Summary of Cost Effectiveness for other Project Types (thousands of $/ton)

Project Type	Number of Projects	Low	High	Mean	Median
Inspection and maintenance	5	$1.8	$5.8	$3.7	$1.9
Charges and fees	6	$0.8	$49.4	$16.6	$10.3
Miscellaneous TDM	8	$2.3	$33.2	$15.0	$12.5
Conventional fuel replacement buses	5	$11.0	$39.9	$20.6	$16.1
Alternative-fuel vehicle programs	2	$4.0	$31.6	$17.8	$17.8
Employer trip reduction	7	$5.7	$175.5	$48.0	$22.7
Conventional transit service upgrades	10	$3.8	$120.1	$37.7	$24.6
Park-and-ride lots	4	$8.6	$70.7	$41.3	$43.0
Modal subsidies and vouchers	14	$0.8	$471.0	$87.6	$46.6
New transit capital systems/vehicles	6	$8.5	$470.8	$127.0	$66.4
Transit shuttles, feeders, paratransit	15	$12.3	$1,974	$335.6	$87.5
Alternative-fuel buses	11	$6.7	$568.7	$225.4	$126.4
HOV facilities	2	$15.7	$336.8	$176.2	$176.2
Telework	10	$13.3	$8,227	$1,248	$251.8

Note: $/ton adjusted to the year 2000.
Source: Transportation Research Board, *The Congestion Mitigation and Air Quality Improvement Program: Assessing 10 Years of Experience*, Special Report 264, 2002.

One notable observation from the findings of TRB Special Report 264 is the wide variation in cost effectiveness *within* project types. Nearly every project type has examples that reduce emissions for less than $20,000 per ton. But many project types also have examples with poor cost effectiveness. This suggests that the specific context of each project may have greater bearing on cost effectiveness than the project type.

It is clear from this literature review that very little is known about the emission reduction cost effectiveness of most TFCA project types, particularly transit signal priority, bicycle paths/lanes/routes, bicycle racks on buses, pedestrian facility improvements, and traffic calming. The experiences of TFCA project sponsors represent a major potential source of information to develop a better understanding of these project types. The next task in our Performance Review will make use of this information by reviewing and assessing a sample of actual TFCA projects.

1 INTRODUCTION AND PURPOSE

This document summarizes existing literature on the transportation and emission reduction impacts of selected transportation control measures (TCMs). The document focuses on selected TCMs funded by BAAQMD's Transportation Fund for Clean Air (TFCA) program for which emission reduction effectiveness appears to be the most uncertain. Specifically, literature was reviewed on the following ten types of TFCA projects:

- Regional rideshare programs
- Vanpool/buspool programs
- Traffic signal timing
- Incident management
- Transit signal priority
- Bicycle paths, lanes, and routes
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Quantifying the emissions impacts of these types of projects is often challenging. Evaluations of ridesharing and vanpool/buspool programs, for example, generally require surveys of participants. Estimating emission impacts from signal timing and incident management projects is difficult because these projects typically affect only vehicle speeds, rather than vehicle trips or vehicle miles of travel. Evaluations of bicycle, pedestrian, and traffic calming projects must be carefully structured to determine how these projects change vehicle starts and vehicle travel, not just levels of walking and bicycling. As a result, little research has been conducted to quantify the emissions impacts of these types of projects.

For each of the project types of interest, we discuss transportation impacts, emissions impacts, and other health and economic impacts. This literature review provides a baseline of knowledge for the remainder of the Performance Review of TFCA Projects. Subsequent tasks will (1) determine the emissions impacts of a sample of TFCA projects for each of the project types listed above and (2) develop recommendations for changes to project sponsor reporting and for future program evaluation methods.

2 METHODOLOGICAL ISSUES

We reviewed and summarized literature covering each of the project types listed in Section 1. For emission reduction cost-effectiveness, the literature review relies heavily on Transportation Research Board (TRB) Special Report 264, entitled *The Congestion Mitigation and Air Quality Improvement Program: Assessing 10 Years of Experience*.[1] This comprehensive report reviewed and summarized all relevant literature published before 2002 (more than 80 sources), and also adjusts estimated emission impacts from different studies so they are in comparable terms.

We conducted additional literature searches in order to identify any studies that report emission reduction cost effectiveness that have been published since 2002 (and thus not covered by the TRB report). No such studies were identified. We reviewed a variety of other literature that discusses the transportation impacts, public health impacts, and economic impacts (but not necessarily emission reduction impacts) of the selected strategies. Reductions in vehicle trips and vehicle travel are closely correlated with emission reductions.

As discussed in the following sections, the literature contains surprisingly little information on emission reduction cost effectiveness for the project types of interest. While there are many studies that provide estimates of the travel impacts of TCMs, and a number that provide estimates of emissions impacts, relatively few provide emissions impacts and cost information, both of which are needed to determine cost effectiveness. Without estimating emission reduction cost effectiveness, it is impossible to accurately compare across projects. Most of the examples provided in TRB Special Report 264 come from only a handful of sources.

Because some studies use different methodologies for calculating cost effectiveness, it is sometimes inappropriate to compare results across studies. TRB Special Report 264 attempts to facilitate comparison by using the reported cost and impact information and re-calculating cost effectiveness using a standardized methodology. This methodology differs from that currently used by the Air District in several respects:

- For projects lasting more than one year, costs and benefits that occur in future years were discounted to reflect the time cost of money and the value placed on immediate consumption. For costs, this involved spreading costs evenly over the life of the project and then applying a discount rate. For benefits, the methodology assumes that the emissions benefits of some projects will increase over time, some will remain constant, and others will decline. Like costs, future benefits were then discounted by applying a discount rate. The current Air District methodology does not apply discounting.
- The methodology calculates the total emission reduction by summing 1.0 times VOC emissions and 4.0 times NOx emissions. (NOx emissions were given a higher weight because of their importance in achieving ozone standards in many regions and because of the link between NOx and fine particulate formation.) Particulate and CO emissions are not included in the total emission reduction calculation. Before this year, the Air District methodology summed VOC, NOx, and PM-10 emissions with equal weighting. This year, in keeping with ARB guidance, the Air District applies a weighting factor of 10 to PM emissions.

For these reasons, *the cost effectiveness figures presented from TRB Special Report 264 cannot be directly compared to current Air District TFCA cost effectiveness estimates.*

3 TRANSPORTATION AND EMISSIONS IMPACTS BY PROJECT TYPE

This section presents a summary of the literature findings on transportation impacts, emissions impacts, and other public health and economic impacts for each of the ten project types of interest. Where available, emissions impacts are presented for four criteria pollutants: hydrocarbons (HC), nitrogen oxides (NOx), carbon monoxide (CO), and particulate matter less than 10 microns in diameter (PM-10). Note that all strategies that reduce vehicle use (VMT or idling) also reduce fuel consumption and greenhouse gas emissions.

3.1 Regional Rideshare Programs

Regional rideshare programs provide area-wide carpool services, including ridematching, employer outreach, and incentives to commute by carpool. Most TFCA funding in this category has gone to MTC’s

Regional Rideshare Program. Ridesharing programs reduce vehicle trips by increasing the average number of persons riding in a vehicle. Riders must share common travel destinations.

The impacts are typically measured through developing a "placement rate" for each activity, which is then converted into a trip reduction figure, or through assuming a percentage reduction in vehicle travel from the targeted group. One methodology in common use – including by MTC in the Bay Area – was developed by the Survey Research Center of California State University-Chico. This defines "placement" as "any change to a non-SOV commute mode within a specified period after service contact with the rideshare program."

Transportation Impacts

There is no doubt that regional rideshare programs reduce vehicle trips and vehicle travel, although the cost-effectiveness of these programs are less certain. Carpool and vanpool matching is typically one of the primary activities; through maintaining a database of individuals seeking a carpool partner, the program can assist in the formation of carpools and help set up vanpools. The transportation impacts are calculated based on (1) the length of the placement (i.e., how long the mode shift is maintained, typically based on a longitudinal panel study); (2) the prior mode (so that credit is not given for trips previously made by transit, for example); (3) assumptions on trip length; and (4) a deduction for any access trips (e.g., if the participant drives to the carpool staging area).

