ICF CONSULTING

Bay Area Air Quality Management District

Performance Review of Selected TFCA Project Types

Final Report

August 1, 2006

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EXECUTIVE SUMMARY

Since 1992, the Bay Area Air Quality Management District's Transportation Fund for Clean Air (TFCA) program has allocated more than $300 million for projects that reduce motor vehicle emissions in the Bay Area. While the overall success of the TFCA program is clear, there is uncertainty in the amount of emission reduction achieved by some types of projects. This is particularly true of projects that seek to improve the attractiveness of walking, bicycling, transit, and ridesharing modes and, as a result, encourage solo automobile drivers to switch modes.

The objective of this study is to independently evaluate the emission reduction cost-effectiveness of the following types of TFCA projects:

- Regional rideshare programs
- Local rideshare programs
- Vanpool/buspool programs
- Carpool/vanpool incentives
- School carpool match programs
- Bicycle paths, lanes, and routes
- Bicycle lockers, racks, and parking stations
- Bicycle racks on buses
- Traffic signal timing
- Transit signal priority
- Traffic calming and pedestrian facility improvements

A separate literature review performed as part of this study found limited research on the emissions impacts of many of these project types. For some of these project types (e.g., bicycle parking, bicycle racks on buses, traffic calming, and pedestrian facility improvements), there has been virtually no research on the emissions impacts. This study also provides the District with recommendations for changes to the process for evaluating the impacts of projects during the TFCA application and post-project evaluation periods.

Table ES-1 summarizes the results of our analysis. We were able to evaluate at least one project in eight of the eleven categories. In every category of projects that we were able to evaluate, the median cost-effectiveness is less than $90,000 per ton of emissions reduced (based on the TFCA award amount). The mean cost-effectiveness is less than $90,000 per ton in five of the eight categories. In total, we found that 54 of the 73 evaluated projects have a cost-effectiveness less than $90,000 per ton.

Table ES-1: Summary of Cost-Effectiveness of Evaluated Projects

Project Type	Number Evaluated	Cost-Effectiveness ($ per ton)	
		Mean	Median
Regional Rideshare Program	7	$11,090	$7,791
Local Rideshare Programs	1	$19,434	$19,434
Vanpool/Buspool Programs	6	$79,891	$70,772
Carpool/Vanpool Incentives	8	$17,307	$15,533
School Carpool Match	4	$141,192	$80,231
Bicycle Paths and Lanes	27	$125,747	$37,683
Bicycle Parking	5	$159,257	$68,944
Bicycle Racks on Buses	—	—	—
Traffic Signal Timing	15	$88,412	$32,769
Transit Signal Priority	—	—	—
Traffic Calming and Pedestrian Facility Improvements	—	—	—

In many cases, the mean cost-effectiveness in Table ES-1 is based on a small sample that exhibits a large variation among projects. Therefore, the mean cost-effectiveness values are not necessarily representative of all completed projects in a given category. The confidence interval around the mean is particularly large for school carpool match, bicycle paths and lanes, and traffic signal timing projects. In these cases, a significantly larger sample size would be necessary to more precisely estimate the mean cost-effectiveness.

Table ES-2 presents a comparison of the median cost-effectiveness based on the District's TFCA application estimate, the District's post-project evaluation, and our evaluation. For several of the project categories evaluated, our estimated median cost-effectiveness is very similar to the District's post-project estimate (e.g., Regional Rideshare Program, carpool/vanpool incentives, bicycle paths and lanes, and traffic signal timing). In other cases, our estimated median cost-effectiveness is significantly higher than the District's, although still within the $90,000 threshold.

Table ES-2: Comparison of Median Cost-Effectiveness Estimates

Project Type	Number Evaluated	Median Cost-Effectiveness ($ per ton)		
		TFCA Application (District)	Post-Project Evaluation (District)	ICF Evaluation
Regional Rideshare Program	7	$10,326	$10,252	$7,791
Local Rideshare Programs	1	$46,717	$28,873	$19,434
Vanpool/Buspool Programs	6	$21,086	$33,701	$70,772
Carpool/Vanpool Incentives	8	$11,735	$13,247	$15,533
School Carpool Match	4	$28,452	$26,835	$80,231
Bicycle Paths and Lanes	27	$19,979	$41,667	$37,683
Bicycle Parking	5	$27,058	$38,169	$68,944
Bicycle Racks on Buses	—	—	—	—
Traffic Signal Timing	15	$30,912	$40,085	$32,769
Transit Signal Priority	—	—	—	—
Traffic Calming and Pedestrian Facility Improvements	—	—	—	—

In the case of bicycle racks on buses, transit signal priority, and traffic calming and pedestrian improvement projects, we were unable to determine the emission reduction impacts of any projects. This is primarily because the project sponsors did not conduct an adequate user survey or did not report survey results in sufficient detail to allow an accurate quantification of impacts.

For most projects covered by this review, an accurate determination of post-project emissions impacts requires one or more user surveys coupled with usage counts to expand the survey results. The necessary size of the surveys depends in part on the total population of users and the variability among projects. At a minimum, survey data collection would cost $10,000 for each project if performed by a third-party consultant, and significantly more in some cases. Most sponsors do not have adequate resources or expertise to design, implement, and analyze such a survey. Therefore, we recommend that in most cases, sponsors not be required to conduct post-project user surveys or collect usage counts. Our specific recommendations for the project types reviewed are summarized below.

Regional Rideshare Program

- We do not recommend any changes to the overall methodology used to calculate the cost-effectiveness of this program. We do recommend some changes to the calculation of the input values and use of survey results. For example, factors used to avoid double counting between program categories should be updated annually based on a database review or survey. The placement rate as reported in the project Final Report should be interpreted as two one-way trips per day. And the accuracy of the average one-way trip length should be improved by calculating trip lengths directly using origin and destination information in the ridematching database.

Local Rideshare Programs

- We recommend that the District generally not seek to quantify emissions impacts of these projects, since the cost of conducting surveys needed to accurately quantify impacts is disproportionate to the size of these projects.
- Alternatively, the District could make use of the U.S. Environmental Protection Agency's COMMUTER Travel and Emissions Analysis Model to estimate the impacts of local rideshare programs.

Vanpools, Carpool/Vanpool Incentives, and School Carpool Match

- We do not recommend any changes to the basic methodology for evaluating these types of projects. However, we recommend that sponsors not be required to conduct participant surveys as part of the monitoring process. Most sponsors do not have the resources and expertise to conduct a survey that will yield accurate results. Instead, we recommend that, through a comprehensive survey, Bay Area-specific default values be established for factors such as prior mode, days of effectiveness, the percentage of riders who drive to carpool/vanpool pickup, and the length of access trips.

Bicycle Paths, Lanes, & Routes

- In the TFCA application process, the District should estimate the increase in bicycle usage and reduction in automobile trips based on existing bicycle volumes in the corridor, rather than existing traffic volumes.
- No post-project evaluation of emission reductions should be performed for these projects, since most project sponsors do not have the resources and expertise necessary to conduct an extensive user survey that would be required to accurately quantify emissions impacts.

Bicycle Parking

- In the TFCA application process, the District should revise the default assumptions regarding the number of vehicle trips eliminated per bicycle locker and bicycle rack.
- No post-project evaluation of emission reductions should be performed for bicycle parking projects, unless new research on the impacts of these projects becomes available. Requirements for post-project utilization counts should be eliminated.

Bicycle Racks on Buses

- The District should not attempt to estimate the cost-effectiveness of bicycle racks on buses projects.

Traffic Signal Timing

- The District should modify the evaluation process for signal timing projects to account for induced demand and to eliminate the 25 percent cap on speed increase.

Transit Signal Priority

- Because Transit Signal Priority is normally implemented as part of a package with other Bus Rapid Transit (BRT) improvements, this category should be extended to allow broader BRT projects or other BRT elements.
- Using results from the literature, the District should establish a standardized process for estimating the emission reductions of these projects based on the reduction in bus travel time and, if applicable, increase in bus frequency.

Traffic Calming and Pedestrian Improvements

- The District should not attempt to estimate the cost-effectiveness of traffic calming and pedestrian improvement projects, unless new research on the impacts of these projects becomes available.

1. INTRODUCTION

Since 1992, the Bay Area Air Quality Management District's Transportation Fund for Clean Air (TFCA) program has allocated more than $300 million for projects that reduce motor vehicle emissions in the Bay Area. While the overall success of the TFCA program is clear, there is uncertainty in the amount of emission reduction achieved by some types of projects. This is particularly true of projects that seek to improve the attractiveness of walking, bicycling, transit, and ridesharing modes and, as a result, encourage solo automobile drivers to switch modes.