Overall transportation impacts are highly dependent on the size of the service area, the number of clients served, and the size of the carpool matching database. For example, Commuter Connections in Washington, DC reports daily reductions of 793 trips and 28,516 vehicle miles traveled from its rideshare operations center. Los Angeles MTA reports 3,221 daily trips reduced and a daily VMT reduction of 73,442. For comparison, MTC's Regional Rideshare Program in the San Francisco Bay Area has reduced 6,667 daily vehicle trips and 262,745 daily miles of vehicle travel.[2]

Emissions Impacts

Ridesharing programs reduce vehicle travel and associated emissions. TRB Special Report 264 identifies five "programmatic ridesharing" projects for which cost effectiveness has been calculated. However, for two of these projects, the cost effectiveness is based on estimates of project impacts performed before implementation, rather than ex-post evaluations. We therefore exclude these two examples because we believe they may be unreliable. These remaining three projects are:

- *University Rideshare Program:* Student and staff-based rideshare program for colleges and universities within the 10-county Atlanta Regional Commission area.[3]
- *Commuter Assistance Program:* A county-level rideshare program in Riverside County that offers incentives to first-time ride-sharers and users of other drive-alone modes.[4]
- *CTS Telephone Ridematching:* A telephone ridematching information system for residents of Victor Valley, California, who did not have access to teleservice staff to record callers' information for ridematching purposes. Commuters were able to enter data using touch-tone phones, and then were sent ridematching information by mail.[5]

Cost and emissions impacts for these three projects are summarized in Table 1. The mean and median cost effectiveness are $8,225 per ton and $7,398 per ton, respectively. The CTS Telephone Ridematching project was particularly cost effective due to low developmental costs, relatively good matching success (i.e., 20 percent placed into carpools), and very long distance commutes.

Table 1: Cost and Emission Impacts for Regional Rideshare Programs

Project	Emissions Reductions (Tons/Year)				Annual Benefits (Tons/Yr)	Annual Cost (2000 $)	Cost/Ton (2000 $)
	HC	NO_x	CO	PM_{10}			
University Rideshare Program (Atlanta)	4.00	4.00	–	–	15.0	$111,268	$7,398
Commuter Assistance Program (Riverside County)	2.75	2.75	22.75	1.75	26.4	423,287	16,034
CTS Telephone Ridematching (San Bernardino County)	19.10	19.10	–	9.55	95.5	118,752	1,243

Source: Transportation Research Board, *The Congestion Mitigation and Air Quality Improvement Program: Assessing 10 Years of Experience*, Special Report 264, 2002.

Several factors can affect the emission reductions achieved through regional ridesharing programs. One important issue to consider is the travel mode participants used before joining a carpool, which determines how many vehicle trips are reduced. In some cases, a rideshare program might divert commuters from transit, which could actually increase vehicle trips and emissions. In most cases, however, there is little competition between ridesharing and transit.

It is also important to avoid double counting of trip reductions for programs that are supported by multiple agencies, or cases in which more than one program activity contributes to a change in commute behavior (such as ridematching and incentive programs).

Other Public Health Impacts and Economic Impacts

Because ridesharing results in fewer peak-period trips, it can reduce congestion, which in turn has beneficial health and economic impacts. Roadway accident rates are lower in uncongested conditions, meaning fewer personal injuries and fatalities. If participants walk or bicycle to a ridesharing pick-up location, they benefit from increased physical activity (discussed further in Section 3.9). Research has found that repeated exposure to traffic congestion can elevate blood pressure and increase negative mood states. Such health conditions can, in turn, lead to unsafe driving.[6] [7]

Ridesharing participants can accrue economic benefits if they are foregoing driving personal vehicles, and therefore, reducing fuel consumption and the need for additional car maintenance. One study has estimated that the majority of annual household transportation expenditures, almost $6,200, went towards buying, fueling, and maintaining personal cars and trucks in 1998. Seventeen percent of transportation expenditures went to gasoline, motor oil, and taxes on those products, followed by maintenance and repairs at ten percent.[8]

Reducing roadway congestion delay can have major economic benefits. This includes the value of time for automobile drivers and passengers, as well as commercial vehicle drivers. Reducing congestion can also improve business competitiveness by expanding the potential number of workers or shoppers who can reach a given destination or expanding the market reach of suppliers. Other economic benefits accrue due to reductions in vehicle operating costs, such as excess fuel consumption and maintenance costs for vehicles delayed in congestion, and reduced roadway accident costs, since crash rates are higher in congested conditions.

3.2 Vanpool/Buspool Programs

Vanpool and buspool programs typically provide vehicles owned by an organization such as a business, non-profit, or government agency. The vans or buses may be operated by a driver or by the commuters themselves. Some programs provide outreach services to attract potential riders. Vanpools and buspools are particularly well suited for longer commutes. The TFCA grants in this category have gone mostly to county-operated programs, as opposed to city-operated programs.

Transportation Impacts

Vanpooling and buspooling reduce vehicle miles traveled by serving commuters who live in a common geographic area and who share a destination. In addition to reducing VMT, these programs also reduce vehicle trips (cold starts) if riders are picked up at their homes or travel to a central pick-up location by non-motorized means (walking, bicycling, etc).

Like regional ridesharing programs, vanpool and buspool programs vary widely in size. Many are small and provide only a handful of vans or buses. In contrast, the program operated by the Seattle regional transit agency (King County) is one of the nation's largest, with more than 1,000 active vanpools.[9] In the Bay Area, for comparison, the 511 Vanpool Program had a fleet of 597 in FY 2003-04.[10] The amount of vehicle travel reduced depends on the number of participants and the commute length. A large vanpool program in Chicago, for example, has 252 vanpools and eliminates 2,529 trips and 120,000 vehicle miles traveled each weekday.[11] A much smaller program in Palmdale resulted in a reduction of 66 trips and 3,700 vehicle miles traveled per day, using six vanpools.[12]

Emissions Impacts

Vanpool/buspool programs reduce vehicle travel and associated emissions. TRB Special Report 264 includes cost effectiveness estimates for six vanpool/buspool projects, as follows:

- *Regional Vanpool Program:* A region-wide vanpool program in Houston, Texas operated as a market-driven alternative to the Employer Trip Reduction program. The program operated a home-to-worksite program that used leased vans.[13]
- *Palmdale Community Vanpool:* This project provides vanpool rider and fuel subsidies for new vanpools formed in Palmdale, California. This project is a joint venture between the City of Palmdale and a local developer. Early results from this project included 100 riders in six new vanpools.[14]
- *Torrance Vanpool:* This project provided a new rider subsidy and marketing campaign to support vanpooling in Torrance, California.[15]
- *City of Anaheim Commuter Express Buspool:* This project provided a new commuter express bus service from Chino Hills to Anaheim. It is a joint venture project between the city and five employers. Funds were used to subsidize and market service.[16]
- *UCLA Vanpool Expansion:* This project provided funding to expand an employee vanpool program at the University of California, Los Angeles, allowing for the purchase and subsidization of 25 new vans and marketing to increase employee awareness about the program.[17]
- *Coronado Transportation Management Association Vanpool:* Using bridge toll funds, the City of Coronado and TMA formed 33 new vanpools with 243 riders by marketing service and subsidizing fares. [18]

The effectiveness of these six projects is summarized in Table 2. The mean and median cost effectiveness of these project is $24,270 per ton and $10,501 per ton, respectively.

Table 2: Cost and Emission Impacts for Local Rideshare and Vanpool/Buspool Projects

	Emission Reductions (Tons/Year)						
Project	**HC**	**NO_x**	**CO**	**PM_{10}**	**Annual Benefits (Tons/Yr)**	**Annual Cost (2000 $)**	**Cost/Ton (2000 $)**
Regional Vanpool Program (Houston)	30.00	62.00	–	–	278.0	$1,708,208	$6,145
Palmdale Community Vanpool	0.65	1.08	–	0.45	5.0	54,516	10,984
Torrance Vanpool	0.53	0.85	–	0.38	4.0	96,593	24,347
City of Anaheim Commuter Express Buspool	0.38	0.68	–	0.30	3.1	31,380	10,017
UCLA Vanpool Expansion	1.00	1.58	–	0.68	7.3	652,379	88,960
Coronado TMA Vanpool	4.95	8.05	–	3.40	37.2	191,932	5,164

Source: Transportation Research Board, *The Congestion Mitigation and Air Quality Improvement Program: Assessing 10 Years of Experience*, Special Report 264, 2002.

Like ridesharing, it is important that emissions impact estimates consider the form of transportation that participants previously used before joining the carpool or vanpool. It is also important to consider the emissions from the vanpools and buspools themselves.

Other Public Health Impacts and Economic Impacts

Similar to regional ridesharing programs, vanpool and buspool programs can reduce congestion, which results in public health and economic benefits. Less congestion means fewer roadway accidents. The economic costs of congestion can be very large. Reducing congestion creates economic benefits for both passenger vehicles and commercial vehicles by reducing travel time and vehicle operating costs (fuel, maintenance, etc.). Reducing congestion can also improve business competitiveness, as discussed in Section 3.1.

3.3 Traffic Signal Timing

Traffic signal timing projects improve arterial traffic flow, allowing vehicles to travel more smoothly. This can result in less vehicle idling, higher average speeds, and less rapid acceleration and deceleration, which generally reduce emissions. Signal timing projects typically attempt to synchronize multiple traffic signals along a corridor. A signal timing project could also be focused on a single intersection, for example by retiming an existing signal or upgrading a signal to a more advance control device. Most TFCA grants in this category go to corridor-wide projects.

Transportation Impacts

There are a large number of available traffic signal control technologies. The effect of these technologies on traffic flow (and emissions) depends heavily on proper technology selection and installation. In the 1980s, for example, field tests found that when signals were upgraded from standard, pre-timed systems to “adaptive control” systems that use real time data from detectors to perform constant optimizations, the simpler methods performed better on average.[19]

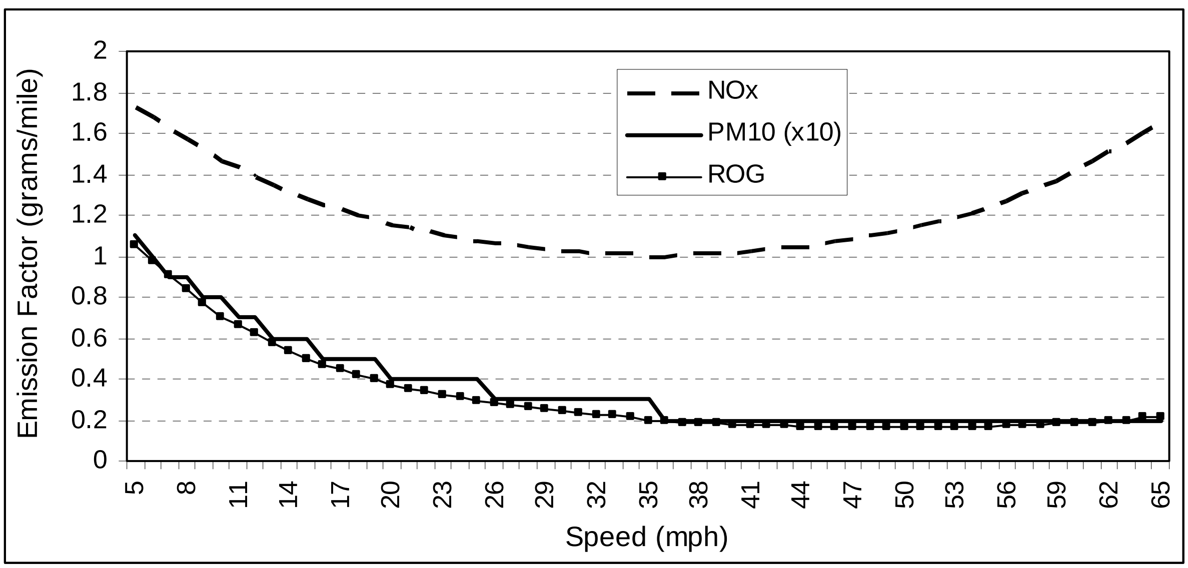
When properly installed, traffic signal control improvements can be very effective at reducing congestion. For example, the Texas Traffic Light Synchronization Grant Program II was found to have reduced vehicle delay by 30 percent and fuel consumption by 14 percent.[20] A California program improved 3,172 signals across the state, resulting in a 15 percent reduction in delay and a 9 percent reduction in fuel consumption.[21] These results include any impacts on counterflow and cross traffic.

Emissions Impacts

Vehicles generally have lower emissions rates in free-flow conditions than in stop-and-go conditions. When signal timing projects reduce vehicle stops and delay, they typically reduce emissions. However, the standard emission factor models cannot directly estimate the impacts of changes in acceleration and deceleration patterns. Rather, emission factors are developed for average travel speeds, which include stops, accelerations, decelerations, and steady speeds.

On arterial streets, NOx emission factors are lowest around 35 mph using ARB's EMFAC model (see Figure 1). They increase as speeds drop below 35 mph and increase above 35 mph. Thus, if signal timing results in improved traffic flow with speeds up to 35 mph, emissions tend to fall. But if speeds increase above 35 mph, emissions might actually rise. Current research is focused on developing emissions models that can better capture acceleration effects (so-called "modal emissions models").

Figure 1: Influence of Speed on Emission Factors



Note: PM-10 factors reflect exhaust emissions only. PM-10 factors are multiplied by 10 to allow graphing using the same scale as the other pollutants.
Source: California Air Resources Board, Methods to Find the Cost-Effectiveness of Funding Air Quality Projects, May 2005.

TRB Special Report 264 identifies five signal synchronization projects for which cost effectiveness has been calculated. However, two of the examples involve pre-implementation estimates of emission reduction, rather than ex-post evaluations. We therefore exclude these two examples because we believe they may be unreliable. These three projects are:

- *Arterial Street Signal Connect:* This project improves traffic flow and transit quality by interconnecting traffic signals along arterials with high transit use in Philadelphia. Public transit was assumed to benefit from coordinated traffic signals on lower volume roadways where there is the best likelihood that all vehicles can travel in the "green band" throughout.[22]

- *Maryland Route 2 Signal Systemization:* This project coordinates traffic signals along an arterial in the Baltimore region.[23]
- *Pulaski Road Signal Interconnect:* This project coordinates traffic signals along the Pulaski Road arterial from the Stevenson Expressway to 87th Street in the Chicago region.[24]

The emissions impacts of these three projects are summarized in Table 3. The mean and median cost effectiveness of these project is $13,690 per ton and $7,934 per ton, respectively.

Table 3: Cost and Emission Impacts for Signal Timing Projects

	Emission Reductions (Tons/Year)						
Project	**HC**	**NO_x**	**CO**	**PM_{10}**	**Annual Benefits (Tons/Yr)**	**Annual Cost (2000 $)**	**Cost/Ton (2000 $)**
Arterial Street Signal Connect (Philadelphia)	13.00	1.43	–	–	8.5	$231,156	$27,168
Maryland Rt. 2 Signal Systemization	3.00	0.30	–	–	0.8	6,326	7,934
Pulaski Rd. Signal Interconnect (Chicago)	7.50	–	–	–	5.4	32,139	5,968

Source: Transportation Research Board, *The Congestion Mitigation and Air Quality Improvement Program: Assessing 10 Years of Experience*, Special Report 264, 2002.