The objective of this study is to independently evaluate the emission reduction cost-effectiveness of the following types of TFCA projects:

- Regional rideshare programs
- Local rideshare programs
- Vanpool/buspool programs
- Carpool/vanpool incentives
- School carpool match programs
- Bicycle paths, lanes, and routes
- Bicycle lockers, racks, and parking stations
- Bicycle racks on buses
- Traffic signal timing
- Transit signal priority
- Traffic calming and pedestrian facility improvements

A separate literature review performed as part of this study found limited research on the emissions impacts of many of these project types. For some of these project types (e.g., bicycle parking, bicycle racks on buses, traffic calming, and pedestrian facility improvements), there has been virtually no research on the emissions impacts. This study also provides the District with recommendations for changes to the process for evaluating the impacts of TFCA projects during grant application and post-project evaluation periods.

To conduct this evaluation, we first developed methodologies to evaluate each project type. We reviewed existing guidance documents and analytical tools developed for analyzing similar projects. When possible, we identified the most recent and robust approaches to calculating emissions impacts for each project category and, as necessary, developed default inputs that are supported by empirical research.

After finalizing our methodologies, we reviewed TFCA project files to obtain necessary data inputs for our independent evaluation of project cost-effectiveness. Our file review focused on collecting information primarily from project monitoring forms, and in some cases, from cost-effectiveness worksheets completed by the District.

In many cases, we reviewed all the available files in a category (e.g., regional rideshare, vanpools, rideshare incentives, bicycle racks on buses, signal timing, transit signal priority, traffic calming, and pedestrian improvements). In other cases (e.g., bicycle lanes, bicycle paths, and bicycle parking), we reviewed a large sample, focusing on projects for which monitoring information was most complete. In total, we reviewed files for more than 180 projects. Many of the project files we reviewed were ultimately not useful for our evaluation because they lacked critical data needed to estimate emission reductions.

We obtained emission factors for oxides of nitrogen (NOx), reactive organic gasses (ROG), and particulate matter less than 10 microns in diameter (PM-10) developed by the California Air Resources Board (CARB) and reported in the CARB/Caltrans guidance for evaluating Congestion Mitigation and

Air Quality (CMAQ) and motor vehicle registration fee projects.[1] In general, to determine a project's emissions impacts, we applied the emission factors that were available and applicable the initial year the project began receiving TFCA funds so as to ensure comparability with the District's results.

We calculated the emissions reduced over the lifetime of each project as the sum of NOx, ROG, and PM-10 emissions. We divided the TFCA award amount by the emission reduction to determine cost-effectiveness. For each project category, we calculated the median and mean cost-effectiveness based on all projects evaluated. Because the mean cost-effectiveness reflects the sample of project evaluated and may not be representative of all projects in a category, we also conducted a statistical analysis to estimate the confidence interval around the mean cost-effectiveness in each project category.

[1] *Methods to Find the Cost-Effectiveness of Funding Air Quality Projects*, California Air Resources Board and Caltrans, May 2005 (and previous editions).

2. Evaluation of TFCA Projects

This section presents the results of our evaluation. For each project type, we discuss:

- Our estimate of the average emission reduction and cost-effectiveness based on a sample of completed projects
- The sample size needed to improve the accuracy of the cost-effectiveness estimate
- The information historically used by the District to evaluate projects
- The information and methodology necessary to accurately determine emission reductions from projects
- Our recommendations for future evaluations

2.1. Regional Rideshare Program

The Regional Rideshare Program (RRP), managed by the Metropolitan Transportation Commission (MTC), is one of the largest single recipients of TFCA funding. The RRP is designed to reduce vehicle trips and vehicle miles traveled (VMT) by providing assistance and encouragement to individuals and employers to use alternative modes. The overall goal is to shift individuals from single occupant vehicles (SOVs) to carpools, vanpools and other transportation alternatives and help individuals sustain this shift. The program typically claims credit for emissions reductions achieved through four distinct categories:

- **Ridematch lists—**new or updated matchlists provided to individuals by the RRP, enabling them to find car- or vanpool partners
- **Transit and other mode information—**information provided to clients calling for "How To Guides," general transit information, the Bike Buddy program, Commuter Checks, and other referrals.
- **Vanpool formation—**information and assistance to put new vanpools on the road (this does not include filling empty vanpool seats, which is covered under ridematch lists)
- **Placement calls—**calls made to clients in the RRP database to follow up on whether they were able to find a match, whether they were successful in forming a ridesharing arrangement, or to inform them when a new database entrant may be a suitable match

Evaluation

We evaluated the emission reductions and cost-effectiveness (based on TFCA award amount) for seven Regional Rideshare projects. Table 2-1 shows the results of our evaluation as well as the District's estimates from the project application and post-project evaluation for the same projects. Our evaluation found a mean cost-effectiveness of $11,090 per ton. This is lower than the District's estimates from the TFCA application and post-project evaluation.

Table 2-1: Emissions Reductions and Cost-Effectiveness of Evaluated Regional Rideshare Projects

Projects sampled = 7

	Emission Reduction (tons/year)			Cost-Effectiveness ($/ton)		
	TFCA Application (District)	Post-Project Evaluation (District)	ICF Evaluation	TFCA Application (District)	Post-Project Evaluation (District)	ICF Evaluation
Mean	127	120	173	$22,408	$15,435	$11,090
Median	128	128	170	$10,326	$10,252	$7,791

The mean cost-effectiveness presented in Table 2-1 reflects the seven evaluated projects. The actual mean cost-effectiveness of all nine completed RRP projects may be different from this sample mean. As shown in Table 2-2, we can say with 95 percent confidence that the actual mean cost-effectiveness of RRP projects lies between $7,961 and $14,219 per ton.

Table 2-2: Cost-Effectiveness Confidence Interval of Evaluated Regional Rideshare Projects

Confidence Interval Around Mean Cost-Effectiveness (ICF Evaluation)		
Sample Size	**Lower Bound**	**Upper Bound**
7	$7,961	$14,219

Evaluation Information

Historically, the District has considered ridematching lists, placement calls, and vanpool formation activities when estimating the emission reductions attributable to the Regional Rideshare Program. The key measurable outcome for rideshare programs is "placements," which represent the proportion of program registrants who are "placed" into a ridesharing mode. This results in mode shift and maintenance of that mode shift. By determining the number of placements achieved by the RRP and gathering additional data about the nature of those placements, several additional outcomes, such as reduction in VMT and reduction in vehicle trips, can be quantified.

The impacts of rideshare matching (both the provision of new and updated matchlists and placement calls) have historically been calculated based on a methodology developed for Caltrans by the Survey Research Center at California State University-Chico.[2] This provides a robust, standardized approach that is commonly used by rideshare agencies and is sufficient to accurately estimate emissions impacts, provided that input values are properly determined.

The District had relied on results from the quarterly matchlist survey to determine placement rates. This is administered to a randomized sample of people in the ridematching database who requested a matchlist, received an updated matchlist, or received a placement (follow-up) phone call from program staff in the course of the previous quarter. The reported number of placements should be interpreted as two one-way trips per day.

Recommendations

We do not recommend any changes to the overall methodology used to calculate the cost-effectiveness of the RRP. However, we do recommend some changes to the calculation of the inputs used and the presentation of results in order to improve transparency, many of which are already being implemented in conjunction with the change in RRP contractor. Recommended changes are as follows:

- Factors used to avoid double counting between program categories should be updated annually based on a database review or survey.
- The placement rate as reported in the project Final Report should be interpreted as two one-way trips per day.
- The accuracy of the average one-way trip length should be improved by calculating trip lengths directly using origin and destination information in the ridematching database.

[2] King, Michael & Barbara Alderson, "Rideshare Placement Measurement: A Proposed Standard Methodology," Survey Research Center, California State University, Chico. June 1995.

- The number and length of access trips should be updated based on client surveys.
- The value for the average number of vanpool riders *not* in RRP databases and days of effectiveness should be updated based on the surveys of new vanpool starts and vanpool riders which are already undertaken by the RRP on a regular basis.
- Information used to calculate carpool and vanpool emissions should be updated based on mode and carpool/vanpool occupancy data from the client surveys.
- The District should continue to assume one year of effectiveness, rather than the longer periods suggested by MTC and its contractors.
- Given the focus of the RRP and the methodological difficulties in quantifying emissions reductions from website information, outreach, and other RRP activities, District monitoring should only take account of rideshare matching and vanpool formation, provided that the RRP continues to achieve a cost-effectiveness well within the District's threshold and is competitive against other submitted projects.