In addition to the speed effects discussed above, properly estimating the impacts of signal timing should account for the following issues:

- Induced Travel Demand – An increase in traffic speeds may induce additional vehicle travel, which may offset some of the air pollution benefits. Speed improvements might also discourage walking and bicycling.
- Diverted Traffic – Signalization improvements can cause some traffic that previously traveled on other routes to switch to the roadways with the improvements. Because this new traffic is not "induced travel" but "diverted traffic," the increase in VMT from diverted traffic should typically not be used in calculating increased emissions, unless there is evidence of lengthy diversions.
- Peak vs. Off-Peak Hours – Since traffic conditions vary over the course of each day and by day of the week, it is important to isolate the time periods for which the improvement will have a measurable effect on traffic flow.

The analysis of the three projects listed in Table 3 did not account for induced and diverted traffic.

Other Public Health Impacts and Economic Impacts

If signal timing projects increase vehicle speeds or traffic volumes, or reduce pedestrian crossing time at signalized intersections, they could potentially discourage walking and bicycling on the affected street. By reducing vehicle delay, signal timing projects might also make driving more attractive at the expense of other modes. A reduction in walking or bicycling has negative public health impacts, as discussed in Section 3.9.

Signal timing projects that use adaptive control have been shown to reduce vehicle accidents (particularly rear-end collisions).[25] However, some of the safety benefits of signal timing projects may be offset by an increase in collisions or increase in collision severity due to higher speeds.

Signal timing projects generate economic benefits because they reduce congestion. These benefits accrue primarily from a reduction in driver and passenger travel time, and from a reduction in vehicle operating costs. As noted above, signal timing projects have been shown to significantly reduce fuel consumption.

3.4 Incident Management

Incident management projects seek to detect and clear a roadway incident site quickly and effectively, thereby minimizing the congestion impacts of the incident. An incident management program can be applied region-wide, such as MTC's Service Authority for Freeways/Expressways (SAFE), or can be focused on a specific corridor. It has been estimated that roughly half of total highway roadway delay is caused by incidents, including delay caused by traffic incidents (crashes, vehicle disablements, cargo spills), non-traffic incidents (bridge collapse, emergency road work), or other unexpected activity (severe weather events, natural disasters).[26] Incident management programs can have a significant effect on traffic speeds and emissions. If fewer incidents occur or are cleared away more quickly, vehicles idle less and travel at higher speeds. Incident management projects also minimize drivers' need to seek alternate routes to avoid congestion due to incidents. The alternate routes can frequently be longer than the original route and the increased VMT would result in greater emissions. However, because it reduces congestion, incident management has the potential to induce more vehicle travel.

Most incident management projects are focused on highways, and highway projects are not eligible for TFCA grants. However, incident management can also be employed on arterial streets.

Transportation Impacts

Incident management programs are intended to quickly identify and clear traffic incidents, and have been shown to significantly reduce congestion delay. The following are examples of these transportation impacts:

- *Freeway Service Patrol, Hayward, California:* A study of MTC's program along a 9-mile stretch of I-880 estimated a reduction of 20 vehicle-hours per crash and 42 vehicle-hours per breakdown.[27] (a vehicle-hour is equivalent to one vehicle traveling for one hour)
- *Motorist Assistance Program, Houston, Texas:* As a result of the program, average incident duration was estimated to be reduced by approximately 15 minutes.[28]
- *Courtesy Patrol Program, Denver Colorado:* This six-month pilot program resulted in average delay savings for morning and evening commutes of 98 vehicle-hours and 75 vehicle-hours per incident, respectively.[29]
- *Minnesota Highway Helper Program, Minnesota*: It was estimated that the duration of a vehicle stall was reduced by 8 minutes when assisted by a highway helper, and that each minute of incident duration caused 5 vehicle-hours of delay. Thus, the program eliminated 40 vehicle-hours of delay for each incident addressed.[30]

Emissions Impacts

The MTC Freeway Service Patrol program on I-880 discussed above was estimated to reduce emissions by 8 pounds of HC and 20 pounds of NOx avoided per vehicle breakdown, or 0.04 tons of HC and 0.88

tons of NOx avoided per day. [31] TRB Special Report 264 identifies only two examples of incident management projects for which cost effectiveness can be calculated, as follows:

- *Advanced Transportation Management System - Freeway Incident Management:* Funds were used for the implementation of an incident management program on Atlanta-region urban highways to monitor and control traffic flow.[32]
- *Maryland Department of Transportation CHART Program:* Maryland's Coordinated Highways Action Response Team (CHART) operates a traffic and roadway monitoring system that clears incidents and re-open lanes using emergency response units and technology such as portable travelers advisory radio transmitters for traffic management, and portable variable message signs.[33]

Table 4 shows the impacts of the two projects. These two examples show such a large difference in cost effectiveness ($2,352 per ton vs. $199,846 per ton) that the average of the two ($101,099 per ton) is not very meaningful. Both of these examples are focused primarily on highways, and as noted above, such projects are not eligible for TFCA grants. The literature reviewed has no reliable estimates of cost effectiveness of incident management projects focused on arterial streets.

Table 4: Cost and Emission Impacts for Incident Management Projects

	Emission Reductions (Tons/Year)						
Project	**HC**	**NO_x**	**CO**	**PM_{10}**	**Annual Benefits (Tons/Yr)**	**Annual Cost (2000 $)**	**Cost/Ton (2000 $)**
ATMS Freeway Incident Management (Atlanta)	165.00	158.00	–	–	362.6	$853,087	$2,352
Maryland DOT CHART Program	5.33	42.00	228.25	–	95.5	19,095,000	199,846

Source: Transportation Research Board, *The Congestion Mitigation and Air Quality Improvement Program: Assessing 10 Years of Experience*, Special Report 264, 2002.

An accurate estimate of the traffic flow and emissions effects of a roadway incident requires obtaining vehicle speed data from loop detectors, and comparing speeds with and without an incident. Traffic volumes and speeds can then be used to estimate emissions. Using the average freeway service patrol response time, it is possible to estimate the reduction in incident duration attributable to the incident management program. Applying such a detailed methodology to a long corridor or an entire region is difficult and time-consuming, however.

Other Public Health Impacts and Economic Impacts

Aside from emission reductions, incident management programs generate health benefits because they reduce vehicle crashes. For example, the I-95 Traffic and Incident Management System in Philadelphia resulted in a 40 percent overall reduction in freeway incidents.[34] Because they clear incidents more rapidly, incident management programs are particularly effective at reducing "secondary incidents" that are caused by traffic backups during an incident. The TransGuide Intelligent Transportation System in San Antonio reportedly reduced such secondary crashes by 30 percent. [35]

Incident management programs create economic benefits because they reduce congestion. The economic benefits of congestion reduction are discussed in Sections 3.1 – 3.3. The Houston Motorist Assistance program, mentioned above, provided annual benefits estimated at $3.6 million, based on savings in travel delay.[36] The Courtesy Patrol program in Denver resulted in an estimated savings of $85,000-93,000 due to reduced travel delays.[37] Minnesota's Highway Helper program reports annual delay savings of $1.4 million, for a project costing $600,000 annually.[38]

Incident management programs are unique in that they target "non-recurrent" congestion, as opposed to recurrent congestion that occurs in the same location every day when demand exceeds capacity. Studies have shown that non-recurrent delay is often more important to the freight sector than recurrent delay because it affects travel time reliability (i.e., the variability in travel time). One study indicated that on average, trucking companies value savings in travel time at between $144 and $192 per hour, while savings in non-scheduled delay are valued at $371 per hour.[39] In other words, the time late (unexpected delay) was valued at roughly twice the rate of travel time.

3.5 Transit Signal Priority

Transit Signal Priority (TSP) is an operational strategy that reduces delay to transit vehicles at signalized intersections. The operation of the signal is changed to allow buses to achieve higher average speeds by reducing interruption and stop times at controlled intersections. The overall goal of TSP is to increase ridership by improving schedule adherence and reducing travel times throughout the route and specifically in the most congested segments of the route. TSP can lead to a more reliable, higher level of transit service which ultimately attracts more riders to transit and reduces the number of auto trips. In addition, TSP can contribute to a reduction in emissions as it shortens the length of time buses stop (idle) at signals.

Transportation Impacts

There is little doubt that transit signal priority reduces bus travel times and improves reliability. In turn, there is a large volume of research demonstrating the impact of travel times on transit ridership (increased) and auto trips (decreased).[40] On average, transit agencies have displayed a 15 percent travel time savings with very little impact to other traffic. This would suggest a ridership increase of 9 percent, but there is little firm data to quantify the level of vehicle trip reductions achieved. Rider surveys have not been able to distinguish between TSP and other improvements (such as stop consolidation and queue jump lanes) since these are typically introduced as a package. Some TFCA TSP projects also bundle project attributes. Table 5 summarizes the transportation impacts of some examples of transit signal priority projects.

Table 5: Examples of TSP Transportation Impacts

Location	No. of Intersections	Reduction in Bus Travel Time	Other Impacts
Tualatin Valley Hwy, Portland, OR	10	1.4 to 6.4%	
AC Transit, Oakland, CA	62	9%	
King County Metro, Seattle, WA	28	5.5 to 8% at peak hour	35-40% reduced travel time variability and 25-34% reduction in intersection delay
MTA Los Angeles, CA	654	6 to 8%	Metro Rapid project as whole has increased ridership by 4-40%; 1/3 are new transit riders
PACE, Chicago, IL	15	15%	
Pierce Transit, Tacoma, WA	110	N/A	40% reduction in transit signal delay
TransLink, Vancouver, BC	63	16%	40-50% reduction in travel time variability

Source: ITS America. Note that some studies may report benefits from other project components (e.g., new buses).

Emissions Impacts

There is little or no research which either directly links TSP with reduced auto trips, or calculates the cost effectiveness of TSP as an emissions reduction strategy. There are two main reasons for this: (1) the lack of before and after data on TSP impacts (raw ridership number fail to indicate the percentage of riders who previously drove); and (2) the fact that most TSP programs are bundled with bus rapid transit (BRT) projects that include other improvements such as greater stop spacing, bus branding and access to dedicated guideways, making it difficult to separate out the impact of TSP alone.

Broader BRT and similar projects, however, have been able to demonstrate significant modal shift and emissions reductions. For example, the 98 B Line in Vancouver, Canada resulted in a 23 percent modal shift from auto to transit in the corridor, including the effects of service rebranding, real-time information, and other program elements, as well as TSP. According to a recent study by Vancouver regional planning agency TransLink, the modal shift to the 98 B Line (BRT service) has led to emission reductions in the Vancouver region.[1] The study concludes that the number of auto trips that have shifted to the 98 B Line provide an estimated reduction of:

- CO_2: 1,323 tons/year
- PM: 0.01 tons/year
- NO_x: 5.5 tons/year

The impact of TSP on travel times and emissions for private automobiles and other vehicles has been reported as negligible or non-existent.

[1] Based on findings from the study, “Bus Rapid Transit in Vancouver: A Review of Experience”, Brian Mills, TransLink 2004.

Other Public Health Impacts and Economic Impacts

There is little research linking TSP directly to wider public health impacts, except as part of a broader set of programs that aim to reduce dependence on the private auto. However, there will be health benefits from (1) reduced emissions (particularly from buses idling at traffic signals), and (2) walking to and from the transit stop, to the extent that drive-alone trips are shifted to transit. TSP projects typically also provide priority for emergency vehicles and reduce response times, bringing additional public health gains.

TSP does bring fiscal benefits through reducing transit operating costs. PACE in Chicago reports that TSP allowed the same level of service to be provided with one less bus. Pierce Transit in Tacoma, WA reports a net economic benefit to the general public of $14.2 million per year through signal coordination.[41] In addition, TransLink identified a savings of six buses based on the impacts of improved reliability and the reduction of travel times.

3.6 Bikeway (Paths, Lanes, Routes) Projects

Investments in bicycle paths, lanes, and routes improve the transportation system for bicyclists and can encourage drivers to travel by bicycle. If people switch from driving to bicycling for some or all of their trips, emissions are reduced due to less vehicle miles traveled and fewer vehicle trips.

Transportation Impacts

Communities with more bicycle paths, lanes, and routes tend to have a larger portion of bicycle commuters. One study found that bicycle commuting increases 0.075 percent for each mile of bikeway per 100,000 residents, all else being equal.[42] Another study found that in U.S. cities with more than 250,000 residents, each additional mile of bicycle lane per square mile is associated with a roughly one percentage point increase in bicycle commute mode share.[43]

Bicycle usage typically increases following construction of a new bicycle lane or path. For example, bicycle usage on Valencia Street in San Francisco increased 144 percent (from 88 to 215 bicyclists per hour) during PM peak hour following the installation of bicycle lanes.[44] New users of a bicycle facility will typically include existing cyclists who switch from some other route as well as induced new cyclists. Achieving emission reductions depends on inducing use by new cyclists who previously used motorized transportation.

Several studies have found that the number of new bicyclists using a facility is a function of the number of existing cyclists in the corridor. A 1995 FHWA compendium of bicycle trip generation data concluded that, based on observed before and after data for bike projects, a new bicycle facility will increase bicycle trips by 65 percent.[45] This figure has been widely used as a way to estimate the likely travel and emissions impact of bicycle paths or lanes.

Researchers at the University of Minnesota have recently developed a new methodology to estimate use of a new bicycle lane that attempts to refine previous methods.[46] Their research finds that the likelihood that an individual is induced to use a new bicycle lane depends on the distance between the individual's residence and the bicycle lane. The methodology applies a probability to the number of existing cyclists living in three buffer zones: within ¼ mile of a new facility, ¼ to ½ mile of a new facility, and ½ mile to 1 mile of a new facility. The number of new induced bicyclists can then be estimated using the following relationships:

- Within ¼ mile: number of new cyclists = 104 percent of the number of existing cyclists

- ¼ to ½ mile: number of new cyclists = 54 percent of the number of existing cyclists
- ½ mile to 1 mile: number of new cyclists = 21 percent of the number of existing cyclists

This research, however, does not shed light on the number of automobile trips reduced as a result of new bicycle facilities. New cyclists observed on a facility could have previously driven, walked, used transit, or not traveled at all.

Emissions Impacts

TRB Special Report 264 identifies only one example of a bikeway project for which emission reduction cost effectiveness can be calculated:

- *Philadelphia Bike Network:* The Bike Network is a system of on-street, five-foot wide lanes for bicycles and shared vehicle lanes that connect via a 300-mile network throughout Philadelphia. Network facilities are comprised of over 60 miles of bike lanes, 40 miles of multi-use trails, and 800 bike racks installed in the City center.[47]

Table 6 summarizes the impacts of this project; it has a cost effectiveness of $67,520 per ton.

Table 6: Cost and Emission Impacts for Bikeways (Paths, Lanes, Routes) Projects

	Emission Reductions (Tons/Year)						
Project	**HC**	**NO_x**	**CO**	**PM_{10}**	**Annual Benefits (Tons/Yr)**	**Annual Cost (2000 $)**	**Cost/Ton (2000 $)**
Philadelphia Bike Network	7.50	6.50	–	–	4.8	$322,024	$67,520

Source: Transportation Research Board, *The Congestion Mitigation and Air Quality Improvement Program: Assessing 10 Years of Experience,* Special Report 264, 2002.

Estimating the emission reductions that result from new bicycle paths, lanes, and routes is challenging primarily because of the difficulty in determining the prior travel mode of users of the facility. Some users will be bicyclists who divert from other routes. Other users will divert from walking or transit. Still other users may be recreational cyclists who previously were not traveling. Only bicyclists who previously traveled by automobile will result in emission reductions. Most bicycling trips are less than five miles, so most bikeway projects have the potential to affect only automobile trips less than this length. In the Bay Area, 52 percent of all automobile trips are less than five miles in length, although this percentage varies greatly by neighborhood.[48]

Bicycle paths, lanes, and routes can vary widely in their effectiveness. The most effective facilities are those that include no steep grades, provide access to major activity nodes, offer a safer alternative than existing routes, and allow for relatively steady travel speeds (i.e., do not have stop signs at each intersection).