2.2. Local Rideshare Programs

TFCA grants for local rideshare programs fall into the category of "other ridesharing/trip reduction" projects. Projects in this category encompass a broad variety of efforts, from countywide trip reduction to employer- or school-specific programs. The projects often include a mix of transit, carpool and vanpool incentives; rideshare matching; personalized trip planning; Guaranteed Ride Home; bicycle facilities; and/or general marketing of commute alternatives. Frequently, these efforts are conducted under the broader aegis of an employer outreach program.

Evaluation

We were able to independently evaluate emission reductions and cost-effectiveness for only one project in this category. For this project, our evaluation found a cost-effectiveness of $19,434 per ton, based on TFCA-awarded dollars. This is lower than the cost-effectiveness estimated in the District's TFCA application and in the District's post-project evaluation.

Evaluation Information

The TFCA local ridesharing/trip reduction projects are difficult to evaluate. As noted above, each project typically includes multiple elements, from Guaranteed Ride Home to rideshare matching to transit incentives. The relatively small size of each project element makes a comprehensive evaluation disproportionately difficult if each is to be evaluated independently.

The District has historically relied on surveys reporting travel behavior and default values to estimate trip reduction impacts of local rideshare programs. Generally, for ridesharing projects, the District assumes the maximum number of vehicle trips reduced per day is one percent of the target population. Where available, the District uses survey results to estimate prior travel mode. However, very few of the project sponsors have collected useful survey information before and after implementation of a project.

In order to accurately quantify the effects of these projects, multiple user surveys would be needed in order to assess each project element. These surveys would collect information on the extent of user participation, prior travel mode of participants, trip length, as well as the characteristics (length and mode) of any access trips. The surveys would need to be large enough to minimize sampling error; the necessary size of each survey sample would depend on the total population of participants. Such a survey effort would likely cost at least $20,000 if performed by a third-party consultant, and possibly much more depending on the number of project elements.

Note that there is potentially some double counting of trip reduction impacts with other TFCA-funding projects, notably the Regional Rideshare Program. We do not consider this to be a significant problem because it is unclear exactly which impacts are being captured in the cost-benefit analysis of local ridesharing programs. The number of rideshare matches generated through employer outreach which are subsequently credited in the RRP evaluation is within the margin of uncertainty of any estimates of the impacts of local employer outreach programs.

Recommendations

Sponsors of local rideshare projects are often required to conduct a survey of participants as well as provide other information on program outputs, such as the number of transit tickets or pieces of information delivered. This information is typically insufficient to evaluate program impacts. On the other hand, any attempt to provide more comprehensive information would be disproportionate to the funding award. If the District wishes to continue funding projects in this category, we recommend that monitoring requirements should in most cases be limited to information necessary to ensure that the Funding Agreement conditions were adhered to, such as samples of outreach materials.

We do not recommend use of comprehensive surveys to establish new default values for local rideshare/trip reduction projects. This is because the projects in this category are highly variable; their different emphases, baseline conditions, and levels of effort make it difficult to support a single default value that is supported by survey data or other research.

Instead, we offer several options for future evaluation of projects in this category:

- Do not seek to quantify emissions impacts, and accept that the nature of these types of projects involves disproportionate cost to do so accurately.
- Use the U.S. Environmental Protection Agency's COMMUTER Travel and Emissions Analysis Model to estimate the impacts of rideshare programs. The user would be required to enter the level of transportation demand management effort (based on a 5 point scale), employer size, and some transportation background information such as regional mode share. Defaults can be used for many of these inputs. Once the analyst is familiar with the model, and has the inputs available, it would require approximately one hour to run the spreadsheet model for each project.
- Continue to use current defaults, with the number of daily one-way trips reduced equivalent to 1 percent of the target population (more strictly defined as the number of employees actually worked with). Access trips could be quantified based on the values established for the Regional Rideshare Program. While we do not believe that this is the most accurate method of assessing program impacts (most notably, it produces the same impact regardless of the level of effort), it does enable quantitative results to be reported.

2.3. Vanpools and Buspools

Vanpools provide an attractive and, in most cases, less costly alternative to driving alone, thereby reducing vehicle trips and vehicle miles traveled. Vanpools match 7 to 15 passengers and one driver for commuting to and from work. Incentives for commuters who choose to vanpool range from use of carpool or high-occupancy vehicle (HOV) lanes, ability to work while commuting, and in some cases, monthly subsidies and the use of a Guaranteed Ride Home program.

Evaluation

We evaluated the emission reductions and cost-effectiveness (based on TFCA award amount) for six vanpool projects. Table 2-3 shows the results of our evaluation as well as the District's estimates from the project application and post-project evaluation. Our evaluation found a mean cost-effectiveness of $79,891 per ton. This is higher than the $43,780 mean cost-effectiveness estimated from the District's post-project evaluation of the same six projects, but within the $90,000 per ton threshold.

Table 2-3: Emissions Reductions and Cost-Effectiveness of Evaluated Vanpool Projects

Projects sampled = 6

	Mean Emission Reduction (tons/year)			Cost-Effectiveness ($/ton)		
	TFCA Application (District)	Post-Project Evaluation (District)	ICF Evaluation	TFCA Application (District)	Post-Project Evaluation (District)	ICF Evaluation
Mean	2.0	1.8	0.8	$24,765	$43,780	$79,891
Median	1.6	1.1	0.5	$21,086	$33,701	$70,772

The mean cost-effectiveness shown in Table 2-3 reflects the six sampled projects only and may not be representative of all eight completed vanpool projects. We conducted a statistical analysis to determine the confidence interval around the mean cost-effectiveness. As shown in Table 2-4, we can say with 95 percent confidence that the mean cost-effectiveness of *all* vanpool projects lies between $52,665 and $107,116 per ton.

Table 2-4: Cost-Effectiveness Confidence Interval of Evaluated Vanpool Projects

Confidence Interval Around Mean Cost-Effectiveness (ICF Evaluation)		
Sample Size	Lower Bound	Upper Bound
6	$52,665	$107,116

As with local rideshare projects, there may be some double counting between vanpool projects and other TFCA funding categories. For example, vanpool formation projects or the Regional Rideshare Program may be counting the same riders as local vanpool projects. Without data on the precise vans that riders are joining, however, it is not possible to quantify the extent of any double counting.

Evaluation Information

The District has historically estimated the cost-effectiveness of vanpool projects by combining vanpool ridership data with estimates of the prior mode of vanpool riders and trip length. Emissions from access trips and the vanpool trip itself are deducted from the total reduction. The basic evaluation methodology employed by the District is appropriate and will yield accurate results provided that the input parameters are accurately determined.

In the TFCA application, the District uses input parameters provided by sponsors, often based on past projects. In the post-project evaluation, the District relies on ridership and trip length information provided by sponsors. Where available, the District uses survey results to estimate prior travel mode, access trip length, and access mode. However, very few of the project sponsors have collected useful survey information before and after the implementation of a project, and there are methodological problems with several of the surveys that have been conducted. The lack of survey results creates challenges for estimating the emissions impact of vanpool projects, and in many cases the District must rely on professional judgment to estimate input parameters.

To accurately quantify travel impacts, a user survey must collect the following information:

- Travel mode before project
- Vanpool trip length
- Travel mode to access vanpool pickup
- Length of access trip

In order to estimate the percent of vanpool riders who previously drove alone with an accuracy of 5.0 percentage points, a survey would need to obtain approximately 400 valid responses. Given that most TFCA-funded projects do not have this many riders, a regional survey would be required. It therefore makes sense to conduct this survey under the auspices of the Regional Rideshare Program, using the call center and other resources of the program contractor. If conducted by a third-party consultant, the cost of a telephone survey would be approximately $10,000. This assumes that telephone numbers for a representative sample of vanpool riders can be made available by regional and local rideshare programs or vanpool operators.

Recommendations

We do not recommend any changes to the basic methodology for evaluating vanpool projects. As noted above, project sponsor surveys are often insufficient to determine the evaluation input parameters, due in part to the sponsor's lack of sufficient resources and survey research expertise. Most sponsors do not have the ability to conduct a survey that is large enough to achieve accurate results. Therefore, we recommend that sponsors not be required to conduct participant surveys regarding prior mode and trip length. Instead, we recommend that, through a comprehensive survey, Bay Area-specific defaults be established for prior mode, days of effectiveness, the percentage of riders who drive to the vanpool pickup, and the length of these access trips. This would avoid the need for individual projects to conduct their own surveys and avoid common methodological problems such as biased sampling.