Other Public Health Impacts and Economic Impacts

The physical activity of bicycling has significant health benefits. As discussed in Section 3.9, there is strong evidence that lack of physical activity is a contributor to worsening health. Bicyclists also face a higher crash risk than other modes. However, several studies have found the health benefits of cycling to outweigh the risk of injury due to a crash.[49]

Automobile travelers who switch to bicycling can reduce their expenditures on fuel and vehicle maintenance, although these economic gains might be offset by an increase in travel time. One study suggests that bicycle lanes on arterial streets create economic development benefits for businesses, although there has been little rigorous research on this issue. [50]

3.7 Bike Racks, Lockers, Parking Stations

Improved bicycle parking facilities can increase the convenience and security of bicycle parking, which can encourage more trips by bicycle. When new bike trips replace automobile trips, emissions are reduced. Bike racks provide a secure frame to which a bicycle can be locked. Bicycle lockers enclose a bicycle within a locked cage. Attended bicycle parking stations are a relatively new concept in the U.S.; in the Bay Area there are several located at rail transit stations, two of which have received TFCA funds.

Transportation Impacts

The threat of bicycle theft and vandalism are deterrents to potential cyclists. Secure bicycle parking can encourage more travel by bicycle. Some new bicycle trips will replace automobile trips. As discussed in Section 3.6, bicycling is typically used for trips less than five miles, so most bicycle parking projects have the potential to eliminate only these shorter automobile trips. Improvements to bicycle parking at transit stations can potentially encourage automobile commuters to switch to a bicycle-plus-transit commute mode for much longer trip distances (especially since many bike parking projects are at rail and bus terminals/stations). There has been little research on how improvements to bicycle parking affects travel choices.

Emissions Impacts

TRB Special Report 264 identifies the following five bicycle parking projects for which emission reduction cost effectiveness can be calculated:

- *Frankfort, IL Suburban Bike Rack Incentive:* A bicycle rack installation program in Frankfort, Illinois.[51]
- *Los Angeles City Bike Lockers:* This project involved the installation of bike lockers at Metrolink stations.[52]
- *Santa Clarita Bike Lockers:* This project involved the installation of bike lockers at Metrolink stations.[53]
- *Orange Country Transportation Authority Bike and Ride:* This project involved installation of bike racks on buses serving key commuter destinations and bike racks at those employer worksites.[54]
- *Coronado TMA Bike Program:* Using bridge toll funds, City of Coronado and the Coronado Transportation Management Association formed Bike Club with 271 members and provided bike storage facilities for 274 bikes.[55]

The emissions impacts of these projects are summarized in Table 7. The mean and median cost effectiveness is $123,129 per ton and $98,759, respectively.

Table 7: Cost and Emission Impacts for Bike Racks, Lockers, and Parking Station Projects

	Emission Reductions (Tons/Year)						
Project	**HC**	**NO_x**	**CO**	**PM_{10}**	**Annual Benefits (Tons/Yr)**	**Annual Cost (2000 $)**	**Cost/Ton (2000 $)**
Frankfort, IL Suburban Bike Rack Incentive	0.25	0.25	—	—	0.2	$27,232	$145,471
LA City Bike Lockers	0.13	0.18	—	0.08	0.2	16,149	65,445
Santa Clarita Bike Lockers	0.05	0.05	—	—	0.1	18,091	295,605
OCTA Bike and Ride (Orange Co.)	0.15	0.20	—	0.08	0.3	29,660	98,759
Coronado (CA) TMA Bike Program	0.50	0.50	—	0.25	0.9	9,182	10,364

Source: Transportation Research Board, *The Congestion Mitigation and Air Quality Improvement Program: Assessing 10 Years of Experience,* Special Report 264, 2002.

The cost of bicycle parking tends to be very low, so only small trip reduction impacts can make these projects cost-effective. For example, the cost to install a bike rack is roughly $150 - $300, and the cost to install a bike locker is about $1,000. By comparison, the cost to provide a car parking space is estimated to be $2,200 in a surface lot or in a $12,500 garage.[56]

The location of a bicycle parking facility can be a major determinant of its success at eliminating automobile trips and reducing emissions. Bicycle parking should be located in visible and prominent locations – easily identifiable by cyclists and visible enough to deter thieves.

To assess the emissions impacts of bicycle parking facilities, it is important to account for users of a facility who previously parked their bicycles elsewhere, arrived at their destination using another non-motorized mode, or did not travel. Only new bike trips that replace automobile trips (or transit trips) result in reduced emissions. Attended bike stations are generally located at rail transit stations. For users of these facilities who previously drove to their final destination, it is important to account for the full trip length and subsequent VMT reduction, rather than just the length of the bike trip.

Other Public Health Impacts and Economic Impacts

To the extent that improved bicycle parking facilities encourages more bicycle use, these projects have positive physical health benefits. While bicycling has a higher crash risk than most other modes, studies have found that this is more than offset by the benefit of increased physical activity.[57]

3.8 Bike Racks on Buses

Bicycle and transit programs have grown significantly over the past 15 years. One of the most common methods for transit agencies to accommodate bicyclists is by providing bike racks on buses. Most agencies use front-mounted racks that carry two bicycles; however, a few locations are beginning to use racks that can carry up to five bikes at a time. Although bicycle on bus usage has increased over the years, there is very little reliable data that shows the impacts on ridership and emission reduction.

Transportation Impacts

A just-released report from the Transit Cooperative Research Program provides an overview of the relationship between bicycles and transit based on the results of an online survey of transit agencies in the US and Canada.[58] Fifty-six transit properties responded to the survey. Survey results show that almost all agencies have seen a steady increase in bicycle usage over time especially on systems that have bike racks installed on the entire fleet, making the service more reliable and predictable for bicyclists.

Although few agencies track bike rack usage, several agencies have reported positive impacts of the program by recording historical data. For example, Ann Arbor Transportation Authority (MI) saw a 17 percent increase of bikes on buses during the second year of the program; HARTline in Tampa, FL had a 33 percent increase from 2003 to 2004. Results from the survey show that the cost of installing a front mount bicycle rack can range from $500 to $1000 per vehicle. It is important to note that the cost report only provided data about bike rack usage, not the actual ridership or travel time impacts of bikes on buses.

Another recent study surveyed 18 transit agencies with bikes on bus (BOB) programs.[59] The study found that 24 percent of BOB users are new to transit and that 80 percent of them stated that the BOB program was the reason they began taking the bus. In addition, survey results indicated that 75 percent of the BOB passengers that were not new to transit rode the bus more often due to the BOB services. The study found that most BOB passengers used the service during commute periods; however, off peak usage has increased over the past several years. One of the challenges to the BOB program is that most agencies are constrained by the capacity limitation of the racks. Very few transit agencies allow passengers to bring bikes on the bus when the racks are full.

Emissions Impacts

While bikes on bus programs aim to attract more riders to transit, very little data is available on their impact on transit ridership, let alone emissions reductions or cost-effectiveness. Furthermore, few agencies track usage of racks. The only reliable survey data does suggest that while racks primarily provide an amenity to existing riders, a significant minority is new to transit. However, even this study does not provide data on the prior mode (e.g., auto or bicycle), or address travel choices for specific trips.

However, since the cost of the equipment and installation is relatively inexpensive ($500 to $1000 per vehicle), the program is attractive to transit agencies interested in increasing their potential service population while providing an additional amenity to their passengers.

Other Public Health Impacts and Economic Impacts

Very little data is available on wider public health impacts and economic impacts of bike racks on buses. However, as a program designed to encourage bicycling, public health impacts can be expected to be positive, although difficult to quantify.