2.4. Carpool/Vanpool Incentives

Rideshare and carpool incentives are used to attract commuters to join an existing carpool/vanpool or to form a new carpool/vanpool. The projects in this category provide incentives such as gas scrip money, half-off monthly fare of vanpool, and/or driver bonuses to commuters who participate. The overall goal is to shift individuals from SOVs to an alternative mode.

Evaluation

We were able to independently evaluate the emission reductions and cost-effectiveness for eight projects in this category. As shown in Table 2-5, our estimated mean cost-effectiveness for the eight projects is $17,307 per ton, nearly identical to the District's post-project evaluation and similar to the mean cost-effectiveness from the TFCA applications. All eight evaluated projects have a cost-effectiveness of less than $30,000 per ton.

Table 2-5: Emissions Reductions and Cost-Effectiveness of Evaluated Carpool/Vanpool Incentive Projects

Projects sampled = 8

	Mean Emission Reduction (tons/year)			Cost-Effectiveness ($/ton)		
	TFCA Application (District)	Post-Project Evaluation (District)	ICF Evaluation	TFCA Application (District)	Post-Project Evaluation (District)	ICF Evaluation
Mean	5.9	6.0	4.0	$19,767	$17,453	$17,307
Median	6.4	6.0	4.1	$11,735	$13,247	$15,533

The mean cost-effectiveness in Table 2-5 reflects the eight sampled projects only. We can say with 95 percent confidence that the cost-effectiveness of *all* completed carpool/vanpool incentive projects lies between $11,609 and $18,073 per ton.

Table 2-6: Cost-Effectiveness Confidence Interval of Evaluated Vanpool Incentive Projects

Confidence Interval Around Mean Cost-Effectiveness (ICF Evaluation)		
Sample Size	Lower Bound	Upper Bound
8	$11,609	$18,073

There may be some double counting between vanpool incentive projects and other TFCA funding categories. For example, vanpool formation projects or the Regional Rideshare Program may be counting the same riders as rideshare incentive projects. Without data on the precise vans that riders are joining, however, it is not possible to quantify the extent of any double counting.

Evaluation Information

Historically the District has used information from participant surveys in order to evaluate carpool/vanpool incentive projects. This information includes:

- Average daily ridership
- Percent of riders who previously drove alone
- One-way trip length
- One-way access trip length
- Percent of riders who drive to vanpool pickup

Emissions from access trips are deducted from the total reduction. Emissions from new vanpool trips are not included in this evaluation because these rideshare incentive projects are intended to fill empty seats in existing vanpools/carpools, rather than create new vanpools/carpools.

The methodology used by the District is sufficient to accurately estimate emission reductions. However, as discussed in Section 2.3, most past sponsor survey efforts have not collected accurate information regarding prior travel mode and trip length due to small sample sizes and other methodological problems. A survey would need to obtain approximately 400 valid responses in order to accurately estimate the percent of participants that previously drove alone and the average trip length. Survey research experts would need to be involved in the design, implementation, and analysis of the survey. Such a survey would cost approximately $10,000 if performed by a third-party consultant, assuming that telephone numbers of a representative sample of participants could be made available by project sponsors.

Recommendations

As with vanpool projects discussed in Section 2.3, we do not recommend any changes to the basic methodology for evaluating carpool/vanpool incentive projects. We recommend that sponsors not be required to conduct a survey of participants, because the cost and expertise necessary to obtain accurate results from the survey is beyond the means of most sponsors. We recommend that a comprehensive survey be used to develop Bay Area-specific defaults for prior mode, days of effectiveness, the percentage of riders who drive to the vanpool pickup, and the length of these access trips. This would avoid the need for individual projects to conduct their own surveys and avoid common methodological problems such as biased sampling.

2.5. School Carpool Match

School carpool match projects attempt to reduce the number of vehicle trips to and from schools, placing an emphasis on student and parent education and facilitation of group transportation. This category encompasses a range of projects, including the following:

- Carpool ridematching
- Bicycle/walk/rollerblade groups
- Personalized transit plans
- School traffic management support

Evaluation

We evaluated five projects in this category, estimating emission reductions for all five projects and cost-effectiveness for four projects. Our findings are shown in Table 2-7, together with the District's application and post-project estimates for the same projects. Our evaluation found a mean cost-effectiveness of $141,192 per ton. The cost-effectiveness varies widely among projects; we found two of the evaluated projects to be relatively cost-effective (less than $30,000 per ton), while the other two appear to have relatively poor cost-effectiveness (more than $130,000 per ton).

Table 2-7: Emissions Reductions and Cost-Effectiveness of Evaluated School Carpool Match Projects

Projects sampled = 4

	Mean Emission Reduction (tons/year) [a]			Cost-Effectiveness ($/ton)		
	TFCA Application (District)	Post-Project Evaluation (District)	ICF Evaluation	TFCA Application (District)	Post-Project Evaluation (District)	ICF Evaluation
Mean	3.0	4.3	1.4	$47,479	$40,272	$141,192
Median	3.6	2.1	1.2	$28,452	$26,835	$80,231

Note a: Emission reduction based on a sample of 5 projects.

The average values in Table 2-7 are based on a small sample with high variability. Therefore, the mean cannot be assumed to represent the emission reductions or cost-effectiveness of *all* school carpool match projects. As shown in Table 2-8, the actual mean cost-effectiveness of all 20 completed projects in this category could be anywhere between $0 and $385,415 per ton. A sample of 18 projects would be needed to narrow this confidence interval so that the upper and lower bound are within 20 percent of the mean.

Table 2-8: Cost-Effectiveness Confidence Interval of Evaluated School Carpool Match Projects

Confidence Interval Around Mean Cost-Effectiveness (ICF Evaluation)			Necessary Sample Size to Narrow Confidence Interval		
Sample Size	Lower Bound	Upper Bound	Sample Size	Lower Bound	Upper Bound
4	$0	$385,415	18	$114,261	$168,220

Evaluation Information

Historically, the District has evaluated school carpool match projects using information from sponsors on the number of vehicle trips eliminated per day and the average distance of those trips. Sponsors often obtain this information using surveys of participants. In some cases, survey results have been insufficient to estimate vehicle trip reductions, and the District has relied on staff professional judgment and default values. In the TFCA application, the District assumes the number of trips eliminated per day is equal to 1.0 percent of the target population. In most cases, the target population is assumed to be the student population.

An accurate evaluation of a school carpool match project requires a relatively large survey of participants. The survey should solicit the following information separately for both morning and afternoon trips:

- Whether participated in alternative school transportation outreach program.
- Current mode of transportation to/from school and vehicle occupancy.
- Mode of transportation to/from school prior to program participation and vehicle occupancy.
- School trip distance.
- Number of days participating in program per week.

In order to obtain survey results that represent with sufficient accuracy (plus or minus 5.0 percent) all project participants, the survey should obtain approximately 400 valid responses. A survey research expert is needed to assist with designing the survey instrument, determining the necessary sample size, directing the survey implementation, and interpreting survey results. Such a survey would likely cost $5,000-$15,000 if conducted by a third-party consultant, assuming that paper surveys would be distributed by teachers, or at the college level that student e-mail addresses would be provided by the project sponsor. The cost varies considerably depending on the number of schools that are included in the sample.

Recommendations

Our recommendations for the evaluation of school carpool match projects are as follows:

- In the TFCA application, the District should revise the default assumption that the number of trips eliminated is equal to 1.0 percent of the target population. Most sponsors assume the target population to be the entire student body, and our evaluation of past projects suggests that the number of trips eliminated is typically significantly less than 1.0 percent of the student population.
- Default values for trip length should not be used. Sponsors should be able to accurately estimate trip length using their knowledge of the participating schools and residential locations.
- Sponsors should not be required to conduct a user survey as part of the monitoring process. The cost and expertise necessary to conduct an accurate survey is beyond the means of most sponsors. We

recommend that, through a comprehensive survey, an accurate default value be established for the number of vehicle trips eliminated per number of school carpool program participants. This default value can be used to evaluate completed projects, with sponsors providing project-specific values for number of participants and trip length.

2.6. Bicycle Paths, Lanes, & Routes

Investments in bicycle paths, lanes, and routes improve the transportation system for bicyclists and can encourage drivers to travel by bicycle. This can reduce automobile VMT and trips. TFCA projects in this category include bicycle paths (Class 1), bicycle lanes (Class 2), and bicycle routes (Class 3).

Evaluation

We evaluated the emission reductions and cost-effectiveness (based on TFCA award amount) for 27 bicycle path and bicycle lane projects. Table 2-9 shows the results of our evaluation as well as the District's estimates from the project application and post-project evaluation. The mean cost-effectiveness of the projects we evaluated is $125,747 per ton and the median is $37,683. The range in cost-effectiveness is large, from a low of $3,294 to a high of $703,710. Among the 27 projects evaluated, 19 have a cost-effectiveness less than the $90,000 per ton threshold.