3.9 Pedestrian Facility Improvements

Pedestrian facility improvement projects include the construction and/or improvement of sidewalks, crosswalks, pedestrian bridges, or other facilities intended for pedestrian travel. Most pedestrian projects improve existing pedestrian facilities by enhancing streetscape aesthetics (decorative paving, landscaping, signage, benches, lighting, etc.) or enhancing pedestrian safety (crosswalks, intersection bulb-outs, etc.).

Pedestrian projects can encourage drivers to switch to walking, thereby eliminating vehicle trips (cold starts) and VMT. Most pedestrian trips are less than two miles, so most pedestrian facility projects have the potential to reduce only short automobile trips. As a result, pedestrian facility improvements often have the greatest impact on non-work trips (e.g., shopping, school, and recreational trips). In the Bay Area, 25 percent of all automobile trips are less than two miles in length, although this percentage varies greatly by neighborhood.[60] In addition, improvements to pedestrian connections to transit systems have the potential to divert long automobile trips to walking-plus-transit trips.

Transportation Impacts

A number of studies have shown that areas with a pedestrian-friendly environment have more walking activity. One study compared two Puget Sound area neighborhoods that are similar in terms of gross residential density and intensity of commercial development: Wallingford in Seattle and Crossroads in Bellevue.[61] The analysis shows that Wallingford – the neighborhood with a high level of pedestrian network connectivity – has almost three times as much pedestrian activity as Crossroads, which has a low level of pedestrian connectivity. The study findings suggest that, controlling for population density, income, land-use mix, and other land use characteristics, the extent of pedestrian facilities is an important determinant of pedestrian travel. This study, however, does not address the implications for reducing vehicle travel.

Some studies suggest that residents in areas with a better pedestrian environment drive less on average.[62] But while there is clear evidence that better pedestrian design is associated with increased pedestrian activity, this does not necessarily translate into fewer vehicle trips. Studies have found that residents in places that have greater accessibility and pedestrian access are more likely to walk, but that many of these trips are in addition to driving trips.[63] A study of four Bay Area neighborhoods finds that residents of “traditional” neighborhoods make three to five times as many shopping trips by walking as residents of more auto-oriented neighborhoods.[64] However, residents of both types of neighborhoods make about the same number of auto trips to regional shopping centers.

Other research has focused specifically on how the pedestrian environment influences travel to school by children. Researchers in California recently completed an assessment of the success of the state’s Safe Routes to School program by observing travel behavior at 10 schools before and after the implementation of pedestrian facility improvements. At schools that received sidewalk improvements (gap closure), the number of children walking to school generally increased following completion of the project.[65] Research conducted for the U.S. EPA involved the development of a model of travel mode to school. The presence of sidewalks along streets near the school was found to have a significant positive effect on walking mode share.[66]

Emissions Impacts

There is very little research that directly links pedestrian facility improvements with a reduction in emissions. Given the clear evidence that people walk more in pedestrian-friendly neighborhoods, it is likely that significant improvements to pedestrian facilities do cause some drivers to switch to walking for short trips, resulting in reduced emissions.

Some pedestrian projects are likely to have more travel and emissions impacts than others. A distinction should be made between a new pedestrian facility (e.g., a case in which a sidewalk did not previously exist) and an improved pedestrian facility. Pedestrian projects are likely to be more effective when they provide a direct link to an activity node, like a transit station, commercial center, or office park. Pedestrian improvements within a commercial district can encourage shoppers to reach multiple destinations by foot, rather than driving short distances.

Other Public Health Impacts and Economic Impacts

There is strong evidence that lack of physical activity is a contributor to worsening health. Sixty-five percent of U.S. adults are overweight, an increase from 56 percent between 1988 and 1994, according to Food and Drug Administration data from 2002. The data show similar increases in adult, child, and adolescent obesity, with attendant health problems.[67] The FDA found these health problems to be directly, although not solely, linked to declines in physical activity.[68] The FDA findings are among numerous recent studies to link declining physical activity with worsening health. Other studies have focused on children's health and decline in children's physical activity in particular, and found more children being diagnosed with sleep apnea, type 2 diabetes, hypertension, and high cholesterol.

Lack of physical activity is tied in part to pedestrian environment factors, as well as land use factors. To date, the research into the links between transportation, land use, and activity and health trends has come largely from either the urban planning field or the public health field. Generally, the planning research concludes that increased densities, mixed land uses, gridded street networks, and the presence of sidewalks are positively correlated with nonmotorized travel,[69] objectively measured physical activity,[70] and reduced odds of being obese.[71] The public health research has, in general terms, found that physical activity is linked to subjective measures of accessibility to features such as trails, bicycle paths, or recreation centers, as well as to neighborhood characteristics.[72] The literature also finds that pedestrians and cyclists are quite sensitive to design elements.[73]

There is anecdotal evidence that investments in pedestrian facilities can promote economic development, particularly in retail districts. However, we did not identify any research that has isolated the economic development effects of pedestrian improvements.

3.10 Traffic Calming

Traffic calming involves physical modifications to a street with the intention of slowing vehicle traffic in order to improve safety and livability. Traffic calming devices include speed humps, raised crosswalks, traffic circles, chicanes, chokers, and textured pavements. Some definitions of traffic calming also encompass devices such as partial diverters and street closures that are intended to reduce traffic volumes on certain streets.

Traffic calming can reduce emissions when it encourages drivers to switch to walking or bicycling. Traffic calming can also potentially reduce vehicle emissions if it results in slower, steady-state speeds or less acceleration and deceleration. However, traffic calming can also increase emissions if it leads to more acceleration and deceleration.

Transportation Impacts

The effectiveness of traffic calming is typically measured by how it changes the 85th percentile traffic speed mid-block. Many "before and after studies" have been carried out by local governments to assess the speed impacts of traffic calming projects. Table 8 shows a compilation of these results. Speed humps, speed tables, and half closures are the most effective at reducing mid-block speeds.

Table 8: Traffic Speed Effects of Traffic Calming

	Sample Size	85th Percentile Speed Afterward	Average Change in 85th Percentile Speed	Average % Change
12' Speed Hump	179	27.4 mph	-7.6 mph	-22%
22' Speed Table	58	30.1	-6.6	-18
Traffic Circle	45	30.3	-3.9	-11
Narrowing	7	32.3	-2.6	-7
Choker (1 lane)	5	28.6	-2.6	-14
Half Closure	16	26.3	-6.0	-19

Source: Ewing, R. *Traffic Calming: State of the Practice*, Institute of Transportation Engineers, Washington, D.C., 1999.

Implementation of traffic calming measures has been shown to increase pedestrian and bicycle activity in the area. Much of this research has occurred in Europe. One study found that when traffic calming was installed on a main road bisecting multifamily housing development, 20 percent of the residents said they walked more in the area and 12 percent said they allowed children to walk more.[74] As discussed in Section 3.9, other studies have found that residents walk more in neighborhoods that are more pedestrian friendly.[75] At least one study has found that residents in a pedestrian-friendly community tend to walk and bicycle more, ride transit more, and drive less than comparable households in other areas, although the pedestrian-friendly nature of the community resulted from factors other than traffic calming.[76] There has been no research that attempts to directly link traffic calming to a reduction in vehicle use.

Emissions Impacts

Traffic calming can reduce emissions when it encourages automobile drivers to walk, bicycle , or use transit instead. When traffic calming causes mode diversion to walking or bicycling, it eliminates vehicle travel (VMT) and vehicle starts. Like pedestrian and bicycling projects, the affected trips are generally short, so the benefits of eliminating vehicle starts are sometimes greater than the benefits of the VMT reduction.

Traffic calming also affects vehicle operating practices, which affects emissions. Generally speaking, per mile vehicle NOx emission rates are lowest around 35 mph, and increase with lower and higher speeds. Thus, if traffic calming reduces average speeds from 40 mph to 35 mph, NOx emissions would likely drop, assuming no major changes in acceleration patterns. If speeds were reduced from 35 mph to 25 mph, however, NOx emissions would likely rise, again assuming no major changes in acceleration patterns.