Table 2-9: Emissions Reductions and Cost-Effectiveness of Evaluated Bicycle Path and Bicycle Lane Projects

Projects sampled = 27

	Mean Emission Reduction (tons/year)			Cost-Effectiveness ($/ton)		
	TFCA Application (District)	Post-Project Evaluation (District)	ICF Evaluation	TFCA Application (District)	Post-Project Evaluation (District)	ICF Evaluation
Mean	0.3	0.1	0.2	$35,472	$114,798	$125,747
Median	0.2	0.1	0.1	$19,979	$41,667	$37,683

The average cost-effectiveness in Table 2-9 reflects the sample of projects reviewed and may not be representative of *all* bicycle path and lane projects. As shown in Table 2-10, we can say with 95 percent confidence that the mean cost-effectiveness of all 135 completed bicycle path and bicycle lane projects lies between $58,062 and $193,431. In order to narrow this confidence interval so that the lower and upper bound are within 20 percent of the mean, we would need to evaluate a sample of 88 projects.

Table 2-10: Cost-Effectiveness Confidence Interval of Evaluated Bicycle Path and Bicycle Lane Projects

Confidence Interval Around Mean Cost-Effectiveness (ICF Evaluation)			Necessary Sample Size to Narrow Confidence Interval		
Sample Size	Lower Bound	Upper Bound	Sample Size	Lower Bound	Upper Bound
27	$58,062	$193,431	88	$100,784	$150,709

Evaluation Information

Historically, the District has estimated the increase in bicycle use and corresponding reduction in automobile use based on average daily traffic (ADT) on the facility to receive the bicycle lane (or in the case of bicycle paths, ADT on an appropriate parallel roadway). The estimated increase in bicycle use varies from 0.1 percent of ADT to 0.8 percent of ADT, depending on the traffic volume, the length of the bikeway, and the type of bikeway (Class 1, 2, or 3). In some cases, District planners apply professional judgment to estimate the increase in bicycle use if vehicle count information is unavailable or inapplicable. The District calculates new bicycle miles of travel using a default average trip length of 3 miles and assumes the increase in bicycle miles of travel replaces VMT.

During the TFCA application process, the volume of existing bicyclists in a corridor is sufficient to estimate the likely increase in bicycle usage. Based on recent research, new bicycle travel on a bicycle path or lane should be estimated as approximately 85 percent of pre-project bicycle volumes.[3] This percentage would be significantly lower for a Class 3 bicycle route. Some of the new bicyclists on a new bicycle path or bicycle lane previously traveled by automobile, and this mode diversion reduces emissions. Others likely traveled by other modes (transit, walking, rideshare), and this mode division would not reduce emissions. To estimate the reduction in automobile trips, the increase in bicycle usage should be multiplied by the Bay Area's regional automobile mode share for all trip purposes (56 percent).[4]

Calculating the reduction in VMT requires an estimate of trip length. All else being equal, one would expect that a longer bicycle path or lane would reduce more VMT than a shorter one. Nationally, the average bicycle trip length is 1.94 miles.[5] This is nearly identical to the typical (median) length of a TFCA bicycle path or lane project (2.0 miles). Therefore, the length of a bicycle path or lane project can generally be used as the trip length.

After completion of a bicycle path, lane, or route project, accurately determining its impact on automobile use and emissions would require an extensive survey of users. Such a survey would need to obtain the following information:

- Current travel mode(s) and number of days per week using that mode(s)
- Prior travel mode(s) before project completion and number of days per week using that mode(s)
- Total one-way trip length

The necessary number of survey responses depends in part on the variability among the responses; we estimate that approximately 400 valid responses would be required in order to estimate, with a precision of 5.0 percent, the portion of facility users who previously drove alone. Such a survey effort, intercepting bicycle facility users and providing them with mail-back surveys, would likely cost $10,000 if performed by a third-party consultant for a single facility, although the cost is highly dependent on user volumes. Some facilities may not attract a sufficient number of users to enable this sample size to be achieved.

In addition, usage counts would be needed to estimate the annual number of users. Collection of bicycle counts can potentially introduce significant error into the estimation of bicycle volumes due to variation by the day of the week and by season.[6] In order to ensure that the sample mean bicycle volume is within 20 percent of the actual mean, bicycle counts must be conducted on at least 20 separate days, and possibly

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3 Krizek, Kevin J. et al, NCHRP Project 7-14, *Guidelines for Analysis of Investment in Bicycle Facilities, Final Report,* Transportation Research Board, August 2005.

4 Metropolitan Transportation Commission. *Regional Travel Characteristics Report: Bay Area Travel Survey 2000: Volume I (Weekday).*

5 National Household Travel Survey, U. S. Department of Transportation, 2001.

6 Niemeier, Debbie A., "Longitudinal Analysis of Bicycle Count Variability: Results and Modeling Implications," *Journal of Transportation Engineering*, Volume 122, No. 3, May/June 1996.

many more depending on the variability in counts. This collection of bicycle count data would likely cost at least $15,000 if performed by a third-party consultant.

Recommendations

Our recommendations for the evaluation of bicycle path, bicycle lane, and bicycle route projects are as follows:

- In the TFCA application process, the District should estimate the increase in bicycle usage and reduction in automobile trips based on existing bicycle volumes in the corridor. For bicycle paths and lanes, new bicycle travel should be estimated as approximately 85 percent of pre-project bicycle volumes. To estimate the percentage of new cyclists who previously drove, we recommend applying the Bay Area's regional automobile mode share for all trip purposes (56 percent). Thus, the estimated reduction in automobile trips resulting from a new bicycle path or lane will be equal to 48 percent (85 percent * 56 percent) of existing bicycle volumes. It can be expected that bicycle routes cause fewer new bicycle trips and less reduction in automobile travel than bicycle paths or lanes. Absent any new research findings, we recommend that the District evaluate the impacts of bicycle routes on a case-by-case basis and generally assume that trip reduction benefits will be 25 to 50 percent that of bicycle paths and lanes in the same location, consistent with the District's current approach.
- To estimate the reduction in VMT, we recommend generally assuming an average trip length equal to the length of the bicycle path or lane. Exceptions should be made for short "gap closure" projects, such as a bicycle bridge, where the length of the facility would not be indicative of the length of bicycle trips generated by the project.
- In the post-project evaluation, an accurate quantification of emissions benefits requires an extensive survey of users. Most project sponsors do not have the resources and expertise necessary to conduct such a survey. Therefore, we recommend that no post-project evaluation of emission reductions be performed for these projects. Sponsors should not be required to conduct post-project bicycle usage counts, since this information is typically subject to a large margin of error and does not contribute to an accurate estimation of emission reduction impacts. The District should rely on the TFCA application estimates of cost-effectiveness, applying staff professional judgment to modify results as necessary.

2.7. Bicycle Parking

Improved bicycle parking facilities can increase the convenience and security of bicycle parking, which can encourage more trips by bicycle. When new bicycle trips replace automobile trips, emissions are reduced. TFCA bicycle parking projects include bicycle racks, bicycle lockers, and attended bicycle parking stations. 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 ("bikestations") provide a bicycle-parking-and-retrieving service for users and can also provide commuter support and bicycle repair services. They are often located at high-volume transit stations.

Evaluation

We were able to evaluate the emission reductions and cost-effectiveness (based on TFCA award amount) for five bicycle parking projects. Table 2-11 shows the results of our evaluation as well as the District's estimates from the project application and post-project evaluation. Our evaluation found a mean cost-effectiveness of $159,257 per ton and a median of $68,944 per ton. The range in cost-effectiveness was quite large among the projects we evaluated, from a low of $20,770 per ton to a high of $444,251 per ton. Of the five projects, we found three to have cost-effectiveness less than $90,000 per ton.

Table 2-11: Emissions Reductions and Cost-Effectiveness of Evaluated Bicycle Parking Projects

Projects sampled = 5

	Mean Emission Reduction (tons/year)			Cost-Effectiveness ($/ton)		
	TFCA Application (District)	Post-Project Evaluation (District)	ICF Evaluation	TFCA Application (District)	Post-Project Evaluation (District)	ICF Evaluation
Mean	0.3	0.9	0.09	$23,917	$46,191	$159,257
Median	0.2	0.2	0.03	$27,058	$38,169	$68,944

The mean cost-effectiveness shown in Table 2-11 reflects the five sampled projects only and, given the small sample size and large variation among projects, it is unlikely to be representative of *all* bicycle parking projects. As shown in Table 2-12, we can say with 95 percent confidence that the mean cost-effectiveness of all 57 completed bicycle parking projects lies between $0 and $366,203 per ton. Thus, the mean cost-effectiveness of projects we evaluated is not very meaningful and cannot be used to accurately infer the cost-effectiveness of all bicycle parking projects. In order to narrow this confidence interval so the lower bound and upper bound are within 20 percent of the mean, we would need to evaluate 39 bicycle parking projects.