Emission rates are significantly higher during periods of acceleration. Because some traffic calming projects can cause an increase in vehicle acceleration and deceleration, they might increase emissions even if they don't change average speeds. Other traffic calming projects result in smoothing of traffic speeds, reducing acceleration and braking, which tends to improve vehicle efficiency and reduce emissions.

There have been no detailed studies in the U.S. of the emissions impacts of traffic calming. Research in Europe has focused on how traffic calming changes emissions from vehicles affected by the implementation. One report reviews various research on this subject carried out in the 1980s and1990s, summarized in Table 9.[77] The results in Table 9 reflect only emissions impacts resulting from changes in vehicle speed and acceleration; they do not account for any reduction in vehicle use due to mode shift to walking or bicycling. Because the results of these studies vary so widely, and because of changes in emission control technologies and emission factor models, it is difficult to draw definitive conclusions about the impacts of traffic calming on vehicle emissions.

Table 9: Traffic Calming and Vehicle Emissions – European Studies

		Change in emissions from affected vehicles		
Country	**Measures**	**NO_x**	**HC**	**CO**
Area-wide Traffic Calming				
Germany	Area with extensive traffic calming	-38 to -60%	-10 to -25%	+7 to +71%
Holland	Speed humps	Decrease	No change	Increase
Holland	Area with extensive traffic calming	Decrease	Increase	Increase
Single-Road Traffic Calming				
UK	Speed humps	0 to -20%	+70 to +100%	+70 to +80%
Sweden	Traffic circle, reduced speed limit	+1%	N/A	+2%
Sweden	Speed humps	+18%	N/A	+20%

Source: Boulter, P G, and D C Webster, *Traffic calming and vehicle emissions: A literature review*, Transportation Research Laboratory (England), TRL Report 307, 1997.

Other Public Health Impacts and Economic Impacts

The primary purpose of traffic calming is to improve safety. Traffic calming generally results in fewer vehicle collisions, and collisions that do occur are less severe because of lower speeds. Many local governments have collected before and after collision data at locations where traffic calming is installed. Based on data from 193 sites, the number of collisions was reduced by an average of 51 percent following implementation of traffic calming. It should be noted, however, that traffic calming often diverts traffic to other streets, and most assessments of collision impacts fail to account for the reduction in traffic volumes.[78] Fewer collisions mean fewer injuries and fatalities, and a reduction in the economic loss associated with collisions. This is especially critical where the collision is between a motor vehicle and a pedestrian or bicyclist.

As noted above, many studies in Europe have documented an increase in walking and bicycling following implementation of traffic calming schemes. As discussed in Section 3.9, studies have found that a better pedestrian environment is associated with more walking, better physical health, and reduced obesity. It is likely that most traffic calming projects result in positive health effects due to increased physical activity.

There has been limited research to consider the effects of traffic calming on property values, and this research points in different directions.[79] Traffic calming is more likely to increase residential property values if it reduces traffic volumes on the affected street or significantly improves aesthetics. There are anecdotal examples in Florida and Michigan of traffic calming on commercial streets leading to increased retail sales and business retention.[80]

4 SUMMARY

This document reviews literature on the transportation, emissions, and other public health and economic impacts of ten types of projects funded by the TFCA program. There is evidence that all types of ridesharing, bicycle, and pedestrian projects can reduce automobile use and associated emissions. Signal timing and incident management projects can reduce congestion and associated emissions. All project types can also generate other public health and economic benefits.

For six of the ten project types, we identified calculations of emission reduction cost effectiveness in the literature, summarized in Table 10. Among these six project types, regional ridesharing and traffic signal timing projects appear to be the most cost-effective, followed closely by vanpool/buspool projects. Bicycle parking projects appear to be less cost effective, among the project types for which information is available. No cost effectiveness estimates are available for four of the project types considered, and two others (incident management and bicycle path/lane/route projects) have only one or two examples in the literature. While there is evidence that these six project types can reduce emissions, it is difficult to draw firm conclusions about their cost effectiveness. Note that while the signal timing and ridsharing projects appear more cost effective than bicycle and pedestrian projects, the former often to not provide the other public health benefits that result from bicycle and pedestrian projects.

Table 10: Summary of Annual Cost Effectiveness by Project Type (thousands of $/ton)

Project Type	Number of Projects	Low	High	Mean	Median
Regional Ridesharing	3	$1.2	$16.0	$8.2	$7.4
Vanpool/Buspool	6	$5.2	$89.0	$24.3	$10.5
Signal Timing	3	$6.0	$27.2	$13.7	$7.9
Incident Management	2	$2.4	$199.8	$101.1	$101.1
Transit Signal Priority	0	N/A	N/A	N/A	N/A
Bicycle Paths, Lanes, and Routes	1	$67.5	$67.5	$67.5	$67.5
Bicycle Racks, Lockers, Parking Stations	5	$10.4	$295.6	$123.1	$98.8
Bicycle Racks on Buses	0	N/A	N/A	N/A	N/A
Pedestrian Facility Improvements	0	N/A	N/A	N/A	N/A
Traffic Calming	0	N/A	N/A	N/A	N/A

Note: $/ton adjusted to the year 2000.
Source: Transportation Research Board, *The Congestion Mitigation and Air Quality Improvement Program: Assessing 10 Years of Experience*, Special Report 264, 2002.

In order to put the Table 10 results in a broader context, Table 11 summarizes the cost effectiveness of other projects types reviewed in TRB Special Report 264, ranked by median cost-effectiveness. These findings suggest that regional ridesharing, traffic signal timing, and vanpool/buspool projects are among the most cost-effective of all 20 project types reviewed in the report. Only inspection and maintenance programs (which are not funded by the TFCA program) appear to more cost-effective. Projects involving charges and fees appear to be one of the most cost-effective types of projects; such projects are eligible for TFCA funding but none have been implemented to date.

Table 11: Summary of Cost Effectiveness for other Project Types (thousands of $/ton)

Project Type	Number of Projects	Low	High	Mean	Median
Inspection and maintenance	5	$1.8	$5.8	$3.7	$1.9
Charges and fees	6	$0.8	$49.4	$16.6	$10.3
Miscellaneous TDM	8	$2.3	$33.2	$15.0	$12.5
Conventional fuel replacement buses	5	$11.0	$39.9	$20.6	$16.1
Alternative-fuel vehicle programs	2	$4.0	$31.6	$17.8	$17.8
Employer trip reduction	7	$5.7	$175.5	$48.0	$22.7
Conventional transit service upgrades	10	$3.8	$120.1	$37.7	$24.6
Park-and-ride lots	4	$8.6	$70.7	$41.3	$43.0
Modal subsidies and vouchers	14	$0.8	$471.0	$87.6	$46.6
New transit capital systems/vehicles	6	$8.5	$470.8	$127.0	$66.4
Transit shuttles, feeders, paratransit	15	$12.3	$1,974	$335.6	$87.5
Alternative-fuel buses	11	$6.7	$568.7	$225.4	$126.4
HOV facilities	2	$15.7	$336.8	$176.2	$176.2
Telework	10	$13.3	$8,227	$1,248	$251.8

Note: $/ton adjusted to the year 2000.
Source: Transportation Research Board, *The Congestion Mitigation and Air Quality Improvement Program: Assessing 10 Years of Experience,* Special Report 264, 2002.

One notable observation from the findings of TRB Special Report 264 is the wide variation in cost effectiveness *within* project types. Nearly every project type has examples that reduce emissions for less than $20,000 per ton. But many project types also have examples with poor cost effectiveness. This suggests that the specific context of each project may have greater bearing on cost effectiveness than the project type.

It is clear from this literature review that very little is known about the emission reduction effectiveness of some TFCA project types, particularly transit signal priority, bicycle paths/lanes/routes, bicycle racks on buses, pedestrian facility improvements, and traffic calming. The experiences of TFCA project sponsors represent a major potential source of information to develop a better understanding of these project types. The next task in our Performance Review will make use of this information by reviewing and assessing a sample of actual TFCA projects.

ENDNOTES

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