Table 2-12: Cost-Effectiveness Confidence Interval of Evaluated Bicycle Parking Projects

Confidence Interval Around Mean Cost-Effectiveness (ICF Evaluation)			Necessary Sample Size to Narrow Confidence Interval		
Sample Size	Lower Bound	Upper Bound	Sample Size	Lower Bound	Upper Bound
5	$0	$366,203	39	$127,470	$191,044

Evaluation Information

Bicycle parking projects are among the most difficult projects for which to evaluate emission reduction cost-effectiveness. There is virtually no empirical data from the literature on the travel or emission reduction impacts of bicycle parking. Historically, the District has relied primarily on facility capacity information, usage counts, and default values to estimate the trip reduction impacts of bicycle parking projects. In the TFCA application, the District makes the following assumptions:

- Bicycle locker projects – the number of vehicle trips eliminated per day is equivalent to a project's bicycle locker capacity
- Bicycle rack projects – the number of vehicle trips eliminated per day is equivalent to half a project's bicycle rack capacity

In the post-project evaluation, the District has typically assumed that the number of vehicle trips eliminated per day is equivalent to a project's daily usage. Alternatively, the District has relied on user surveys, which were required as part of the monitoring process prior to 2001.

In most cases, a user survey, in combination with usage counts, is necessary to accurately quantify the emissions impacts of bicycle parking projects. Information collected through the user survey must include:

- One-way trip distance
- Number of days per week facility is used

- Current travel mode(s) and number of days per week using that mode(s)
- Prior travel mode(s) before facility installation and number of days per week using that mode(s)

In order to estimate the percent of bicycle parking facility users who previously drove alone with an accuracy of plus or minus 5.0 percentage points, a survey would need to obtain approximately 400 valid responses. If conducted by a third-party consultant, the cost of a mail-back survey attached to parked bicycles would be approximately $10,000, although this is highly dependent on the frequency of use and the degree to which parking locations are geographically clustered. A large number of bicycle parking facilities would need to be sampled in order to obtain a sufficient number of responses; therefore, this survey would probably need to be conducted across several TFCA-funded projects.

In addition to collecting information through a survey, usage counts are needed to estimate the annual number of facility users. The usage of bicycle parking facilities will exhibit random daily variation as well as variation due to factors such as weather conditions. Because of these variations, there will be a large inherent margin of error in any attempt to infer annual usage characteristics from a single day of data collection. In order to ensure that the sample mean bicycle parking count is within 20 percent of the actual mean, counts must be conducted on at least 20 separate days, and possibly many more depending on the variability in counts. This collection of bicycle parking count data would likely cost at least $15,000 if performed by a third-party consultant.

Many sponsors may not have sufficient expertise to design a user survey and count program that sufficiently minimizes this error. Therefore, a survey research expert is needed to assist in the design, implementation, and analysis of a survey for estimating the impacts of bicycle parking projects, including determining a necessary sample size that would yield representative results.

Recommendations

Our recommendations for the evaluation of bicycle parking projects are as follows:

- For the TFCA application, we recommend a revision to the District's default assumptions regarding the number of vehicle trips eliminated per bicycle locker and bicycle rack. Based on our evaluation of a limited sample of projects, the current default values appear to be too high.
- In the post-project evaluation, it is very difficult to accurately quantify the emissions effect of bicycle parking projects. Most sponsors do not have the expertise and resources to conduct a user survey that would provide an accurate indication of the travel and emissions impacts of these projects. Therefore, we recommend that no attempt be made to quantify the emissions effects of bicycle parking projects, unless new research becomes available that would allow for the estimation of default values. Requirements for post-project utilization counts should be eliminated.

2.8. Bicycle Racks on Buses

Bicycle Racks on Buses projects retrofit transit vehicles with bicycle racks, enabling access to transit stops by bicycle at both ends of the trip. These projects can make transit more convenient and attractive to potential users. When they cause automobile drivers to switch to transit, these projects reduce emissions.

Evaluation

We were not able to quantify the emission reductions and cost-effectiveness of any completed bicycle racks on buses projects due to the limited monitoring information provided by the project sponsors. Using project cost information and limited information on bicycle rack usage for four projects, we estimated the potential range of emission reduction cost-effectiveness. Of these four projects, we estimate that one is likely to have met the $90,000 per ton threshold.

Evaluation Information

The cost-effectiveness of bicycle racks on buses depends on three major variables: the usage of the racks, the proportion of users who would have otherwise made the trip by automobile, and trip length. In the past, several transit agencies have provided the District good data on bicycle rack utilization. However, sponsors have provided no reliable information that can be used to estimate the proportion of users who would otherwise have driven. Trip length is also subject to considerable uncertainty. The available research literature on bicycle racks on buses does not provide any information that could be used to develop default values for TFCA project evaluation. For these reasons, the cost-effectiveness estimation process historically used by the District for bicycle racks on buses projects relies heavily on staff professional judgment.

An extensive survey of users would be necessary to accurately evaluate these projects. Such a survey would collect the following information:

- Number of days per week currently using the bicycle+bus mode
- Other current travel mode(s) and number of days per using the mode(s)
- Prior travel mode(s) before bike rack installation and number of days per week using the mode(s)
- Total trip length

In addition, usage counts would be needed to expand the survey results. The necessary sample size for the survey and usage counts depends on the total population of users and the variability in responses.

Recommendations

Few projects in this category can be expected in the future, as most new transit vehicles now include factory-fitted bicycle racks, and most existing Bay Area bus fleets have already been retrofitted with racks. The cost of conducting a user survey large enough to accurately estimate emissions impacts cannot be justified for these projects, most of which are less than $100,000. Thus, unless additional research data becomes available, the District should not attempt to estimate the cost-effectiveness of bicycle racks on buses projects. While these projects may still be worthy of TFCA funds, their emissions impacts cannot be accurately quantified given present knowledge.

2.9. 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, all of which generally reduce emissions. Signal timing projects typically attempt to synchronize multiple traffic signals along a corridor, sometimes upgrading signals to more advanced devices. A signal timing project could also be focused on a single intersection.

Note that by increasing traffic speeds, these projects may have a negative impact on pedestrian and bicycle safety, thereby discouraging travel by non-motorized modes. As such, signal timing projects could counteract other types of TFCA projects. The effect of any one project on walking and bicycling activity would be small and probably impossible to quantify accurately.

Evaluation

We evaluated the emission reductions and cost-effectiveness (based on TFCA award amount) for 15 signal timing projects. Table 2-13 shows the results of our evaluation as well as the District's estimates from the project application and post-project evaluation. Our evaluation found a mean cost-effectiveness of $88,412 per ton, very similar to the mean cost-effectiveness from the District's post-project evaluation of the same 15 projects. The range in cost-effectiveness among evaluated projects is large and the mean is skewed by several outliers. Of the 15 projects reviewed, we found 10 to have cost-effectiveness less than $50,000 per ton.

Table 2-13: Emissions Reductions and Cost-Effectiveness of Evaluated Signal Timing Projects

Projects sampled = 15

	Mean Emission Reduction (tons/year)			Cost-Effectiveness ($/ton)		
	TFCA Application (District)	**Post-Project Evaluation (District)**	**ICF Evaluation**	**TFCA Application (District)**	**Post-Project Evaluation (District)**	**ICF Evaluation**
Mean	2.6	3.6	3.1	$42,513	$91,258	$88,412
Median	1.7	1.2	1.4	$30,912	$40,085	$32,769

The median cost-effectiveness shown in Table 2-13 reflects the 15 sampled projects only and may not be representative of *all* signal timing projects. As shown in Table 2-14, we can say with 95 percent confidence that the median cost-effectiveness of all 73 completed signal timing projects lies between $25,157 and $151,668. In order to narrow this confidence interval so the lower bound and upper bound are within 20 percent of the median, we would need to evaluate 55 signal timing projects.

Table 2-14: Cost-Effectiveness Confidence Interval of Evaluated Signal Timing Projects

Confidence Interval Around Mean Cost-Effectiveness (ICF Evaluation)			Necessary Sample Size to Narrow Confidence Interval		
Sample Size	**Lower Bound**	**Upper Bound**	**Sample Size**	**Lower Bound**	**Upper Bound**
15	$25,157	$151,668	55	$71,210	$105,615

Evaluation Information

The District uses information on traffic volume and speeds before and after a signal timing project to calculate the change in emissions. For the TFCA application, sponsors conduct direct measurements of existing traffic speeds in the project corridor, typically using a floating car study. Sponsors rely on traffic modeling to forecast the effects of the proposed project. After completion, sponsors conduct direct measurements of traffic speeds, again using a floating car study. Because emission factors tend to decrease with higher speeds, the benefits of signal timing projects are calculated by subtracting post-project vehicle emissions from pre-project emissions.

The information obtained by the District is sufficient to quantify the emissions impacts of signal timing projects with reasonable accuracy. However, several factors can introduce error in the evaluation. Traffic volumes and speeds vary from day to day. At some locations where the variation in traffic volume is minimal, a single day of traffic counts may be sufficient to estimate the average daily traffic volumes with reasonable accuracy (i.e., plus or minus 20 percent). At other locations, as many as five days of counts may be needed to achieve that level of precision in the estimated average volume.

Additional error is introduced through the application of emission factors. The existing emissions models, such as CARB's EMFAC model, are not well suited to calculate the emissions impacts of changes in traffic congestion and speeds. Some researchers have developed more accurate micro-simulation models for estimating the emissions effects of traffic flow patterns, but the use of such models would increase evaluation costs significantly and their results are not currently accepted by CARB.

It is important that the estimation of signal timing benefits focus on the hours and days when the benefits are likely to accrue. Most TFCA applicants recognize this, and they measure and forecast speeds for the time periods when they believe the signal timing will reduce emissions (typically the morning and evening peak periods, or all day). However, a small number of applicants have reported speeds for a narrow time period that does not likely capture the majority of the project's benefits. Traffic speed and volume data should be collected for the morning (7-10 am) and evening (4-7 pm) peak periods at a minimum. In cases where a project would result in additional benefits outside peak periods, sponsors should be encouraged to report traffic speeds and volumes for additional times to be used in estimating emissions impacts.

Recommendations

We recommend several modifications to the evaluation process for signal timing projects, summarized below.

- Induced Traffic – Higher average speeds can encourage increased vehicle travel. We recommend that the District account for the impacts of induced traffic by applying an elasticity factor that represents the percent change in traffic volumes associated with a percent change in travel time. Based on a range of empirical evidence, we recommend the District apply a travel time elasticity of -0.25. The new emissions created by this induced traffic should then be subtracted from the project's emissions benefits.
- Cap on Speed Increase – The current District evaluation methodology imposes a maximum speed increase of 25 percent. For streets with low existing speeds (e.g., 15 – 20 mph), signal timing might result in more than a 25 percent speed increase. Therefore, we do not recommend that a cap be placed on the increase in traffic speed.

2.10. 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.

Evaluation

Since 1992, the District has completed two Transit Signal Priority projects using funds from the TFCA program. We were unable to perform an evaluation of the emission reductions and cost effectiveness of these projects because of the limited data reported by project sponsors. While the indications are that these projects have increased bus speeds or reduced bus idling at intersections, there is insufficient information to independently quantify the emissions impacts.

Evaluation Information

Most TSP projects are bundled with bus rapid transit (BRT) projects that include other improvements such as greater stop spacing, bus branding, and access to dedicated guideways. Because of this, it is usually difficult to separate out the impacts of TSP alone.

The District evaluated the two past TSP projects using sponsor-provided information on idling time, travel speeds, and ridership impacts, applying staff professional judgment to determine vehicle trip and emission reductions.

Estimating the impacts of TSP projects requires obtaining the following information at a minimum:

- Bus travel time savings, for each affected route
- Increase in bus frequency resulting from TFCA funding (if applicable), for each affected route

This information is normally collected by transit agencies as a matter of course. If available, project-specific modeling can be used to determine how changes in bus travel time and frequency affect bus ridership; otherwise, studies conducted in other regions can provide default values for these relationships. Information from other Bay Area studies can provide default values to estimate the portion of new riders that previously drove alone.

Recommendations

Given that TSP is normally implemented as part of a package with other BRT improvements, it is often difficult to disentangle the specific impacts of TSP from the wider benefits of BRT. For this reason, we recommend that the Transit Signal Priority category be extended to allow broader BRT projects or other BRT elements to qualify, including:

- Transit signal priority or preemption
- Bus-only or queue jump lanes
- Pre-paid fare collection systems
- Stop consolidation
- Bus bulbs
- Real-time transit information

This category should include any project that reduces transit travel times, as the method of analysis is the same.

For smaller projects that focus on transit signal priority, pre-paid fare collection, or other speed enhancements, the emissions reductions can be calculated based on the reduction in travel time (and increase in frequency if applicable). We recommend the following calculation methodology:

- **Step 1. Estimate ridership increase from travel time savings.** Project-specific modeling data will often be available. In other cases, default travel time savings of 10 percent[7] from TSP and an elasticity of -0.6[8] can be assumed based on the research literature and Bay Area experience.
- **Step 2. Estimate ridership increase from enhanced frequency.** Project-specific modeling data will often be available. In other cases, a standard elasticity of -0.5 can be used to estimate the ridership change.[9]

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7 See the literature review conducted for this project for a summary of research findings.

8 JHK & Associates, CM/AQ Evaluation Model, Texas Transportation Institute, 1995.

9 Transportation Research Board. *Traveler Response to Transportation System Changes.* TCRP Report 95. Washington DC. 2005, p. 9-5.

- **Step 3. Estimate vehicle trip reduction.** Information from AC Transit's evaluation of the San Pablo Rapid Bus project can be used to estimate the following default value – each new transit trip would eliminate 0.25 vehicle trips.[10]
- **Step 4. Estimate emissions reduction.** Project-specific data will need to be provided on trip length. This value can be calculated using the following formula: average load / average boardings per run * route length. Emissions factors can be used to convert these VMT and trip reductions into emissions savings.

For BRT or rapid bus projects that involve a broader set of improvements such as bus branding and stop consolidation, additional vehicle trip reductions are likely. Project sponsors will normally have more detailed ridership projections developed through the planning phase or results from similar projects undertaken by the agency. These can be used to develop a project-specific set of assumptions for application and monitoring purposes, in some cases coupled with the default values for prior mode and other variables.

2.11. Traffic Calming and Pedestrian Improvements

Traffic calming refers to a variety of techniques to slow traffic and improve street safety. Traffic calming can reduce emissions when it encourages drivers to switch to walking and bicycling. Traffic calming can also potentially reduce vehicle emissions if it results in smoothing traffic speeds and reducing acceleration and braking. However, some research has suggested that traffic calming devices such as speed humps might increase vehicle emissions by causing more acceleration and deceleration.

Improvements to pedestrian facilities encourage more walking. When travelers switch from driving to walking, emissions are reduced due to less VMT and fewer vehicle starts. 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 trips are typically less than two miles in length, so most pedestrian facility projects have the potential to reduce only short automobile trips. In addition, improvements to pedestrian connections to transit systems have the potential to divert long automobile trips to walking-plus-transit trips.

Evaluation

We were unable to evaluate the cost-effectiveness of any of the five completed projects in this category because the sponsor-reported survey data was insufficient to estimate travel impacts.

Evaluation Information

Five traffic calming and pedestrian improvement projects have been completed to date. To evaluate these projects, the District has used pre- and post-project usage counts to determine impacts on pedestrian and bicycle activity, and applied professional judgment to estimate the impacts on vehicle travel. In one instance, data from an extensive user survey was also used to estimate project impacts.

This category of projects is probably the most difficult to evaluate of all TFCA categories. While research has shown a positive correlation between the propensity to walk and the quality of the pedestrian environment, this correlation is usually quantified by comparing travel behavior across a large number of areas and using statistical methods to control for other factors. It is much more difficult, if not impossible, to isolate the impact of physical improvements on walking and automobile use in a single location. This is in part because pedestrian activity is influenced by many factors, some of which are unrelated to the physical environment, and it is nearly impossible to control for all these factors at a single location.

[10] Nelson\Nygaard, Evaluation of Rapid Bus Service in the San Pablo Avenue Corridor. Final Report to AC Transit, February 2005.

It is likely impossible to accurately estimate the emissions impacts of some TFCA pedestrian improvement projects. This is particularly true for projects that result in improvements to sidewalks, crosswalks, and other pedestrian infrastructure in a commercial or residential district. While such projects do likely increase pedestrian activity and, to a lesser extent, reduce driving, it is often impossible to control for all the others factors that affect travel behavior.

It may be possible to quantify the emissions impacts of other pedestrian improvement projects, such as those focused on access to a transit station. With these types of projects, it is easier to identify and survey the affected population, and any change in pedestrian activity is less likely to be a product of local land use changes or other confounding factors. A user survey would need to collect the following information:

- One-way trip distance
- Current travel mode(s) and number of days per week using that mode(s)
- Prior travel mode(s) before project and number of days per week using that mode(s)

Survey research experts should be involved in designing the survey instrument, determining the necessary sample size, directing the survey implementation, and interpreting survey results. We estimate that approximately 400 valid survey responses would be needed in order to estimate the reduction in automobile use with a precision of plus or minus 5.0 percent. Such a survey would cost approximately $10,000 if conducted by a third-party consultant. Usage counts would also be needed in order to estimate annual pedestrian (and possibly bicycle) usage.

Recommendations

We recommend that the District not attempt to quantify the emissions impacts of traffic calming and pedestrian improvement projects. For some such projects, it is likely impossible to accurately estimate the emissions impacts. For other projects whose impacts could possibly be quantified, the cost of conducting a survey necessary to accurately quantify the impacts would be beyond the means of most project sponsors. If new research on the travel reduction impacts of these projects becomes available in the future, it may be possible to develop default values to use in evaluating these types of projects.

3. CONCLUSIONS

This report summarizes the results of a performance review of selected TFCA projects. We conducted an independent evaluation of completed TFCA projects in 11 categories in order to determine emission reductions and cost-effectiveness. Table 3-1 summarizes these results. We were able to evaluate at least one project in eight categories. In every category of projects that we were able to evaluate, the median cost-effectiveness is less than $90,000 per ton of emissions reduced (based on TFCA award amount). The mean cost-effectiveness is less than $90,000 per ton in five of the eight categories. In total, we found that 54 of the 73 evaluated projects have a cost-effectiveness less than $90,000 per ton.

Table 3-1: Summary of Cost-Effectiveness of Evaluated Projects

Project Type	Number Evaluated	Cost-Effectiveness ($ per ton)	
		Mean	Median
Regional Rideshare Program	7	$11,090	$7,791
Local Rideshare Programs	1	$19,434	$19,434
Vanpool/Buspool Programs	6	$79,891	$70,772
Carpool/Vanpool Incentives	8	$17,307	$15,533
School Carpool Match	4	$141,192	$80,231
Bicycle Paths and Lanes	27	$125,747	$37,683
Bicycle Parking	5	$159,257	$68,944
Bicycle Racks on Buses	—	—	—
Traffic Signal Timing	15	$88,412	$32,769
Transit Signal Priority	—	—	—
Traffic Calming and Pedestrian Facility Improvements	—	—	—

In many cases, the mean cost-effectiveness in Table 3-1 is based on a small sample that exhibits a large variation among projects. Therefore, the mean cost-effectiveness values are not necessarily representative of all completed projects in a given category. The confidence interval around the mean is particularly large for school carpool match, bicycle paths and lanes, and transit signal priority projects. In these cases, a significantly larger sample size would be necessary to more precisely estimate the mean cost-effectiveness.

Table 3-2 presents a comparison of the median cost-effectiveness based on the District's TFCA application estimate, the District's post-project evaluation, and our evaluation. For several of the project categories evaluated, our estimated median cost-effectiveness is very similar to the District's post-project estimate (e.g., Regional Rideshare Program, carpool/vanpool incentives, bicycle paths and lanes, and traffic signal timing). In other cases, our estimated median cost-effectiveness is significantly higher than the District's, though still within the $90,000 threshold.

Table 3-2: Comparison of Median Cost-Effectiveness Estimates

Project Type	Number Evaluated	Median Cost-Effectiveness ($ per ton)		
		TFCA Application (District)	Post-Project Evaluation (District)	ICF Evaluation
Regional Rideshare Program	7	$10,326	$10,252	$7,791
Local Rideshare Programs	1	$46,717	$28,873	$19,434
Vanpool/Buspool Programs	6	$21,086	$33,701	$70,772
Carpool/Vanpool Incentives	8	$11,735	$13,247	$15,533
School Carpool Match	4	$28,452	$26,835	$80,231
Bicycle Paths and Lanes	27	$19,979	$41,667	$37,683
Bicycle Parking	5	$27,058	$38,169	$68,944
Bicycle Racks on Buses	—	—	—	—
Traffic Signal Timing	15	$30,912	$40,085	$32,769
Transit Signal Priority	—	—	—	—
Traffic Calming and Pedestrian Facility Improvements	—	—	—	—

In the case of bicycle racks on buses, transit signal priority, and traffic calming and pedestrian improvement projects, we were unable to determine the emission reduction impacts of any projects. This is primarily because the project sponsors did not conduct an adequate user survey or did not report survey results in sufficient detail to allow an accurate quantification of impacts.

During the TFCA application process, the District has generally estimated the emission reductions of a project using default values derived from past projects and staff professional judgment. After completion of a project, the District has historically relied on sponsor-provided user surveys and/or usage counts combined with default values and staff professional judgment to determine emission reductions. In many cases, surveys conducted by project sponsors have been inadequate to accurately determine travel impacts due to methodological problems with survey design, implementation, or analysis.

For most projects covered by this review, an accurate determination of post-project emissions impacts requires one or more user surveys coupled with usage counts to expand the survey results. The necessary size of the surveys depends in part on the total population of users and the variability among projects. At a minimum, survey data collection would cost $10,000 if performed by a third-party consultant, and significantly more in some cases.

Most sponsors do not have adequate resources or expertise to design, implement, and analyze such a survey. Therefore, we recommend that in most cases, sponsors not be required to conduct post-project user surveys or collect usage counts. Our specific recommendations for the project types reviewed are summarized below.

Regional Rideshare Program

- We do not recommend any changes to the overall methodology used to calculate the cost-effectiveness of the RRP. We do recommend some changes to the calculation of the input values and use of survey results. For example, factors used to avoid double counting between program categories should be updated annually based on a database review or survey. The placement rate as reported in the project Final Report should be interpreted as two one-way trips per day. And the accuracy of the average one-way trip length should be improved by calculating trip lengths directly using origin and destination information in the ridematching database.

Local Rideshare Programs

- We recommend that the District generally not seek to quantify emissions impacts of these projects, since the cost of conducting surveys needed to accurately quantify impacts is disproportionate to the size of these projects.
- Alternatively, the District could make use of the U.S. Environmental Protection Agency's COMMUTER Travel and Emissions Analysis Model to estimate the impacts of local rideshare programs.

Vanpools, Carpool/Vanpool Incentives, and School Carpool Match

- We do not recommend any changes to the basic methodology for evaluating these types of projects. However, we recommend that sponsors not be required to conduct participant surveys as part of the monitoring process. Most sponsors do not have the ability to conduct a survey that is large enough to achieve accurate results. Instead, we recommend that, through a comprehensive survey, Bay Area-specific defaults be established for factors such as prior mode, days of effectiveness, the percentage of riders who drive to carpool/vanpool pickup, and the length of access trips.

Bicycle Paths, Lanes, & Routes

- In the TFCA application process, the District should estimate the increase in bicycle usage and reduction in automobile trips based on existing bicycle volumes in the corridor, rather than existing traffic volumes.
- No post-project evaluation of emission reductions should be performed for these projects, since most project sponsors do not have the resources and expertise necessary to conduct an extensive user survey that would be required to accurately quantify emissions impacts.

Bicycle Parking

- In the TFCA application process, the District should revise the default assumptions regarding the number of vehicle trips eliminated per bicycle locker and bicycle rack.
- No post-project evaluation of emission reductions should be performed for bicycle parking projects, unless new research on the impacts of these projects becomes available. Requirements for post-project utilization counts should be eliminated.

Bicycle Racks on Buses

- The District should not attempt to estimate the cost-effectiveness of bicycle racks on buses projects.

Traffic Signal Timing

- The District should modify the evaluation process for signal timing projects to account for induced demand and to eliminate the 25 percent cap on speed increase.

Transit Signal Priority

- Because Transit Signal Priority is normally implemented as part of a package with other Bus Rapid Transit (BRT) improvements, this category should be extended to allow broader BRT projects or other BRT elements.
- Using results from the literature, the District should establish a standardized process for estimating the emission reductions of these projects based on the reduction in bus travel time and, if applicable, increase in bus frequency.

Traffic Calming and Pedestrian Improvements

- The District should not attempt to estimate the cost-effectiveness of traffic calming and pedestrian improvement projects, unless new research on the impacts of these projects becomes available.